EXCESS

FleXible user-CEntric Energy poSitive houseS

Deliverable 1.2: Stocktaking of PEB Examples

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Responsible	Organisation	Contributing WP
Andreas Jaeger	ICLEI	WP1

Abstract
The stocktaking exercise provides insights on a range of challenges and opportunities for positive energy building (PEB) development in Europe. Findings in this report relate to the geographic distribution of PEBs, common technologies used and variations of their use across climatic zones. Further, the report analyses stakeholder engagement levels for PEB development and arrangements to allow buildings to sell surplus energy to grid operators. The report also includes an evaluation of financing arrangements and rates PEB affordability, transferability and replicability. The case studies developed in the context of the EXCESS project are introduced and catalysts, challenges as well as PEB replication potentials are synthesised. The final conclusions of the stocktaking exercise and case studies are presented, suggesting further research and recommendations on the actions to take and main points to consider in order to promote PEBs.

Keywords
Positive Energy Buildings; PEBs; Net-Positive; Deep Renovation; Sustainable Construction.

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1.0	06.07.2020	*Stocktaking Exercise and Case Studies*	Javier Llorente [CENER]; Andreas Jaeger, Carsten Rothballer and Julen Imana Sobrino [ICLEI];

			Andreas Tuerk, Ingrid Kaltenegger and Tamara Trumbić [JR]; María Cantalapiedra, Erick Maass [Urb-atelier]; Koen Allaerts [VITO]; Mia Ala-Juusela, Krzysztof Klobut, Zarrin Fatima [VTT]
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EXECUTIVE SUMMARY

The report presents the EXCESS stocktaking exercise, which resulted in the identification of 58 positive energy buildings (PEBs) with a combined surface area of 400,314 m². Findings describe the development of PEBs in Europe, particularly over the past 11 years. A breakdown of the establishment of PEBs suggests that presently office buildings are the most common PEB type, followed by single family homes. With regard to PEB renovations it is observed that these are still comparatively rare, with the cost of such deep renovation activity potentially being a key deterrent. The analysis reveals that PEBs are under or overrepresented in certain parts of Europe, with certain countries and regions (e.g. Baltic States and Eastern European countries) having no or few cases whilst significant clusters can be found in countries such as France and Germany. The research also examined the types of technologies integrated in PEBs, with photovoltaics being found to be the most common, and it also presents how the selection of technologies appears to differ across climate zones.

Further, findings in relation to stakeholder engagement are described and it is highlighted that there appears to be a greater need for the collaboration of specialist firms to design and implement buildings with net-positive energy balances. With regard to energy trading agreements it is observed that only little documentation pertaining to individual cases can be found, which suggests the need for further in-depth research. Lastly, issues around financing arrangements underpinning PEB development as well as their affordability, transferability and replicability of PEB projects are described and analysed. Whilst a first analysis of PEB financing and affordability is presented, authors emphasise the need for more robust data on the basis of which higher upfront costs and amortisation rates could be calculated more reliably.

The 10 case studies presented in this report were identified on the basis of the stocktaking exercise. PEBs were selected to showcase a variety of building uses (residential, commercial, public, mixed-use), different building sizes and to include new construction as well as renovation projects. Further, the case studies were selected to cover a range of countries and climate zones. The detailed case studies go beyond the data collected by desk-research during the stocktaking exercise, to provide more in-depth information regarding the local initiation context, integrated technologies, building performance indicators, levels of stakeholder engagement, challenges and opportunities as well as replication potential.

Overall, the case studies support a number of observations made in the context of the stocktaking exercise, including the importance of stakeholder engagement and the close collaboration of specialist firms to design and realise a complex PEB. One important finding is that in many of the cases, the aim was not only to achieve PEB status, but more holistic sustainable design goals played a role. With regard to building technologies, the cases both highlight the need to innovate and push boundaries, but also show that market-ready technological solutions exist. Whilst details on project financing are not always available, preliminary findings suggest that higher upfront costs can be a barrier to the broader roll-out of PEBs and government incentives do play a role in helping projects to get off the ground. Some cases, on the other hand, demonstrate that PEBs can already be realised without significant external financial support, with cost savings during operation representing a strong business case. With regard to catalysts and challenges it is found that the client's vision can play a key role in driving a project, whilst challenges can include longer planning and design phases of PEB projects and technical skills shortages. Examining the replication potential for PEBs in Europe, many approaches show great promise for replication within the countries of individual projects, but also beyond.

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1 Introduction

1.1 Purpose of the document

The primary goal of the EXCESS (FlEXible user-CEntric Energy poSitive houseS) project is to demonstrate how nearly-zero energy buildings can be transformed into positive energy buildings (PEBs). In this context four innovative demonstration projects in four climate zones will be realised that introduce technical solutions to enable buildings to produce more renewable energy than they consume over the course of a year. In conjunction with these demonstrators, the EXCESS consortium also explores challenges and opportunities associated with upgrading single technologies within existing building systems; enabling factors for local energy trading as well as new services to grid operators or utilities.

This report provides an overview of realised and planned PEBs across Europe as well as 10 more detailed case studies. The report and case studies focus on building-integrated technical and technological solutions (VITO and CENER), synergies with the shared definition and concept for PEBs (VTT), whilst ICLEI and other partners focussed on the initiation context, financial schemes, costs of energy and buildings solutions, social, indoor, environmental, aesthetic and regulatory frameworks as well as implementation steps. Lastly, the report contains observations on barriers and opportunities for PEBs.

1.2 Scope of the document

The stocktaking exercise and case studies, as well as the observations on challenges and opportunities associated with issues such as technological solutions and financing frameworks represents a knowledge resource for stakeholders engaged in realising user-centric energy positive houses and helps to inform future EXCESS activities. Further, the data gathered and observations made in this report provide a departure point for further research to support evidence-based policy making.

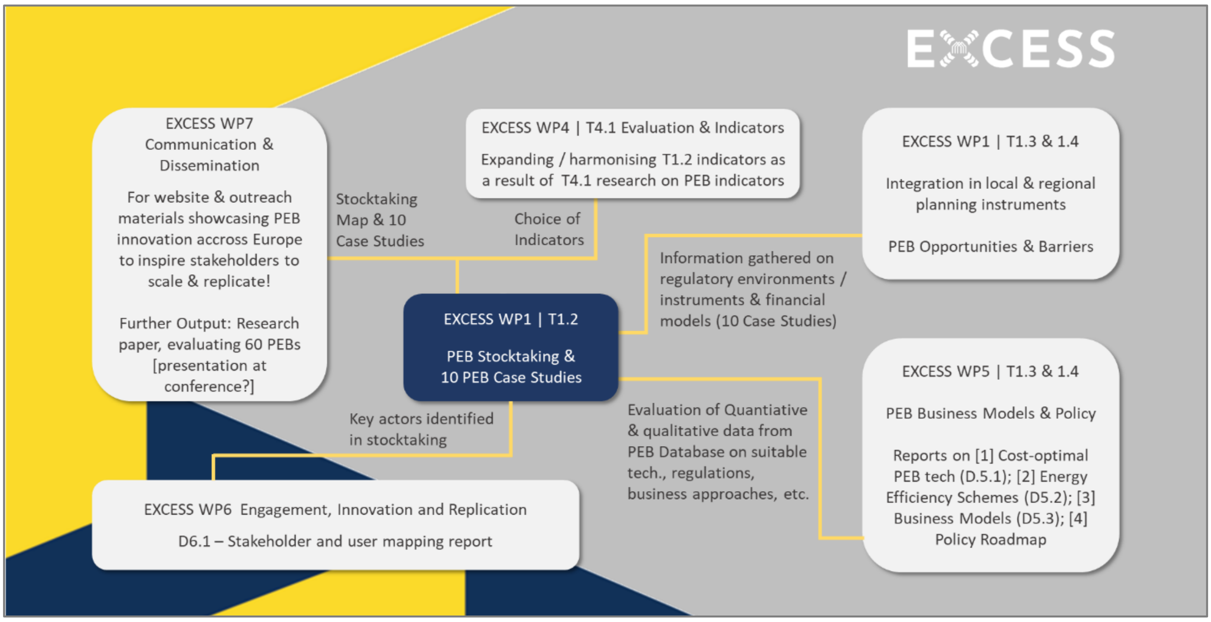

Figure 1 | Potential linkages of the stocktaking exercise to further EXCESS project activities

1.3 Structure of the document

The report is subdivided into three main sections, with chapter 2 presenting the achievements of the stocktaking exercise and general observations in relation to the sample of PEBs identified, which will become more significant, as the sample size of projects increases and more reliable data is obtained. The case studies are introduced in chapter 3, with a description of the selection process and relevant observations preceding these. Tying the stocktaking exercise and case studies together, chapter 4 draws conclusions from the qualitative and quantitative data obtained and outlines next steps to be taken. Lastly, the report includes a set of annexes, to provide readers with descriptions of the individual PEBs identified and tables that present selected data. The full case study examples are presented in the attachments.

2 Stocktaking of positive energy buildings in Europe

2.1 Timeline and methodology

The stocktaking of positive energy buildings (PEBs) in Europe as part of the EXCESS project commenced in late 2019, with ICLEI developing an initial set of indicators to guide data collection. The initial matrix encompassed data pertaining to the PEB's location, relevant contact points that could potentially contribute further information, the PEB's status of completion, levels of stakeholder engagement, information on energy trading agreements, project financing information as well as an assessment of the respective PEB case's degree of transferability and affordability. In the following months the indicators were expanded to provide more detail on the PEB's use of specific technologies, building typologies and more detailed information on project costs as well as the PEB's geographic coordinates.

In early 2020, the initial list of 15 PEBs identified by consortium partners was steadily expanded by ICLEI. By conducting desk research as well as by reaching out to experts in the field, a list of 57 PEBs across Europe could be presented by ICLEI in beginning of March 2020. Initial findings suggested that PEBs were mostly being developed in oceanic climates and the identification of cases in Mediterranean and Nordic climates proved challenging.

Next, the identified cases were examined in more detail and a number of the initially identified buildings were struck off the list, as they did not sufficiently fulfil PEB criteria. In March and April 2020 further desk research led to the identification of additional PEBs and the total at the time of compiling this report is back to 58 cases. It should be noted that in these last months, EXCESS partners were able to identify a number of interesting projects in Mediterranean and Eastern European countries (these regions had been underrepresented in the initial stocktaking). The more geographically diversified data set now offers the chance to conduct a more robust analysis, which is documented in the following subchapters.

Information was found online by conducting country-specific research using commonly used descriptive terms for positive energy buildings and examining academic literature. The most useful resource found was the French website L'Observatoire des Bâtiments BEPOS et Basse Consommation (Observatory for buildings with positive energy and low consumption), which is one of the reasons, why French cases are very well represented in the dataset. Further online resources that helped the identification of PEBs included the European BUILD UP website as well as the Construction21 platform.

2.2 Introducing the PEBs and general observations

In the context of the stocktaking exercise 58 PEBs across Europe were identified and this chapter provides a brief overview of these as well as general observations pertaining to, amongst others, their development over time, typologies, distribution, commonly found technologies and levels of stakeholder engagement. The sample has been limited as far as possible to PEBs as opposed to also including nearly-zero energy buildings (NZEBs).[1]

It should be noted that this analysis is based on a small sample size as well as limited qualitative and quantitative data. Observations therefore should be seen as a departure points for further research, which the EXCESS team will pursue in the course of the project as data availability and quality improves and the sample size increases. The table below provides an overview of the PEBs identified and further information on these is provided in Annexes 1 to 3. The PEB numbers, which will be referred to when highlighting specific PEBs to facilitate finding further information in the Annexes do not rank the PEBs, but rather the number denotes the order in which the cases have been identified.

Table 1 | Overview of the PEBs included in the stocktaking exercise

PEB No.	Name of PEB Example	Country	Climate Zone (Barenbrug Holland BV)	Status	Year
01	Plus-Energie-Bürohochhaus, TU Wien	Austria	Continental	Realised	2014
02	Powerhouse Kjørbo	Norway	Nordic	Realised	2014
03	Freiburg's New City Hall	Germany	Continental	Realised	2017
04	Hikari Complex	France	Mediterranean	Realised	2015
05	Residence Ma. Curie 2	France	Mediterranean	Realised	2019
06	Residence etudiant arc en Meyran	France	Mediterranean	Realised	2016
07	Residence Esperia	France	Oceanic	Realised	2013
08	Positive Energy High School	France	Oceanic	Realized	2017
09	Eco-Renovation of KTR France HQ	France	Mediterranean	Realized	2018
10	P.A.T.H Turnkey House	France	Oceanic	Realized	2014
11	Willibald-Gluck-High School	Germany	Continental	Realized	2015
12	Lantti-talo	Finland	Nordic	Realised	2012
13	Powerhouse Brattørkaia	Norway	Nordic	Realised	2019
14	Solace (Demo) House	Poland	Continental	Realised	2019
15	ileeid house	Ireland	Oceanic	Realised	2009
16	SIB ZERO+ House	Denmark	Oceanic	Realised	2009
17	Sunlighthouse Pressbaum	Austria	Continental	Realised	2010
18	Elithis Tower	France	Oceanic	Realised	2009
19	OVG's TNT Centre	Netherlands	Oceanic	Realised	2011
20	Svart Hotel [Arctic Circle]	Norway	Nordic	Planned	2023
21	Active Office	United Kingdom	Oceanic	Realised	2018

[1] NZEBs that should be mentioned, even if not featured in the list, include the innovative Finnish projects Puuseppa Student Apartments in Kuopio and the Villa Isover in Hyvinkää, as both are very close to being energy positive. Further, the ZERO-PLUS Settlement Project in Italy and the ZERO-PLUS Demohouse in Cyprus should be highlighted, as very few / no examples of highly energy efficient (or energy positive buildings) were found in these countries. The ZERO-PLUS project is funded under Horizon 2020, running from 2015 to 2020.

