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# Rethinking Abandoned Buildings as Positive Energy Buildings in a Former Industrial Site in Italy

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**Abstract:** The transition from nearly zero-emission building (NZEB) to positive energy building (PEB) models is a new trend, justified by the need to increase the efforts to address the climate change targets and the ambition for a clean energy transition in the construction sector. In line with this scenario, this study assumes that PEB may be applied to meet climate change targets and promote new approaches to urban regeneration plans. It focuses on the functional and energy regeneration of abandoned buildings, considering that many abandoned European buildings are often located in a strategic part of the city. Therefore, the research question is as follows: to what extent can abandoned buildings be converted into a PEB? What would be the meaning of this new association? In order to answer this question, this study developed a procedure to transform an abandoned building into a PEB, implemented through a case study of a former Italian industrial site. Findings pointed out the variables impacting PEB configuration and were used to support a discussion, stressing how rethinking abandoned buildings as PEB may drive new trends to synchronise the socio-technical evolution of energy infrastructure and urban regeneration plans.

**Keywords:** building retrofit; positive energy building; Pareto front; multi-objective optimisation; energy planning



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## 1. Introduction

According to the International Energy Agency, the construction sector is responsible for one-third of the global energy consumption and nearly 40% of $CO_2$ emissions. In 2019, the $CO_2$ emissions from buildings reached a record level of 10 $GtCO_2$ due to increasing demand for heating and cooling systems and extreme weather events [1]. Excessive emissions from the atmosphere lead to global warming and climate change, badly affecting the environment and communities. Thus, to overcome this issue and reduce $CO_2$ emissions, increasing the building's energy performance and clean power generation are the primary concerns of new building regulations across Europe.

The European target to improve energy efficiency in buildings has led to the nearly zero-energy building (NZEB) model, which has become mandatory for all new buildings by the end of 2020 [2]. Moreover, the target of NZEB covers existing buildings by integrating long-term renovation strategies [3]. Therefore, the main target of the NZEB model consists of reducing the building's energy use by integrating advanced materials and smart systems to optimise the energy performance of the building's components, along with a decrease in energy supply by using renewable energy resources [4,5].

Therefore, applying the NZEB model across Europe presents a promising solution for improving buildings' energy efficiency and reducing greenhouse gas emissions. However, meeting climate change targets [6] and the ambition for a clean energy transition in the construction sector still require more efforts, actions, and energy policies [7]. This is because existing buildings are the primary energy consumption source, representing 75% of the current EU building stocks, and will be standing until 2050 [8]. Moreover, the EU buildings' stock is relatively old, with more than 40% of it being built before 1960 and 90% before 1990, and the replacement rate of existing constructions by new constructions is very low, about 1% per year [9].

Consequently, several studies focused on developing methods and tools to deliver efficiency action plans through a systematic approach to the proper selection and identification of the best retrofit options for existing buildings [10], multi-objective optimisation and energy modelling of energy systems and building envelope retrofit [11–13], and innovative policy strategies for achieving large long-term savings from retrofitting existing buildings [14], among others. Thus, research has delivered a complex framework of light, medium, and deep building retrofitting actions on existing buildings, which are expected to significantly impact the building's energy performance and reduce energy consumption. In addition to these efforts, a new trend has recently emerged, which is based on a positive energy balance scenario [15].

This potential new trend is the evolution of NZEB to positive energy building (PEB) models [16–20]. According to the EXCESS project, a research and innovation programme funded by the European Union's Horizon 2020, PEB is an energy-efficient building that produces more energy than it uses via renewable sources, with a high self-consumption rate and high energy flexibility, over one year [21]. Thus, the PEB model would be a promising alternative to achieve the climate change targets [22,23].

This study hypothesises that PEB models could be applied to meet climate change targets and promote new approaches to urban regeneration plans, taking into account that many abandoned buildings exist across Europe, often located in a strategic part of the city [24]. In such a scenario, the research question posed is:

- To what extent can abandoned buildings be converted into a PEB? What would be the meaning of this new association?

In order to answer this question, this study developed a procedure to transform an abandoned building into a PEB, implemented through a case study of a former Italian industrial site.

The paper is structured as follows: The next section explores the recent literature, pointing out a research gap. Section 2 introduces the workflow adopted and the case study developed. Section 3 presents the results. Section 4 discusses the results and limitations; finally, Section 5 concludes and proposes future research developments.

*Literature Review and Research Gap*

Promoting the translation from NZEBs to PEBs involves actions on the building envelope and plant systems. Several studies emphasised the interactions between energy retrofit actions and the emerging technologies [25–29]. However, a limited number of studies have reviewed these interactions in order to envision buildings as components of the future energy infrastructure [30].

For example, Ref. [31] developed a pioneering study on the new trend towards positive energy buildings, stressing the need for accurate simulation models and a building optimisation approach. However, this study focused on technological advancement, overlooking urban regeneration implications concerning a new infrastructural vision. By contrast, [32] pointed out the need for a new infrastructural theory in order to connect the evolution of energy infrastructure with new forms of spatial organisation. However, such a study neglects operative implementation strategies.

In this regard, Ref. [4] explored the transition from nearly zero-energy buildings (NZEBs) to positive energy buildings (PEBs), collecting results from the most advanced experiences in Europe, stressing the lack of regulatory, economic, social, and technological barriers to PEB implementation. What emerged from this study is that despite the advantages that the PEB model could have, its application is still limited to the technical sphere. In fact, the PEB model is still not integrated into national legislation for many European member states.

Thus, the topic of PEB replicability in different socio-economic and geographic contexts is one of the main challenges. A contribution in this direction was provided by some studies [33,34], which explored replication strategies for positive energy districts as an aggregation model of PEBs at scale. These studies stressed the necessity of a profound replication modelling to deepen the understanding of up-scaling processes. The key aspect that emerged from these studies is that the replication process strongly depends on cooperation with stakeholders. However, the lack of urban planning procedures dedicated to PEB remains a significant barrier.

In order to contrast the current socio-technical barriers, some studies focused on a meso-scale approach named the positive energy block, which is a form of building aggregation composed of at least three buildings, which are so effective that they generate more energy than they consume [18]. A few studies have recently explored this meso-scale approach. For example, Ref. [35] analysed the transition from a traditional urban block to a positive energy block. It is interesting to note how this study promoted the use of shared on-site renewable energy to preserve the historic values of building blocks. However, the main topic of the study was mainly focused on novel technologies (i.e., smart grids and internet and communication technologies) applied within a valuable environment of the historic city centre. Similarly, Ref. [36] proposed a multi-criteria decision-making optimisation framework for PEB, analysing scenarios based on adaptable criteria applied to a set of school buildings, returning a hierarchical classification concerning those buildings, which can potentially act as positive nodes of the future energy network.

