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Integration of Biophilic Design and Energy-Based Building Elements for Carbon Emission Reduction: A Comprehensive Analysis

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Abstract: This paper presents a novel approach to reducing energy consumption and carbon emissions in the construction industry by integrating biophilic design and energy-based building elements. The research focuses on the implementation of natural elements such as plants, daylighting, natural ventilation, and views of nature into building design to enhance energy efficiency and decrease carbon emissions. The investigative approach of this study involves a thorough analysis of the application of natural materials like wood, stone, and wool as passive energy strategies to lessen the dependence on active heating and cooling systems. The research also scrutinizes daylighting techniques and the integration of green structures and vegetation in buildings to exploit natural solar energy. The key findings reveal that the combination of energy-based building elements with biophilic design can significantly reduce energy consumption and carbon emissions in buildings. The research underscores the importance of natural elements in building design and their substantial contribution to energy efficiency. The study concludes that the amalgamation of biophilic design principles and energy-efficient building components presents a potent solution to the challenges of energy use and carbon emissions in the construction sector. This approach transcends prior efforts in the literature by showcasing the practical application of natural elements in architectural design to attain sustainability objectives. The novelty of this work lies in its comprehensive analysis of various natural elements and their impact on energy efficiency, and the emphasis on the practical implementation of these elements in building design to achieve tangible reductions in energy consumption and carbon emissions. This research contributes to the ongoing discourse on sustainable construction practices and offers valuable insights for architects, designers, and policymakers in the field.

Keywords: Biophilic design; Carbon emissions; Daylighting; Energy-based building elements; Geothermal systems; Natural materials; vegetation

Nomenclature:

EBE	=	Energy-based Building Elements
BEBE	=	Biophilic designed Energy-based Building Elements
HVAC	=	Heating Ventilation Air Conditioning
UNEP	=	United Nations Environment Programme

1. Introduction

The study explores innovative strategies for integrating passive and active energy-based building elements (EBE) with biophilic design to enhance energy efficiency and reduce carbon emissions in buildings. By leveraging natural resources such as daylight, vegetation, and renewable energy sources, the research addresses the need for sustainable building practices. The novel approach focuses on combining elements like large windows, skylights, light shelves, light tubes, green roofs, and green walls to create a harmonious relationship between buildings and nature. Furthermore, the study emphasizes the potential of these strategies to contribute to the reduction of energy consumption and carbon emissions, promoting a more sustainable and environmentally friendly built environment. Energy-based building elements are components that can be used to construct and improve the energy efficiency of buildings. These elements can range from specialized insulation and glazing to mechanical systems that maximize energy efficiency[1]. Additionally, the use of renewable energy sources such as solar panels and wind turbines, as well as energy-efficient lighting, appliances, and HVAC systems, can further improve the overall energy efficiency of a building[2]. By leveraging the right combination of energy-based building elements combined with energy-saving practices such as conservation and energy efficiency measures, buildings can become more efficient and sustainable. Despite the wealth of knowledge available, there are still gaps in the research, particularly in the practical application of natural elements in building design for achieving sustainability goals. This study seeks to fill these gaps by providing a comprehensive analysis of various natural elements and their impact on energy efficiency. By delving into the practical application of green roofs, green walls, and other biophilic design elements, this research aims to bridge the gap between theoretical knowledge and real-world implementation, contributing valuable insights to the field of sustainable building practices.

1.1 Energy-Based Building Elements: Understanding Passive and Active Components for Energy Efficiency

An energy-based building element is a building component that uses energy to operate. In general, energy-based building elements use energy to perform functions, such as lighting, heating, cooling, or security. In some cases, the energy used to operate the building elements is derived from renewable resources, such as solar energy. Energy-based building elements can be divided into two categories: passive and active as shown in (**Table 1**). Passive energy-based building elements, such as walls, roofs, and windows, rely on natural solar or wind energy to operate. Active energy-based building elements, such as pumps, boilers, and air conditioners, require a significant amount of energy to operate.