PEB No.	Name of PEB Example	Country	Climate Zone (Barenbrug Holland BV)	Status	Year
22	New Montessori School	Norway	Nordic	Realised	2018
23	Heliotrope Solar Home	Germany	Continental	Realised	1994
24	Sobek's Aktivhaus B10	Germany	Continental	Realised	2014
25	Le Parc de l'Ensoleillée	France	Mediterranean	Realised	2013
26	L6 - L'OREAL Group Research Laboratory	France	Oceanic	Realised	2018
27	Energy Positive Social Housing and Offices	France	Oceanic	Realised	2014
28	NEWTONPROJEKT Haus 1	Germany	Continental	Realised	2018
29	Technical High School for Health Professionals	Luxembourg	Continental	Realised	2019
30	"Aerem " factory	France	Mediterranean	Realised	2018
31	Gustave André School Extension	France	Mediterranean	Realised	2018
32	Education and Leisure Hub	France	Oceanic	Realised	2018
33	Concert or Conference Hall "The House for All"	France	Mediterranean	Realised	2018
34	Head office of the Caisse d'Epargne Bank	France	Oceanic	Realised	2017
35	Mauges Public High School	France	Oceanic	Realised	2015
36	New HQ of GA Group	France	Mediterranean	Realised	2014
37	Green Building Kirstein & Sauer	Germany	Oceanic	Realised	2015
38	Venlo City Hall	Netherlands	Oceanic	Realised	2016
39	Student Residences	France	Oceanic	Realised	2017
40	The Home for Life	Denmark	Oceanic	Realised	2009
41	Maison Air et Lumière	France	Oceanic	Realised	2011
42	Green Office® Meudon	France	Oceanic	Realised	2011
43	Green Office® Spring	France	Oceanic	Realised	2019
44	Green Office® Link	France	Mediterranean	Realised	2017
45	Green Office® Rueil	France	Oceanic	Realised	2014
46	Green Office® Châtenay	France	Oceanic	Realised	2015
47	PRD Office	France	Oceanic	Realised	2014
48	Energy Positive Dwelling	Netherlands	Oceanic	Realised	2016
49	Efficiency House Plus	Germany	Continental	Realised	2015
50	aquaTurm Water Tower Hotel	Germany	Continental	Realised	2017
51	SOLARHAUS	Spain	Oceanic	Planned	2021
52	Passivistas - the house project	Greece	Mediterranean	Realised	2016
53	Passive House in Sicily	Italy	Mediterranean	Realised	2012
54	Family Center Sandhäuschen	Germany	Oceanic	Realised	2013
55	Commercial Building Kobra	Slovenia	Mediterranean	Realised	2011
56	Student Dormitory Varazdin	Croatia	Mediterranean	Realised	2017
57	Energy-Plus Primary School	Germany	Continental	Realised	2011
58	MGG²² Residential Development	Austria	Continental	Realised	2019

2.2.1 PEB development over time

The earliest PEB identified in our exercise was built in 1994 in Freiburg im Breisgau, Germany, and further information on this single-family dwelling named Heliotrope Solar Home can be found in the annexes to this report (PEB no. 23). The most recent example of a PEB being planned relates to a hotel that is to be built in the middle of a Norwegian fjord, inside the arctic circle (PEB no. 20). Whilst some information sources indicate that completion of the Svart Hotel is scheduled for 2023, the project appears to have been put on hold, due the current economic crisis and uncertainties regarding the fallout of the Covid-19 pandemic.

Examining the 58 case dataset overall, PEB development in Europe appears to have been gaining traction since the year 2009, with a number of single family detached demonstration projects being realised in Denmark and Ireland as well as a 33.5 m tall office building with 4,500 m² floor space completed in Dijon, France (Elithis Tower, PEB no. 18). Since 2009 the rate of PEB development appears to be generally increasing, with the years 2014 and 2018 recording particularly high numbers (Figure 2). In terms of square metres of PEB realised, the year 2014 also stands out, with 92,205 m². The second highest amount of square metres realised to PEB standard was recorded in 2017, with 78,435 m² (Figure 3).

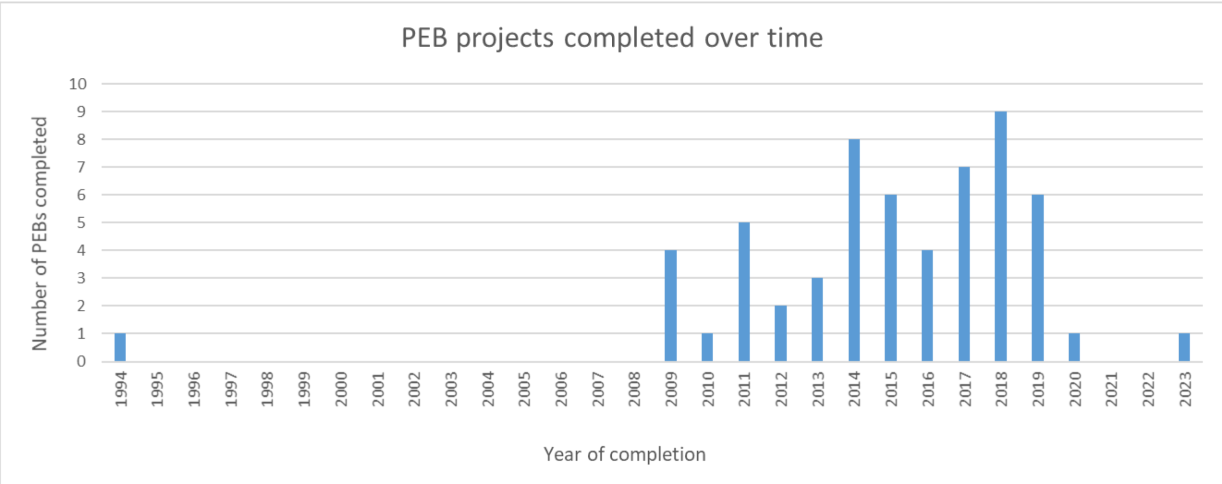

Figure 2 | Graph of PEB completions in Europe in the past years

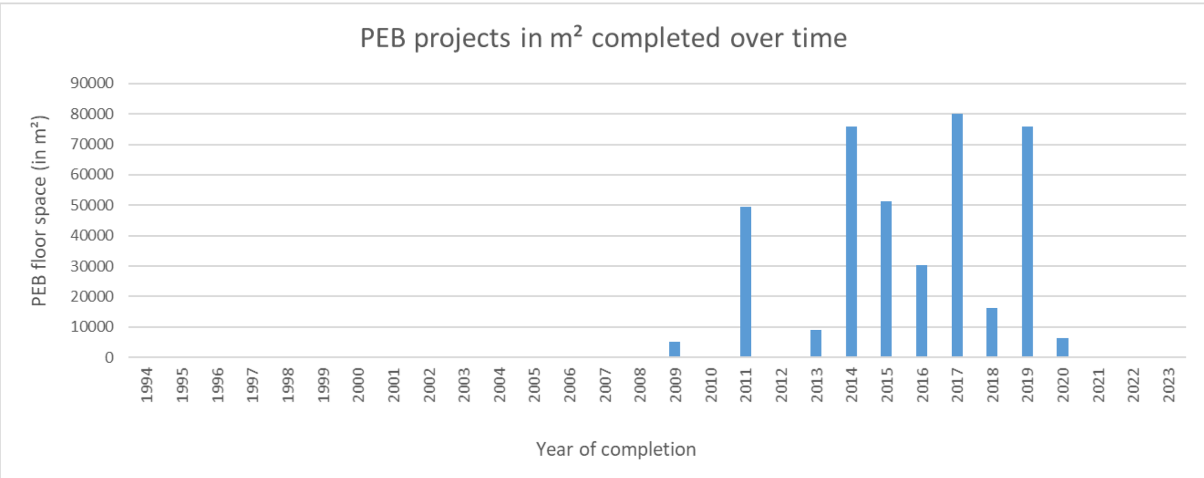

Figure 3| Graph of completed PEB floor space in the past years

2.2.2 PEB typologies / uses

Examining the function of the buildings reveals that 40.3% of buildings in our dataset are commercially used, 38.8% of PEBs are used for residential purposes and 20.9% are public buildings. Disaggregating these classifications further, office buildings are in fact the most common type of PEB in this dataset (31.3%), with single family residential dwellings (19.4%) and educational buildings (14.9) coming in at second and third place, respectively. Multi-unit residential developments account for 13.4% of the PEBs in the dataset.

At the other end of the spectrum, it is noteworthy that no health or emergency services buildings were found that are energy positive and only one industrial building fulfilled the PEB criteria (the Aerem factory in PEB no. 30, which is featured in a stand-alone case study in the attachment). Further underrepresented PEB types include laboratories (1.5%) as well as public administration buildings, community centres and hotels (all 3.0% each).

2.2.3 PEB renovation vs. new construction

Only 7 out of the 58 PEBs analysed were renovation projects. As deep renovations of buildings to PEB standard is of great interest to the EXCESS consortium, three of these are featured in stand-alone case studies that are presented in Chapter 3 and the attachments. The earliest PEB renovations were completed in 2014, whilst new construction of PEBs began to pick up in 2009 already. This might indicate that skills, technologies or economic factors could be holding back activity. Particularly when examining the average cost for PEB renovations, which stands at approx. EUR 1700 / m², the business case for this level of energy efficient retrofit may not be sufficiently strong to gain traction under current market conditions.

2.2.4 Trends in PEB dimensions and form

Positive energy buildings come in all shapes and sizes, ranging from small prefabricated residential dwellings such as the SOLACE house with 45 m² (see case study in the attachments) to large office complexes like the 35,000 m² Green Office® Rueil in Rueil-Malmaison, France. Measured in surface area, there is no clear trend that PEB developments with certain functions (e.g. commercial, residential, etc.) have been increasing in size significantly since 2009. It would appear, however, that building taller residential PEBs with eight or more floors is becoming feasible, but more data would be required to confirm this observation.

With regard to building form it can be noted that numerous buildings incorporate bioclimatic design principles, particularly to ensure daylight penetration into the building to decrease the need for artificial lighting, whilst controlling excess solar gain. Further, it can be observed that - in smaller residential buildings especially - roof pitches and orientations are frequently specified to allow for maximum solar energy gain in the respective PEB's geographic location. Larger PEBs tend to feature flat roofs and in some cases it is mentioned specifically that these are kept free of building services modules, to allow for the maximum amount of solar panel coverage. A further PEB feature that can influence building form are natural ventilation considerations, with designers creating interior spaces to harness stack-effects to extract air from the building envelope with minimal mechanical energy use.

2.2.5 PEB distribution across Europe and four climate zones

The stocktaking exercise identified most PEBs in France, with 46.6% of PEBs located in the country. Germany takes second place with 17.2%, followed by Norway (6.9%). European territories where comparatively few or no PEBs could be identified include Southern Europe, Eastern Europe and the Baltic States.

Using the climate zoning map of a Dutch seed company (see map below on the left), the EXCESS team identified 26 PEBs in the oceanic climate zone (229,874 m²), 13 PEBs in the continental climate zone (85,121 m²), 8 PEBs in the Mediterranean climate zone (20,259 m²) and 5 in the Nordic climate zone (24,279 m²). In oceanic climates the majority of PEBs are commercially used (53.8%), followed by residential and public use (42.3% and 23.1% respectively). In Mediterranean and Nordic climates commercial uses were most frequently encountered, whilst in continental climates residential PEBs are most represented in the sample.

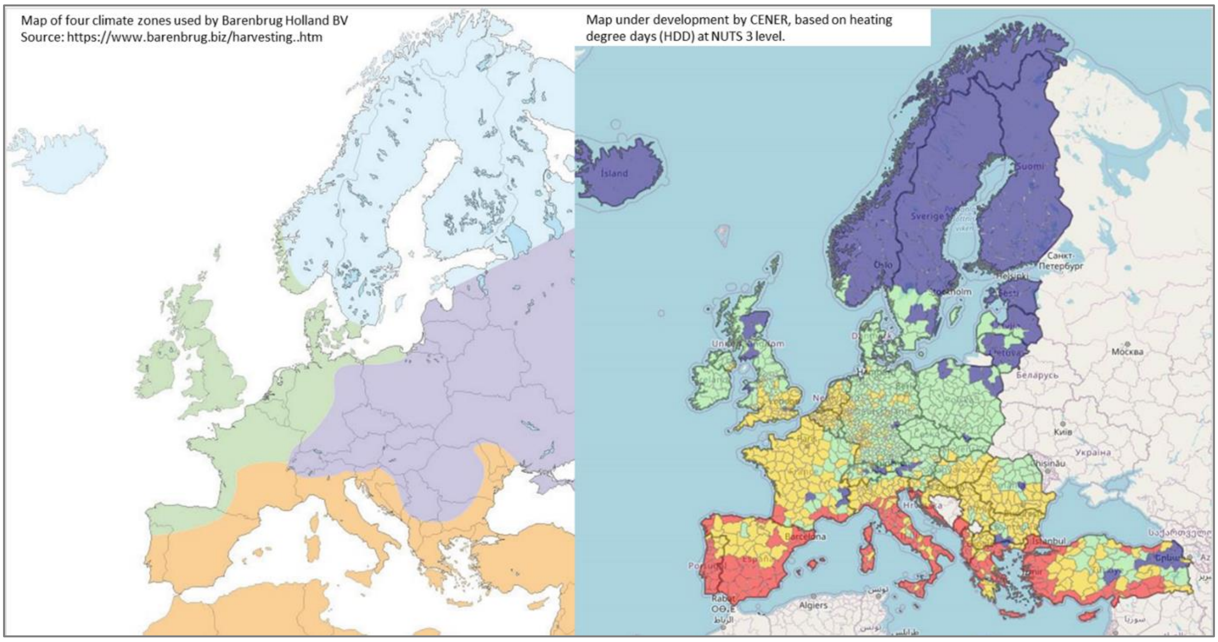

Figure 4 | Climate Zones in Europe, showing a zoning approach of a seed supplier (left) and an approach based on heating degree days being developed by CENER (right).