Therefore, while the above-mentioned studies represent innovative research frontiers concerning emerging energy paradigms, the analysis of the literature pointed out that the relationships between PEB models and novel urban regeneration plans have not been sufficiently explored. In addition, this gap acquires additional relevance when the PEB transition is associated with the value for reuse in the economic, cultural, social, and architectural spheres [37–39] instead of being considered as a mere technical apparatus. Prior studies [40–42] focused on the need to regenerate abandoned buildings, with a particular focus on establishing compatible activities, which may facilitate the preservation of original building integrity. However, these studies neglected the energy demand sphere, which instead emerges as a relevant aspect to deliver a PEB model.

Against this background, this paper is aimed at combining these two aspects, rethinking abandoned buildings as positive energy buildings. This combination is expected to lead to new trends to synchronise the evolution of energy infrastructure and urban regeneration plans.

## 2. Materials and Methods

This study aims to identify strategies capable of transforming an existing building into a positive energy building (PEB). The approach adopted refers to the design science research method (DSM), which, according to [43,44], is an appropriate method for practical applications. In this study, the practical application consists of evaluating the variables that impact the delivery of a PEB. Moreover, in this study, the existing building is an abandoned building. Following this scope, a comprehensive, framework was first developed and then applied to a real case study (an abandoned building) to test its feasibility and specificity.

Figure 1 illustrates the workflow adopted. The process was articulated in three main phases: input/pre-processing, simulation and optimisation phase, and output/decision making.

Like other studies [45–47], the input phase consists of creating the baseline model and setting the simulation parameters required by DesignBuilder. Figure 1 reports the main building properties in terms of data location, data dimension, construction features, activities, and the energy code applied. DesignBuilder was chosen as the energy performance simulation software because of its flexibility and usability as an evaluation tool concerning the building's energy performance and the analysis of the impact of possible changes in the building's systems in a fast and cost-efficient manner [48,49]. DesignBuilder allows the researcher to establish a set of options characterising the energy calculation implemented by the EnergyPlus modelling engine, which is tested according to the ASHRAE Standard 140 methodology.

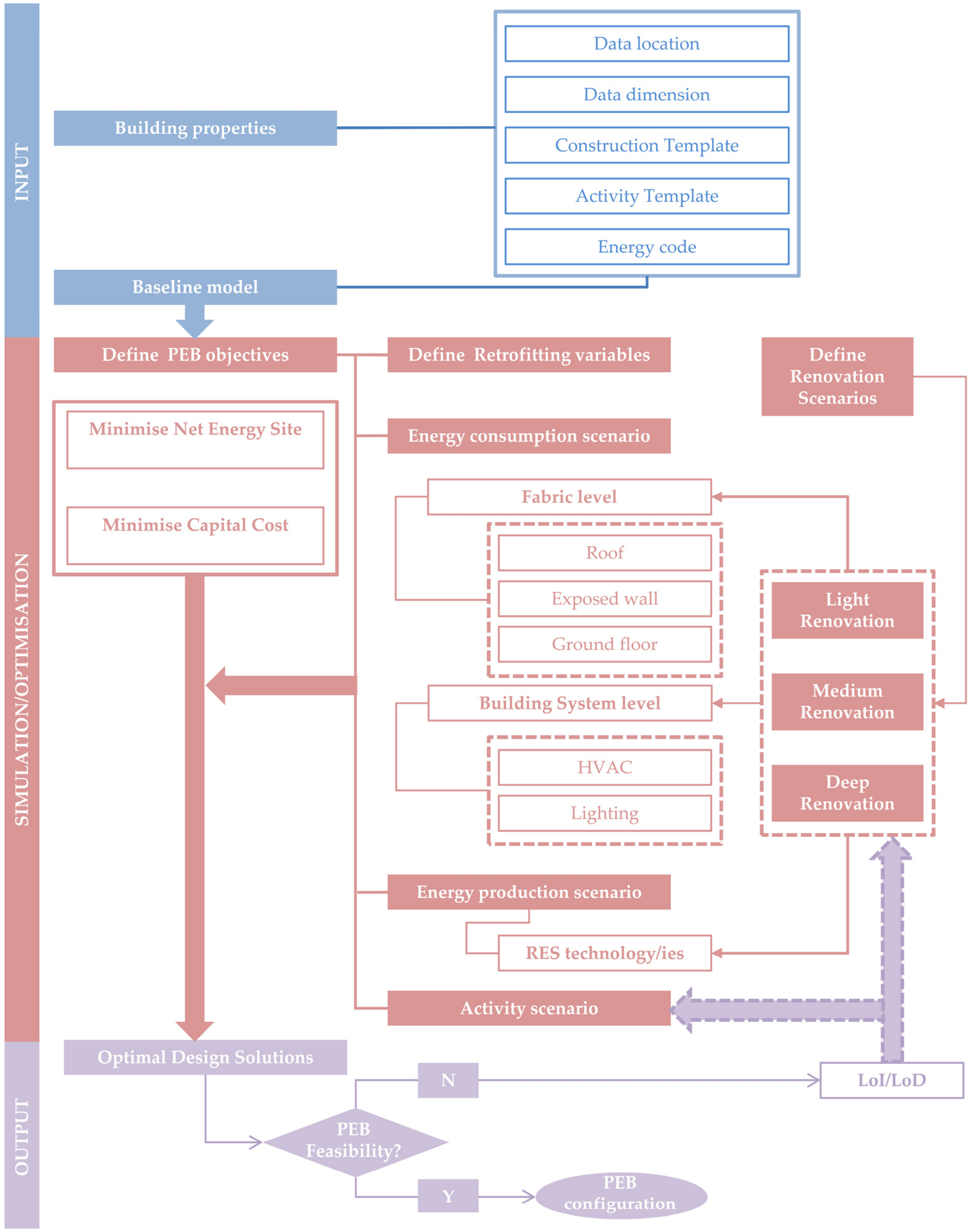



**Figure 1.** Workflow adopted.

As an output of this phase, the building was characterised by geometry and thermal zones, establishing the boundary conditions in which these zones operate (i.e., location, weather data, and energy code standard). The level of information varies with the level of design (e.g., feasibility or detailed design). The level of detail increases the duration and complexity of the simulation.