The main types of energy used to operate energy-based building elements are electrical, thermal, and mechanical. Electrical energy is used to power lights, appliances, and security systems. Thermal energy is used to heat buildings, and mechanical energy is used to operate pumps and fans. Designing efficient passive energy-based elements can reflect on the energy saving for the entire building. Insulation is a key element in any energy-efficient building. Different types of insulation, such as spray foam, rigid board, and blanket insulation, may be used to create an airtight envelope that reduces energy loss through walls and doors. Glazing is also an important factor in energy efficiency. Specialized glazing materials – such as low-emissivity coatings – can be used to reduce the amount of energy lost through windows and skylights. Mechanical systems are an integral part of energy-efficient buildings. High-efficiency furnaces and air conditioners use less energy to produce the same level of comfort as traditional systems. Properly sized and installed ductwork can reduce energy losses in the air distribution system. Additionally, energy recovery ventilation systems can reduce energy consumption while improving air quality[3].

Table 1. Classification of the active and passive EBEE according to the main types of Energy used to operate them

Energy Type	Active Energy-Based Elements	Passive Energy-Based Elements
Electrical	Lights, Appliances, Security Systems	Low-emissivity coatings for windows and skylights
Thermal	Heating Systems	Insulation (spray foam, rigid board, blanket insulation)
Mechanical	Pumps, Fans	High-efficiency furnaces and air conditioners, Properly sized and installed ductwork, Energy recovery ventilation systems

1.2 Biophilic Design: Optimizing Human Health and Energy Efficiency

Biophilic design aims to increase the connection between people and nature in the built environment. The incorporation of natural elements, such as plants and natural lighting, with the design of a building can be done through the use of green roofs, sky gardens, atriums, living walls, and other features that create an environment that is both aesthetically pleasing and beneficial to health and wellbeing. It also considers the use of natural materials and textures, such as wood, stone, and glass, to create harmony between the environment and the built space[4]. Biophilic design is a powerful strategy to reduce energy consumption in the built environment by enabling users to interact better with their surroundings and adapt to the changing climate. there are two dimensions and six elements of biophilic design[5].

The organic or naturalistic dimension, which relates to shapes and forms in the built environment that reflect the human connection to nature. This dimension includes the following elements:

a) Environmental features, such as plants, animals, natural materials, colors, water, and sunlight.

b) Natural shapes and forms, such as biomorphic forms, patterns, textures, and fractals.

c) Natural patterns and processes, such as sensory variability, information richness, and dynamic systems.

The place-based or vernacular dimension, which relates to features that connect a landscape or building to the culture and ecology of its local area. This dimension includes the following elements:

a) Light and space, such as natural light, spatial harmony, and prospect and refuge.

b) Place-based relationships, such as geographic identity, historic identity, and ecological identity.

c) Evolved human-nature relationships, such as cultural attachment, symbolic meaning, and human adaptation.

2. Methodology

The paper utilized a dual-method research approach to explore the relationship between energy-based building elements and biophilic design: a comprehensive literature review and an in-depth analysis of case studies.

• Comprehensive Literature Review Method The comprehensive literature review served as a tool for gaining a theoretical understanding and establishing a robust theoretical foundation for energy-based building elements and biophilic design. This method was selected due to its capacity to provide a wide-ranging overview of the intricate and multifaceted relationship between energy-based and biophilic design elements. (**Table 2**) summarizes the intersection between active energy based elements and biophilic design while (**Table 3**) summarizes the intersection between active energy based elements and biophilic design.

• Benefits of the Comprehensive Review The comprehensive review is instrumental in identifying gaps in the existing literature and establishing a theoretical framework for the research. It highlights the key principles for achieving Biophilic designed Energy-based Building Elements (BEBE), specifically the environmental feature element in the organic dimension and the light and space element in the place-based dimension.

