Discussion paper: Understanding Positive Energy Buildings and Neighbourhoods - towards a common definition

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1. Why positive energy buildings?

The building sector plays an important role in the transition to a climate-neutral society [1]. This transition is at the heart of the European Green Deal[1] and in line with the EU's commitment to global climate action under the Paris Agreement[2]. The reduction of GHG emissions by at least 55% by 2030, requires energy efficient buildings and a high portion of local renewable energy production.

In this scenario, Positive Energy Buildings (PEBs) represent a step forward from Net Zero Energy Buildings. In particular, they shall contribute by:

- decarbonizing the built environment, including surrounding buildings, by exchanging energy among them or with the grid
- reducing the energy grid congestion
- providing a flexible energy asset that allows buildings and energy communities to act as an integrated part of the energy system
- ensuring healthy and comfortable indoor environment, embracing occupants' diversities and needs
- supporting users' energy-related practices and their flexibility
- minimizing their own carbon footprint.

In this direction, a consolidated definition is needed in order to enable the design, assessment, and documentation of PEBs in different contexts, climates, cultures, and markets.
This paper aims to present a joint understanding of the essence and benefits of Positive Energy Buildings applied to the residential sector, as discussed within the three sister projects Cultural-E (https://www.cultural-e.eu/ led by Eurac Research), EXCESS (https://positive-energy-buildings.eu/ led by Joanneum Research), and syn.ikia (https://www.synikia.eu/ led by NTNU), which were funded under the Programme H2020-EU.2.1.5.2/Call topic2. The key identified points to be considered in context of PEBs are the different level of system boundaries, the energy balance, the embodied energy, the dynamic matching and the renewable energy sources. In order to achieve a wider agreement on the terminology and physical boundaries for PEBs, the three projects also discussed their findings with a bigger group of stakeholders working on PEBs or related fields [2].

[1] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1588580774040&uri=CELEX:52019DC0640
[2] https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

2. What are Positive Energy Buildings?

As a general requirement, a PEB shall produce more energy than it consumes, and feed renewable energy source (RES)-based energy to the grid or other surrounding buildings. In this way, PEBs can support areas with older or listed buildings with architectural constraints, where the transition to zero energy level would not be cost-efficient or feasible.

This implies more interaction with the energy grids, which needs to be taken into account in the definition, more than in the case of Net Zero Energy Buildings. In addition, PEBs shall contribute to reducing the energy grid congestion by providing a flexible energy asset that allows buildings and energy communities to act as integrated parts of the energy system and exchange energy (electrical, thermal energy, or other future energy carriers) among them or with the grid. This also enables the accommodation of potential energy demand variations due to alterations of the standard context of users/householders and/or within building communities.

The positive energy balance should be achieved alongside key functional requirements related to occupants' well-being, users' expectations and satisfaction, and other materials and environmental aspects. Therefore, a user-centered design approach should be adopted for the design of PEBs i.e., to provide a comfortable and healthy indoor environment for its occupants and raise their awareness on how daily practices impact on the building energy demand and its overall performance.

3. Key aspects of PEBs definition

The three sister projects had each developed their own definition[3] at the early phase of the joint approach. According to these statements, contents do not differ significantly and a common understanding is here proposed. The three projects agree that the PEB is an energy-efficient building that produces more energy from renewable sources than it consumes over a time span of one year.

In a PEB, non-renewable primary energy consumption shall be minimized by means of energy efficiency measures, while ensuring comfortable and healthy indoor environments. Then, the residual energy demand is met by RES, with the aim to produce an additional amount of energy. Furthermore, the positive balance shall be reached while ensuring a high self-consumption and an energy flexible asset.

Although the definitions in the three projects focus mainly on new residential buildings, they are also applicable to buildings that undergo major renovations.

The three definitions include a series of key aspects that need to be stated in a consistent framework for PEB, and in particular:

- On and off-site RE generation
- Balance contributions
- Balance metrics
- Timescale
- Type of balance
- Dynamic matching
- Smartness and flexibility
- Embodied energy and GHG emissions
- Indoor Environmental Quality

[3] https://www.cultural-e.eu/peb-definition/; https://positive-energy-buildings.eu/news?c=search&uid=u8cjD5Hy; https://www.synikia.eu/library/

On-site vs off-site RE generation

The physical boundary primarily indicates how to differentiate between on-site and off-site RE generation (i.e., the systems that are within the physical boundary are considered "on-site" and the rest are "off-site"). The physical boundary could spread from the household to the building, and to the neighbourhood.