The second phase focused on simulation and optimisation. Figure 1 displays the PEB objectives and the retrofitting variables involved characterising the retrofitting scenarios. The overall retrofitting options consist of two levels of interventions: energy consumption level and energy production level. In this regard, firstly, two contrasting objectives were established in the context of PEB. These are capital costs and net site energy consumption (i.e., total site fuel consumption minus any on-site generation). Therefore, both these objectives were minimised. Secondly, a set of variables were listed. These variables represent the retrofitting options that may be adopted to reach the objectives mentioned above. In detail, a range of values may be associated with these variables (e.g., the range of transmittance value for exposed walls). These variables refer to the fabric and/or building system level.

A vast literature [50–52] reports that retrofitting options may be achieved by reducing building energy consumption with or without integrating renewable energy sources. In line with the scope of this study, an integrated approach systematised fabric and system levels. According to [53], this is performed by adopting three retrofitting scenarios: light, medium, and deep. In addition, a particular focus was paid to the activity variations, which were included as a retrofitting variable to assess the impact of new activities on the PEB configuration, which is relevant for the case of an abandoned building.

Similarly, three energy production levels were developed to explore the implications of the integration of renewable energy sources (RESs) on energy savings. These energy production scenarios are light, medium, and deep RES integration. The concept of RES integration is flexible and may be associated with the typology of the energy source (e.g., solar or wind). This study focused on photovoltaic (PV) integration. Other RESs are out of the scope of this paper.

Once the variables were set, the simulations were launched. Results were delivered in the form of Pareto front, a technique used in several prior works focused on energy retrofit [54–56], and, here, its use was extended to explore the feasibility of producing buildings that produce more energy than they consume.

Then, the final phase (i.e., output) was to assess and compare optimal design options reported by the Pareto front, exploring the effect of variations in retrofitting options on the model energy performance and identifying feasible packages of retrofitting actions for both the objectives set previously. This is carried out by adopting a violin diagram tool to visualise the data distribution and probability density, focusing on the activity variations. Figure 1 points out the feedback process in case the PEB feasibility has not been achieved. This phase allows the designer to decide whether to move to the next level and increase the level of detail and information for the PEB's feasibility. Thus, the workflow is characterised by cyclical feedback to address the PEB configuration.

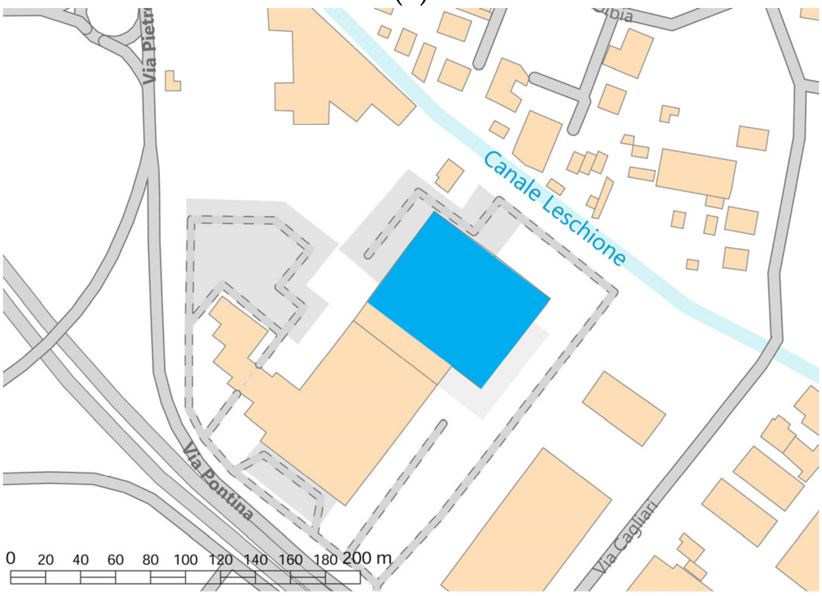
The following section reports an application of the workflow proposed.

*Case Study*

In Italy, the area of abandoned buildings belonging to the local municipalities is 19 million square meters [57]. Thus, it is a priority for the Italian government to enhance a real estate asset valued at EUR 12.1 billion [58]. In line with this priority, an abandoned industrial building in Italy was used as a case study to apply the proposed workflow.

The case study is located in Aprilia (Figure 2a), along with a thoroughfare connecting Rome and Latina (Figure 2b). It is a public building and a landmark portraying a piece of history of the urban development of this area: from the industrial boom, i.e., 1960, to nowadays. In 2015, the building was involved in the first step of a regeneration process funded by the PLUS programme [57]. Currently, in order to complete the regeneration process, multiple retrofitting options are needed to be tested. Developing a new functional programme compatible with the existing fabric is a priority here.

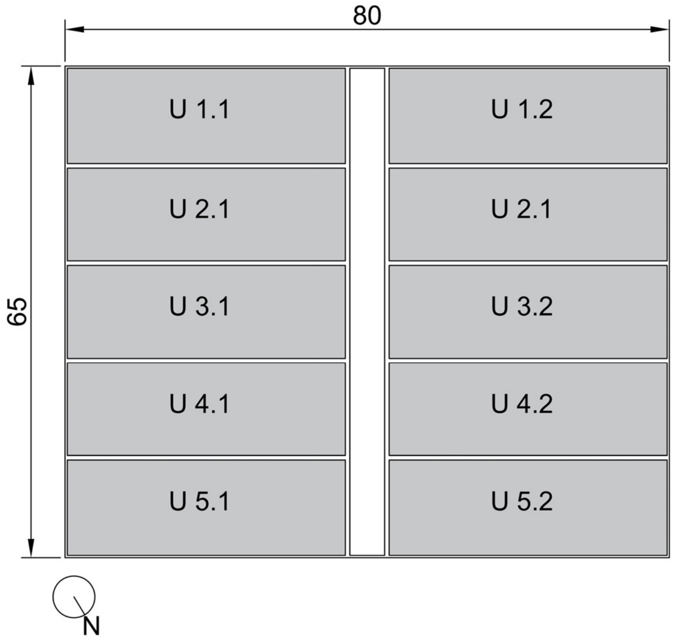

(**a**)




(**b**)

**Figure 2.** (**a**) Building location. (**b**) Building site.

Figure 3a,b show the original organisation of the internal spaces (i.e., U1 to U5 were all industrial warehouses) and the external configuration, respectively. The factory was built around 1970; it covers 5000 square meters of indoor space. The building has a rectangular shape with sides of 80 × 65 m and a unique level with a height of 9 m. The façades are differentiated: those south-east and north-west are the main elevations characterised by large openings of 4 m, and the other façades have limited openings. The building consists of a long central corridor connecting a series of ten large warehouses: five face the south-east façade and five are on the north-west façade. The structural system consists of precast concrete frames, and the vertical walls are made with precast concrete modular panels (i.e., Uwall = 2.700 W/m$^2$K), while the roof system and ground floor are made with reinforced concrete slabs (i.e., Uroof = 2.900 W/m$^2$K and Ugroundfloor = 2.759 W/m$^2$K).