• Case Studies Analysis The case studies provided a more detailed and practical perspective. They involved an in-depth investigation of specific instances where BEBEs have been implemented. This method offered a practical viewpoint, complementing the theoretical insights gained from the literature review.

Table 2. The intersection between active energy based elements and biophilic design

Energy Type	Active Energy-Based Elements	Biophilic Design Dimensions	Biophilic Design Elements
Electrical	Lights, Appliances, Security Systems	Organic/Naturalistic	Environmental Features
Thermal	Heating Systems	Place-Based/Vernacular	Light and Space
Mechanical	Pumps, Fans	Organic/Naturalistic	Natural Patterns and Processes

Table 3. The intersection between passive energy based elements and biophilic design

Energy Type	Passive Energy-Based Elements	Biophilic Design Dimensions	Biophilic Design Elements
Electrical	Low-emissivity coatings for windows and skylights	Place-Based/Vernacular	Light and Space
Thermal	Insulation (spray foam, rigid board, blanket insulation)	Organic/Naturalistic	Environmental Features
Mechanical	High-efficiency furnaces and air conditioners, Properly sized and installed ductwork, Energy recovery ventilation systems	Organic/Naturalistic	Natural Patterns and Processes

3. Biophilic designed Energy-based Building Elements BEBE Potential for Reducing Carbon Emissions

Biophilic design includes the use of natural materials, daylighting, and vegetation in Building energy-based elements, these elements can help reduce energy consumption by automatically adjusting systems to meet the needs of occupants[6].

3.1 Natural Materials as Passive BEBE

Using natural materials to reduce the amount of Carbon emissions into the atmosphere contributes to the mitigation of climate change as shown in (**Table 4**), according to natural material type and its thermal performance. It is becoming increasingly important in both residential and commercial spaces. Natural materials, such as wood, stone, and wool, contribute to the energy efficiency of a building by reducing the need for active heating and cooling systems, thereby saving energy. They also enhance the comfort of the building's occupants by helping to maintain a stable indoor temperature and humidity level.

3.1.1 Wood

Wood is a natural insulator and has superior thermal performance compared to other conventional building materials. It is often used in passive house construction due to its excellent insulation properties[7]. Wood building systems have been developed to offer greater airtightness to minimize energy consumption. The thermal properties of wood products are 400 times better than steel and 10 times better than concrete[8].

Wood is a renewable resource that absorbs CO_2 from the atmosphere as it grows[9]. When used in construction, wood continues to store this carbon, effectively keeping it out of the atmosphere[10]. Buildings framed in wood release 26% less carbon than steel-framed buildings and 31% less than concrete-framed buildings[10]. Moreover, when wood products are disposed of, they biodegrade, releasing their stored carbon back into the soil[9]. The use of transparent wood in construction could potentially revolutionize the industry, offering a sustainable alternative to traditional building materials[11,12]. Transparent wood is usually prepared by impregnating a resin that matches the refractive index of cellulose in a delignified wood template[11]. Studies have shown that the new transparent wood has 85% light transmittance, 71% haze, high strength and lightweight, both glass transparency and low thermal conductivity, more energy saving and easy to degrade[12].

3.1.2 Stone

Stone, particularly in the form of stone wool, is used in passive house construction for insulation. Stone wool insulation serves to minimize the heat exchange with the outside environment. It is a preferred product when constructing Passive Houses[13]. Stone, particularly in the form of basalt, can absorb a significant amount of carbon. This process, known as carbon sequestration, involves a chemical reaction that converts CO_2 into a solid, chalk-like material. This method of carbon storage is considered safer and more permanent than other forms of carbon capture and storage[14].