For the on-site supply, the building can harvest RES energy from within the building lot [3].

For the off-site options the building may get RE available by a shared infrastructure owned by the building stakeholder or occupants. This is the case of different buildings sharing energy through a local distribution grid or duct, to enable energy flexibility logics at the neighbourhood level.

The definition of physical boundaries has a great impact on the potential of reaching PEB targets and decision making need to take that into account depending on building type, usage, and location. For instance:

- Establishing physical boundaries at household level in a multi-family building would empower users but the benefits of PEB would be reduced if scaled down and limited to a single apartment. Furthermore, all apartments in a new building are conceived in a similar way and this may not be feasible in cases where RE generation is shared among households.
- A building in a rural area could have a higher potential to locally produce energy from RES than buildings in urban and sub-urban areas, due to the greater availability of spaces and lower density of the built environment.
- Compact and high-rise buildings may have less potential to produce energy locally because of the limited available space for installing RE technologies.

Flexible definitions of physical boundary may allow an extension at neighbourhood scale without falling into positive energy district definitions [4][5][6] or energy communities. The RES facility could be placed on the neighbouring lot in case it is directly connected to the energy system of the PEB, managed by the PEB building's energy management system and the energy accounted for PEB energy balance.

In order to meet the PEB requirements, **on-site RES production must be favored, off-site could be included in some rare cases, e.g. from neighbouring lot with straight connection to the building's energy system and under direct control from the PEB. The authors suggest defining priorities for RE supply options considering the availability of resources, ownership of buildings and other available lots, the performance of the grid in terms of energy mix and transportation, the distance of RE supply from the building, and the availability over building lifetime**. Purchasing off-site RE sources, green energy, or CO_2 credits is not leading to a PEB as PEB definition aims to drive changes in the permanent design of buildings and energy supply options towards the long-term decarbonization, independently of the type of purchased energy that may change in the lifespan.

Balance contributions

The definition of the contributions to be included in the energy balance is essential to guide the design process towards the Positive Energy target.

International standard EN ISO 52000-1:2018 [7] defines the types of energy use that should be included in the energy balance, including heating, cooling, ventilation, humidification, dehumidification, domestic hot water and lighting. According to EPBD Annex I[4], the contributions to be included in the energy balance are heating, domestic hot water (DHW), air-conditioning, ventilation, lighting (for non-residential). These refer to the energy uses necessary to keep the

[4] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L0844&from=EN

building in liveable and comfortable conditions. Plug loads are excluded from standard balance calculations due to their uncertainty and dependence on users' habits and lifestyles, which lead to a more complex analysis in the design phase. However, including also plug loads in the balance ensures that the building has an energy production surplus to be shared with other buildings.
In considering the contributions of the energy balance, several points arise for discussion, as follows.

- The minimal requirement of a building may be to offset the energy consumption for DHW, heating and cooling from locally harvested RE (building integrated production);
- Accounting for the user-related energy use in the balance may discourage, or prevent compact or high-rise buildings from being PEB, given that in these buildings the technical and economic viability for deploying RE could be limited due to their lower availability of envelope surfaces for PV installation;
- By including user-related energy consumption (i.e., plug loads and e-mobility) in the balance, building energy end-users are empowered to reduce their energy consumption. This would also involve changing the mindset of designers from performance-driven to user-centered design;
- E-charging is emerging rapidly as new user need; by including the E-charging in the balance in case of multi-family buildings may lead to significant increase in the total energy consumption. Also, temporal profile of energy demand may change in respect to standard conditions of use. Furthermore, in some countries, EV charging stations would be in separate energy networks;
- A wider perspective also includes the embodied energy of the building materials and components.

Despite the open discussion, the three projects conveyed that a **PEB definition shall at least include the following energy uses: heating, cooling, ventilation, DHW, lighting and auxiliary.**

Balance metrics

The metric adopted for weighting and comparing the different energy carriers of the building energy demand and production represents a key point in the calculation of the energy balance. All balance items need to be converted using the same metric. Using primary energy as main metric is consolidated in the sector and also required by the European Commission (EU EPBD directive 2018/844).
The target of positive energy should be verified by a primary energy balance, considering the national conversion factors being final energy, or CO_2 emissions complementary metrics.
However, it is worth noting that national conversion factors depend on the national electricity mix that might vary over time (i.e., due to the increase of RE share), and they are strongly affected by national contexts and energy infrastructure systems. For this reason, comparing buildings' performance in different Countries in terms of primary energy might not be the best option.
According to the electrification trends, in most cases, the balance can be expressed also in terms of final energy since only one energy carrier is involved. This would make the building performances more transparent and comparable as well as having the possibility to directly compute the building energy balance based on measurements.