(**a**)

(**b**)

**Figure 3.** (**a**) Internal spaces before the intervention (U: warehouses). (**b**) Façade before the intervention.

The initial step returned the baseline model, including the geometry, building's properties, and boundary conditions. Table 1 presents the required climate data input.

**Table 1.** Climate data.

| | Location | Orientation | Weather Data File | ASHRAE Climate Zone |
|---|---|---|---|---|
| **Climate data** | Latina (IT) | 225 | ITA_pratica di mare | 3C Warm–Marine |

After creating the baseline model, the next step established the thermal zone features. The building was explicitly articulated in 10 thermal zones. Then, light, medium, and deep retrofitting scenarios were set, establishing the range of variation concerning the variables selected. Then, for each scenario, an appropriate template was designed (Table 2).

**Table 2.** Setting of light, medium, and deep retrofitting scenarios.

| Level | Variables | Light | Medium | Deep |
|---|---|---|---|---|
| **Fabric** | U-Walls | 0.36 W/m$^2$K | 0.27 W/m$^2$K | 0.18 W/m$^2$K |
| | U-Basement | 0.38 W/m$^2$K | 0.28 W/m$^2$K | 0.18 W/m$^2$K |
| | U-Roof | 0.33 W/m$^2$K | 0.24 W/m$^2$K | 0.16 W/m$^2$K |
| | U-Internal wall | 0.80 W/m$^2$K | 0.80 W/m$^2$K | 0.80 W/m$^2$K |
| | U-Windows | 1.75 W/m$^2$K | 1.5 W/m$^2$K | 0.8 W/m$^2$K |
| **System** | Lighting (Normalised power intensity) | 5.0 W/m$^2$ | 3.3 W/m$^2$ | 2.5 W/m$^2$ |
| | Heating system COP | 2.00 | 2.80 | 3.50 |
| | Cooling system COP | 2.50 | 3.50 | 4.50 |
| **Energy production** | % PV on Roof Areas | 20% | 50% | 100% |
| | % PV performance | 20% | 20% | 20% |

At the fabric level, retrofitting options included the U-value variation of exposed walls, roof, and glazing. Concerning the light and medium fabric scenario, the U-value adopted referred to the Italian legislation framework [59], which includes a set of values to achieve the reference building standard and fiscal incentives targets, while the deep scenario adopted the U-value of the reference building standard reduced by 50% (i.e., building envelop Class A).

Here, the variation in cost refers to the thickness of insulation adopted. At the building system level, the variables were set only related to the HVAC and lighting system. For HVAC, three variables were set, adopting three heat pump technologies with an increasing value of the seasonal co-efficient of performance (i.e., COP). As a result, the plant system cost associated with light, medium, and deep renovation is 176.67 Euro/m$^2$, 223.78 Euro/m$^2$, and 259.11 Euro/m$^2$, respectively. In addition, three variables were set for the lighting system classified in terms of normalised power intensity.

At the energy production level, only one type of renewable energy was considered: solar photovoltaic panels as the most appropriate renewable technology for this case study, considering the weather conditions and the building integration opportunities. Three levels of PV panel integration were defined: light, medium, and deep PV integration covering 20%, 50%, and 100% of the roof area, respectively. A standard efficiency of the PV module was used (i.e., 20%).

Furthermore, Table 3 shows the specifications concerning the main activities tested in the first round. The main variations are occupancy density, fresh air, and mechanical ventilation per area. The data refer to the Design Builder database (i.e., ASHRAE standard) [60].

Specifically, two tests were conducted:

(1) Retrofit strategies without the integration of PV. This test was characterised by assigning a single activity to all the 10 thermal zones, with 7 variations (see Table 3). In addition, 3 variations (i.e., light, medium, and deep) were assigned to fabric and system levels. By doing so, the number of variations was limited, increasing the reliability of the results. The expected output was to classify the impact of variables, specifically focusing on the role of the activities assigned to the building.

(2) Retrofit strategies with the integration of PV. This test was characterised by integrating the energy production scenario (i.e., light, medium, and deep) and the results from test 1.

The following section illustrates the main results, focusing on using the Pareto front and violin diagram to explore how this abandoned building can be transformed into a PEB.

**Table 3.** Main specifications concerning some tested activities.

| | Warehouse | Conference | Restaurant | Office | Theatre | Delivery | Retail | Education | Auditorium |
|---|---|---|---|---|---|---|---|---|---|
| **Occupancy density (People/m$^2$)** | 0.05 | 0.10 | 0.75 | 0.05 | 0.37 | 0.00 | 0.08 | 0.26 | 1.61 |
| **Set Point Heating (°C)** | 18 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| **Heating set back (°C)** | 12 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 |
| **Set Point Cooling (°C)** | 25 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 |
| **Cooling set back (°C)** | 28 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 |
| **Fresh air (L/s-person)** | 0.00 | 3.54 | 3.54 | 2.36 | 4.71 | 0.00 | 3.54 | 4.79 | 2.36 |
| **Mech. vent per area (L/s-m$^2$)** | 0.30 | 0.30 | 0.91 | 0.30 | 0.30 | 0.61 | 0.30 | 0.6 | 0.305 |

## 3. Results

The first result focuses on the retrofit strategies without the integration of PV (i.e., test 1). In this regard, Figure 4 shows eight optimal design solutions (OD1-OD8), whose range of a couple of values concerning net site energy consumption and total building cost varies from 529,047 kWh, EUR 6,957,745 (OD1), to 365,254 kWh, EUR 7,838,496 (OD8).