3.1.3 Wool

Wool, especially sheep's wool, is a natural insulator that can be used in passive house construction. It is breathable, helping to create a more comfortable indoor environment, and it can absorb and release moisture without reducing its thermal performance. Wool insulation can be used in roofs, walls, and floors[15]. Wool is a short-term store of atmospheric carbon. Approximately 50% of the weight of clean wool is pure biogenic carbon. This carbon is removed from the atmosphere for the fibre's life – from when grown on the sheep, through the wool product's use phase – until it is disposed of and biodegrades. This process helps to reduce the amount of CO_2 in the atmosphere[16].

Table 4. Natural Materials Thermal Performance and Carbon Reduction

Material	Thermal Performance	Carbon Reduction
Wood	Superior insulation; 400x better than steel, 10x better than concrete	Absorbs and stores CO_2; releases less carbon than steel/ concrete buildings
Stone	Used as stone wool for insulation	Absorbs CO_2, converting it into a solid material
Wool	Breathable insulator; used in roofs, walls, floors	Stores atmospheric carbon; 50% of clean wool weight is pure carbon

3.2 Daylighting as Passive BEBE

Daylighting is a passive energy strategy that maximizes the use and distribution of natural diffused daylight throughout a building's interior to reduce the need for artificial electric lighting. (**Figure 1**) shows how large windows can bring natural light into different spaces.

3.2.1 Large windows:

Large windows allow more natural light to enter a building, reducing the need for artificial lighting. They can be designed to enhance natural air flows and take advantage of them. High-performance windows also offer greater insulation, reducing energy consumption. Large windows allow more natural light to enter a building, reducing the need for artificial lighting[17].

3.2.2 Skylights:

Skylights bring light into a room year-round, especially in rooms located at the center of a building. They collect natural light and use it to directly heat spaces, without converting it to electricity. Skylights bring light into a room year-round, especially in rooms located at the center of a building[18].

3.2.3 Light shelves:

Light shelves are passive devices that promote the quantity and even distribution of daylight throughout a building by collecting natural light and reflecting it into darker areas of the building. They increase light penetration into a building and reduce glare. Light shelves are passive devices that promote the quantity and even distribution of daylight throughout a building by collecting natural light and reflecting it into darker areas of the building[19].

3.2.4 Light tubes:

Light tubes, also known as solar tubes or tubular daylighting devices, capture sunlight on the roof and convey it down a reflective tube into a room. They provide a source of light in areas that may not have access to windows or skylights. They bring daylight deeper into buildings where natural light had previously not been an option. Light tubes, also known as solar tubes or tubular daylighting devices, capture sunlight on the roof and convey it down a reflective tube into a room[20].

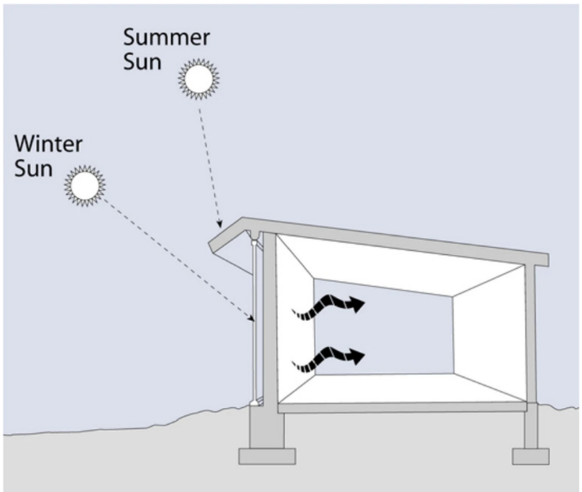

Figure 1. Large windows, skylights, light shelves, and light tubes strategies can bring natural light into different spaces, such as classrooms, offices and corridors.[17]

3.3 Vegetation and Green Structures as Passive BEBE

Using vegetation and green elements in buildings such as walls, roofs, and windows, are a great way to reduce carbon emissions. These elements harness natural solar and wind energy to operate, reducing the need for traditional energy sources and providing an energy-efficient solution to help reduce our carbon footprint. The active energy-based building elements can also use natural resources such as geothermal to operate. To further decrease carbon emissions, biophilic-designed energy-based building elements (BEBE) can be used to create an environment that is friendly to plants and natural elements. This can be done through a green roof, filtering air and creating moisture with plants, using natural materials in building construction, and creating an urban landscape that is friendly to pedestrians and cyclists. Additionally, buildings can be designed in a way that takes into account the natural environment and uses biophilic design principles to reduce the amount of heat that is generated, thus reducing the resulting carbon emissions.