Whilst the zoning approach used by Barenbrug Holland BV places the EXCESS demonstration projects[2] into four different climate zones, it is arguably less useful in the context of the stocktaking exercise, as it was not designed for buildings, but centres on plant growing conditions. A zoning approach by CENER, which is still under development, creates four main climate zones, based on heating degree days (HDD) at NUTS 3 level (see map to the right, in Figure 4). As this approach to zoning is more tailoured to buildings, the PEBs were also categorised according to the tentative CENER classification. Interestingly, when categorising PEBs according to this classification, a significant majority of buildings are located in the “Low to Moderate HDD” zone (69%), with the “Moderate to High HDD” zone trailing behind with 14% of PEBs. The remaining percentage (17%) is evenly spread across the low and high HDD zones.

[2] The EXCESS project is testing innovative yet cost-competitive building technology packages in the cities of Graz (AT), Hasselt (BE), Espoo (FI) and Nivalis (ES). Adopting a holistic approach that takes climatic conditions into account, EXCESS partners have set themselves the ambitious goal of retrofitting nearly-zero energy multi-storey residential buildings into Positive Energy Buildings (PEBs) or building new PEBs from the ground up.

2.2.6 Common technologies integrated in PEBs

With regard to building technologies it should be noted that in many cases it proved impossible to find complete information for individual cases and it is highly likely that figures and percentages attributed to specific technologies presented in this subchapter are much higher in reality. Nevertheless, the analysis does provide some insights into potential trends that could be explored further by conducting more in-depth research.

Examining the key technologies installed in the buildings, it is clear that photovoltaic (PV) panels are by far the most common, with all PEBs using these to some degree. Another very frequently installed technology is an energy efficient mechanical ventilation system (81%), which is often coupled with heat recovery systems (86%). In 70% of cases the integration of an energy management system and sensors was mentioned, but this figure is likely to be much higher. Energy efficient heating is another common feature incorporated in PEBs (69%), with energy efficient cooling being mentioned much less often (33%).

In relation to energy generation besides PVs, solar thermal collectors are quite a common feature of PEBs (33%) with systems that tap into geothermal energy or energy in the ground / groundwater being integrated less often (17% and 12%, respectively). Boilers (or plants / burners) using renewable fuels also feature in PEBs relatively often (28%) and are used for energy generation, emergency back-up or to cover peak demands. Four PEBs may be using boilers running on fossil fuels, which would not be in line with the EXCESS definition of PEBs[3], but the exact fuel type could not be confirmed by desk research. Building-integrated wind power generation appears to feature quite rarely (6.9%). Very much connected to generation is, of course, the capability to store energy and in 43% of the cases examined, thermal storage is explicitly mentioned. Storing electrical energy in batteries on the other hand seems to be much less common, with only 10% of PEBs using such technology.

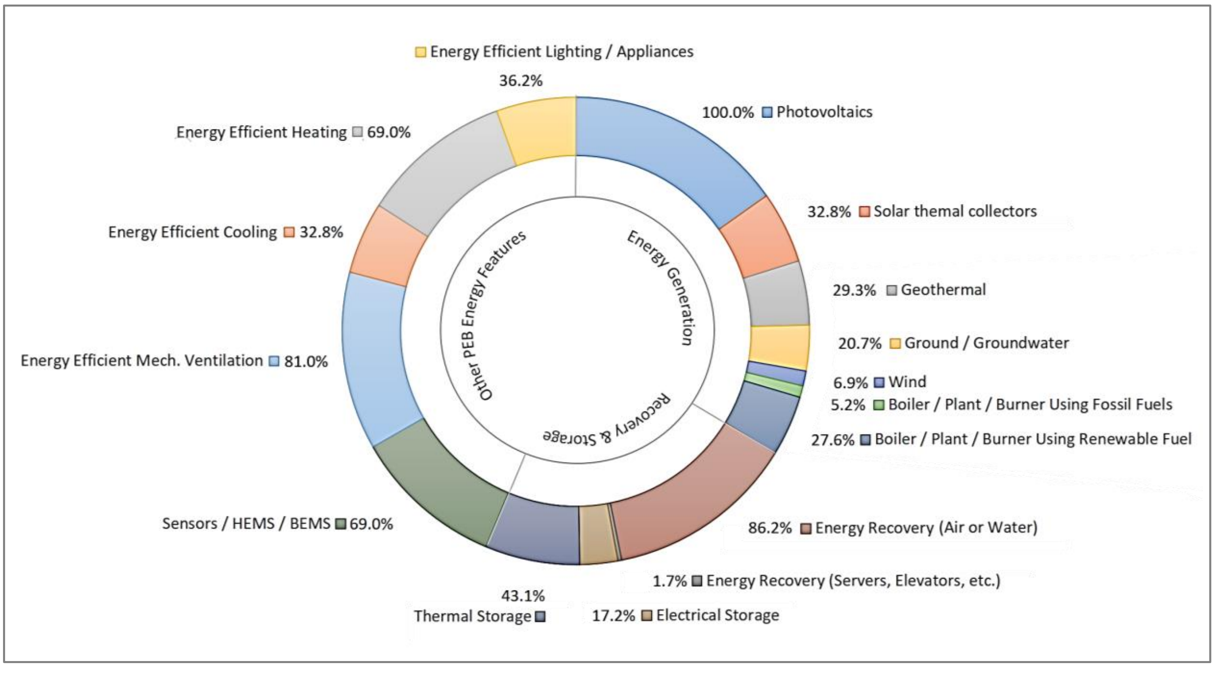

Figure 5 | Visualisation of key technologies used in 58 PEBs across Europe

[3] See Ala-Juusela et al. 2020. EXCESS Deliverable 1.1: PEB as enabler for consumer centred clean energy transition: shared definition and concept.

Breaking down PEB technology integration according to the Barenbrug climate zones, solar thermal collectors appear to be most popular in continental countries (54%) and geothermal energy systems are more commonly used in Nordic as well as Mediterranean climates (40% and 43% respectively). Energy systems using ground or groundwater heat are most frequently used in continental climates (31%). Wind energy is harnessed in continental and oceanic climates, but no PEBs use building-integrated wind power in the other two climate zones. Thermal storage systems are integrated into PEBs relatively evenly across climate zones, but electrical storage appears to be more prevalent in the Nordic climate zone (60%). Energy efficient cooling is mentioned most often in documentation related to PEBs in Mediterranean climates and energy efficient heating is most frequently mentioned in documentation for PEBs in Nordic climate zones.

Using the CENER zoning approach based on HDD at NUTS 3 level, solar thermal generation is mentioned most frequently in "Low HDD" zones (40%) and geothermal as well as electrical storage in "High HDD" zones (40% and 60% respectively). The incorporation of thermal energy storage is mentioned relatively evenly across all climate zones, with documentation for PEBs in "Moderate - High HDD" climates mentioning this solution 7-10% more frequently than in others. Data on the integration of further PEB technologies across the tentative CENER – HDD zones is visualised in the graph below (Fig. 6).

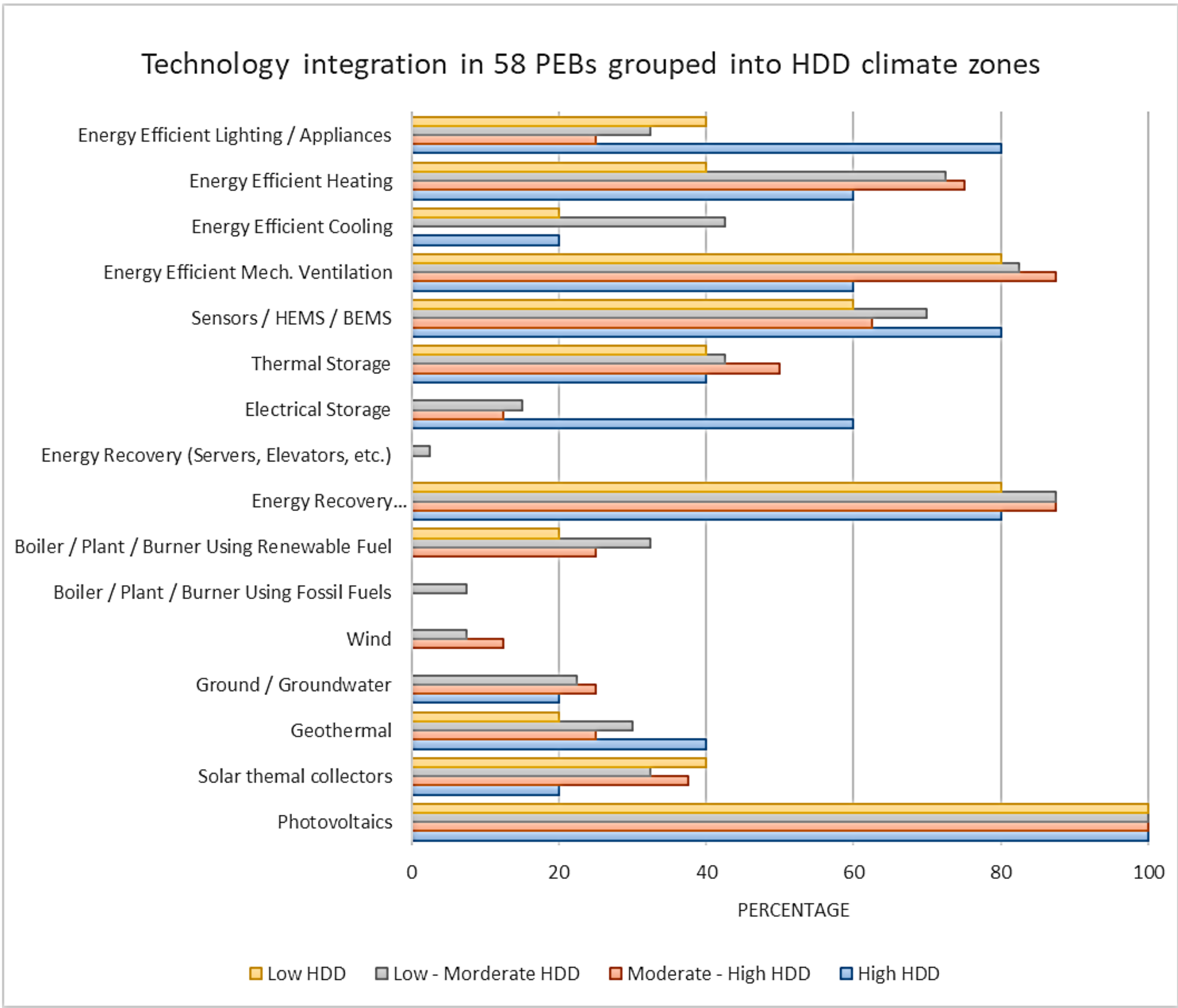

Figure 6 | Graph showing PEB technology integration across four HDD climate zones

2.2.7 Stakeholder interaction

Interaction of actors in the conception, design, planning and construction of buildings is a key feature for successful construction projects. In the case of positive energy buildings, collaboration between specialist firms and the deep engagement of the client and building users appears to be even more crucial. Indeed, an average of 7.7 partners were involved per PEB in the 58 cases analysed, with office buildings such as the OVG's TNT Centre even requiring the collaboration of 24 different organisations. However, it should also be noted that smaller sized projects such as the Concert or Conference Hall "The House for All" (PEB No. 33) are characterised by high levels of engagement, bringing together 22 stakeholders.

The EXCESS team rated stakeholder involvement on the basis of the number of companies involved as well as statements made pertaining to stakeholder engagement in PEB documentation found. The rating is therefore subject of change, as further quantitative and qualitative data for individual PEBs comes to light. Presently, 52% of PEBs are rated as having very high or high stakeholder engagement and 33% are rated as having medium-high engagement. Medium levels of stakeholder involvement were attributed to 14% of the cases, but this figure should be considered with caution as information pertaining to the buildings was not sufficiently detailed to draw definitive conclusions. Only one of the PEBs was rated as having medium-low engagement levels, as only few participating firms could be identified and, due to the prefabricated nature of the project, it was not clear to what extent client and user-specific needs or desires could be incorporated (Sobek's Aktivhaus B10, PEB No. 24).

With regard to stakeholder engagement, two developers of PEBs deserve a special mention, as they appear to be driving PEB construction in their respective countries. The French developer Bouygues Immobilier stands behind a great number of sustainable residential, office, retail and neighbourhood projects. A number of the developer's projects that have been identified in this stocktaking exercise stand out for high levels of stakeholder engagement, including the Hikari Complex (see case study Chapter 3 and attachments for further details) and the Green Office® developments (PEB No. 42 – 46). A further big player in the field of PEB development is the Powerhouse alliance, which is developing highly innovative projects in Norway and beyond that seem to benefit from the strong and longstanding collaboration of involved firms, high levels of client interaction and ambitious sustainability targets (see case study Chapter 3 and attachment on the Powerhouse Kjørbo for further information). Examining the work of these two players suggests that business models underpinning PEB development are most effective when bringing together construction companies that have the right skills and are experienced in collaborating with one another.

On the client side it should be noted that many of the companies and individuals commissioning PEBs appear to be guided by considerations of environmental sustainability and occupant well-being. In office buildings with positive energy performance it is also noteworthy that many of the tenants appear to be companies that place considerable emphasis on reducing their environmental impact, as documented in corporate responsibility strategies.

2.2.8 Energy trading agreements

Information on energy trading agreements and grid integration is rarely described in documentation related to individual PEBs. Understanding that grid-integration is a key factor for realising PEBs, nearly-zero energy buildings and for decarbonising our built environment generally, data gathering and pinpointing innovative approaches to grid connectivity and energy trading remains a priority for EXCESS consortium partners.