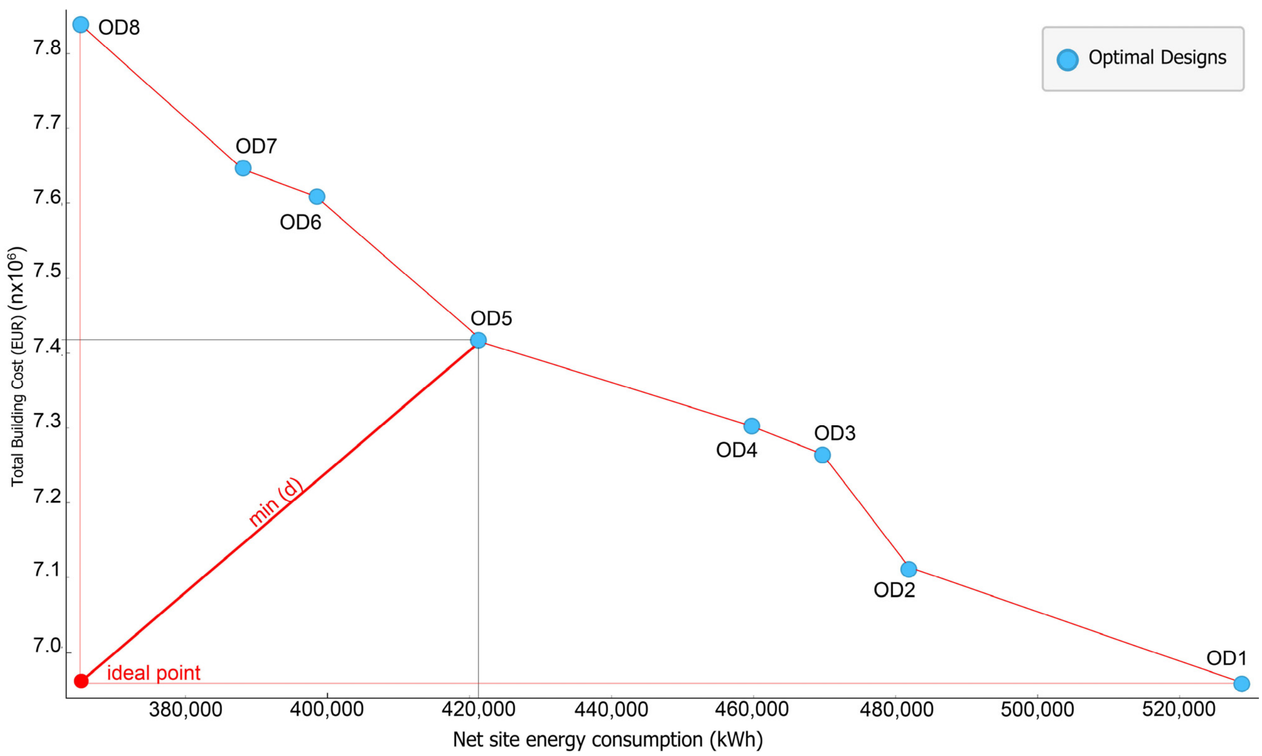



**Figure 4.** Optimal design solutions without PV integration.

In detail, the graphical construction based on the ideal point identifies OD5 (i.e., 421,252 kWh; EUR 7,417,267) as a balanced solution. In addition, the Pareto front displays the following variations: the OD1-OD2 variation, which points out a significant reduction in net site energy consumption with a marginal increment in total building cost. By contrast, the OD2-OD3 variation shows an increment in cost, which is not followed by a significant reduction in net site energy consumption. Then, it is evident that there is a significant decrease in net site energy consumption with a small cost increment between OD4 and OD5. Concerning the variation pattern of OD5-OD6-OD7, it is pretty similar to OD2-OD3-OD3. Finally, focusing on the OD7-OD8 variation, the Pareto front shows proportional variation between energy consumption and cost.

Going into the technical detail of such variations, Figure 5 shows the characteristics of each optimal design solution, stressing the combination in terms of building construction (Figure 5a), activities (Figure 5b), lighting (Figure 5c), and HVAC (Figure 5d). Thus, Figure 5 allows us to focus on specific energy consumption aspects without losing the big picture. For example, focusing on the OD5 solution, the retrofitting combination is construction—deep, lighting—deep, HVCA—medium, and store room, while the optimal design solution (i.e., OD8) refers to construction—medium; lighting—medium; HVCA—deep, and office area.

