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NET POSITIVE ENERGY BUILDINGS IN ARCHITECTURAL CONTEXT

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ABSTRACT

Considering the rapid depletion of natural resources because of increasing comfort conditions in living spaces and increasing expectations from buildings due to developing technology and climate change, today it has become inevitable to develop effective policies to meet the energy demand of buildings and to create renewable and sustainable systems. In this context, new generation building design in architecture requires regulations that reduce energy consumption, protect natural resources while considering climatic conditions and carbon emissions. In this study, buildings with net-positive energy were evaluated with the comparative analysis method and inferences were made for new generation building designs. In the first step, the properties of buildings with net-positive energy are discussed. Then, it is aimed to evaluate the buildings in which the design principles determined for a positive energy building are applied according to these features. In this context, ten buildings, which can produce more energy than the energy they consume and whose designs were made by considering the energy criteria developed according to different climatic regions, were examined. It is aimed the outcomes of this study to raise awareness against building design concepts with net-positive energy and contribute to raise the number of buildings designed with energy concepts.

Contribution/ Originality: Currently, energy-producing buildings and net positive energy buildings have become much more important considering the issues of climate change, limited energy resources and greenhouse gas emissions. In this study, buildings with net-positive energy from different climatic regions according to their energy equipment in the architectural context were evaluated with the comparative analysis method and inferences were made for new generation building designs.

1. INTRODUCTION

In addition to the natural disasters such as droughts, floods, fires and earthquakes encountered globally in the last two decades, climate change problems have affected the entire world [1]. Climate change problems have revealed that new policies and systems should be developed according to different climate regions [2]. The development of industry and globalization phenomena also gradually increase the need for energy and natural resources by bringing about climate change. The energy consumed in buildings accounts for 40% of the total energy [3] and causes approximately 40% greenhouse gas emissions around the world [4]. Considering the last half century, energy systems have been developed against energy consumption [5-7]. Achieving greenhouse gas emission reduction targets for the built environment requires an integrated approach with sustainability [8]. In addition to inadequacy of current economic and technical knowledge, climate change events, including rapid depletion of natural resources, environmental pollution and global warming, have forced architects to turn to new technological developments in building design [9]. In this context, studies focusing on the conservation and sustainability of energy have been conducted in the discipline of architecture, depending on climate and other factors. Recently, the number of building design concepts with integrated renewable energy systems has increased. In this context, buildings with net-positive energy have emerged as a new building design concept emphasizing the importance of active energy [10].

In the literature, there are several definitions of buildings with net-positive energy. The European Commission defines a positive-energy building as a building that produces, on average, more energy per year than it receives from external sources Reda and Fatima [11]. Cole [12] named systems that produce more than they should meet their own needs and add value to the ecological environment. Zhang, et al. [13] explained that a positive energy-built environment could be a key solution for energy systems in the transition toward carbon neutrality. Birkeland [14] termed net-positive development as physical development by increased economic, social and ecological capital with a positive impact on the life cycle relative to previous conditions. Salom, et al. [15] defined an autonomous positive energy-built environment as maintaining the internal energy balance at any point in time in a net-positive annual energy balance within geographical boundaries. Oree and Anatah [16] defined positive energy buildings as buildings that produce more than the expected annual energy performance. Hernandez and Kenny [17] defined positive-energy buildings as systems that earn more in terms of cost than they pay annually. Drobnič, et al. [18] named these buildings as buildings that provide demanded energy without a grid connection. Kılkış and Kılkış [19] stated that positive energy buildings are buildings that produce a more high-quality energy than they consume annually.

