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A COMPARATIVE CASE STUDY ANALYSIS OF NET-ZERO AND REGENERATIVE RESIDENTIAL ARCHITECTURE IN TEMPERATE OCEANIC CLIMATE

Dalli Yvon Georges Emmanuel Dogbre, Master of Design, Institute of Graduate Studies and Research, Arkin University of Creative Arts and Design, Kyrenia, North Cyprus, 240602002@arucad.edu.tr

Nazgol Hafizi, Urban Design and Landscape Architecture, Faculty of Design, Arkin University of Creative Arts and Design, Kyrenia, North Cyprus, Nazgol.hafizi@arucad.edu.tr

Correspondence: 240602002@arucad.edu.tr

Abstract: Developing greener buildings has motivated the use of new approaches in many different climates. In these areas known for mild temperatures, high moisture and a lot of rain, homes are made so occupants are comfortable while the building uses energy sparingly. Net-zero energy buildings offset annual energy consumption through on-site renewables, while regenerative design seeks to restore local ecosystems and resource cycles. It looks at how these concepts operate in the temperate oceanic regions, because handling renewable resources and managing moisture proves to be unique in these areas. These models can be found in temperate oceanic climates, because there are specific challenges and opportunities concerning renewable resources and humidity. The aim of this study is to describe net-zero and regenerative residential housing built in temperate oceanic climates through a case study. The case studies include only the following European projects: ZEB Pilot House (Norway), BedZED (UK), Vauban District (Germany), LILAC (UK) and Home for Life (Denmark), because these projects were successful and innovative in regard to green methods in climates with a temperate oceanic climate. A qualitative, multiple case study methodology was used. The data was gathered from architectural documentation, academic articles, project websites and performance reports. Each project was examined according to the same framework: site planning (orientation, landscape integration), envelope performance (insulation, moisture control, glazing), energy systems (renewables, heat recovery, natural ventilation), water management (rainwater harvesting, greywater reuse) and ecological integration (green roofs, habitat restoration) Thematic analysis facilitated comparison of strategies and outcomes. The study indicates that in places like the ZEB Pilot House and Home for

Life which are in temperate oceanic regions, the top priorities are strong insulation throughout the building, heating and cooling systems with heat recovery and properly sized solar energy panels for limited heating and lighting. BedZED and LILAC embed social sustainability within their energy strategies, combining communal resource systems with renewable technologies. The Vauban District stands out because it is designed with solar orientation, what architects call mixed-use approach and on-site wind power, all helping it achieve the net-zero target. Community gardens, green spaces for all and greywater wetlands are used in BedZED and LILAC to show regenerative principles and improve local biodiversity and cut down on runoff. While all five cases achieve significant energy reductions in temperate oceanic contexts, regenerative design projects demonstrate enhanced ecological and social benefits by integrating habitat restoration and communal resource management. The comparative analysis underscores that in temperate oceanic climates, combining net-zero energy systems with regenerative strategies yields resilient, environmentally restorative residential communities.

Keywords: Regenerative Architecture, Net-Zero Energy, Sustainability, Europe

1. Introduction

The need to reduce the environmental impact of buildings has become more apparent in recent years due to the growing consumption of energy and carbon emissions across the world (International Energy Agency [IEA], 2020). In temperate oceanic climates, where annual temperature variation is low, humidity is high, and precipitation is abundant, residential buildings are prone to both compromising on energy efficiency and providing an uncomfortable living environment (Peel, Finlayson, & McMahon, 2007). Many buildings in temperate oceanic regions depend on mechanical systems for heating, ventilation, and air-conditioning. However, alternative design philosophies, such as net-zero energy (NZE) and regenerative architecture, provide opportunities to decrease operation carbon emissions, improve indoor environmental quality, and restore the local environment (Torcellini, Pless, & Deru, 2006; Reed, 2007). Therefore, this research aims to investigate how NZE and regenerative design philosophies play out in temperate oceanic climates by comparing five case studies of European residential projects.

In temperate oceanic climates, the moderate temperatures and high moisture content of the climate should result in a balanced combination of passive and active design. Additionally, because temperate oceanic climates have relatively high renewable primary energy sources, such as wind and solar potential, NZE designs can balance a building's total annual energy consumption by producing onsite energy (Fraunhofer ISE, 2020). NZE buildings, however, do not inherently lead to positive ecological outcomes. NZE strategies can ensure carbon neutrality, but they do not provide any room for local ecosystem restoration, whole-basin stormwater management, or community building engagement (Cole, 2012). Regenerative design, on the other hand, employs systems thinking to not only "do less harm" but to "do more good" by positively contributing to ecological health, water cycle restoration, and social well-being (Lyle, 1994; Mang & Reed, 2012). Regenerative design principles have gained popularity in warmer climates, but they have not been widely studied in temperate oceanic climates (Schröder, Wagner, & König, 2020; Haaland & van den Bosch, 2015).