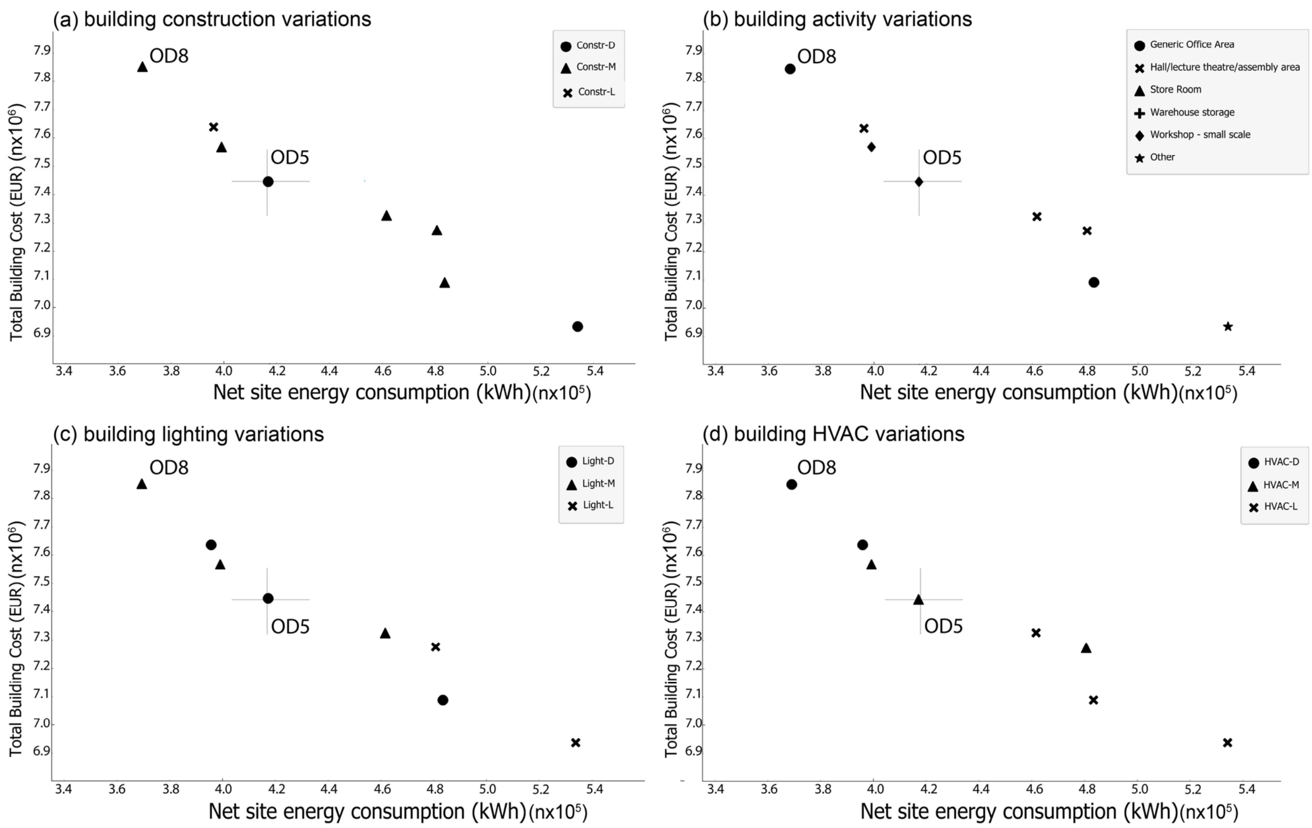



**Figure 5.** Main variables related to the optimal design solution. (**a**) Building construction variations; (**b**) Building activity variations; (**c**) Building lighting variations; (**d**) Building HVAC variations.

By comparing the above-mentioned solutions, it emerges that the cost variation parameter is associated with HCVA and/or activity. Thus, the first test considered unitary activity variation. In other words, the 10 thermal zones are assumed always to have the same activity. Nevertheless, the results show significant activity variation related to the eight optimal design solutions (see Figure 5b). Thus, further exploration of these results is needed in order to better understand the role of the activities.

Figure 6 displays the contribution of activity variations concerning the energy consumption level.

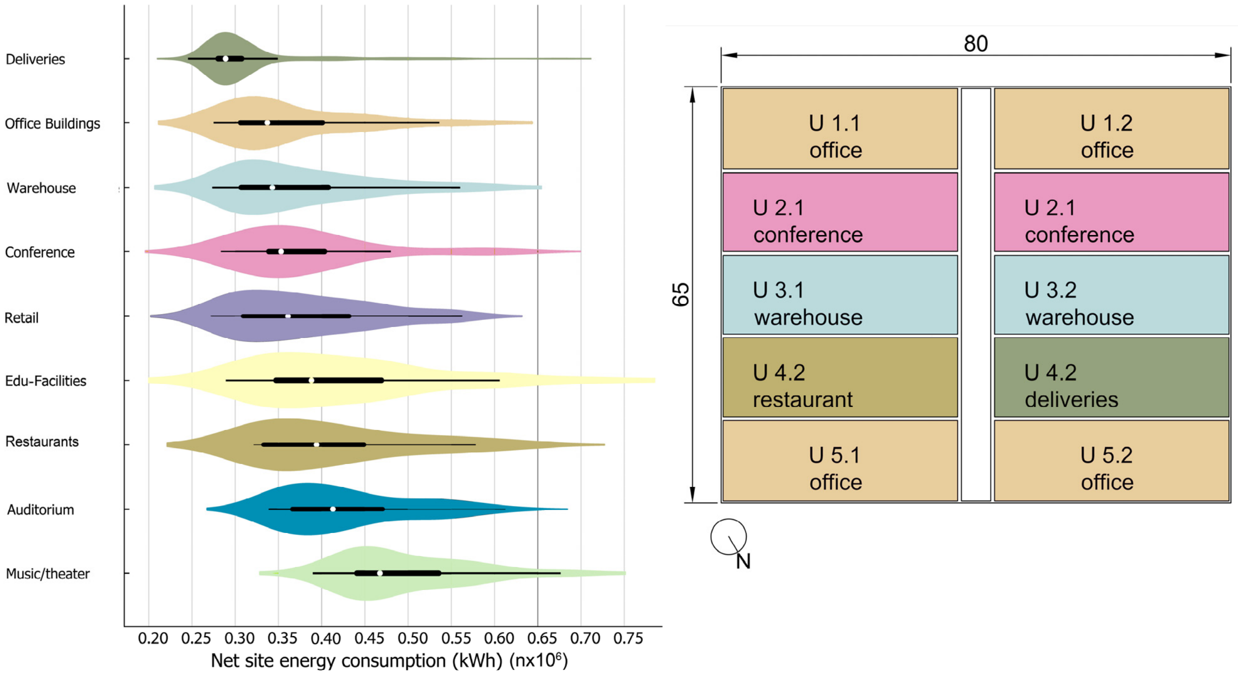



**Figure 6.** Building activity variations related to the net site energy consumption.

Thus, "deliveries" is the activity associated with less energy consumption. It is followed by "offices" and "warehouses", which have similar average values and probability distributions. Next, "education facilities" have an extensive distribution toward high energy consumption values. Finally, "theatre" has the most impact on the energy consumption value.

Therefore, Figure 6 returns a hierarchical classification of activities in terms of energy demand and, consequently, the activities that make the configuration of PEB harder. At the current level of information and detail, this study has opted to configure a functional mix according to the social expectations associated with the regeneration of the building. Thus, Figure 6 also shows the activity distribution adaptation of the baseline model adopted to run the second test (i.e., the retrofit strategies with the integration of PV).

Figure 7 shows the optimal design solutions with PV integration (i.e., test 2). As expected, findings point out three clusters associated with the tree levels of PV integration (i.e., PV-20%, PV-50%, and PV-100% of the roof area). It also highlights the key variations (i.e., V1, V2, V3, and V4).

Going into detail, the pattern of variation is similar for the three clusters. However, V1 is substantially related to the variation of the construction scenario, while the corresponding solutions in clusters PV-50 and PV-100 are related to the lighting variation. V2 shows that a respective reduction in energy consumption does not balance the increment in cost.

In addition, comparing the range of value of net site energy consumption between Figure 1 (test 1) and Figure 7 (test 2), it emerges that after establishing the set of activities, variations in the ratio between the energy consumption/cost have profoundly changed. Therefore, the findings confirm that the activities' variations impact the PEB configuration rather than the fabric and plant system variations.

Numerically, PEB configurations may be achieved with PV-100 configurations, although the gap in cost is significant. In addition, it is interesting to note that some solutions within the PV-50 cluster allow the building to achieve nearly zero-consumption targets. Thus, it is plausible to state that there is a PEB solution with a percentage of PV greater than 50% and less than 100% (i.e., see Figure 7—ideal PEB solution).