Positive energy buildings have taken the stage since 2010 and today are still in the development process [2]. Buildings with net-positive energy require a system-based approach that maximizes energy performance with more complex systems and energy partnerships [20]. Buildings are equipped with smart technologies to trigger active management of energy consumption and production by proactive energy users [21]. Units are connected to smart grid systems to promote energy sharing at the regional level [22]. In this context, the net-positive balance means that the annual excess of electrical energy fed to the grid is greater than the annual electrical energy received from the grid [23]. In energy optimization, the consumption, production and storage of electricity are among the most important parameters [24]. It is recommended to use technologies such as photovoltaic panel systems, heat pump, energy and thermal storage systems and electric vehicles to obtain maximum efficiency from energy [25]. Legal regulations and clean energy packages are required to use these technologies. It is important to identify new use cases and revenue streams along with economic optimization and market integration [26]. A balanced and renewable energy transformation can be achieved by developing local and national strategies [27]. In order to better adapt the building to climatic conditions and to follow up the average of seasonal changes in consumption, a 1-year equilibrium period should be taken as a basis [28].

Versatile planning is required for constructing positive energy buildings, which have difficulties as well as advantages. Buildings need complex and integrated systems. In this context, interdisciplinary teamwork is essential in the construction of the building. On the other hand, the planning and maintenance chain from the building design to the final product, and the selection and deciding of local systems according to geography and climatic data are the main difficulties [29]. For the resolution of local systems, positive energy zones should be considered by creating smart cities [30]. The lack of adequate infrastructure in small-scale cities causes the construction process of the building to be implemented in these regions to be prolonged [31]. The use of integrated technological innovations comes to the fore at this point [32]. Depending on the changes in energy systems in different climatic regions, different construction systems should be planned [33]. Energy storage systems should be developed when the conditions are considered more difficult in the northern climate. Additionally, the regulation of the air outside the building and the air quality inside the building should be evaluated according to the climatic conditions [34]. In addition to natural factors, technical obstacles, the inadequacy of infrastructure, lack of governmental and institutional support, standardization and lack of public awareness are among the reasons that make it difficult to implement such building designs [35]. In Figure 1, the mentioned properties of positive energy buildings are shown schematically.