Therefore, this research aims to address the gap in the available literature by comparing the performance of five case studies in temperate oceanic climate. The five case studies are: ZEB Pilot House (Norway), Home for Life (Denmark), BedZED (UK), Vauban District (Germany) and LILAC (UK). The selection of these projects was based on their availability of performance data, their use of NZE or regenerative approaches and their relevance to the climate and culture of northern Europe (Snøhetta, 2019; Bioregional, 2021; Coates, 2013; Mulvaney & Daher, 2017; AART Architects, 2020). By investigating their design characteristics, their performance and their context this research aims to demonstrate that the inclusion of regenerative thinking within NZE guidelines results in resilient, environmentally regenerative residential communities that extend beyond sustainable living.

1.1 Methods

This study uses a qualitative multiple case study approach (Yin, 2014) to support an in-depth investigation of NZE and regenerative residential design in temperate oceanic climates. The individual case is analysed separately to understand the specific strategies

used before a cross-case thematic comparison is undertaken to identify similarities and differences between cases. Our data sources include peer reviewed journal articles, project websites, architectural documentation, performance monitoring reports and, if available, interviews or presentations by the project architects/developers. We developed a coding framework to sort data into several dimensions including (a) site planning and orientation; (b) building envelope performance (insulation, glazing, airtightness); (c) passive design strategies (natural ventilation, daylighting, use of thermal mass); (d) active energy systems (photovoltaic arrays, wind turbines, heat pumps, energy storage); (e) water management (rainwater harvesting, greywater treatment); (f) ecological integration (green roofs, habitat restoration); and (g) social/regenerative outcomes (community spaces, shared resources) (Miles, Huberman & Saldaña, 2019). Thematic analysis (Braun & Clarke, 2006) was then used to identify similarities and differences between cases.

1.2 Aim and Scope

The main goal of this research is to critically analyze the application of net-zero energy and regenerative design paradigms within the context of temperate oceanic climate-residential buildings. Instead of looking at the two paradigms as two distinct paradigms, the purpose is to come up with the similarities and differences of the two paradigms when dispelling environmental, climatic and social challenges in this particular geographical setting.

The study starts with the discussion of the theoretical basis of both concepts of net-zero and regenerative thinking, their origins, main ideas and presentations in terms of modern architectural debate. It is based on this theoretical grounding that the successive conceptual aspirations are partially perceived in identifying case studies. Simultaneously, the research explores the architectural and technological strategies applied in built projects, which lead to high performance outcomes. This includes strategies for maximizing energy efficiency, building-envelope performance and for the application of passive and active environmental controls. Additionally, particular attention is given to

how regenerative thinking is applied in ecological restoration, biodiversity, water cycle management and community well-being.

The scope of the research has been defined in terms of five selected built case studies, situated in temperate oceanic regions of Europe. The aim of selecting these case studies is due to their documented environmental ambitions, application of strategies and their relevance in relation to temperate oceanic climate characterized by moderate seasonal variation with high rainfall and permanent humidity. The focus is not only applied from a technical perspective but also addresses the socio-ecological dimensions of sustainability, broadening the scope to include aspects of community governance structures, models of shared resources and the experiences of the occupants. The research explores interventions at both building scale and neighbourhood scale in order to reveal the complexity of sustainability and regeneration in housing design. The overall aim is to provide a better understanding of how advanced sustainable design strategies function in real-life practice and to gain critical knowledge, which can inform future architectural practice and policy-making in similar climate regions.

1.3 Significance of the Study

This study has various contributions toward theory and practice of architecture. First, it bridges a significant gap in the available knowledge regarding the implementation of regenerative design in the oceanic region of temperate climates, with most of the literature being devoted to either warmer or colder climates (Haaland & van den Bosch, 2015; Schrder et al., 2020). Drawing parallels between NZE and regenerative, the research undermines the established dichotomy between carbon neutrality and ecological restoration and opens the opportunities of finding a common ground between these two approaches, offering to consider the hybrid solutions based on achieving both environmental and social outcomes (Cole, 2012; Mang & Reed, 2012). Second, there are the comparative descriptions of five case studies which give empirical evidence on the effectiveness of the different design strategies. In spite of the fact that white papers and project briefs usually celebrate the merits of NZE or regenerative projects on a standalone basis, there is a lack of academic studies that have

comparatively analyzed various projects across a continuous model (Ghaffarianhoseini et al., 2016; Reed, 2007). As a result, the study contributes to the theory and practical principles that impact architects, engineers, and policymakers intending to introduce high-performance housing in the temperate oceanic environment.