3.3.1 Green roofs

Green roofs have emerged as a viable option for reducing global carbon emissions, providing multiple benefits such as reduced energy consumption, CO_2 emissions, and urban air pollution, as well as increased biodiversity. A green roof is composed of vegetation planted on a waterproof membrane that covers either the entire or part of a building's roof. Potential benefits of green roofs include improved air quality, reduced temperatures in urban areas, conservation of energy, reduced stormwater runoff, and reduced CO_2 emissions[21-23]. Additionally, As shown in (**Figure 2**), it has been linked to improving people's connection to nature and creating a sense of well-being. It can also help to reduce a building's energy consumption and carbon footprint, while also promoting sustainability. Integrating biophilic design with building energy-based responsive elements can be a powerful way to reduce energy consumption. Biophilic design is the integration of nature into a built environment, and it can help create a healthier, more comfortable and efficient. Examples of biophilic design include the use of natural materials, daylighting, and vegetation. Building energy-based responsive elements, on the other hand, are elements such as smart lighting, occupancy, and daylight sensors that enable building systems to respond to occupants and the environment. These elements can help reduce energy consumption by automatically adjusting systems to meet the needs of occupants[6]. Green roofs can reduce the heat-island effect, leading to cooler temperatures and decreased cooling costs in the summer. They also offer additional insulation, leading to lower heating costs in the winter. Green roofs have the potential to reduce carbon emissions from buildings through both carbon sequestration and the reduction of energy used in heating and cooling. It notes that green roofs can reduce carbon dioxide emissions from buildings by up to 10%, and can also reduce peak stormwater runoff by up to 70-80%[21,24].

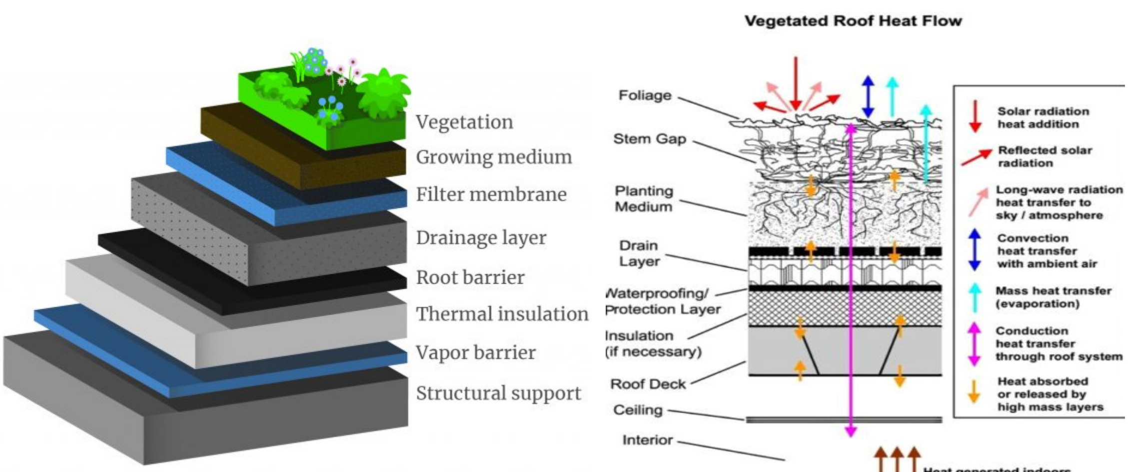

Figure 2. This figure shows the different components of a green roof and how they contribute to reducing heat and stormwater runoff. And heat transfer diagram for green roofs. [23]