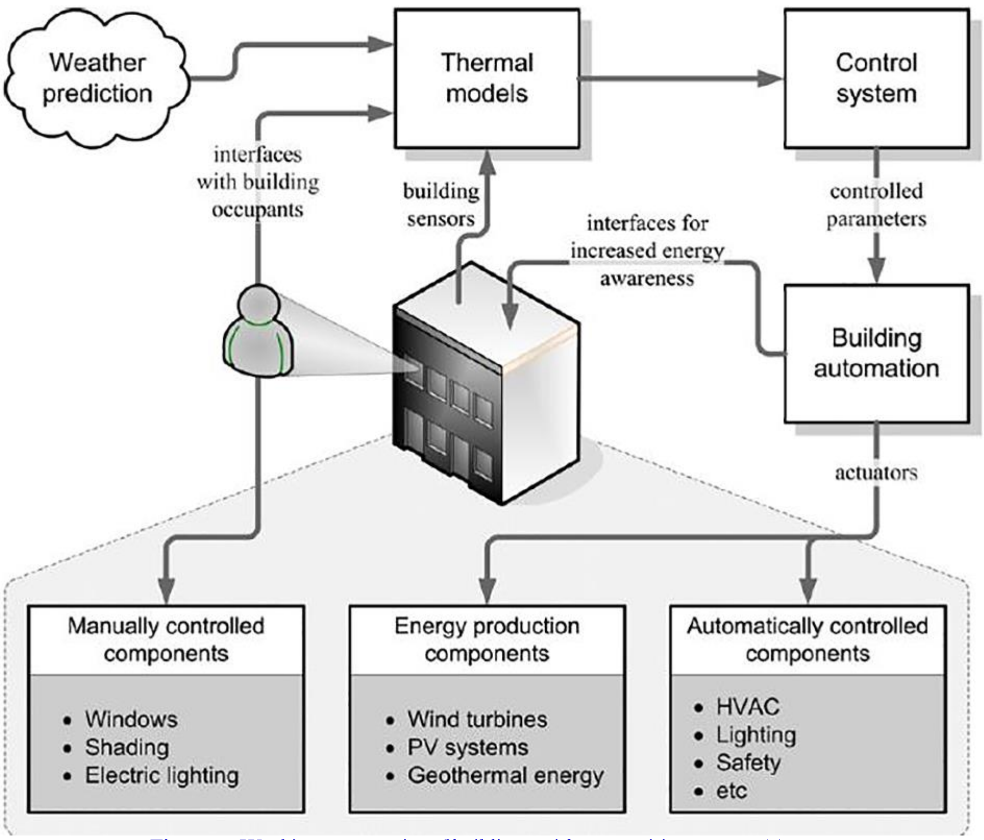

Figure 1. Working systematics of buildings with net-positive energy [3].

Within the scope of this study, it is aimed to evaluate the buildings in which the design principles determined for a positive energy building are applied in line with the information obtained from the literature review. In this context, using case study method, 10 buildings were selected from different climatic regions that can produce more energy than they consume. Comparative analysis method was also used in this study to evaluate the projects whose design criteria and features were reached through literature review. Considering the results of this study and the energy criteria developed according to different climatic regions, the structural equipment of the net positive energy building concepts for which the designs were made was determined and the design principles of a positive energy building have been revealed to guide the designers.

2. NET-POSITIVE ENERGY BUILDINGS

Today, buildings with net-positive energy are developing owing to the advantages they provide and the number of such buildings is increasing day by day. In particular, studies have been conducted to transform the buildings designed as net zero energy into positive energy buildings and to produce more energy they need. At this stage of this comparative study, ten buildings were selected through the literature, which are well-known examples of net positive-energy buildings while having different certificates and several strategies for energy production. In addition to the passive systems used in these buildings, the active design principles were introduced according to the climate, the location of the buildings and the energy criteria. The design and planning features of these buildings were tabulated for the comparative analysis. After the introduction of the buildings and comparisons, evaluation and discussions of the study were presented in the following.

The North House is designed as a housing prototype produced with prefabricated construction technique as a concept project focusing on the use of solar energy. The aim of the design is to increase awareness by applying developing technologies, to concentrate on solar energy and energy saving issues and to make data reference for high-performance buildings because of monitoring, testing and evaluation of these systems. Photovoltaic panels, domestic hot water supply, infiltration, heating and automation systems constitute the equipment of the building. Depending on these systems, indoor temperature, humidity and carbon dioxide emissions are controlled [36]. Façade elements can move kinetically and perform the shading function [37].

Roxbury E+ consists of 3-storey residences. The project is the first to be completed under the Energy Plus (E+) Green Building Program for the city of Boston, a pilot initiative to develop energy-positive sustainable housing. In addition to the natural landscape, infiltration and rainwater collection tanks provide a long-term water management plan in 4 residential buildings while using sustainable building materials. Energy equipment such as drought-resistant landscaping was used to minimize overall water consumption. The building was arranged to maximize natural light and ventilation. A three-story-high stairwell connects the first, second and third floors, allowing natural light to penetrate the interior of the house and providing passive ventilation. Optimized convection airflow in the building design allows warm air to be carried from the lower floors of the house to the upper floor of the house. Each residence was equipped with 38 photovoltaic panels to provide energy and a thermal solar panel to provide domestic hot water [38].

The Golisano Institute for Sustainability is a teaching and research building located on the University of Rochester Institute of Technology (RIT) campus. The four-storey building includes offices, laboratories, classrooms and meeting spaces. Variable flow or speed hot water pumping systems, air filtration systems, a 10-ton geothermal heat pump system, high-performance window glasses, durable lighting systems with lower illumination intensity, vertical axis wind turbines, eight geothermal wells and electric vehicle charging stations are the features of the building. The building was constructed as a combination of distributed energy systems within, on and around the building, powered by a fuel cell that can supply all its electricity from an electrical grid. Fuel cell power makes it possible for the building to be net-positive. The building also provides more than 50 percent energy efficiency compared to a traditional building [39].