Timescale

While a building can generate enough or more energy from RES during its lifespan to cover total energy needs, other building could be energy or carbon neutral on a smaller timescale. Thus, it is needed to specify the time period over which the metric is balanced, namely the period of balance.
The period of balance can vary significantly from monthly, yearly or lifespan. **The annual balance seems to be the most practical for the purpose of PEB**, as the energy use in the building may vary on a yearly basis due to several reasons i.e., climatic change and change in number of

occupants. Hence, annual basis will be adopted in the definitions of PEB parameters, while lifespan will be used in the sustainability assessment and should be considered in the initial planning and analysis of PEB designs. In life cycle and/or sustainability assessments, in order to annualize the embodied energy demand as in building life cycle assessment studies, 60-year lifespan is typically assumed (for fabric and technologies) including all the energy involved across the building life, then split by year to identify when the balance is predicted to become positive.

Type of balance

Two possible types of balance can be adopted: i) the balance between building load and renewable energy generation, or ii) the balance between the imported energy to the building and the exported energy to the grid. Both types of balance have advantages and disadvantages depending on their application in the design or operational phase of the building.

The load/generation balance can be easily proposed in the design phase since most of the current building codes require load calculations, but it completely overlooks the building-grid interactions.

The import/export balance gives more complete information about the interactions between the building and the grid but it requires a detailed estimation of the energy load, production and self-consumption profiles. However, these profiles can be easily metered during the operational phase of the building.

Other aspects that are key to define how to quantify the balance include the following: the assessment time period (hourly and/or monthly), the matching factors (calculated and/or estimated) and the weighting factors for primary energy (fixed or variable over time).

Dynamic matching

Dynamic matching is expressed by two main aspects: load matching and grid interaction. Load matching shows how the local energy generation compares to the building energy uses. Grid interaction shows how the energy exchanged between the building and an energy carrier infrastructure (power grid; district heating network, etc.). Corresponding key performance indicators (KPIs) should be computed on sub-hourly or hourly basis to correctly characterize the simultaneous use of on-site produced energy and the energy exchanged with the grids, and to calculate the hourly delivered or exported energy in/from the building.

The positive energy balance shall be reached through a good timely matching of energy demand and supply from on-site RES system in order to reduce the impact of PEB on the energy grid.

Smartness and flexibility

Smartness and flexibility refer to the ability of the built environment to manage its energy demand and local generation according to climate conditions, user needs and preferences and grid requirements**. The degree of management of flexibility assets present in a PEB is a key element for an optimal interaction with the grids, the flexibility index and the Smart Readiness Indicator (SRI) some of the ones in discussion to assess it [8].**

Embodied energy and GHG emissions

Embodied energy is the sum of all the energy required to build and dismantle a building along the entire lifecycle. Determining what constitutes this lifecycle includes assessing the relevance and extent of energy into raw material extraction, transport, manufacture, assembly, installation and disassembly. Analogously, embodied GHG emissions are emissions arising during manufacturing and processing of building materials, throughout the lifespan.

The concept can be useful in determining the effectiveness of energy-producing or energy saving buildings, the real replacement cost of a building, and, because energy-inputs usually entail greenhouse gas emissions, in deciding whether a product contributes to or mitigates global warming. Embodied energy and embodied GHG emissions impacts represent a significant and growing proportion of the total energy and emissions, and it is increasingly accepted that the focus on reducing the overall consumption and emissions of a building must consider the embodied impacts alongside the operational energy [9]. Thus, the purpose of including embodied energy in the energy balance is to compare the amount of energy produced or saved by the building to the amount of energy consumed in producing it.
A critical issue in embodied energy computation is that different types of energy (oil, wind, solar, nuclear and so on) emit different amounts of carbon dioxide, so the actual amount of carbon dioxide emitted when a component is made will be dependent on the type of energy used in the manufacturing process and where it is produced. Furthermore, available data on embodied energy and emissions related to material extraction, transportation, building construction processes may be less reliable than data covering component manufacturing and supply chain. Finally, embodied impact of building should also consider other aspects as consumption of virgin material and recycling rates.
It can be also challenging to include embodied energy impacts in case of building renovations.
Due to these facts, **embodied energy cannot be considered in the annual balance. Nevertheless, an overall lifecycle impact assessment is recommended to ensure an overall environmental payback and to make aware choices of building materials to be adopted in the construction [10].**