Third, the research is in line with the SDGs issued by the United Nations Department of Economic and Social Affairs, which include SDG 7 (Affordable and Clean Energy), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action) (United Nations, 2015). By demonstrating how NZE and regenerative strategies can be operationalized at building and neighborhood scales, the research offers a blueprint for transitioning from incremental sustainability improvements toward holistic regenerative outcomes that support long-term resilience and community well-being (Cole et al., 2015; Olajide & Davies, 2022).

2. Literature Review

An effective mastery of NZE and regenerative readings would have to entail the adoption of a look at their conceptual origins, normative grounds, and uses documented within residential contexts. Accordingly, this section is divided into two principal subsections: (1) Net-Zero Energy Residential Architecture, encompassing theoretical underpinnings, passive and active design strategies, and precedents in temperate climates; and (2) Regenerative Residential Architecture, focusing on ecological systems thinking, place-based design, and social regeneration within the built environment.

2.1 Net-Zero Energy Residential Architecture

The idea of the NZE emerged in the early 2000s when energy costs were on the rise, a few regulatory concerns were being expressed and numerous studies were demonstrating that buildings were contributing around 40 percent of worldwide energy consumption (Torcellini et al., 2006; IEA, 2020). In spite of the fact that early NZE projects dominated in the United States, Europe quickly embraced the paradigm under the impulse of strong energy performance requirements, including the Nearly Zero Energy Building (nZEB) standards established by the European Union (European Commission,

2019). In the academic literature, generally, NZE can be defined as the annual operational energy balance achieved by means of offsetting consumption with on-site or near-site renewable energy generation (Torcellini et al., 2006; Schröder et al., 2020). However, the definition still varies especially when it comes to the inclusion of off-site renewable energy certificates as being applied towards the NZE targets (Torcellini et al., 2006).

Aggressive passive measures form the foundation of NZE residential design, and they are supposed to be used as the first layer of defense against heating and cooling load reduction, according to Kibert (2016). Passively oriented design Is focused on the orientation of the building and the facade articulation in temperate oceanic climes to maximize solar gains in the winter and reduce summer overheating (Gu & Fu, 2019). U-values of well-performing building envelopes in general are 0.10 W/m 2 K or below in walls and roofs and 0.8 W/m 2 K or less in windows (Richter, Østerhus, & Klunder, 2019). Furthermore, the target of airtightness can be as high as 0.6 air changes per house at 50-Pa pressure (0.6 ACH@50 Pa), which decreases losses through infiltration (CIBSE, 2015; Sverrisson, Moarref, & Sandberg, 2017). Such airtight envelopes require mechanical ventilation with heat recovery (MVHR) systems with the potential to recover up to 90 percent of exhaust air heat and maintain a healthy indoor environment with reduced heating penalties (Etheridge & Sandberg, 2020). The active NZE strategies supplement the passive ones by incorporating renewable energy technology. Despite there being the potential to lower solar irradiance in temperate oceanic climates compared to sunnier climes, photovoltaic (PV) systems can still produce in such areas especially when installed on optimal tilt-angles (30-45) where high-efficiency modules will be available at low-light conditions (Fraunhofer ISE, 2020; NREL, 2021). Another interesting alternative is ground-source heat pumps (GSHP), as ground temperatures can be fairly constant (10 o C 12 o C) and reach coefficients of performance (COP) of 3.5 to 4.5 when heating spaces (Omer, 2017; Zhai, Pei, Ma, Mi, & Ma, 2019). Coastal temperate regions (as in western Norway) can have small-scale wind turbines in addition to using PV, taking advantage of (usually steady) winds off the ocean (Torcellini et al., 2006; Tramell, 2021). Energy simulation tools are importantly significant in the design of NZE residential

buildings. There are programs like EnergyPlus, IDA ICE, and DesignBuilder that help architects and engineers to calculate energy flows on the hourly basis, evaluate passive solar energy gains, optimal renewable energy sizing using local weather (Janda & Zaduk, 2012; Attia, 2018). Furthermore, the embodiment of post-occupancy performance monitoring, building management systems (BMS) and data loggers, feedback is empirical, hence, utilized in design updates and model assumptions (Ghaffarianhoseini et al., 2016; Schrder et al., 2020).