Green roofs can help to reduce urban air pollution, as the vegetation absorbs CO_2 and other pollutants, improving the quality of the air before it is released into the atmosphere. Green roofs can also reduce stormwater runoff, providing a valuable service to urban areas by limiting the amount of polluted runoff that enters receiving bodies of water. This can help to reduce the risk of flooding, improve water quality, and limit erosion. Finally, green roofs offer the potential to provide animal habitats, creating areas for birds and insects in urbanized environments.

3.3.2 Vertical green structures

A. GrreenWalls

Green walls usually contain potted plants rather than climbers, they can act as potential carbon sinks to reduce carbon emissions. According to the United Nations Environment Programme (UNEP), urban green initiatives, such as green walls, can potentially reduce carbon emissions from buildings by up to 30%. Green walls are vertical surfaces consisting of vegetation, soil, and other components, which can absorb and store carbon from the atmosphere. These living walls provide insulation and reduce the amount of energy needed for cooling and heating. In addition, green walls can improve air quality by filtering out pollutants and dust particles, increasing the amount of oxygen in the atmosphere, and reducing noise levels[25,26]. As shown in (**Figure 3**), environmental advantages of green walls, such as reducing heat island effect, improving air quality, and sequestering carbon.

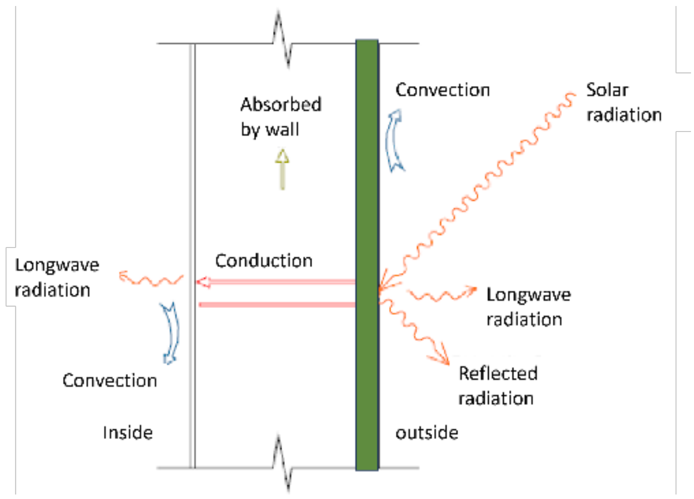

Figure 3.This figure shows the different environmental advantages of green walls, such as reducing heat island effect, improving air quality, and sequestering carbon.

B. Green Facades

Green facades generally have climbing plants weaving themselves in and around a framework of mesh, wires, or cables they are a potential strategy for reducing carbon emissions. (**Figure 4**) provide a variety of benefits, such as reduced energy costs, improved air quality, increased biodiversity, and improved aesthetics. Additionally, they can be used to offset emissions from other sources, making them an essential component of a comprehensive climate change mitigation strategy.

There are several studies that have found that green facades can reduce the temperature of buildings. For example, a study conducted in Maryland showed that green facades cooled ambient air temperatures by an average of 2.5 to 3.2°F (1.4 to 1.8°C) in June, July, and August Traunfeld[27]. Another study in Hong Kong predicted a maximum decrease of 15.1°F (8.4°C) in an urban canyon if both walls and roofs were covered by vegetation[26].