4. Barriers and drivers for an increased acceptance and adoption of PEBs

Some examples of PEBs that are available over the EU building stock [11] demonstrated that the uptake of PEBs strongly depends on the availability of RE sources and the national electricity mix. Market ready technological solutions already exist. Depending on the context, higher upfront costs can be a barrier to the broader roll-out of PEBs and government incentives can play a role in helping projects to get off the ground.
Barriers and drivers for the uptake of PEBs [12] include aspects like the complexity of PEB concept, and the related need for an integrator to handle the project from design to operation and maintenance, or the immaturity of the regulatory environment, which e.g. affects the reliability of the life-cycle analyses. Lack of awareness of the PEB concept is a common barrier, and relevant for wide variety of actors, from general public to professionals and regulators.

4.1 User-centric design approach

The impact of occupant behavior on the performance of buildings nowadays becomes more crucial as soon as buildings are progressively more endowed with smart technologies and improved thermal systems [13]. Thus, occupants and consequently user-centric design approaches are key to make PEBs successful.

User behaviour modelling must be part of the integrated energy design process and operation strategies for PEBs, with the scope to achieve succeeding outcomes towards a positive annual energy balance by embedding criteria which captures and integrates user diversity and its complex interrelationship with energy performance during the whole building cycle.

Users do not set out to use energy; rather, they seek access to energy services to reach a certain level of comfort and productivity. Contrary to the conventional approach -where users' practices, attitudes and expectations tend to be flattened towards a generalized use of technologies and standards of comfort- user-centric design considers all these factors taking into account cultural and social diversities.

Informed and engaged **'Positive Energy Citizens' can significantly contribute to achieving PEB's performance targets, by managing to (i) control demand within the energy production profiles of building systems and (ii) strengthen the dynamic matching potential between the renewable energy generated and households' dynamics**. Occupants might become key targets of the energy systems' control systems aimed to shape the building performance to a yearly positive energy balance. As a result, users might be able to react and to adapt their energy needs towards PEB limits, by ways in which aspects of everyday life change its current social organization of normality towards the reduction of consumption patterns, adequate integration of technology and adaptation of domestic practice that could mitigate the significant use of environmental resources [13][14].

Nevertheless, Positive Energy Citizens, as PEB occupants, do in various ways shape energy demand dynamics, not merely from a conscious behavior perspective. PEB design should integrate this idea of agency and practice, along with user diversity and thus differentiated sets of baseline conditions in accordance with specific profiles. In addition, PEB should incorporate energy flexible assets which enable the accommodation of potential energy demand variations due to alterations of the standard context of the householders and/or within the building community.

Similarly, Post Occupancy Evaluation (POE) campaigns data from high-efficient building occupants are determinant to guide a successful building design and performance strategies which incorporate tailored and valuable criteria directly from the user context, accounting for cultural and climatic drivers that directly affect energy consumption patterns. Indoor Environmental Quality (IEQ) requirements are currently strictly defined based on ideal conditions that generally match with a subjective sensation of neutrality. Consequently, design is usually aimed at very tight and static environments, where transition and stimuli are not permitted, with very narrow ranges to be equally maintained for all the subjects [15]. However, different users embrace a great variety of backgrounds, perceptions, behaviors, and expectations, driven by the need of achieving comfort and convenience, interested in having access to services and not in energy consumptions per se [16]. Thus, the situation is far more complex, and occupants' perception and attitudes reveal to be, also in this case, highly influenced both by contextual boundaries and other socio-cultural influences. Indoor Environmental Quality (IEQ) aspects and occupants' needs must be now put at the heart of a new design and operation paradigm, where IEQ is not only a side-effect deriving from other processes, but it is a key point in the checklist of achievements. Thus, it is necessary to acknowledge in the lifespan of PEBs the 1) thermal, 2) visual, 3) acoustic, and 4) air quality environments, implementing defined, quantified, and measurable Key Performance Indicators (KPIs) specific for all the four mentioned IEQ areas. These IEQ KPIs must be verified during all the phases of the building by means of design and calculation (design phase), and post-occupancy monitoring (operational phase).

The spatial and material configuration of a building is also one of the most important determinants of occupants' experience of comfort, security and productivity, and how energy is used in the building to achieve this. An effective user-centric PEB design aims to incorporate socio-cultural drivers affecting energy demand -which are multidimensional and uncertain-, in opposite to the current trend which only focuses on energy and IEQ [17].