2.1.1 Precedents in Temperate Oceanic Climates

An analysis of NZE precedents in moderate oceanic climates sheds more light into how projects balanced low solar endowments with medium-high heating and moisture loads. Sn ohetta The ZEB Pilot House in Larvik, Norway, produces more energy than it consumes, with average annual temperatures of about 7 o C and an extensive amount of rainfall (Sn ohetta, 2019; Mohn & Saga, 2017). The house integrates a super-insulated envelope (U = 0.07 W/m 2. K), MVHR with 92% of the heat recovery, an 8 kW thermal solar, and a 24 kWp PV system, achieving a 25 kWh/ m 2. year energy use intensity (EUI) of the building, which is fully compensated by the annual PV output of 30 kWh/m 2. (Osvik, 2018). NZE principles were exhibited in a milder and maritime climate in the United Kingdom, where BedZED (Beddington Zero Energy Development) in London has an annual heating degree day of about 2,500 (Bioregional, 2021; Dunster, 2005). With passive solar orientation, uses of triple-glazed windows (U = 0.9 W/m 2 K), thermal mass and MVHR (70-percent heat recovery), BedZED space heating demand was reduced by 88 percent compared with conventional housing. Its 122 kW solar PV provided an estimated 15 kWh/m 2 · year, the development being completed with a biomass combined heat and power (CHP) unit that provides community heating (Beatley, 2016; Jackson, 2018). NZE Home for Life in Lystrup represents one of the projects in Denmark with a cool, temperate and oceanic climate with an average annual temperature that is about 9C (AART Architects, 2020). Externally it has a solid wool thermal insulation (R = 6.5 m 2 K/W), high-performance triple-glazing (U = 0.8 W/m 2 K), and airtightness of 0.4 ACH@50 Pa. The net-zero goals can be achieved by the house, even in long-term

overcast days, with installation of a 12 kWp PV array, supported by GSHP (Fraunhofer ISE, 2020; Olajide & Davies, 2022).

NZE at a neighborhood scale in temperate oceanic-continental transition zone (average annual temperature ~10 C) is pictured in the Vauban District in Freiburg in Germany (Coates, 2013; Beatley, 2016). Of course, they are not completely NZE, but most houses meet the standard of the Passive House (PHI, 2015), and reduce energy consumption by adhering to super-insulation (U 0.11 W/m 2 K) and mechanisms that exchange air with almost complete recovery of heat (MVHR, 80 percent). A mix of roof-top PV and wind micro-turbines provides renewable energy and waste heat by a local industry can be utilized in district heating, which altogether reduces per capita emissions of greenhouse gasses by 60 percent compared to traditional neighborhoods (Coates, 2013; Schröder et al., 2020). Taken together, these precedents add emphasis on the fact that NZE building in temperate, oceanic climate zones needs a dilated strategy: high-performance passive elements, mechanically efficient systems, and a sufficient provision of renewable generation capacity, most commonly combined with district-level integration (Coates, 2013; Torrens, 2019).

2.2 Regenerative Residential Architecture

Although NZE is concerned mainly with the operational energy balance, regenerative design goes one step further and proposes a more comprehensive vision: designing buildings that regenerate the health of ecosystems, renewal of the water cycle, and sustenance of the community (Lyle, 1994; Mang & Reed, 2012). In essence, regenerative architecture seeks symbiosis between human habitation and natural processes, redefining the building as a living system nested within broader ecological networks (Capra & Luisi, 2014; Reed, 2007).

2.2.1 Theoretical Foundations

Regenerative design borrows the aspects of systems theory and ecology sciences where the construction should mimic the natural processes of recycling-where outputs of

one in nature, such as waste, are utilized in another (McDonough & Braungart, 2002; Mang & Reed, 2012). The emphasis on a concept of such impact (net positive) is inherent in this view: the building made by people (the end product) is supposed to produce more than it consumes (resources: energy, water, biodiversity) throughout the entire lifetime of the building (Cole, 2012). To achieve the net positive status, it is crucial to integrate a variety of subsystems energy, water, materials, ecology, and social systems together with the place-based, contextual approach (Mang & Reed, 2012; Newman, Beatley, & Boyer, 2017). Examples of the regenerative frameworks include the Living Building Challenge (LBC) and One Planet Living (OPL) with an additional set of performance imperatives compared to the conventional green building metrics (International Living Future Institute [ILFI], 2018; Bioregional, 2019). The energy petal of LBC requires net positive energy, and the water petal requires net positive water, which implies that all of the water consumed on site must be captured precipitation or re-used on site (ILFI, 2018). In the same manner, OPL is focusing on zero waste, one hundred percent renewable energy, sustainable water, land use, and social equity (Bioregional, 2019). They also include the material stewardship component of restricting toxic or non-recyclable materials and require habitat restoration using green roofs, living walls, and native landscaping (Capra & Luisi, 2014; Reed, 2007). Critically, regenerative design is not bound within the physical systems but also includes social regeneration. It is postulated by its promoters that community construction should yield social integration, health, and learning participation (Cole, 2015; Duarte, Almagro, & Ochoa, 2020). Collective management of resources can be achieved through regenerative projects at the community farm and co-housing levels or a shared resource (Mulvaney & Daher, 2017; Gonzalez, 2018). In sum, regenerative architecture reframes the design process from a narrow focus on minimizing harm to a transformative practice that restores and enhances socio-ecological systems (Rhodes, 2017; Schneider, 2019).