Of the 58 PEBs analysed, information on grid connections could only be found for 26 projects. In most cases details were limited, hence policy-relevant conclusions can hardly be drawn from these. Information for 7 of the 26 PEBs simply states that the buildings are connected to grids (5 to district heating and 2 to the electricity grid), but no details whether these connections are used bi-directionally is provided. In the case of 6 PEBs - located in Austria, France, Germany and Ireland – it is explicitly stated that surplus electricity is fed into the grid and feed-in tariffs are being availed of. In the case of the Greek PEB demonstration project "Passivistas: TheHouseProject", which is featured as a stand-alone case study in the attachments, a feed-in tariff is available, but according to an interviewee the rates are set too low, to make this worthwhile. 6 of the 24 PEBs share surpluses with neighbouring buildings or via micro-grids. Five buildings, which are located in France, Germany, the Netherlands, Norway and the UK feed surplus electricity into the grid, benefiting from feed-in tariffs, and one PEB in France (OVG's TNT Centre, PEB No. 19) shares thermal energy with neighbouring buildings and feeds electricity into the grid. The only PEB for which feed-in tariffs have been agreed for the export of excess thermal as well as electrical energy into the district- / city-wide grid is the NEWTONPROJEKT Haus 1 project in Germany (PEB No. 28) and further information on this lighthouse project is provided in a case study (Chapter 3 and attachments).

2.2.9 Financing, affordability, transferability and replicability of PEBs

Detailed information on financing arrangements for building projects are mostly not published and for 28 seemingly privately financed PEBs it is not clear whether, or to what degree, grants or subsidies were accessed. In 22 cases the PEBs - which include schools, community centres and public administration buildings - were publicly funded in their entirety. Information available for 8 PEBs indicates that whilst predominantly privately financed, public funds were also accessed. The Greek PEB "Passivistas" (PEB No. 52) stands out for having received significant amounts of private sector sponsorship support whilst not availing of any public funds.

With regard to affordability, subchapter 2.2.3 already touched upon the high cost of PEB renovations. For new construction the average price lies at around EUR 2,160 per square metre. This figure is based on data from 34 PEBs and has in parts been derived from estimated floor space figures. Further, it is unclear whether grants or subsidies have already been reflected in the project costs quoted. Assuming that figures and assumptions made are fairly accurate, constructing PEBs would appear to be considerably more expensive than traditional buildings. In addition to calculating an average square meter price for newly constructed PEBs, buildings were also rated[4] individually: 11 PEB new builds, including the Elithis Tower in France (PEB No. 18), the Commercial Building Kobra in Slovenia and the Student Dormitory Varazdin in Croatia (PEB No. 55 and 56) were deemed to be highly affordable. 4 newly constructed PEBs were given a medium-high rating in terms of affordability, 19 PEBs received a medium affordability rating and 11 PEBs were ranked as being of medium-low affordability. The Concert or Conference Hall "The House for All", was ranked as the least affordable, as data suggests that it cost EUR 3,966 /m² to realise.

Rating the PEBs in terms of their transferability and replicability potential was to some degree compromised by a lack of detailed project information and the ratings[5] are subject to change, once

[4] The rating uses the following square meter cost categories: high = below EUR 1,600 /m²; medium-high = EUR 1,600 to 2,000 /m²; medium = 2,000 to 2,400 /m²; medium-low = 2,400 to 2,800 /m²; low = above 3,000 /m².

[5] Ratings on Transferability and replicability take into account financial considerations, as well as qualitative information obtained in desk research.

more detailed documentation on individual buildings comes to light. Based on the information at hand, 4 PEBs were evaluated as being highly transferable and replicable. Two PEBs, the Sobek's Aktivhaus B10 (PEB No. 24) and the SOLACE Demo House (PEB No. 14), were given a high mark, as the buildings are prefabricated off-site and can be quickly and easily assembled anywhere across Europe. Two passive houses, one being the Greek Passivistas retrofit project and the other a newly built home in Sicily (PEB No. 53), were given top marks as they demonstrate that PEBs are feasible in Mediterranean climates and can be realised at reasonable price points, using readily available and proven technologies. 23 PEBs were given a medium-high rating, 26 a medium rating, 4 received a medium-low rating and 1 PEB[6] a low rating.

2.3 Additional outputs

To showcase the results of the stocktaking exercise, the PEBs were mapped using Geographic Information System (GIS) software and the map has been uploaded to the [EXCESS website](), to provide visitors an overview of PEBs in Europe and enable them to find basic information for each project. Presently, the map includes data on building location, their status and (planned) year of completion, the EXCESS climate zone as well as surface area.

Over the project cycle the map will be further developed as new PEBs are reported to the consortium and additional data points from the stocktaking matrix, including website links to information resources will be added.

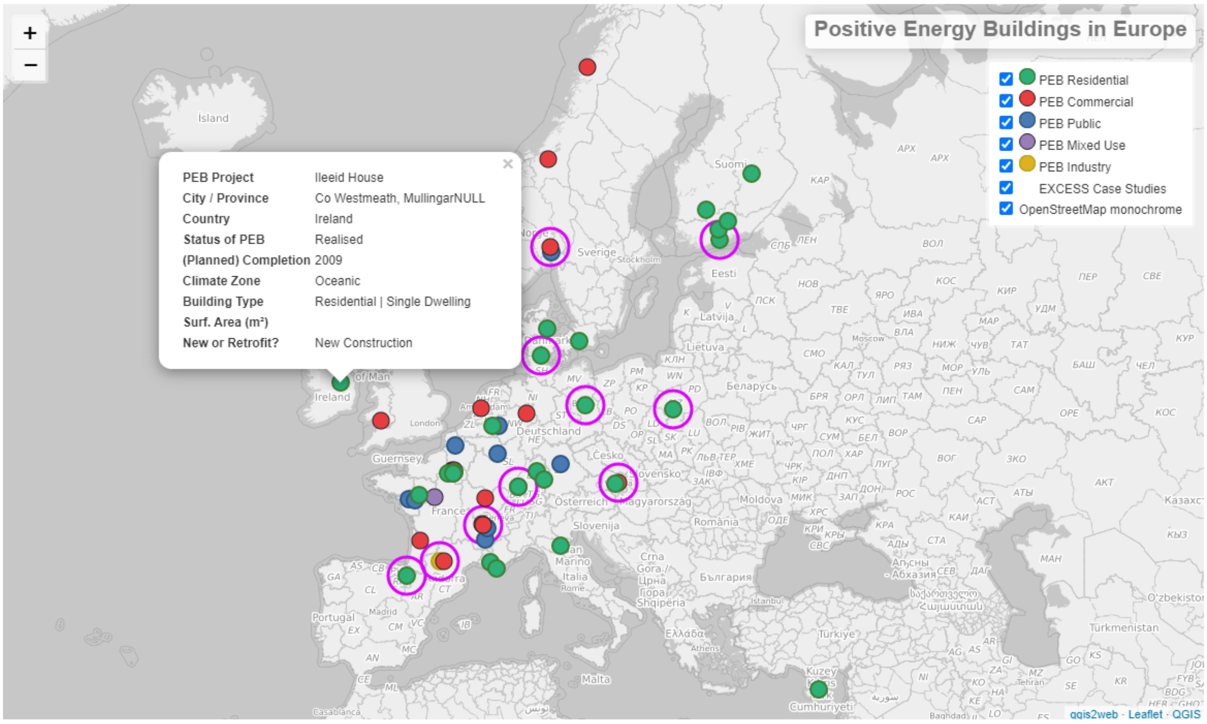

Figure 7 | Online map showcasing the PEBs identified in the stocktaking exercise

[6] The Svart Hotel was given a low rating, as the planned development appears to be highly complex, with it being located in the middle of a Fjord in the Arctic Circle.

3 Case studies

As next step after the stocktaking exercise, the project partners ICLEI, JR, URB, VITO and VTT developed a number of detailed case studies to provide insights regarding the development of positive energy buildings in Europe that go beyond the overarching stocktaking exercise. The case studies presented in this report will also be published on the EXCESS website as stand-alone outputs and advertised via social media in biweekly intervals. It is envisaged that the cases will serve to inspire built environment stakeholders to embrace innovative approaches to improve the sustainability performance of building renovations and new construction.

The individual case studies are presented in the attachments, while this part of the report describes the work process leading up to the finalisation of the cases and also delves into some of the key findings. The analysis includes findings related to the market readiness of technologies, barriers to project implementation, necessary levels of stakeholder engagement as well as catalysts, barriers and replication potentials for the selected European PEBs.

3.1 Timeline and milestones

The provisional case study selection suggested by ICLEI was presented and agreed upon by EXCESS consortium partners in March 2020. Reflecting the focus of EXCESS on residential buildings, five of the cases selected relate to single and multi-unit residential PEB developments and one further case is a mixed-use development that includes apartment units. To showcase the diversity of PEB types, the team also included a public administration building, two office buildings that were retrofitted to a PEB standard as well as a positive energy industrial building. Further, the team sought to ensure that all four climate zones would be represented in the final case study selection.

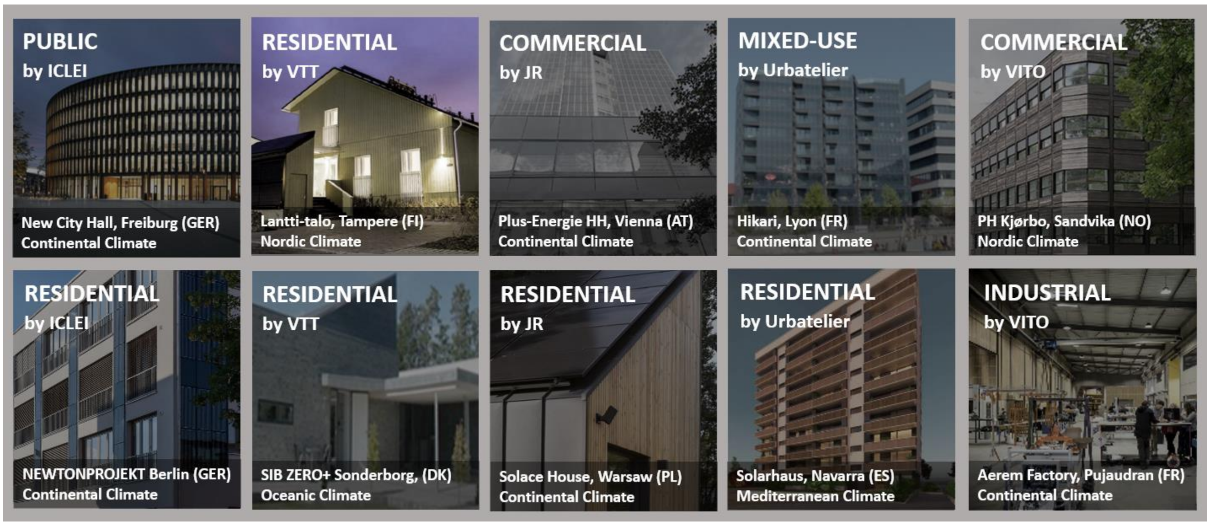

Figure 8 | Overview of PEBs selected for more in-depth case studies

The case studies provide more in-depth information on individual PEB projects, going beyond the basic data collected in the course of desk-research for the stocktaking exercise. In particular, the cases provide further detail on technologies used, building performance indicators as well as challenges, opportunities and PEB replication potential. Case study authors obtained this additional information by conducting interviews with - or by receiving written contributions from – involved stakeholders.

Whilst authors endeavoured to provide a neutral perspective, the reliance on inputs by stakeholders may, in some cases, have led to challenges to PEB realisation being underdocumented.

With European countries going into progressively restrictive levels of lockdown in March 2020 project partners faced considerable difficulties in reaching stakeholders involved in PEB development. In light of these knock-on effects, ICLEI and the EXCESS project coordinator JOANNEUM RESEARCH set about developing further case studies, to be used as possible back-ups. The switch of case studies means that presently no PEB from an oceanic climate is included in the report.

Case studies not featured in this report are the commercial building Kobra in Slovenia and the student dormitory Varazdin in Croatia (PEB No. 55 and 56, respectively) as well as the SIB ZERO+ case study from Denmark (PEB No. 16), which is located in an oceanic climate. These three cases will be supplemented with further data and presented alongside the 10 PEBs as stand-alone case studies in the summer and autumn of 2020. Bringing the total of case studies to 13, the project team has therefore been able to mitigate COVID-19 impacts and will be delivering more case studies than planned.

3.2 Key observations related to the PEB case studies

The PEB case studies presented in the report confirm some of the general observations made in the context of the stocktaking exercise – particularly regarding building form, technologies integrated and levels of stakeholder engagement. The dependency on further qualitative and quantitative data from companies and institutions involved in individual projects has limited the authors' ability to select performance indicators that allow for the comparison across PEBs and also made it more difficult to pinpoint challenges. Lastly, it should be noted that detailed information on barriers and opportunities pertaining to regulatory frameworks and financing for PEB development could not be identified in many cases. The below section provides a summary of observations that could be made against the backdrop of these limiting factors.

3.2.1 Building features and technologies

In relation to building design it is noteworthy that many of the featured cases follow a life-cycle approach that examines energy and emissions attributable to materials, the construction process, the operational phase as well as end-of-life recyclability. Further, a number of cases incorporate bioclimatic design features to maximise daylight penetration (thus reducing the need for artificial lighting), whilst also managing solar gains by adapting the building form or specifying exterior shading. The strategic configuration of interior spaces to enable natural ventilation should also be highlighted as a means to reduce energy consumption and, lastly, it is clear that roof space is seen as a precious commodity in PEB design, with architects and planners tending to seek to maximise the available surface area for the installation of photovoltaics and / or solar thermal collectors.