The European Climate and Cultural Atlas for Plus Energy Building Design (2CAP-Energy Atlas) [18] incorporates datasets aiming at supporting the profiling of users' domestic energy patterns and users' expectations towards indoor environments. This contributes to the understanding of how these variations are translated into different energy-intensive practices at household level across EU territories.

4.2 Technologies: smartness vs complexity

Despite a wide availability of technologies on the market (or at high TRL), designers still lack support to properly integrate them in the overall building design and to evaluate the building performance as well as ensure this performance during the use phase. Traditional rules of thumb for sizing do not likely apply. Subsystems and controls end up to be complex and not well documented, causing issues during commissioning and O&M of subsystems (lighting, HVAC, etc.). It is therefore essential to equip experts in the building sector with knowledge and skills to support a rapid uptake of positive energy buildings.

Furthermore, user interaction with smart control systems is key to ensure expected building performance during operation. PEBs need a central control system that organically manages all the devices in the apartment and is able to guide users towards more energy efficient options considering their expectations and needs about indoor conditions.

Finally, complexity and cost for introducing needed technologies for energy production and management, but also relatively low life for such devices and services, are a major risk for streamlining investments in PEBs. The possibility to have better control over own energy production and demand is however increasing the interest on PEBs [12].

4.3 Market and regulatory environments

In EXCESS project, a study of the market and regulatory environments in the four demo countries was carried out at end of 2020 [12]. While there are some evident similarities in the countries related to the market and regulatory environment, there also seem to be different points of emphasis.

Regarding the market, it was common for all demo countries that new construction is slowed down, and it is concentrated in cities and in multi-storey buildings. It seems that the renovation pace is lagging behind the energy efficiency targets in many countries. This calls also for more PEB solutions for renovation. Some RES solutions are however prevented by strict regulations related to historic buildings. This contradiction needs to be addressed in order to connect the points of PEB solutions and renovation. The status with the roll-out of smart metering is different in the demo countries.

Common for all countries was the immaturity of the regulations, which seems to build a significant barrier for the PEBs. In syn.ikia's report, on policy mapping and analysis of PEB and SPENs[5], the gaps and weaknesses in the current regulatory framework are analysed as a basis for the ongoing efforts to redefine integrated strategies to the deep decarbonization of the building stock. However, regulations are being formulated for the benefit of PEBs, as they are based on the aims of climate mitigation and CO_2 emission reduction, giving benefits for high energy performance of buildings and renewable installations. Also, the exchange of renewable energy between private consumers is getting easier. One current barrier is the fragmentation of energy regulations related to different fields (gas, heat, electricity) and different levels (national, regional, municipal). Overall, it was also seen problematic if the regulations are constantly changing. This creates a lot of uncertainties for the planning and life-cycle analyses conducted in the design phase.

4.4 Acknowledging the added value of PEBs for the user and the community

Beside the direct benefits coming from the spread of Positive Energy Buildings focused on energy performance and CO_2 emissions' reduction, it is pivotal to acknowledge and address the indirect effects that can be achieved both at a household and a societal level. In fact, the "Plus" of this new generation of buildings should not only embrace the technical and merely quantifiable advantages, but must also show an extra benefit for the people daily living and using these buildings.

These extra-benefits, also named *co-benefits* are, according to the Cultural-E project[6], the added positive values that can be obtained, in addition to the direct and measurable impacts which derive

[5] https://www.synikia.eu/library/

[6] http://www.cultural-e.eu/wp-content/uploads/2022/10/Co-benefits-workshop_compressed.pdf

from high-efficiency energy buildings or from the energy renovation of existing buildings and their technologies. They can be **household** co-benefits if they have an effect on the user's well-being and household economy, or **community** co-benefits if they have wider economic, social and environmental effects. These two levels of co-benefits (i.e., household and community) foresee different target groups, accounting in this way for different economic perspectives. For example, on the one side, **in a private perspective targeting the building owners and promoters, the economic value of a building and the value added by energy related renovation measures are the most relevant indicators** that can potentially increase the willingness to pay for the building. On the other side, **for policy makers, a societal or macroeconomic perspective could demonstrate how policies that are implemented for the reduction of energy and emissions in the building sector may be used to reach other objectives** such as economic and social development, sustainability and equity. At the moment, investors lack guidelines on how to monetize the positive benefits and, when an attempt exists, these aspects are evaluated merely in a qualitative way. On the contrary, their quantification could support investments and the promotion of PEBs among the community. Only considering all these multiple benefits that can derive from PEBs, and all the advantages brought to users and society, a change in the building sector can really happen that takes into account the building and people as a whole. This not only will enhance the occupants' wellbeing and satisfaction, to the extent of societal welfare, but also will bring back positive impacts on the energy and decarbonization goals in a continuous positive circle.