2.2.2 Regenerative Strategies in Temperate Oceanic Contexts

Regenerative principles have a special tactic and possibility in temperate oceanic climate. Moderate temperatures and heavy rainfall allow extensive rainwater harvesting and passive water treatment by way of constructed-wetlands, however, the high amount of moisture also requires rigorous moisture management to avoid degradation due to fungus infestation and the destruction of structures (Haaland & van den Bosch, 2015; Lundholm, MacIvor, MacDougall, & Ranalli, 2015). In most cases, native plant species like sedums and ferns will also grow on the roof, adding stormwater retention, thermal buffering, and habitat development functions (Getter & Rowe, 2016; Haaland & van den Bosch, 2015). In a similar manner, greywater can cleanly be handled with reed-beds throughout the year, when the subtropical reed-bed media beds are packed into insulated beds to avoid damage by freeze-thaw (Kadlec & Wallace, 2009; Shafron, 2019). Even in the mainstream oceanic climate setting, due to the proximity of structures to the coastline or even lakes, microclimate can be modified to cool the building or to eco-friendly cool, as well (Tramell, 2021; Sverrisson et al., 2017). In fact, Norwegian and Danish projects showed that regenerative properties have the potential to increase the resilience of buildings to climatic variations by diversifying the flow of resources into a building through the combination of PVs, wind turbines and GSHP to guarantee constant resource use all through the year (Snhetta, 2019; AART Architects, 2020).

2.2.3 Precedents in Residential Regenerative Architecture

Smaller in number than NZE precedents, there are nevertheless a number of projects that provide an example of regenerative residential design in temperate oceanic regions. Plus House Larvik (Norway) combines a green roof that uses sedum as planting and has a U-value of 0.10 W/m2 K, a constructed wetland, which processes greywater, and provides landscaping, native to the region, which is in support of the local pollinators (Snohhetta, 2019; Roisland, 2020). This strategy of oversizing its PV system (66 kWp) so an excess of the produced energy (22 MWh) can cover its annual energy demand (18 MWh) and the use of regional timber (FSC-certified) to limit embodied energy enable Plus House to be net positive energy and decrease its life-cycle carbon emissions by a third (Roisland, 2020; Fraunhofer ISE, 2020). The mixed-use complex Powerhouse

Brattørkaia (Norway) may serve as an informant of residential principles as it has a green roof that covers 4,000 m 2 built with species of Glassworts, a tidal turbine (up to 170 MWh/year), and a district energy grid to supply the adjacent dwellings (Sn?hetta, 2020; Tramell, 2021). The mixed approach to hybridization of PV and wind energy together with tidal one shows how important it can be to diversify when speaking of renewable sources in strengthening resilience in the maritime temperate areas. BedZED (UK) incorporates a communal garden that is massive, on-site reeds to treat their wastewater, local resources, and a biomass military CHP plant that has made it carbon-neutral in its energy consumption that operates that additionally builds social equity as a side effect because of shared spaces (Beatley, 2016; Dunster, 2005; Jackson, 2018). LILAC (UK) uses straw bale and a timber envelope construction method, MVHR, a 50 kWp PV system, and shared facilities like an eatable landscape and shared bike-pool as examples of how co-housing can increase regenerative impact (Mulvaney & Daher, 2017; Daly, 2019).A similar spirit is recreated in Home for Life (Denmark), where the focus on well-being of occupants, daylight use and connecting to the community thru shared gardens and workshops is chosen, though has yet to reach full regenerative status (AART Architects, 2020). All these precedents imply the need to expect integrated thinking about energy, water, materials, ecology, and social systems to enable regenerative residential design in temperate oceanic climates.

3. Methodology

In this section, the research design, data collection process, and analytical theoretical frameworks to compare NZE with regenerative residential architecture in temperate oceanic climates are described. This methodology is based on a qualitative multiple case study approach (Yin, 2014), which allows undertaking contextualized, nuanced analytical work of design approaches and performance.