In addition to photovoltaics and solar thermal collectors, geothermal energy is often used as an efficient and renewable source for heating and cooling for positive energy buildings. For energy storage, both thermal tanks as well as batteries are being used in the featured case studies. Reducing energy consumption is also a clear priority in PEB design, with energy efficient lighting, appliances and also occupant behaviour being recognised as important to reduce overall energy demand.

With regard to thermal management of buildings a passive house approach is commonly used, with the specification of high insulation levels, a prioritisation for achieving high levels of air tightness and installing mechanical or hybrid ventilation systems, in conjunction with heat exchangers to capture energy from exhaust air. In some cases energy is also recovered from elevators and servers. A further strategy adopted in many buildings is to use a building's solid structural core for thermal storage with heat being stored and slowly released over time.

Going beyond building-related energy concerns it should also be noted that many of the PEBs in the case studies incorporate additional sustainability features, such as rain water collection (for irrigation and non-potable purposes), providing showers and lockers for cyclists to encourage non-motorised or low-emission transport, incorporating EV-charging facilities, etc. The inclusion such features indicates that PEB design is guided not only by the desire to achieve net energy positivity, but is also driven by an integrated and holistic view of sustainable architecture and urbanism.

3.2.2 Stakeholder involvement

The case studies strongly support observations already made in the context of the stakeholder interaction analysis of the stocktaking exercise (Chapter 2.2.7). A client's vision and desire to minimise environmental impacts appears to be a key factor underpinning PEB development in the first place and high levels of engagement from all involved stakeholders seems to be required throughout the design and construction process. Particularly since complex projects require the collaboration of a greater number of specialist firms than is typically the case with conventional real estate development projects, it is indispensable that project teams collaborate well and a level of trust has been established between parties.

3.2.1 Catalysts, challenges & replication potential

Whilst the case of the Greek project Passivistas demonstrates that deep renovations can be carried out cost effectively, using readily available technologies and materials, stronger financial support and regulatory frameworks would undoubtedly accelerate the replication of PEBs. Cases in Germany, Norway and France have benefitted from significant subsidies or grants and until the business case for PEBs is well established, these support mechanisms will continue to play a role in facilitating PEB development. As noted in the context of the case study focussing on the NEWTONPROJEKT in Berlin, Germany, existing schemes such as "KfW-Effizienzhaus 40 Plus" could potentially be improved by moving away from a prescriptive list of technologies that have to be used and embracing a more performance-based approach (that would have to be monitored, reported and verified) instead.

To reduce the up-front cost of PEBs, the analysis of case studies suggests that it may be prudent to adopt more modular, prefabricated building components. The time savings associated with using such approaches could also help to mitigate the longer planning and design phases that are seemingly associated with realising PEBs. This approach also reduces some risks in the construction phase, e.g. related to exposure to moisture. A further cost reduction strategy that seems promising entails encouraging prospective homeowners to form collectives to realise projects, thus reducing margins applied by traditional real estate developers.

Whilst in some of the case studies new solutions were developed and tested, many PEB technologies implemented appear to be market-ready, reliable and cost-competitive. The integration of these technologies into energy management systems can still come with teething problems, with the need to calibrate these to reach energy performance and comfort targets, however. Lastly, a key challenge - that when overcome would catalyse the upscaling of positive energy buildings significantly - is the integration of PEBs into local thermal and electrical grids. Bi-directional grid interaction (at a city, neighbourhood or building-group scale) plays an important role in enabling buildings to achieve net-positive energy balances.

Looking forward, PEB design will undoubtedly evolve as building-integrated energy storage solutions mature further and opportunities, such as those associated with electric vehicle storage capacities, are exploited. Advancements shall be monitored by the EXCESS team continuously and innovative new approaches will be recorded and analysed, so as to inform project-specific actions and contribute to the greater energy efficiency and decarbonisation of Europe's building stock by extension.

4 Conclusions and next steps

The stocktaking exercise has provided valuable data on positive energy buildings across Europe, which will become more robust, as the sample size included in the analytical matrix increases. Already now, however, a number of conclusions could be drawn from the dataset:

- **Learn from the leaders in the pack and examine barriers in countries that lag behind:** France and Germany as well as some Scandinavian countries appear to be leading the way on PEB development and their regulatory frameworks and incentivisation schemes should be analysed in detail so that countries where PEBs are underrepresented can create more supporting environments for PEB development.

- **Some PEB technologies are more popular than others:** Photovoltaic systems are seemingly the go-to technology for PEBs. As financial details in the context of the stocktaking exercise as well as the case studies rarely touch upon costs and amortisation rates of individual technologies, findings cannot definitively pinpoint the reason. The drastic reductions in the price of PV solutions over the past years (in line with Swanson's law[7]) suggests, however, that the technology has become a financially sound investment choice for many construction industry and real estate sector stakeholders. It is also a technology that is relatively easy to install and to connect to the grid, compared with e.g. heating technologies.

  It should be noted that solar thermal collectors and systems tapping into ground(water) / geothermal energy also seem to be gaining traction more broadly, which indicates that these technologies have, or are in the process of reaching, mass-market readiness . Building-integrated wind energy generation and electrical energy storage are not yet being widely adopted and further research on the reasons behind this could support the development of schemes to encourage greater market uptake.

- **Solving complex problems requires high levels of stakeholder collaboration:** To successfully develop PEBs a range of specialised firms must be brought together, and the client's engagement is key to understand needs and expectations.

- **Business models underpinning PEB development:** The most effective business models seem to be created by bringing together construction companies that have the right skills and are experienced in collaborating with one another.

Agreements to feed excess electricity and thermal energy into grids merit further research: Further information on current barriers to integrating PEBs into local electricity grids and heating or cooling networks is needed, so that these can be addressed at the relevant levels of governance.

[7] The "law" stipulates that the cost of the PV cells needed to generate solar power falls by 20% with each doubling of global manufacturing capacity.

More fine-grained data on financial arrangements and affordability is needed: The stocktaking exercise has unearthed a treasure trove of transferable, replicable and scalable approaches to PEB development. To fully exploit these, current locally applicable support schemes and regulations must be understood more deeply. Further the affordability of PEBs must be examined in much greater detail to calculate more precisely how much higher location-specific upfront costs for PEB development are compared to traditional construction or renovation are and how swiftly these are amortised over time.

5 Annexes

5.1 Annex I - short descriptions of the PEBs identified

To complement the section on the stocktaking exercise, Annex I briefly describes the 58 PEB projects individually and links to external web resources are provided. The PEBs are listed in the order in which they were identified in the course of desk research.

PEB No. 1 | Plus-Energie-Bürohochhaus, TU Wien | Vienna, Austria: The Plus-Energy high-rise office building of the University of Technology in Vienna (TU Wien), completed in 2014, is the first example of a sustainable renovation of an office tower, transforming it into a building that gives more energy to the grid than it consumes. It is also a great example of successful interdisciplinary collaboration, simultaneous, integrated planning, as well as a well-developed use concept. In addition to achieving a drastically reduced energy consumption rate (down by up to 88%), the building produces electricity directly through a photovoltaic system integrated into the facade and mounted on the roof as well as via energy recovery from elevators. Energy recovered from the servers waste heat is the main source of heating for the building. This building proves that renovation with a plus-energy concept is not only technically possible but also commercially feasible. External website / PDF Links: LINK I | LINK II

PEB No. 2 | Powerhouse Kjørbo | Sandvika, Norway: Powerhouse Kjørbo is a renovation project of two former office buildings that were originally constructed in 1979. It was the first time that buildings were renovated to a positive energy building standard. In order to comply with Powerhouse's own definition of a positive energy building, energy systems were specified to produce more energy over their lifetime than necessary for the production of construction materials, construction, operation and demolition (plug loads are not taken into account). An important first step towards reaching this target was to reuse and select environmentally friendly construction materials. In addition, a ground-source heat pump system was installed in combination with an efficient ventilation system. External website / PDF Links: LINK I | LINK II | LINK III

PEB No. 3 | Freiburg's New City Hall | Freiburg Im Breisgau, Germany: The New City Hall in the City of Freiburg is a highly energy efficient public building that has received national accolades and international recognition. The municipal building, which was completed in 2017, is a powerful example of how local government's commitment and vision, the effective collaboration of specialist firms and a careful balancing act between economic considerations and environmental sustainability ambitions can result in a modern and future-proof administrative building. In addition to benefits such as lower maintenance and running costs, the working environment of local government staff has improved, and citizens benefit from the concentration of administrative functions and services in one central location. Constructed over a 33-month period and costing 82.5 million Euro, the 24,215 m² building provides office space for 840 local government employees. The distinctive curved design features a highly insulated building envelope with integrated photovoltaics (PV), an expansive array of rooftop

PV and hybrid panels, whilst heating and cooling is achieved via a ground-water coupled heat pump system and groundwater heat exchanger. External website / PDF Links: LINK I | LINK II

PEB No. 4 | Hikari Complex | Lyon, France: This PEB building is located in the new "Lyon Smart Community" area, i.e. Confluence. Designed by the Japanese Architect Kengo Kuma and realized by Bouygues Immobilier, this 12 800 m² block is made up of 3 buildings. These buildings have been designed for office-use (HIGASHI building), housing (MINAMI) and commercial facilities (NISHI). Solar power panels are located on the MINAMI's building south façade, in order to benefit from the seasonal light energy. As the project required an installation from the outside, the R1008 were chosen to simplify mounting and respect the French railing legislation. External website / PDF Links: LINK I

PEB No. 5 | Residence Ma. Curie 2 | La Garde, France: Realised in 2019, the Marie Curie II project was designed to have a low environmental impact. The PEB was equipped with photovoltaic panels on the terrace roof, a wood boiler and was insulated with wood fibre on the exterior, in compliance with the Gold Sustainable Mediterranean Buildings label. External website / PDF Links: LINK I | LINK II | LINK III

PEB No. 6 | Residence etudiant arc en Meyran | Aix en Provence, France: The student residence, which was constructed in 2016, features high levels of externally applied mineral wool insulation and the building has been oriented (and shading devices have been installed) to regulate solar gains. The building is connected to a district heating network that is 63% powered by biomass, its ventilation system is highly energy efficient, and photovoltaic panels have been installed on the roof. External website / PDF Links: LINK I | LINK II | LINK III

PEB No. 7 | Residence Esperia | Montreuil, France: This 23-unit project, which was constructed in 2013, is divided into 2 buildings and is the first collective housing project certified with the BEPOS-Effinergie 2013. The buildings were constructed using a wooden frame structure and feature high-performance insulation. A centralised wood pellet boiler provides heating, a humidity sensitive single flow ventilation system reduces heat loss and 70 m² of photovoltaic panels provide electricity. The project stands out in particular for the high degree of stakeholder involvement in the planning stage and for taking a life-cycle approach to building, so as to understand and mitigate environmental impacts. External website / PDF Links: LINK I

PEB No. 8 | Positive Energy High School | Carquefou, France: The design of the Lycée de Carquefou incorporated passive house strategies and bioclimatic principles from the outset. In addition to the highly insulated building envelope, the team specified an innovative system for cooling and the hybrid photovoltaic collectors on the roofs achieve an efficiency gain of 30%. Further, large thermal water storage tanks were incorporated to preheat water by the sun (and in winter additionally by a wood pellet boiler). The school also features a highly efficient ventilation system, rainwater harvesting and surplus energy is fed into the grid. External website / PDF Links: LINK I LINK II | LINK III

PEB No. 9 | Eco-Renovation of KTR France HQ | Dardilly, France: Prior to relocating the KTR France headquarters to a new location in western Lyon, the company commissioned an ambitious renovation project to make the premises fit for purpose, which was completed in 2018. The building stores thermal energy via four 150 m deep probes (providing heat as well as cooling via the floors in summer), produces electricity via PV panels and includes a storage battery to maximise self-consumption rates. By conducting a life cycle analysis, the project team followed a low-carbon approach that focussed on local renewable materials that benefit local businesses and reduce emissions. External website / PDF Links: LINK I | LINK II

PEB No. 10 | P.A.T.H Turnkey House | Montfort l'Amaury, France: The P.A.T.H. prototype house showcases how prefabrication and a modular approach can be applied to the construction of PEBs.