4.5 Upscaling to neighborhood dimension: from Plus Energy Buildings to Sustainable Plus Energy Neighbourhoods

As discussed along previous sections, the neighbourhood scale seems the appropriate one to accommodate PEBs as part of Positive Energy Districts (PEDs) or Sustainable Plus Energy Neighbourhoods (SPENs). As defined in the syn.ikia's evaluation framework[7] [6], a Sustainable Plus Energy Neighbourhood is a highly energy efficient and energy flexible neighbourhood with a surplus of energy from renewable sources. The syn.ikia definition of a SPEN follows a similar procedure as described for PEB, but the geographical boundary is physically or digitally expanded to the entire site of the neighbourhood development, including local storage and energy supply units. The SPEN framework includes a strong focus on cost efficiency, indoor environmental quality, spatial qualities, sustainable behaviour, occupant satisfaction, social factors (co-use, shared services and infrastructure, community engagement), power performance (peak shaving, flexibility, self-consumption), and greenhouse gas emissions. While the district networks are seen as an excellent way to balance the heating and cooling needs inside the city (e.g. using waste heat), the district heating and cooling infrastructure may need changes to support PEB integration and bi-directional connections. Also, in the present setup with limited storage capacities and the possibility to share the energy, the PEB may disturb the grid stability. Some additional services may be needed, such as energy storage at the grid level and at the building level to accommodate many PEBs in the city infrastructure. This will not only support the building and its on-site consumption and flexibility, but also provide stability and flexibility to the grid. This will also facilitate the energy export to the neighbours [19].

5. Recommendations

The joint work also led to the following recommendations:

- Residential buildings have a great potential to achieve positive energy targets by using energy efficient technology and RES.

[7] https://www.synikia.eu/library/

- Affordability, cost optimality and building value should be considered to motivate stakeholders, practitioners, and occupants to switch towards PEB. Environmental benefits should be considered as well.
- Besides energy balance, it is important to adhere to other Key Performance Indicators (KPIs), as energy flexibility, load matching and grid interaction.
- Standardization protocols to assess the PEB performances and perform Post Occupancy Evaluation (POE) after construction are needed.
- The project management team has to be solid and experienced (and interdisciplinary) to handle the complexity of the project, as well as to be able to explain the benefits of PEBs in an understandable way.
- Experts in the building sector shall be equipped with knowledge and skills to perform proper design, installation, operation and maintenance of the PEB systems.
- Performance-based contracts shall include also the maintenance of the PEB system.
- Technologies for PEB should be simple and easy to maintain. Maintenance costs should be considered in lifecycle cost assessment.
- Embodied energy and embodied carbon should be included in the evaluation in the LCA favoring circular economy and residual value. The requirement to show the life-cycle effects should be made mandatory in the planning phase or in connection of the building permit, not just related to costs, but also to environmental aspects.
- Incentive schemes on surplus of energy or on energy community shall be introduced to favor self-consumption and energy flexibility.
- Enough funding and subsidies shall be allocated to support PEB solutions. Also, the funding and subsidies developed for energy efficiency improvements and RES are working for PEBs.
- EU regulation shall be more impacting than a directive, leading to new building standards.
- PEBs should be seen as key elements towards more sustainable neighbourhoods.
- Occupants' health and wellbeing should be a cornerstone of PEBs' design and operation.
- PEBs should support occupants' daily practices and needs.
- Indirect effects and co-benefits should be included in the overall evaluation of the building, both at the household and at the community level.
- Climate change poses some uncertainties on PEBs operation and performance. Therefore, analytical processes are need to analyse the overall building performance under future climate scenario, ensuring the positive energy balance on the building life span.

Acknowledgments

This research has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreements N. 870072, 870157 and 869918.

The authors would like to express their gratitude to all the workshop participants and acknowledge all the project partners in the three sister projects: EXCESS, Cultural-E, and syn.ikia. In particular, the authors would like to thank Ralph Horne (RMIT), Francesco Reda (VTT), Mari Hukkalainen (VTT) and Inger Andresen (NTNU) for providing us useful insights on the Plus Energy Building concept definition.

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