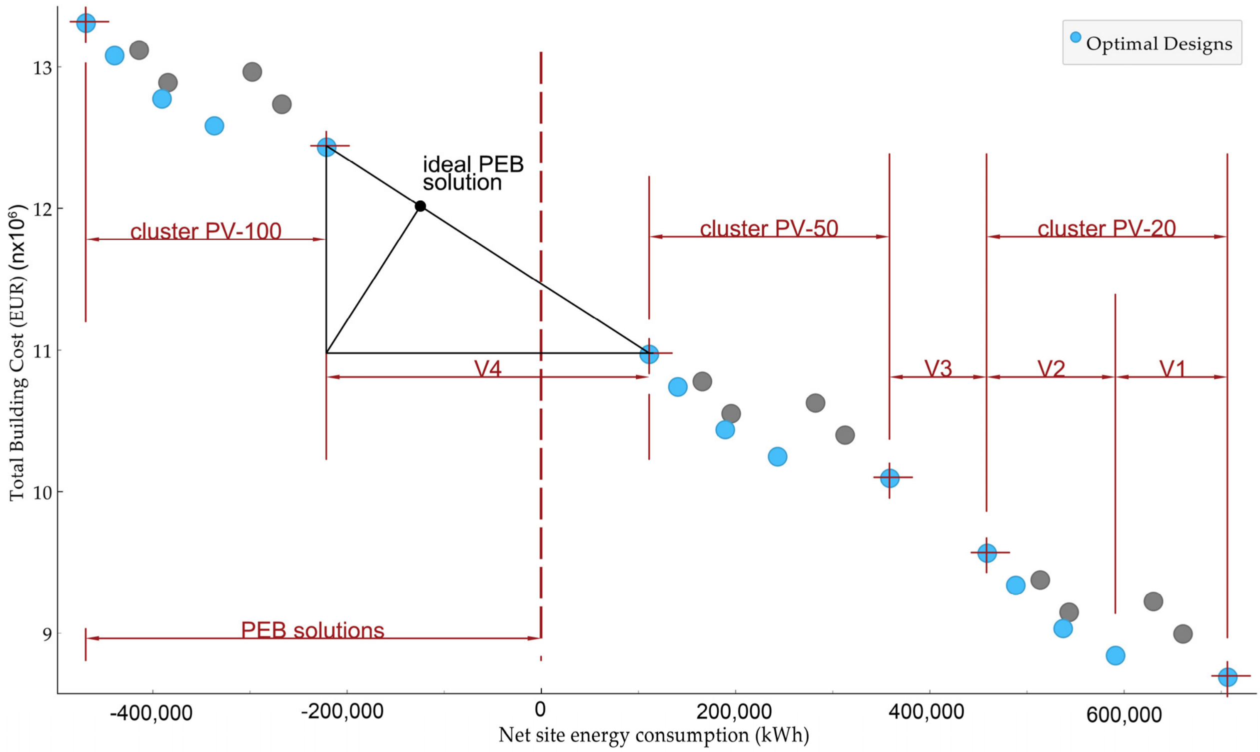



**Figure 7.** Pareto front: design solutions with PV integration.

Furthermore, Table 4 shows the construction, HVAC, and lighting configurations associated with the optimal design solutions. The findings reveal an unexpected result: only one optimal design solution refers to the construction-D configuration. In addition, the best PEB solution is achieved with a construction-light configuration.

**Table 4.** Optimal design solutions: combinations of variables.

| PV-Cluster | Net Site Energy Consumption (kWh) | Total Building Cost (EUR) | Construction | HVAC | Lighting |
|---|---|---|---|---|---|
| PV-20 | 706,778.43 | 8,691,206.51 | D | L | L |
| | 591,186.95 | 8,843,451.33 | M | L | M |
| | 537,241.98 | 9,033,757.36 | M | L | D |
| | 488,466.39 | 9,338,247.01 | M | M | D |
| | 459,023.70 | 9,566,614.24 | M | D | D |
| PV-50 | 358,851.43 | 10,093,883.50 | M | L | L |
| | 243,259.95 | 10,246,128.32 | M | L | M |
| | 189,314.99 | 10,436,434.35 | M | L | D |
| | 140,539.40 | 10,740,924.00 | L | M | D |
| | 111,096.70 | 10,969,291.23 | M | D | D |
| PV-100 | −221,026.89 | 12,431,678.55 | M | L | L |
| | −336,618.37 | 12,583,923.37 | L | L | M |
| | −390,563.33 | 12,774,229.40 | M | L | D |
| | −439,338.93 | 13,078,719.05 | M | M | D |
| | −468,781.62 | 13,307,086.28 | L | D | D |

## 4. Discussion

This study showed a procedure to assess the extent to which an abandoned building can act as a PEB. The discussion is focused on what this new association may mean.

Firstly, the technical feasibility of PEB was demonstrated under specific conditions. The first result of this study (see Figures 4 and 5) showed that it is possible to achieve a PEB configuration by regenerating the abandoned building with activities characterised by a limited occupancy density. In this case, adjacent buildings or other activities may use the surplus of energy production. The second result (see Figure 7) pointed out an alternative to achieve a PEB configuration regenerating the abandoned building based on a mix of activities useful for the local communities. In this case, the surplus of energy production must be defined by integrating an appropriate RES percentage according to the available financial resources.

The conditions mentioned above point out a relevant issue concerning abandoned buildings as PEBs: buildings may absolve a fundamental socio-infrastructural role. Specifically, this new association may contribute to the debate about the relationships between future energy infrastructure and urban landscape, emphasising a possible correlation between these two components and promoting a new form of investment, moving the capital from large-scale energy infrastructure to the regeneration of abandoned buildings as nodes of the future smart grid.

In this regard, it is interesting to note that the procedure proposed can be extended to large-scale applications, fostering a new generation of technological and environmental design strategies. Technological, because such strategies will be based on advanced intelligent devices to connect the energy exchange among the grid nodes. Environmental, because they will be based on the resource locally available to promote the organisation of autonomous energy communities. Pragmatically, these strategies, according to prior studies, may be oriented towards new urban infrastructural visions such as positive energy districts [16], positive energy blocks [17,18,20], and distributed, renewable, and interactive energy systems [32]. All these visions represent emerging paradigms that demand the definition of new implementation rules, revolutionising the sense of making infrastructures.

Here, the role of the design science research method (DSM) lies. However, DSM is usually adopted to evaluate building performance in use [44]; herein, the approach was also adopted to point out the components of the system that impact the PEB configuration. Therefore, in contrast with prior studies [25–29], which focused on the building fabric and plan systems, our findings stressed the role of activities in such a process. What emerges is that DSM is a helpful approach to establishing priorities to achieve technical and social benefits. Findings clearly showed that assigning to the whole building "deliveries" as a primary activity drastically reduced the energy demand, consequently increasing the PEB feasibility. Nevertheless, the social benefits could be pretty limited with such a configuration. Therefore, the adopted optimisation approach, in contrast with prior research [48,54,56,61,62], was not used to achieve a mere balance between the two objectives analysed (net site energy consumption and total building cost) but to explore the extent to which the PEB configuration is feasible about non-technical parameters.