Customers can choose from 34 floor plans, with floor spaces ranging from 140 m^2 to 350 m^2, to suit their needs. Offsite production drives down cost and increases speed (customers can expect the house to be move-in ready after 3 months of on-site assembly and interior finishing). The passive house performs exceedingly well in terms of thermal performance and building technologies such as solar panels, mini wind turbines and other eco-technological equipment are integrated to help the building produce more energy than it consumes. External website / PDF Links: LINK I | LINKII | LINK III

PEB No. 11 | Willibald-Gluck-High School | Neumarkt, Germany: The new Willibald Gluck Secondary School demonstrates that educational buildings have great PEB potential. Annual electricity consumption has remained significantly below the calculations at 28.5 kWh/m^2y. This is mainly due to the fact that the user-specific power consumption is lower than assumed. With an output of around 290 kWp, the PV systems accounts for 35 per cent of the annual balance. The system components are designed so that they can be expanded to 600 kWp. This would enable the school to achieve the energy-plus level. External website / PDF Links: LINK I | LINK II | LINK III

PEB No. 12 | Lantti-talo | Tampere, Finland: The goal of the Lantti House was to use as many renewable and carbon dioxide-storing building materials as possible, whilst simultaneously aiming for energy savings. Design solutions such as detached house models, structural and HVAC solutions were studied as alternatives and evaluated with sensitivity analysis. The energy consumption of the building options in the design phase was repeatedly assessed with simulations. As a result, Lantti is an overall eco-efficient house with an airtight and well-insulated structure. Lastly, as a plus energy house, it produces more electricity than it needs with photovoltaic panels and heats from solar collectors and district heating. External website / PDF Links: LINK I | LINK II

PEB No. 13 | Powerhouse Brattørkaia | Trondheim, Norway: Powerhouse Brattørkaia is the current flagship Positive Energy Building developed by Powerhouse - an alliance of private sector partners in Norway. Construction on the world's northernmost PEB was completed in 2019, providing 17,800 m^2 of office space. The building produces more than twice as much electricity as it consumes. By means of a local micro grid it will supply excess renewable energy to neighbouring buildings, electric buses, cars as well as boats. External website / PDF Links: LINK I | LINK II

PEB No. 14 | Solace (Demo) House | Warsaw, Poland: SOLACE is an invention of a Polish start-up and aims to challenge prevailing paradigms in the housing market. Designed to reduce energy consumption, with solar panels fixed on its tilted roof, it produces more energy than it needs and sells surplus energy to the grid, thus keeping the living and maintenance costs at a minimum. In addition, this house - claimed to be 'the first prefabricated plus-energy house' - is made up of 16 prefabricated parts that are delivered to the customer in only one container and it can be easily assembled in less than 72 hours. External website / PDF Links: LINK I | LINK II | LINK III

PEB No. 15 | Ileeid House | Co Westmeath, Mullingar, Ireland: Ileeid house stands out for being Irelands first carbon negative house and it also generates more energy than it consumes over a one-year period. Completed in 2009, the building is largely heated by the sun, as it was designed using passive solar principles. As a back-up a ground source heat pump in conjunction with a heat exchanger can provide additional warmth and the heat exchanger also serves to enable solar heating. Excess electricity from the PV panels with an output of approx. 7 kW is fed into the grid. A further noteworthy strength of the project is that sustainable and low carbon materials were used wherever possible. External website / PDF Links: LINK I | LINK II | LINK III | LINK IV

PEB No. 16 | SIB ZERO+ House | Sonderborg, Denmark: Denmark's first SIB ZERO+ house was built in 2009 in Sonderborg. The house features a combination of energy efficient insulation, ventilation with heat recovery, passive solar heating, a geothermal heat pump, photovoltaics and a modern energy management system that constantly monitors and optimizes the use of energy. It achieves a positive annual energy balance and sells excess power to the national grid at the market price. The energy consumption of the house was 5133 kWh in 2009 and 2010 (the first 12 months) - including heating, cooking and all domestic appliances. During the same year the 42 m^2 solar panels produced 5160 kWh - an annual surplus of 27 kWh. External website / PDF Links: LINK I

PEB No. 17 | Sunlighthouse Pressbaum | Pressbaum, Austria: The building was designed as a model home to showcase how innovative architectural design, the careful sourcing of building materials, high energy efficiency and integrated renewable energy technology can be integrated into a single-family home of the future. The building's design was strongly influenced by daylight and human comfort considerations. The project has won numerous awards and was the first carbon neutral (in construction and operation) single family home to be built in Austria. External website / PDF Links: LINK I | LINK II | LINK III

PEB No. 18 | Elithis Tower | Dijon, France: Completed in 2009, the Elithis tower was hailed as the first energy office building. Incorporating a host of PEB technologies, such as rooftop PV panels, an efficient ventilation system with heat recovery, energy recovery from computers and other appliances, wood pellet burners. By making innovative design choices (such as installing a sun shield that reduces solar gain on the southern side of the building), primary energy demand could be reduced to 21 kWh/m^{2}y. The building uses sustainable / recycled construction materials where possible. The PEB emits six times fewer greenhouse gas than traditional commercial buildings, yet building costs were comparable. External website / PDF Links: LINK I | LINK II | LINK III | LINK IV

PEB No. 19 | OVG's TNT Centre | Hoofddorp, Netherlands: The office building was designed to meet LEED Platinum standards and be carbon neutral, in line with the client TNT's goal to reduce its environmental impact. PEB technologies include PV-panels and a CHP plant that runs on biological waste. The building design has been carefully considered to ensure daylight penetration without excess solar gain. Further, construction materials were prioritised that are local, renewable and / or recycled. The building is 60% more energy efficient than typical office buildings and exports surplus thermal energy to its neighbours. External website / PDF Links: LINK I | LINK II | LINK III | LINK IV

PEB No. 20 | Svart Hotel [Arctic Circle]| Svartisen, Norway: The Svart Hotel is being planned by the Powerhouse Alliance which has a strong track record in PEB development. The circular hotel is to be located in the middle of a fjord in the arctic circle and has been designed to consume 85% less energy than a conventional hotel built to modern building standards in Norway. Harnessing solar power, the hotel will produce sufficient energy to cover its construction as well as operation. The boat to bring visitors to the hotel will also be charged via this system. External website / PDF Links: LINK I | LINK II

PEB No. 21 | Active Office | Bay Campus, Swansea, United Kingdom: Completed in 2018 the Active Office demonstration project on the campus of Swansea University was the first positive energy office to be built in the United Kingdom. The energy system includes 22 kWp photovoltaic panels on the roof, a 110 kWh battery system and a 2000 litre water tank to store solar heat. Further, the building provides EV charging points as well as a vehicle-to-building charging option. External website / PDF Links: LINK I | LINK II | LINK III | LINK IV

PEB No. 22 | New Montessori School | Drøbak, Norway: The Norwegian Montessori school is the Powerhouse Alliance's first educational building. A key challenge was to develop this PEB with only a comparatively modest budget. The team developed an architecturally well-considered building, deeply engaged stakeholders throughout the process and integrated technologies such as photovoltaics, energy wells to tap into geothermal energy and a highly efficient ventilation system (harnessing the stack effect to extract air from the building). Energy demand of the building is less than 25% than that of a typical school building in Norway and over its lifetime, the building will produce more energy than required for construction, operation and demolition. External website / PDF Links: LINK I | LINK II | LINK III | LINK III | LINK IV

PEB No. 23 | Heliotrope Solar Home | Freiburg Im Breisgau, Germany: The world's first positive energy home was constructed in 1994, guided by the design philosophy that buildings should be emission-free, CO_2 neutral and 100% regenerative. The cylindrical building is completely glazed on one side and heavily insulated on the other. To prevent excess solar gain the building can rotate away from the sun and in winter it turns it's glazed façade towards it. The large photovoltaic system on the roof aligns itself with the sun and vacuum tube collectors provide warm water and space heating. External website / PDF Links: LINK I | LINK II | LINK III | LINK IV

PEB No. 24 | Sobek's Aktivhaus B10 | Stuttgart, Germany: The Aktivhaus B10 can produce twice the amount of energy than it consumes and is produced as an offsite module. B10 includes EV charging stations and exports surplus energy to a neighbouring building. The modular approach was also used in a project in Winnenden-Schelmenholz to accommodate refugees (the modules were designed to have a net-zero energy balance, create zero emissions, be fully recyclable and can be fitted with PV-panels to make them energy positive). External website / PDF Links: LINK I | LINK II | LINK III

PEB No. 25 | Le Parc de l'Ensoleillée | Aix en Provence, France: Completed in 2013 and 2014 the two buildings are the first positive energy buildings realised in a timber construction in France. In addition to their ecological design, the buildings feature a range of PEB technologies including efficient mechanical ventilation systems with heat recovery, overnight natural ventilation systems and photovoltaic panels. External website / PDF Links: LINK I | LINK II

PEB No. 26 | L6 - L'OREAL Group Research Laboratory | Chevilly Larue, France: The laboratory was built to be highly environmentally friendly as well as to ensure the wellbeing of staff. PEB technologies installed include a Canadian well (using stable ground temperatures for heating and cooling), a double flow ventilation system coupled with a heat exchanger, photovoltaics and a micro wind turbine. External website / PDF Links: LINK I | LINK II

PEB No. 27 | Energy Positive Social Housing and Offices | Tours, France: The mixed-use building retrofit in Tours is particularly noteworthy as the PEB includes social housing as well as offices. Geothermal power is harnessed to heat and cool the building, whilst photovoltaics provide electricity. External website / PDF Links: LINK I | LINK II | LINK III

PEB No. 28 | NEWTONPROJEKT Haus 1 | Berlin, Germany: Realised in 2018, the NEWTONPROJEKT in Berlin can be seen as a great model for the future of residential PEB construction in Germany and elsewhere. Benefiting from attractive financing options for energy efficient buildings and applying a collective, user-centric approach to property development, the building ensemble delivers not only more energy than it consumes, but also incorporates a host of environmental sustainability considerations. External website / PDF Links: LINK I | LINK II

PEB No. 29 | Technical High School for Health Professionals | Ettelbruck, Luxembourg: The award-winning technical high school is the largest wooden building in Luxembourg. Much attention was placed on reducing grey energy (using ecological building materials) and a range of PEB technologies were implemented, such as: photovoltaics; solar thermal panels and energy storage; heat pumps; hybrid natural and mechanical ventilation systems; energy efficient computers and optimized LED lighting. External website / PDF Links: LINK I | LINK II

PEB No. 30 | "Aerem " Factory | Pujaudran, France: The Aerem building in the South of France proves that also factories, which typically have a relative high carbon footprint, can reach positive energy standards. The new building was constructed in 2018 and uses a modular steel structure as a basis which can be adapted and extended to make the factory more future proof. The steel structure is insulated with locally harvested straw to further reduce the carbon footprint of the construction materials. Heating and cooling is provided by a geothermal heat pump system in combination with night ventilation. Electricity is generated by photovoltaic panels on the roof. External website / PDF Links: LINK I

PEB No. 31 | Gustave André School Extension | Chabeuil, France: The school extension was realised in a timber construction and used locally sourced straw bales for insulation. The building is powered by photovoltaics and features an energy efficient ventilation system. The installed blinds help to manage solar gain. The extension is connected to the existing gas boiler system for heating and it is not clear whether this uses fossil fuels or biogas. External website / PDF Links: LINK I

PEB No. 32 | Education and Leisure Hub| Berlencourt le Cauroy, France: The building has been designed to nestle into the landscape and includes green roofs to ensure the building is in harmony with its local surroundings. PEB technologies installed include a wood boiler, a photovoltaic array as well as an energy efficient ventilation system. Excess electricity is sold into the grid. External website / PDF Links: LINK I

PEB No. 33 | Concert or Conference Hall | Les Souillères, France: The demonstration project was constructed to be a community centre to be used for conferences and events. Stakeholder engagement was a strong feature in the planning and realisation of the project. The use of ecological materials was prioritised and technologies such as the photovoltaics and the efficient ventilation system make the structure energy positive. External website / PDF Links: LINK I | LINK II

PEB No. 34 | Head office of the Caisse d'Epargne Bank | Bordeaux, France: The new Bank's headquarters have been designed to allow for high levels of daylight penetration. The building's large rooftop PV installation supplies all the electricity required for operation. Thermal energy for heating and hot water is supplied by the district network, however. External website / PDF Links: LINK I | LINK II

PEB No. 35 | Mauges Public High School | Beaupréau, France: The new school construction stands out for having, at the time of completion (in 2015), the largest Canadian Well in France. Electricity is generated from the sun as well as from wind. A "solar carpet" on the roof in conjunction with a heat pump supplies hot water. External website / PDF Links: LINK I | LINK II

PEB No. 36 | New HQ of GA Group | Toulouse, France: The office building is powered by geothermal energy and photovoltaics. The building design seeks to maximise daylight penetration and the wellbeing of building users was strongly emphasised. Surplus electricity is exported to neighbouring buildings in the business park. External website / PDF Links: LINK I

PEB No. 37 | Green Building Kirstein & Sauer | Bielefeld, Germany: The office building draws thermal energy from the district heating network for space heating and warm water. The large photovoltaic array has been angled towards the sun to best coincide with the consumption profile. Further PEB technologies include an energy efficient cooling system, a mechanical ventilation system with heat recovery and a smart building energy management system. External website / PDF Links: LINK I

PEB No. 38 | Venlo City Hall | Venlo, Netherlands: The new City Hall for the City of Venlo is perhaps most recognisable for its large green facade. A key sustainability feature is the cradle-to-cradle approach that was used, aiming to use materials and products in construction and operation that are 100% reusable. A greenhouse on the rooftop traps warm air, which is used to heat the building. Large strategically placed voids in the building allow for natural ventilation and make mechanical ventilation unnecessary. PEB technologies include geothermal energy generation, solar thermal panels and 1000 m² photovoltaics on the southern building facade. The PEB system has been designed to allow for easy upgrading in years to come. External website / PDF Links: LINK I | LINK II

PEB No. 39 | Student Residences | Paris, France: A key feature that sets this PEB apart from others is the heating and hot water system, which uses thermal collectors and very large storage tanks. These tanks are fed with surplus thermal energy in summer, which is then used during the winter months. Further technologies include photovoltaics and an energy generation system that uses waste. External website / PDF Links: LINK I

PEB No. 40 | The Home for Life | Lystrup, Denmark: The CO_2 neutral single-family home in Denmark produces more energy than it consumes by incorporating high levels of insulation, a smart natural ventilation concept and through the strategic placement of windows for daylight and solar gain. Key technologies used in the building include solar thermal collectors coupled with a heat pump and water tank, photovoltaics and a heat recovery system. External website / PDF Links:

PEB No. 41 | Maison Air et Lumière | Verrières-le-Buisson, France: The VELUX model home in France uses the same active building concept used for the "Home for Life" in Denmark. The highly insulated building envelope and strategic window placement reduce heating needs substantially and technologies such as a hybrid natural and mechanical ventilation system with heat recovery as well as solar thermal and photovoltaics help the building achieve a positive energy balance. External website / PDF Links: LINK I | LINK II

PEB No. 42 | Green Office® Meudon | Meudon, France: The office building has been given a shallow footprint, to ensure sufficient daylight penetration. Installed PEB technologies include a controlled natural ventilation system, photovoltaics, a biomass cogeneration plant as well as externally affixed shading devices upon which further PV-panels have been installed. External website / PDF Links: LINK I | LINK II

PEB No. 43 | Green Office® Spring | Nanterre, France: With just under 35,000 m² floor space, the office structure is one of the largest PEBs in Europe. The building incorporates technologies such as a ground water reversible heat pump, photovoltaics, a mechanical double-flow ventilation system with heat recovery and electric boilers for hot water. External website / PDF Links: LINK I | LINK II