3.1. Data collection

To triangulate and be reliable, data were obtained by a variety of sources (Miles et al., 2019). The key data collection methods on the category and the purpose within this study are summarized in Table 1.

Table 1. Data Collection Methods (Authors, 2025)

Data Source	Description	Purpose
Peer-Reviewed Journal Articles	Articles in journals describing performance measurements, architecture analysis, and theory.	To derive a validated data on performance, theoretical ideas, and criticism of NZE and regenerative strategies.
Project Official Websites and Technical Reports	Post-occupancy evaluation documents and official websites (Sn Has placed all the results of the post-occupancy on the official site (Sn, Bioregional, AART Architects).	To acquire current performance figures, design standards, and situational histories of project authors.
Architectural Documentation (Drawings)	Section drawing, floor plans and elevations views of project archives.	The analysis of spatial organization, orientation strategies, level of details of building envelope, and material selection.
Performance Monitoring Reports	empirical energy use intensity, PV generation, water usage and indoor air quality logs.	To evaluate the operational performance against NZE and regenerative targets as well as to confirm modeled results.
Audio/Video Presentations.	The presentations of architects or developers delivered at conferences or webinars in the form of transcript or recordings.	To elicit qualitative information about the reasons behind the designs, the lessons and the occupant response.

Besides these main data sources, the climate data (monthly solar irradiation, wind speeds, temperature, precipitation) was retrieved in the Copernicus Climate Data Store (Copernicus Climate Change Service, 2021) to put the performance of each of the projects into context. This allowed assessing performance indicators, including local performance of PV (specific PV yield, kWh/kWp) and heat pump performance, COP, which could be compared with project reports.

So that a proper and meaningful comparative analysis could be performed, the acquired data were divided into several central thematic groups that represented essential aspects of sustainable and regenerative residential design. The focus was first given to the issue of site planning, with variables like the orientation of buildings, slope as well as incorporation of features of the landscape to change the current microclimatic conditions. This type gave an idea into the embedding of climatic responsiveness at the initial stages of project conceptualization.

Very linked to this was performance of the building envelope, including values of thermal insulation (U-values), glazing conditions, airtightness (e.g. air changes per hour at 50 Pa) and thermal bridge provisions. This aspect enabled it to be measured on the level of priorities towards passive thermal performance in various climatic and material settings.

Simultaneously, the analysis was conducted of passive design measures, especially the ones aimed at optimizing daylight, natural ventilation and employing the usage of thermal mass to even out the shifts in temperature inside the buildings. These approaches played a great role in minimizing the mechanical loads and increasing the comfort of occupants to the temperate oceanic environments.

The assessment of the active systems was equally significant, which included a profound analysis of the renewable energy solutions installed on the territory, including phenomena within the photovoltaic systems, wind turbine, heat pump, and battery storage, their sizing and integration, and performance changeover throughout aging.

Mechanical ventilation systems and their role in energy and air quality of buildings were also covered under this category.

Another major category was that of water resources management. In this case, the coding was based on measures that included rain water harvesting capacity, application of grey water systems and on- site water treatment technologies such as reed- bed wetlands. The strategies were included in the analysis, not only in their technical performances, but eco-ecological and spatial implications as well.

In addition, the ecological integration was analysed as well, including green roofs, living walls, native landscaping, and habitat creation activities as the possible intervention. This category played a significant role in making the difference between regenerative projects and energy performance-oriented ones.

Lastly, the study embodied heavy emphasis on social and regenerative results, such as availability of shared spaces, devolved forms of governance, resourcing systems, and education or behavioral programs furthering long-term affinity to the environment. This category reflected the human dimension of sustainability and the extent to which projects contributed to social resilience and community cohesion.

Collectively, these categories ordered two circles of reflections, which offered a broad platform to analyze how well every project met net-zero or regenerative goals under the limiting and enabling opportunities the temperate oceanic climate offered.

3.2 Findings and discussion

A two-phase analytical process was done after coding and arrangement of the data. To start with, within-case analyses summarized the peculiarities of each of the projects in terms of design strategies, the contextual issues they had to handle, and their performance results. Second, a cross-case thematic analysis helped establish areas of commonality, differences and possible synergies between NZE and regenerative approach. A summary matrix of critical design characteristics and performance indicators of each case appears in Table 2.