The Sustainability Treehouse was designed as an interactive interpretation and collection facility in the forest, an epitome of adventure, environmental management and high-performance building design. The building, which was planned according to the region and climatic conditions, was constructed from local materials such as wood and recycled cortex steel building material. Energy equipment, such as photovoltaic panels, solar collectors, vertical axis wind turbines, hydronic radiant heating, natural ventilation, energy efficient LED (Light-emitting diode) lighting, strategic area optimization by monitoring daylight, rainwater harvesting system, geothermal heating system, water conservation and reuse control exists. As for the architectural design parameters, there is a rooftop classroom, observation platform, education and activity canopies. Rising 125 meters, the building pumps the resulting wastewater into the black water tank. The transformation of water is provided by the purification of rain water [40].

Lincoln Net-Positive Farmhouse was built to consume 70% less energy according to standard building codes, and produces 48% more energy than it needs annually. With the developed energy monitoring system, the energy consumption and energy production of the building users can be observed [41]. Using wide openings, high ceilings and large windows between rooms, light, air and activities work seamlessly between the rooms on the main floor. Thermal bridge formation was prevented through the thick walls and roofs, densely filled with cellulose and insulation. High-performance triple-glazed windows complement the insulated building envelope, and a permanent air barrier minimizes leakage. Plumbing fixtures and toilet bowls consume 60% of the federal standard, while high-efficiency appliances such as dishwashers and washing machines also reduce consumption. An air source heat pump and an energy recovery fan ensure that the building stays warm in winter and cool in summer, providing a continuous supply of fresh air throughout the year [42].

The DPR San Francisco Net Positive Office is the first net-zero energy office building in San Francisco. Making efficient use of daylight, the project used lighting strategies such as solar tubes, skylights, and lighting sensors to improve the quality and access of daylight throughout the building. Biophilic elements were also applied to the walls. Unnecessary power wastage in the components stuck in the sockets and that are not used can be prevented by smart systems. In addition to increasing airflow with indoor ceiling fans, San Francisco's temperate climate is exploited through chimney ventilation using movable windows and skylights. Heating and cooling systems were installed to provide heat recovery. Passive cooling and natural ventilation strategies have been developed, including solar-powered, eight auto-opening skylights. Active energy usage can be monitored with control systems and there is a detailed dashboard. Two solar panels were used for domestic hot water supply. Low-flow plumbing fixtures are used in the building, saving more than 30,000 gallons of water per year [43].

ReStart4Smart Solar House is a net-positive energy-residential project that uses renewable energy and provides very low annual energy requirements, specially designed for the Middle East climate. Photovoltaic panels, wind tower, water tanks and smart home automation systems are the basic energy principles of the building. The interiors are combined in a large living area. The energy strategy of the building was followed in 4 different stages: typological level, technical-construction level, technological level and management level. The name of the building comes from here. LED lighting, double compressor heat pump, charging station, smart sensors, use of artificial intelligence in building control, water and heat recovery systems are the prominent features of the building. The structural elements of the walls consist of gypsum wall board, airgel cover, interspace, load-bearing wood panel, airtel cover, thermo-reflective vapor barrier and concrete wall panel layers, respectively [44].

The Lombardo Welcome Center is the first building in Pennsylvania to be certified as a zero-energy building by the International Living Future Institute and is one of nearly 100 zero-energy buildings in the country. It generates its own energy through renewable energy sources, and Millersville has a goal of being carbon neutral by 2040 as a part of its sustainability policy. There are three types of photovoltaic panels installed in a building; roof, floor and façade [45]. It has 529 photovoltaic panels on the roof and 20 panel systems to monitor the positive energy building status [41]. Behind the building, a vertical loop geothermal heat system consisting of 20 underground wells has been constructed. With the geothermal heating system, heating is provided in cold winter months and cooling in hot summer months. This heating system has brought about less energy consumption by providing heat exchange between the ground and the building [45].