PEB No. 44 | Green Office® Link | Lyon, France: The office building in Lyon achieves net energy positivity thanks to adopting bioclimatic design principles and integrating technologies such as photovoltaics , a rapeseed cogeneration plant with buffer storage, a geothermal energy system as well as an efficient mechanical ventilation system and natural ventilation system. External website / PDF Links: LINK I | LINK II

PEB No. 45 | Green Office® Rueil | Rueil-Malmaison, France: With a net floor area of 35,0000 m² the office building in Rueil-Malmaison, France, is the largest PEB in Europe. The building uses technologies such as photovoltaics, a geothermal heat pump, efficient underfloor heating and cooling as well as a mechanical double-flow ventilation system with heat recovery. External website / PDF Links: LINK I

PEB No. 46 | Green Office® Châtenay | Châtenay-Malabry, France: The mixed-use development harnesses renewable energy generation systems including photovoltaics, solar thermal panels and a geothermal system to produce more energy than the building ensemble consumes over a year. External website / PDF Links: LINK I | LINK II

PEB No. 47 | PRD Office | Pantin, France: The office building is equipped with 450 m² of photovoltaic panels and sells surplus electricity to the grid. External website / PDF Links: LINK I | LINK II | LINK III

PEB No. 48 | Energy Positive Dwelling | Sterksel, Netherlands: The positive energy dwelling has been designed and oriented to capture solar energy to heat the building in winter, while in summer, shades protect occupants from excessive solar gain. Walls are highly insulated and airtight. Further, the house incorporates solar panels, an air-water heat pump for hot water and floor heating / cooling as well as a ventilation system with heat recovery. External website / PDF Links: LINK I | LINK II

PEB No. 49 | Efficiency House Plus | Neu-Ulm, Germany: The renovation project integrated technologies such as photovoltaic panels, a mechanical ventilation system with heat recovery, a brine-water heat pump in conjunction with a 1000 litre tank to provide hot water and heating as well as efficient lighting and appliances. The building envelope's performance was improved by applying exterior insulation panels and installing triple glazed windows. External website / PDF Links: LINK I

PEB No. 50 | aquaTurm Water Tower | Radolfzell, Germany: The conversion of an old water tower into a hotel that delivers a positive energy balance necessitated considerable amounts of effort. Technologies integrated include photovoltaic and solar thermal panels, a geothermal system for heating, decentralised ventilation systems with heat recovery as well as a micro wind turbine. External website / PDF Links: LINK I | LINK II

PEB No. 51 | SOLARHAUS | Navarra, Spain: SOLARHAUS will be one of the first residential Positive Energy Buildings (PEB) in Spain. The unique high-end design is the result of a successful collaboration between the architectural practice Tabuenca-Saralegui, the National Centre for Renewable Energies (CENER) and a forward-looking client, Domeño Construcciones. The building design successfully balances architectural aesthetics, functionality and energy performance, thereby proving that PEBs in Spain are both technically possible as well as commercially viable. The building will feature a powerful rooftop photovoltaic installation, four air-water heat pumps, a highly insulated building envelope, radiant flooring for heating & a heat recovery ventilation system. External website / PDF Links: LINK I

PEB No. 52 | Passivistas: TheHouseProject | Papagos, Greece: Passivistas: TheHouseProject demonstrates that – even in economically difficult times – retrofitting existing residential buildings so that they generate more energy than they consume is both financially and technically feasible in Greece. Bringing together a team of experts and finding support from private sector partners as well as via crowdfunding, renovation works were carried out in 2015 and 2016, using materials and technologies available on the market. The cost for transforming the 125 m² two-level structure into a positive energy building (PEB) will be amortised in under seven years by energy savings. External website / PDF Links: LINK I

PEB No. 53 | Passive House in Sicily | Mascalucia, Italy: The single-family dwelling, which was newly constructed and designed to meet passive house standards, demonstrates that positive energy buildings can be realised in Southern Italy. The building incorporates technologies such as photovoltaic and solar thermal panels, a geothermal system, an energy efficient ventilation system with energy recovery as well as an energy management system. External website / PDF Links: LINK I | LINK II

PEB No. 54 | Family Center Sandhäuschen | Aachen, Germany: The Family Center Sandhäuschen was conceived as a low-energy building, according to the "Aachener Standard" and realised in 2013. In 2016 the building, which houses a day care nursery, was equipped with a 110 module photovoltaic system producing 28.000 kWh per year. Particularly as the building is used during the day time the installation a high self-consumption rate can be achieved and the building produces more energy than it consumes over a year. External website / PDF Links: LINK I | LINK II | LINK III

PEB No. 55 | Commercial Building Kobra | Šentjernej, Slovenia: The commercial building commissioned by the Kobra Team was realized in 2011 and demonstrates that buildings that produce more energy than they consume can be realized in Slovenia and beyond. Whilst the building was financed privately in its entirety, more public support would undoubtedly help the broader replication of such innovative projects in the region. The project stands out in particular for the carefully considered building form that incorporates bioclimatic design principles, the use of passive house specifications and the integration of multiple building technologies in an advanced building management system. External website / PDF Links: LINK I | LINK II

PEB No. 56 | Student Dormitory Varazdin | Varaždin, Croatia: With 243 rooms, each with own toilet, 15 kitchenettes, 6 living rooms, 6 study rooms and a restaurant, along public and green spaces, the Student Center Varazdin is another step in raising the general standard of living for students in Croatia. Design aims for sustainable development and environmental protection in order to achieve a zero-emission carbon tag. Solar power plants on the restaurant and the dormitory, ecological building materials, use of rainwater as sanitary water, water to water heating and cooling pumps, rational use of energy and low energy consumption, CNUS and energy certificate A+, are just some of the features that make this complex one of the first of its kind in this part of Europe. External website / PDF Links: LINK I | LINK II

PEB No. 57 | Energy-Plus Primary School | Hohen Neuendorf, Germany: The school in Hohen Neuendorf, Germany, was newly constructed and designed to be energy positive. Using passive house standards, the building harnesses technologies such as a hybrid ventilation system, shading systems to manage solar gains, integrated photovoltaic panels for electricity generation as well as wood pellet driven combined heat and power generation. External website / PDF Links: LINK I | LINK II

PEB No. 58 | MGG²² Residential Development | Vienna, Austria: The subsidised residential development project was completed in 2019 and incorporates 155 partly freely financed / partly privately financed apartment units. The positive energy building ensemble’s thermal energy needs (heating and cooling) are met by tapping into geothermal energy, using 30 approx. 150 m deep probes in conjunction with heat exchangers and a thermally activated building core. An agreement with a regional wind park operator was reached so that in cases of surplus wind energy the turbines are not but the free electricity is instead fed into the building, converted into thermal energy and is stored in the building core and ground for later use. PEB features of MGG²² include high levels of building envelope insulation and airtightness. The buildings are neither connected to district heating nor to the gas network. Further, the project stands out for its affordability and high levels of comfort it provides to residents. External website / PDF Links (available in German only): LINK I | LINK II

5.2 Annex II - selected tables from the stocktaking exercise

Annexes II to IV present data for selected indicators in relation to PEBs included in the stocktaking exercise. Table 3 below provides local climate information for the PEBs, whilst table 4 (Annex III) covers PEB construction / renovation year, project cost (where available) and building use. Table 5 (Annex IV) provides information on PEB technologies.

Table 2 | Comparing climate classifications for 58 PEBs

Number	Name of PEB example	Tentative CENER Zoning, based on HDD	Zoning of Barenbrug Holland BV	Climatic zone according to Köppen Climate Classification
1	**Plus-Energie-Bürohochhaus, TU Wien**	Low - Moderate HDD	Continental	Dfb - Warm-summer humid continental climate | Cold (continental) | Without dry season | Warm summer
2	**Powerhouse Kjørbo**	High HDD	Nordic	Dfc - Subarctic climate | Cold (continental) | Without dry season | Cold summer
3	**Freiburg's New City Hall**	Low - Moderate HDD	Continental	Cfb - Temperate oceanic climate | Temperate | Without dry season | Warm summer
4	**Hikari Complex**	Low - Moderate HDD	Mediterranean	Cfb - Temperate oceanic climate | Temperate | Without dry season | Warm summer
5	**Residence Ma. Curie 2**	Low HDD	Mediterranean	Csa - Hot-summer Mediterranean climate | Temperate | Dry summer | Hot summer
6	**Residence etudiant arc en Meyran**	Low HDD	Mediterranean	Csa - Hot-summer Mediterranean climate | Temperate | Dry summer | Hot summer
7	**Residence Esperia**	Low - Moderate HDD	Oceanic	Cfb - Temperate oceanic climate | Temperate | Without dry season | Warm summer
8	**Positive Energy High School**	Low - Moderate HDD	Oceanic	Cfb - Temperate oceanic climate | Temperate | Without dry season | Warm summer
9	**Eco-Renovation of KTR France HQ**	Low - Moderate HDD	Mediterranean	Cfb - Temperate oceanic climate | Temperate | Without dry season | Warm summer
10	**P.A.T.H Turnkey House**	Low - Moderate HDD	Oceanic	Cfb - Temperate oceanic climate | Temperate | Without dry season | Warm summer
11	**Willibald-Gluck-High School**	Moderate - High HDD	Continental	Dfb - Warm-summer humid continental climate | Cold (continental) | Without dry season | Warm summer
12	**Lantti-talo**	High HDD	Nordic	Dfc - Subarctic climate | Cold (continental) | Without dry season | Cold summer
13	**Powerhouse Brattørkaia**	High HDD	Nordic	Dfc - Subarctic climate | Cold (continental) | Without dry season | Cold summer
14	**Solace (Demo) House**	Low - Moderate HDD	Continental	Dfb - Warm-summer humid continental climate | Cold (continental) | Without dry season | Warm summer
15	**ileeid house**	Low - Moderate HDD	Oceanic	Cfb - Temperate oceanic climate | Temperate | Without dry season | Warm summer
16	**SIB ZERO+ House**	Moderate - High HDD	Oceanic	Cfb - Temperate oceanic climate | Temperate | Without dry season | Warm summer
17	**Sunlighthouse Pressbaum**	Low - Moderate HDD	Continental	Dfb - Warm-summer humid continental climate | Cold (continental) | Without dry season | Warm summer
18	**Elithis Tower**	Moderate - High HDD	Oceanic	Cfb - Temperate oceanic climate | Temperate | Without dry season | Warm summer
19	**OVG's TNT Centre**	Low - Moderate HDD	Oceanic	Dfb - Warm-summer humid continental climate | Cold (continental) | Without dry season | Warm summer
20	**Svart Hotel [Arctic Circle]**	High HDD	Nordic	ET - Tundra |Polar | Tundra
21	**Active Office**	Low - Moderate HDD	Oceanic	Cfb - Temperate oceanic climate | Temperate | Without dry season | Warm summer
22	**New Montessori School**	High HDD	Nordic	Dfb - Warm-summer humid continental climate | Cold (continental) | Without dry season | Warm summer
23	**Heliotrope Solar Home**	Low - Moderate HDD	Continental	Cfb - Temperate oceanic climate | Temperate | Without dry season | Warm summer
24	**Sobek's Aktivhaus B10**	Low - Moderate HDD	Continental	Cfb - Temperate oceanic climate | Temperate | Without dry season | Warm summer
25	**Le Parc de l'Ensoleillée**	Low HDD	Mediterranean	Csa - Hot-summer Mediterranean climate | Temperate | Dry summer | Hot summer