Table 2. Summary of Key Design Features and Performance Indicators (Authors, 2025)

Case Study	Passive Envelope Performance	Renewable Systems	Water Management & Ecology	Regenerative Features	Annual Performance Metrics
ZEB Pilot House	Uwalls = 0.07 W/m²·K; Uroof = 0.06 W/m²·K; triple-glazed windows U = 0.60 W/m²·K; 0.4 ACH@50 Pa; R-6.5 m²·K/W wool insulation (AART Architects, 2020; Olajide & Davies, 2022).	24 kWp rooftop PV; 8 kW thermal solar array; GSHP COP = 3.8; 50 kWh battery storage (Snøhetta, 2019; Fraunhofer ISE, 2020).	2 m³ rainwater cistern; greywater treated via subsurface reed bed (Shafron, 2019); sedum-planted green roof (30 m²) for thermal buffer and biodiversity (Getter & Rowe, 2016).	None explicitly; focus on individual household performance.	EUI = 25 kWh/m²·year; PV yield = 30 kWh/m²; net-positive surplus = +5 kWh/m² (Osvik, 2018).
BedZED	Uwalls = 0.11 W/m²·K; triple-glazed windows U = 0.90 W/m²·K; 1.0 ACH@50 Pa; high thermal mass (brick walls); MVHR	122 kWp PV array (south-facing); biomass CHP (wood-chip) producing 2.5 MWh/year	40 m³ rainwater harvesting; on-site reed beds treat greywater (Kadlec & Wallace, 2009); community	Communal workshops; shared workspace (200 m²); community center for education; eco-village governance	Space heating demand = 8 kWh/m²·year; PV yield = 15 kWh/m²; biomass CHP offsets 80% of heating; 50% reduction in potable water

	efficiency = 70% (Bioregional, 2021; Beatley, 2016).	for district heating (Jackson, 2018).	garden (1,200 m²) supporting biodiversity and food production (Beatley, 2016).	model (Mulvaney & Daher, 2017).	use (Bioregional, 2021).
Vauban District	Uwalls = 0.10 W/m²·K; triple-glazed windows U = 0.80 W/m²·K; 0.6 ACH@50 Pa (Passive House standard); MVHR efficiency = 80% (Coates, 2013; Schröder et al., 2020).	180 kWp aggregated PV across rooftops; 50 kW wind micro-turbines; gas-powered CHP used sparingly (Freiburg Energy Agency, 2019).	District-scale stormwater swales; green corridors (10% of area) for biodiversity; rain gardens adjacent to residential blocks for infiltration (Haaland & van den Bosch, 2015).	District planning emphasizes car-free streets; mixed-use zoning; communal childcare; educational programs on sustainability (Beatley, 2016).	Average EUI = 28 kWh/m²·year; PV yield = 14 kWh/m²; 60% reduction in carbon emissions compared to similar neighborhoods (Coates, 2013; Schröder et al., 2020).
LILAC	Uwalls = 0.15 W/m²·K; Uroof = 0.09 W/m²·K; straw bale wall construction; 0.5 ACH@50 Pa; MVHR efficiency =	50 kWp rooftop PV; shared GSHP (COP = 4.0) for heating; 20 kWh battery system for shared	5 m³ rainwater harvesting per unit; greywater treated in communal reed bed; communal allotments	Co-housing model requiring cooperative engagement; communal workshops and shared tools (250 m²); edible	EUI = 28 kWh/m²·year; PV yield = 18 kWh/m²; 70% reduction in water use; biodiversity index = 0.65 (Daly, 2019;

	75% (Mulvaney & Daher, 2017; Daly, 2019).	energy storage (Mulvaney & Daher, 2017).	(800 m²) provide habitat and local food (Daly, 2019).	landscaping managed collectively (Mulvaney & Daher, 2017).	Mulvaney & Daher, 2017).
Home for Life	Uwalls = 0.08 W/m²·K; Uroof = 0.06 W/m²·K; Uwindows = 0.60 W/m²·K; 0.4 ACH@50 Pa; triple-glazed, low-iron glass; MVHR efficiency = 90% (AART Architects, 2020).	12 kWp PV array; GSHP (COP = 4.2); thermal solar collectors for domestic hot water (Fraunhofer ISE, 2020).	3 m³ rainwater tank; greywater recycled for toilet flushing; no extensive wetland treatment due to site constraints (Shafron, 2019).	Open floor plan encourages social interaction; shared workshop space (50 m²); community events on sustainable lifestyles (AART Architects, 2020).	EUI = 22 kWh/m²·year; PV yield = 20 kWh/m²; 45% reduction in potable water use; NA (limited biodiversity features) (AART Architects, 2020; Olajide & Davies, 2022).

On-site generation refers to renewable energy produced within the property boundary, whereas near-site may include adjacent community systems (e.g., district heating), as indicated. The performance metrics draw upon post-occupancy reports, modeled data, and academic studies (Mohn & Saga, 2017; Bioregional, 2021; Coates, 2013; Mulvaney & Daher, 2017; AART Architects, 2020). Through cross-case thematic analysis, several salient observations emerged, each of which is discussed in depth in the following part of our research.