The NUS (National University of Singapore) School of Design & Environment is the first net zero energy building in Singapore. The building, which has a usage area of 8500 square meters, is designed on six floors and is multifunctional. The climate-sensitive building has more than 1500 square meters of design studio space, 500 square meters of open space, various public and social spaces, research centers, cafe and library units. The design embodies the principles of native tropical architecture in Southeast Asia. More than 50% of the total area is naturally ventilated owing to verandas, terraces and balconies with plants. The east and west façades are planned as aluminum curtains that filter sunlight and emphasize the connection with the environment. Approximately 50% of the plants selected for use in the building are native species and the rest were brought from the southern tropics and adapted to the environment. Along with landscaping materials, steel, concrete and metal elements are used in the building structure. More than 1200 photovoltaic panels on the roof and fresh air is provided by ceiling fans with an innovative hybrid cooling system to improve air quality [46].

Table 1. The architectural principles of buildings with net-positive energy.

Building name	Building image	Year of construction	Building type/ Function	Climate / Location	Design Team	Certificate	Construction Area	Photovoltaic panel	Wind turbines/ tower	Rain water collection tanks
The North House		2008-2010	Housing prototype	Temperate climate/ 1. Washington DC, USA, 2. Ontario, Canada	University of Waterloo, Ryerson and Simon Fraser, industry partners	Forest Stewardship Council (FSC) certification	74.3 m^2	✓		
Roxbury E+		2013	2-4 person residence	Temperate climate / Massachusetts, USA	Interface Studio Architects	LEED Platinum	732.3 m^2	✓		✓
The Golisano Institute for Sustainability (GIS), RIT		2013	University education and research building	Subtropical climate/ Rochester, New York, USA	FXFOWLE Architects and SWBR Architects	LEED Platinum	777.6 m^2	✓	✓	✓
The Sustainability Treehouse		2013	Education, entertainment and accommodation	Hot humid continental climate/ West Virginia, USA	Mithun	Living Building Challenge certification	311.8 m^2	✓	✓	✓
Lincoln Net Positive Farmhouse		---	Housing	Temperate climate / Massachusetts, USA	ZED / Stephanie Horowitz AIA	LEED Platinum, Zero Energy certification, Living Future Institute REVEAL	395 m^2	✓		
DPR San Francisco Net Positive Office		2014	Office	Mediterranean climate/ San Francisco, USA	FME Architecture + Design	Net Zero Energy certification	1858.9 m^2	✓		
ReStart4Smart Solar House		2018	Housing	Desert climate/ Dubai, United Arab Emirates	Sapienza University, Rome	LEED, Protocollo Itaca, Estidama, EU Energy certification is planned.	Approximately 100 m^2	✓	✓	✓
Lombardo Welcome Center		2018	University education building	Subtropical climate/ Millersville, Pennsylvania, USA	Spillman Farmer Architects	International Living Future Institute - Zero Energy certification	1356 m^2	✓		

NUS School of Design & Environment		2019	University education building	Tropical climate/ Singapore	Multiply Architects, Serie Architects, and Surbana Jurong	Green Mark Platinum, Zero Energy and WELL Gold certification	8500 m^2	✓		
TC Legend 5-Star Bellevue Net Positive House		2021	Housing	Temperate climate / Washington DC, USA	TC Legend team	EPA Indoor Air Plus, Built Green 5-Star and Net Zero Energy certification	242.8 m^2	✓		✓

Note; RIT: The University of Rochester Institute of Technology, DPR: DPR Construction Company, NUS: National University of Singapore, TC: Home Building Company, LEED: Leadership in Energy and Environmental Design, EPA: Environmental Protection Agency, m^2: Meter Square.