Number	Name of PEB example	Tentative CENER Zoning, based on HDD	Zoning of Barenbrug Holland BV	Climatic zone according to Köppen Climate Classification
26	L6 - L'OREAL Group Research Laboratory	Low - Moderate HDD	Oceanic	[Dfb] Humid Continental Mild Summer, Wet All Year
27	Energy Positive Social Housing and Offices	Low - Moderate HDD	Oceanic	[Cfb] Marine Mild Winter, warm summer, no dry season.
28	NEWTONPROJEKT Haus 1	Low - Moderate HDD	Continental	[Dfb] Humid Continental Mild Summer, Wet All Year
29	Technical High School for Health Professionals	Moderate - High HDD	Continental	[Cfb] Marine Mild Winter, warm summer, no dry season.
30	"Aerem " factory	Low - Moderate HDD	Mediterranean	[Cbc] Mild, dry winter, warm and wet summer.
31	Gustave André School Extension	Low - Moderate HDD	Mediterranean	[Cfb] Marine Mild Winter, warm summer, no dry season.
32	Education and Leisure Hub	Low - Moderate HDD	Oceanic	[Cfb] Marine Mild Winter, warm summer, no dry season.
33	Concert or Conference Hall "The House for All"	Moderate - High HDD	Mediterranean	[Csa] Interior Mediterranean - Mild with dry, hot summer.
34	Head office of the Caisse d'Epargne Bank	Low - Moderate HDD	Oceanic	[Cfb] Marine Mild Winter, warm summer, no dry season.
35	Mauges Public High School	Low - Moderate HDD	Oceanic	[Cfb] Marine Mild Winter, warm summer, no dry season.
36	New HQ of GA Group	Low - Moderate HDD	Mediterranean	[Cfb] Marine Mild Winter, warm summer, no dry season.
37	Green Building Kirstein & Sauer	Low - Moderate HDD	Oceanic	[Dwb] Humid Continental Mild Summer, Dry Winter
38	Venlo City Hall	Low - Moderate HDD	Oceanic	[Cfb] Marine Mild Winter, warm summer, no dry season.
39	Student Residences	Low - Moderate HDD	Oceanic	[Cfb] Marine Mild Winter, warm summer, no dry season.
40	The Home for Life	Moderate - High HDD	Oceanic	Dfb - Warm-summer humid continental climate | Cold (continental) | Without dry season | Warm summer
41	Maison Air et Lumière	Low - Moderate HDD	Oceanic	[Cfb] Marine Mild Winter, warm summer, no dry season.
42	Green Office® Meudon	Low - Moderate HDD	Oceanic	[Cfb] Marine Mild Winter, warm summer, no dry season.
43	Green Office® Spring	Low - Moderate HDD	Oceanic	[Cfb] Marine Mild Winter, warm summer, no dry season.
44	Green Office® Link	Low - Moderate HDD	Mediterranean	Cfa - Humid subtropical climate | Temperate | Without dry season | Hot summer
45	Green Office® Rueil	Low - Moderate HDD	Oceanic	[Cfb] Marine Mild Winter, warm summer, no dry season.
46	Green Office® Châtenay	Low - Moderate HDD	Oceanic	[Cfb] Marine Mild Winter, warm summer, no dry season.
47	PRD Office	Low - Moderate HDD	Oceanic	[Cfb] Marine Mild Winter, warm summer, no dry season.
48	Energy Positive Dwelling	Low - Moderate HDD	Oceanic	[Cfb] Marine Mild Winter, warm summer, no dry season.
49	Efficiency House Plus	Moderate - High HDD	Continental	Dfb - Warm-summer humid continental climate | Cold (continental) | Without dry season | Warm summer
50	aquaTurm Water Tower Hotel	Moderate - High HDD	Continental	Dfb - Warm-summer humid continental climate | Cold (continental) | Without dry season | Warm summer
51	SOLARHAUS	Low - Moderate HDD	Oceanic	[Cfb] Marine Mild Winter, warm summer, no dry season.
52	Passivistas - the house project	Low HDD	Mediterranean	[Csb] Coastal Mediterranean - Mild with cool, dry summer.
53	Passive House in Sicily	Low HDD	Mediterranean	[Csb] Coastal Mediterranean - Mild with cool, dry summer.
54	Family Center Sandhäuschen	Low - Moderate HDD	Oceanic	Dfb - Warm-summer humid continental climate | Cold (continental) | Without dry season | Warm summer
55	Commercial Building Kobra	Low - Moderate HDD	Mediterranean	Dfb - Warm-summer humid continental climate | Cold (continental) | Without dry season | Warm summer
56	Student Dormitory Varazdin	Low - Moderate HDD	Mediterranean	Dfb - Warm-summer humid continental climate | Cold (continental) | Without dry season | Warm summer

Number	Name of PEB example	Tentative CENER Zoning, based on HDD	Zoning of Barenbrug Holland BV	Climatic zone according to Köppen Climate Classification
57	**Energy-Plus Primary School**	Low - Moderate HDD	Continental	Dfb - Warm-summer humid continental climate | Cold (continental) | Without dry season | Warm summer
58	**MGG²² Residential Development**	Low - Moderate HDD	Continental	Dfb - Warm-summer humid continental climate | Cold (continental) | Without dry season | Warm summer

5.3 Annex III – construction information and typologies

Table 3 | New construction vs. renovation & building typology

Number	Name of PEB Example	New Construct?	Renovation?	Total Project Cost	Cost per m² (net floor space)	Building Typology												
						Commercial				Residential			Public					
						Office	Retail	Hotel	Laboratory	Single Dwelling	Multi-Unit	Stud. Residence / Retirement Home	Health	Education	Emergency Services	Administration	Community Centre	Industrial
1	Plus-Energie-Bürohochhaus, TU Wien		1	EUR 19.4 M	1437.0	1								1				
2	Powerhouse Kjørbo		1	EUR 12 M	2300.0	1												
3	Freiburg's New City Hall	1		EUR 86 M	3293.1											1		
4	Hikari Complex	1				1	1				1							
5	Residence Ma. Curie 2	1		EUR 11 M	2609.7							1						
6	Residence etudiant arc en Meyran	1		EUR 3.07 M	1278.4							1						
7	Residence Esperia	1		EUR 2.4 M	1350.0						1							
8	Positive Energy High School	1		EUR 38.5 M	3333.6									1				
9	Eco-Renovation of KTR France HQ		1	EUR 1.5 M	1756.0	1												
10	P.A.T.H Turnkey House	1			3500.0					1								
11	Willibald-Gluck-High School	1		EUR 35 M	2245.4									1				
12	Lantti-talo	1		EUR 341 K	2453.2					1								
13	Powerhouse Brattørkaia	1				1												
14	Solace (Demo) House	1								1								
15	ileeid house	1								1								
16	SIB ZERO+ House	1								1								
17	Sunlighthouse Pressbaum	1								1								

						Building Typology												
						Commercial				Residential			Public					
Number	Name of PEB Example	New Construct?	Renovation?	Total Project Cost	Cost per m² (net floor space)	Office	Retail	Hotel	Laboratory	Single Dwelling	Multi-Unit	Stud. Residence / Retirement Home	Health	Education	Emergency Services	Administration	Community Centre	Industrial
18	Elithis Tower	1		EUR 7 M	1555.6	1												
19	OVG's TNT Centre	1				1												
20	Svart Hotel [Arctic Circle]	1						1										
21	Active Office	1				1												
22	New Montessori School	1		EUR 2.6 M	2656.3									1				
23	Heliotrope Solar Home	1								1								
24	Sobek's Aktivhaus B10	1								1	1							
25	Le Parc de l'Ensoleillée	1			1200.0	1												
26	L6 - L'OREAL Group Research Laboratory	1		EUR 20 M	3382.0	1			1									
27	Energy Positive Social Housing and Offices		1			1					1							
28	NEWTONPROJEKT Haus 1	1		EUR 2.5 M	2317.0						1							
29	Technical High School for Health Professionals	1		EUR 10 M										1				
30	"Aerem " factory	1		EUR 5 M	1300.0													1
31	Gustave André School Extension	1		EUR 1.8 M	2244.0									1				
32	Education and Leisure Hub	1		EUR 3.9 M	1536.0									1				
33	Concert or Conference Hall "The House for All"	1		EUR 575 K	3966.0												1	
34	Head office of the Caisse d'Epargne Bank	1		EUR 24 M	2124.0	1												
35	Mauges Public High School	1		EUR 22 M	2000.0									1				
36	New HQ of GA Group	1		EUR 6.5 M	1857.0	1												
37	Green Building Kirstein & Sauer	1		EUR 10 M	1389.0	1												
38	Venlo City Hall	1		EUR 35.3 M	1274.9											1		
39	Student Residences	1		EUR 13 M	2573.0							1						
40	The Home for Life	1								1								
41	Maison Air et Lumière	1								1								
42	Green Office® Meudon	1		EUR 63 M	2703.9	1												
43	Green Office® Spring	1		EUR 78 M	2235.8	1												
44	Green Office® Link	1		EUR 11.5 M	1378.4	1												
45	Green Office® Rueil	1		EUR 70 M	2000.0	1												
46	Green Office® Châtenay	1		EUR 10 M	2475.2	1	1				1							

Number	Name of PEB Example	New Construct?	Renovation?	Total Project Cost	Cost per m² (net floor space)	Building Typology												
						Commercial				Residential			Public					
						Office	Retail	Hotel	Laboratory	Single Dwelling	Multi-Unit	Stud. Residence / Retirement Home	Health	Education	Emergency Services	Administration	Community Centre	Industrial
47	PRD Office	1		EUR 13 M	2078.3	1												
48	Energy Positive Dwelling	1								1								
49	Efficiency House Plus		1	EUR 1.4 M	2400.0						1							
50	aquaTurm Water Tower Hotel		1					1										
51	SOLARHAUS	1									1							
52	Passivistas - the house project		1	EUR 76 K	608.0					1								
53	Passive House in Sicily	1			1800.0					1								
54	Family Center Sandhäuschen	1		EUR 1.6 M	2666.7									1			1	
55	Commercial Building Kobra	1		EUR 2 M	1391.8	1	1											
56	Student Dormitory Varazdin	1		EUR 18.7 M	1175.6							1						
57	Energy-Plus Primary School	1												1				
58	MGG[22] Residential Development	1									1							

5.4 Annex IV – overview of PEB technologies

Table 4 | Positive energy building technologies

Number	Name of PEB example	Photovoltaics	Solar thermal collectors	Geothermal	Ground / Groundwater	Wind	Boiler / Plant / Burner Using Fossil Fuels	Boiler / Plant / Burner Using Renewable Fuel	Energy Recovery (Air or Water)	Energy Recovery (Servers, Elevators, etc.)	Electrical Storage	Thermal Storage	Sensors / HEMS / BEMS	Energy Efficient Mech. Ventilation	Energy Efficient Cooling	Energy Efficient Heating	Energy Efficient Lighting / Appliances
1	Plus-Energie-Bürohochhaus, TU Wien	1							1	1			1				1
2	Powerhouse Kjørbo	1		1					1		1	1	1				1

Number	Name of PEB example	Photovoltaics	Solar thermal collectors	Geothermal	Ground / Groundwater	Wind	Boiler / Plant / Burner Using Fossil Fuels	Boiler / Plant / Burner Using Renewable Fuel	Energy Recovery (Air or Water)	Energy Recovery (Servers, Elevators, etc.)	Electrical Storage	Thermal Storage	Sensors / HEMS / BEMS	Energy Efficient Mech. Ventilation	Energy Efficient Cooling	Energy Efficient Heating	Energy Efficient Lighting / Appliances
3	Freiburg's New City Hall	1	1		1		1		1			1	1	1	1	1	1
4	Hikari Complex	1			1			1	1		1		1	1	1	1	
5	Residence Ma. Curie 2	1						1									
6	Residence etudiant arc en Meyran	1							1					1			
7	Residence Esperia	1						1	1					1			
8	Positive Energy High School	1	1					1	1			1		1	1	1	
9	Eco-Renovation of KTR France HQ	1		1							1	1		1		1	
10	P.A.T.H Turnkey House	1				1		1	1				1	1		1	
11	Willibald-Gluck-High School	1			1						1		1			1	
12	Lantti-talo	1	1									1		1		1	
13	Powerhouse Brattørkaia	1			1				1		1		1	1	1	1	1
14	Solace (Demo) House	1							1				1	1	1	1	1
15	ileeid house	1	1	1				1	1			1	1			1	1
16	SIB ZERO+ House	1		1					1				1	1			
17	Sunlighthouse Pressbaum	1	1		1				1					1			
18	Elithis Tower	1						1	1				1	1			
19	OVG's TNT Centre	1			1			1				1	1	1		1	1
20	Svart Hotel [Arctic Circle]	1							1		1		1			1	1
21	Active Office	1	1								1	1	1	1		1	1
22	New Montessori School	1		1					1				1	1			1
23	Heliotrope Solar Home	1	1	1				1	1			1		1		1	
24	Sobek's Aktivhaus B10	1	1						1		1		1	1	1	1	1
25	Le Parc de l'Ensoleillée	1							1				1	1		1	1
26	L6 - L'OREAL Group Research Laboratory	1			1	1			1				1	1	1	1	
27	Energy Positive Social Housing and Offices	1		1					1					1			
28	NEWTONPROJEKT Haus 1	1	1						1		1	1	1	1		1	
29	Technical High School for Health Professionals	1	1						1			1	1	1		1	1
30	"Aerem " factory	1		1					1			1	1	1	1	1	
31	Gustave André School Extension	1					1		1					1			
32	Education and Leisure Hub	1						1	1				1	1	1		
33	Concert or Conference Hall "The House for All"	1						1	1					1		1	
34	Head office of the Caisse d'Epargne Bank	1							1			1	1	1	1		
35	Mauges Public High School	1	1		1	1			1				1	1	1	1	
36	New HQ of GA Group	1		1				1	1				1	1	1	1	
37	Green Building Kirstein & Sauer	1							1				1	1	1		1
38	Venlo City Hall	1	1	1					1								1

Number	Name of PEB example	Photovoltaics	Solar thermal collectors	Geothermal	Ground / Groundwater	Wind	Boiler / Plant / Burner Using Fossil Fuels	Boiler / Plant / Burner Using Renewable Fuel	Energy Recovery (Air or Water)	Energy Recovery (Servers, Elevators, etc.)	Electrical Storage	Thermal Storage	Sensors / HEMS / BEMS	Energy Efficient Mech. Ventilation	Energy Efficient Cooling	Energy Efficient Heating	Energy Efficient Lighting / Appliances
39	Student Residences	1	1						1			1	1			1	
40	The Home for Life	1	1						1			1	1	1		1	
41	Maison Air et Lumière	1	1						1			1	1	1		1	
42	Green Office® Meudon	1						1					1			1	1
43	Green Office® Spring	1			1			1	1				1		1	1	1
44	Green Office® Link	1		1				1	1			1	1	1	1	1	1
45	Green Office® Rueil	1		1					1				1	1	1	1	
46	Green Office® Châtenay	1	1	1					1				1	1		1	
47	PRD Office	1							1					1		1	
48	Energy Positive Dwelling	1							1					1		1	
49	Efficiency House Plus	1			1				1			1		1		1	1
50	aquaTurm Water Tower Hotel	1	1	1		1			1			1		1		1	
51	SOLARHAUS	1					1		1		1	1	1	1		1	
52	Passivistas - the house project	1	1						1			1	1	1	1		1
53	Passive House in Sicily	1	1	1					1			1	1	1		1	
54	Family Center Sandhäuschen	1															
55	Commercial Building Kobra	1		1	1				1			1	1	1			
56	Student Dormitory Varazdin	1			1				1			1	1	1	1	1	
57	Energy-Plus Primary School	1						1	1				1	1		1	1
58	MGG²² Residential Development	1		1					1			1		1	1	1	

5.5 Annex V – PEB case studies

The case studies have not been affixed to the report, so as to not unnecessarily bloat the file size of this public version of the document. Please refer to the PEB Case Studies section of the project website to download individual case studies: https://positive-energy-buildings.eu/peb-case-studies