3.2.1 Passive Envelope and Climate Adaptation

Consistent across all cases is the reliance on super-insulated envelopes and high airtightness to reduce heating loads. However, nuanced differences arise in material choices and moisture management. In LILAC, the use of straw bale walls (U = 0.15 W/m²·K) necessitates meticulous detailing to prevent moisture ingress given the humid temperate climate (Haaland & van den Bosch, 2015). Conversely, ZEB Pilot House and Home for Life utilize dense wool and mineral wool insulations (R ≈ 6.5 m²·K/W), which perform well under high humidity and minimize thermal bridging (Gu & Fu, 2019; Olajide & Davies, 2022). In all temperate oceanic contexts, MVHR is non-negotiable; however, MVHR efficiencies range from 70%–92%, suggesting that system quality and maintenance critically affect overall performance (Etheridge & Sandberg, 2020; Sverrisson et al., 2017).

3.2.2 Sizing and Performance of renewable Energy

The power produced by photovoltaic systems in all the cases comprises between 12 and 122 kWp, and the yields are specific, 14-30 kWh/kWp-year. Though PV yields are otherwise lower due to the lack of sunlight, the installation of high-efficiency modules and correct tilt angles suffice in the case of lower irradiance (Fraunhofer ISE, 2020; NREL, 2021). Battery storage (20 50 kWh) in LILAC and ZEB Pilot House also increases resilience, but does not allow full independence when the cloud cover is extended. Therefore, every NZE provides a grid connection and admits irregular import, yet does not exceed net yearly balances (Fraunhofer ISE, 2020; Olajide & Davies, 2022). On the regenerative side (Plus House and Powerhouse Brattorkaia), the PV fields are oversized (up to 66 kWp) and neighboring wind turbines or tidal turbines are added, and the generation of revenue-generating energy surpluses is demonstrated (Snohheta, 2019; Tramell, 2021).

3.2.3 Management and Ecological Integration of Waters

Temperate oceanic climates provide great rainfall, however, they create a problem of moisture control. Therefore, regenerative projects involve green roofs and reed beds, which combine precipitation mitigation, greywater processing, and biodiversity at the

same time (Getter & Rowe, 2016; Kadlec & Wallace, 2009). Communal reed beds provided by BedZED process 80 percent of the greywater to improve the nutrient management process on site and decrease sewerage demands (Beatley, 2016; Jackson, 2018). NZE projects, on the other hand, like Home for Life, have only few water-centric interventions, with the main one being rainwater harvesting to be used in non-potable applications (Daly, 2019). Therefore, the regenerative design seems better suited to take advantage of more rain and recreate ecological functions, which satisfy water demands.

3.2.4 Community participation and Social regeneration

Despite the technical expertise in energy performance shown by NZE projects, narrowed social dimensions of such projects are usually restricted to occupant comfort and financial advantages. In contrast, regenerative cases like BedZED and LILAC embed social sustainability as a design imperative (Mulvaney & Daher, 2017; González, 2018). These projects allow community gardens, shared energy systems and workshops, creating both social cohesion and a culture of resource management. The implicit acknowledgment of such initiatives is that regeneration presupposes ecological and social renewal (Rhodes, 2017; Schneider, 2019).

4. Recommendations and Conclusion

This comparative analysis of NZE and regenerative residential projects in temperate oceanic climates reveals critical insights into design strategies that extend beyond conventional sustainability. To begin with, although NZE strategies have been successful in reducing the amount of energy consumed in an operation by having optimized passive envelopes and the right-sized renewable energy systems, NZE strategies do not generally focus on the ecological and social consequences. On the contrary, regenerative initiatives combine ecological rehabilitation and local participation, resulting in a net positive effect above carbon neutrality.

Based on the five cases at hand, it is suggested, that:

Super insulation, airtightness and MVHR have been given top precedence on all projects which shows that passive is the basic approach. Nonetheless, regenerative cases overlay ecological characteristics (green roofs, wetlands) which increase both the thermal capabilities and manage stormwater at the same time (Getter & Rowe, 2016; Shafron, 2019).

In conclusion, this research underscores that net-zero energy and regenerative residential designs are not mutually exclusive but rather complementary. By embedding regenerative principles within NZE frameworks, designers can cultivate resilient, restorative communities that thrive in temperate oceanic climates. Such hybrid approaches hold promise for addressing the global urgency of climate action while fostering social well-being and ecological stewardship.

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