Thus, our findings align with prior studies [22], which stressed the need to coordinate the various parts of the new smart energy systems. However, our findings point out new opportunities, considering the structure of the energy system as a part of the urban landscape. Therefore, our findings may be considered a further contribution to those studies focused on urban renewal efforts based on the regeneration of abandoned industrial buildings. For example, in line with [37–39], who stressed the value of reuse in the economic, cultural, social, and architectural spheres, our study identifies a new avenue to enhance abandoned buildings' cultural, social, and technical value. In addition, while prior studies [38,40] stressed the regeneration or reuse of old industrial buildings by assigning them new compatible activities in terms of the conservation of the aesthetical values, our findings include the energy implications of such activities, which can impact the configuration of a PEB.

Furthermore, according to [41], abandoned landscape projects can be integrated into the topic of PEB organisation, extending the proposed assessment methodology at scale. It may also contribute to implementing the adaptive reuse and sustainability protocols in relationship with the circular economy perspective. In this regard, the approach adopted in this study may be considered a starting point for developing a PEB protocol. Until recently, energy protocols have been related to establishing the energy demand scenarios, often stressing the energy market implications, while the urban and landscape implications have been left in the background. By contrast, our finding shows a procedure based on the level of detail and level of information that can support strategic urban regeneration across time and space. On this subject, the case study of the former industrial building proposed was emblematic, considering the amount of abandoned use across Europe. According to the results in [42], which identified that the main problem in adaptive reuse projects is the random decision of the new activity for heritage buildings without in-depth analysis, this study has focused on the activity programme of regeneration to identify those that are compatible with the fabric features and the current social needs and able, at the same time, to increase the feasibility of a PEB. Thus, the proposed methodology and vision of PEB concerning abandoned buildings, in line with the results of [24], may be used as an approach to restructuring a large number of obsolete industrial sites in European cities, often in attractive city locations and thus able to act as an innovative sample of energy and sustainable urban regeneration.

This study has limitations. It employed the DSM and provided a set of guidelines on how to convert an existing building to a PEB. This framework was based on findings from the literature related to retrofitting measures and the level of interventions on existing buildings. Applying the framework in a real case study validates its feasibility and successfully transforms an existing building to reach a positive energy building level, stressing opportunity and criticalities. In addition, this study has not given a context concerning how to use the energy surplus generated. This issue requires the contextualisation of the role of PEBs, and such contextualisation may open new socio-technical research paths. However, expanding the framework proposed and exploring more innovative socio-technical measures that could affect the way we design our cities and buildings as active parts of the energy infrastructure call for further studies. Indeed, while the technical applicability of the proposed procedure may be confirmed by the abundance of energy modelling tools, the integration into the planning practices at the local level remains the most important challenge. On the one hand, the difficulty to integrate the above-mentioned aspects is due to the resistance of the old organisational apparatus, which used to consider the development of energy infrastructure and the regeneration of cities and buildings as two separate events. On the other hand, the potential socio-technical integrations concerning the PEB configuration act in different layers such that the level of innovation is terrific. One of these multi-level integrations, for example, is the relationships between PEBs and e-vehicles. A recent study [63] found that e-vehicles are much more efficient when used in buildings designed to be energy-positive. Thus, further studies may focus on how the regeneration of buildings can be associated with the development of new e-mobility infrastructure, which will help to make e-vehicles more widely used and accepted, reinforcing the holistic vision concerning PEB as a socio-technical infrastructure for a low-carbon society.

## 5. Conclusions

The need to transition towards a low-carbon society has become a global priority as more countries realise their environment and ecological well-being depend on it. In this regard, a significant focus of the transition towards a low-carbon society is to create positive energy buildings.

This study described and tested a procedure to transform a former industrial site into a positive energy building. It was developed assuming that PEB models could be applied to meet climate change targets and promote new approaches to urban regeneration plans. The originality of this work lies in the association between PEB and abandoned buildings, which was explored and discussed as an opportunity to synchronise the evolution of energy infrastructure and settlements, considering the abundance of abandoned buildings across Europe and their strategic role within the city's structure.

Furthermore, the case study analysed allowed us to establish the extent to which this building can act as a PEB, stressing some generalisations useful to extend the replicability of the approach adopted. Therefore, this study highlighted the following aspects:

- A procedure for developing PEB strategies for abandoned buildings, based on the light, medium, and deep renovation concept, is integrated with a dedicated analysis concerning activity regeneration as a key component to configure a PEB.
- The procedure developed, based on the DSM approach, is also offered as a contribution for decision-makers to develop more appropriate strategies for urban regeneration plans, taking into account socio-technical factors that affect the PEB configuration.
- The procedure developed can be extended at scale to synchronise the evolution of energy infrastructure and urban regeneration plans, promoting further associations (e.g., PEB and e-mobility) and reinforcing the holistic vision concerning PEBs.

In conclusion, this study promoted new research areas, emphasising that the impacts of positive energy buildings may go beyond just energy efficiency. They can help to foster a more sustainable and low-carbon society in many ways. As an emerging infrastructure, PEB will allow us to do old things better: firstly, it contributes to reducing greenhouse gases emitted from the built environment. Secondly, it contributes to reducing the overall energy demand in society. Thirdly, it can create a more sustainable and resilient society, reducing the dependence on external energy sources. In addition, PEB will allow us to do new things. It can help to shape societal attitudes towards sustainability and low-carbon living. Therefore, by investing in positive energy buildings, policymakers can accelerate the transition to a low-carbon society, promoting economic growth, environmental conservation, and new forms of urban landscapes.

However, better integration and communication between social and technical tools are needed to promote stronger relationships between urban regeneration and energy infrastructure evolution. Emphasising the implications of activity in regenerating abandoned buildings as PEBs, this study has traced potential interactions between social and technical spheres. The scope is to connect the infrastructure with the peculiarities of a local context. In this regard, this study stressed the need for planning procedures to identify the extent to which abandoned buildings might act as aggregated PEBs. Furthermore, it emphasised how this new infrastructural vision can assume an urban landscape value to characterise the physical urban organisation of the future low-carbon society. In doing so, this study contributes to establishing a connection between two contemporary issues concerning the evolution of energy infrastructure and the environmental and spatial urban organisation of future settlements.

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