The TC (Home Building Company) Legend 5-Star Bellevue Net-Positive House is a certified residential project located in Washington. Indoor air quality is adjusted with the air filtering mechanism with heating and cooling systems. Additionally, it has the feature of balancing the outdoor air quality against forest fires in the summer months. The two-storey building, built with passive and active solar energy needs in mind, faces south. Three panel windows on the south side provide passive heating and natural light inside the house. White interior paint helps provide daylight, reducing energy demand from the residence's LED lighting. Photovoltaic panels and wall systems also support an energy production by reducing energy consumption. Low-flow water systems and rainwater collection tanks are available. Local wood construction material was used in the buildings and more than 85% of recycled waste was managed [47]. Table 1 shows the architectural principles of these buildings with net-positive energy, whose properties and features are given.

3. FINDINGS AND RESULTS

Projects undertaken by various architectural offices and universities were built in different periods and for different functions. It is seen that these projects are mainly implemented in the USA. Developing university buildings as buildings with net-positive energy, as well as residences and offices, is important in terms of spreading these systems in the future. It has been observed that the number and complexity of architectural buildings has increased from small-scale designs such as housing prototypes to large-scale office and university buildings. Buildings with net-positive energy also receive various certificates depending on their energy generation level, design criteria and advantages. LEED (Leadership in Energy and Environmental Design) Platinum is one of the leading certifications at this point. Additionally, energy certifications vary depending on the country codes which the building has to comply with. Differences are also observed in the certifications of the examined buildings. It can be seen that the construction areas of the projects and equipment of the energy systems are not directly proportional. In the ReStart4Smart Solar House building, which has a smaller construction area compared to large-scale projects, it has been determined that the photovoltaic panel, wind turbines/tower and rainwater collection tanks, which are among the energy systems, are integrated. In the NUS School of Design & Environment project, which has the largest construction area among the buildings investigated, it was determined that only photovoltaic panels were integrated from the three energy equipment.

It has been determined that photovoltaic panels can be used in all buildings with net-positive energy. From this perspective, it can be said that these panels are an important parameter in energy production. Wind turbines/tower and rainwater collection tanks have been integrated in some projects. It can be seen that this energy equipment is included in the building design criteria according to the climate. The use of wind turbines/towers in regions where the wind is affected and rainwater collection tanks in regions with a certain level of annual precipitation average have been evaluated as a suitable solution. It was also found that the buildings examined also paid special attention to the issues related to waste management and material use. As a result, it is seen that the advantages and opportunities in terms of the spread of buildings, producing their own energy and where different energy equipment is applied according to different climatic regions, should be studied and investigated more sensitively by architects and engineers in the near future.

4. CONCLUSIONS

Climate-sensitive design plays an important role in the planning of buildings. Energy consumption of buildings, effective use of non-renewable energy resources, use of renewable energy, material selection, waste management, carbon footprint and greenhouse gas emissions, which are among the building-based factors that trigger climate change and play an important role in climate change, are the net zero energy building design of designers, architects and engineers, shows that it is necessary to be conscious of the use and development of appropriate technology. Including climate and environmental awareness, resource use, waste management and material selection in the design, as well as minimizing energy consumption and using renewable energy sources and technologies will make building stocks last longer. With the increase in the interest in net zero energy building design and therefore the studies and the development of technology in this direction, the net-positive energy-building design and production, which can produce more than its own energy demand, is making progress. Technological mechanisms are designed to protect the infrastructure systems and bring innovations in terms of design and planning by arranging the buildings with net-positive energy according to the climate and energy needs of the region where they are built. Within the scope of this study, 10 buildings using innovative methods were examined and their prominent features in the context of climate and energy were evaluated. The widespread use of building systems with net-positive energy will also provide healthy construction techniques by triggering environmentally friendly and sustainable developments in terms of architectural building stock in the future.

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