Numerous studies have highlighted the benefits of green facades in mitigating carbon emissions. For instance, research indicates that green facades can significantly improve the environmental and thermal performance of building envelopes[28]. They not only enhance the aesthetic appeal of urban environments but also play a crucial role in air purification[29]. Moreover, green facades have been found to reduce indoor temperatures. Specifically, one study suggests that a green facade with dense foliage can decrease the indoor air temperature by approximately 1.7 degrees

Celsius[30]. This reduction in temperature can lead to a significant decrease in air conditioning usage and energy costs. In fact, each decrease in the indoor temperature by 0.5 °C can reduce electricity usage by about 8% for air conditioning in the summer[27]. Therefore, the implementation of green facades is a step towards sustainable and energy-efficient buildings[28]. Overall, green facades provide a variety of benefits, such as improved air quality, increased biodiversity, and reduced energy costs. Additionally, they have the potential to reduce carbon emissions significantly. For these reasons, green facades should be considered a key component of any comprehensive climate change mitigation strategy.

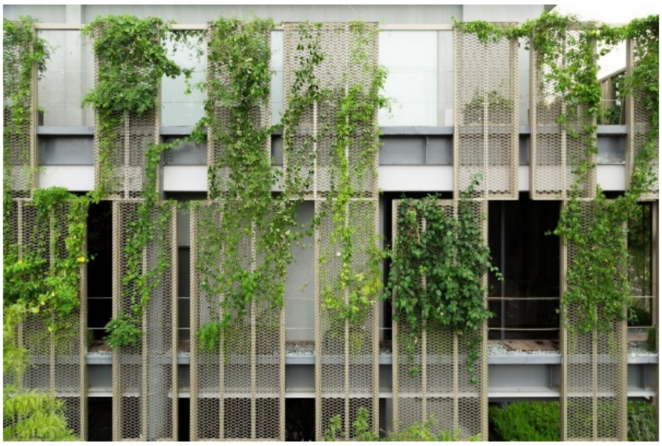

Figure 4. This figure shows the green facades is similar to green walls but integrates with the architectural elements like windows and terraces.[40]

3.4 Geothermal Systems as Active BEBE

Geothermal systems as Active Energy-Based Elements play a crucial role in reducing carbon emissions and mitigating the impact of climate change. They offer a promising pathway towards a more sustainable and low-carbon future[31]. The versatility of geothermal energy as an active energy-based building element and how the diverse and efficient applications of geothermal energy as shown in (**Table 5**). It's a renewable, reliable, and efficient energy source that can significantly reduce a building's carbon footprint. Geothermal energy, or harnessing the natural heat of the Earth, has demonstrated potential for reducing the carbon footprint of buildings. According to the U.S. Department of Energy, geothermal energy can provide long-term cost savings in comparison to traditional heating and cooling systems, as well as reducing emissions of carbon dioxide, sulfur dioxide, and nitrogen dioxide into the atmosphere. Geothermal systems are a type of heating and cooling technology that use the earth's constant temperature as a source or sink of[32]. Geothermal systems can be classified into four main types: horizontal loop, vertical loop, well water loop, and pond or lake loop. These systems differ in the way they exchange heat with the ground or water through pipes or wells[33]. (**Figure 5**) shows a simple geothermal system with a heat source, a reservoir, a production well, a power plant, an injection well, and a reinjection zone.

3.4.1 Horizontal loop system

Horizontal loop systems are a type of geothermal system that is often installed in rural areas where there is ample land available. The system involves burying pipes in trenches dug in the ground. These pipes are filled with a heat transfer fluid and are arranged in a loop, hence the name. The fluid circulates through the pipes, absorbing heat from the ground in the winter and dissipating heat into the ground in the summer. This process provides a stable temperature for heating and cooling purposes.

3.4.2 Vertical loop system

Vertical loop systems are commonly used in commercial and school facilities where land area may be limited. Instead of trenches, vertical holes are drilled deep into the ground, and pipes are inserted. The pipes are also filled with a heat transfer fluid and operate on the same principle as the horizontal loop system. The main difference is that the vertical loop system exchanges heat with the ground at a deeper level, which can be more efficient in certain soil and climate conditions.

3.4.3 Well water loop system

Well water loop systems are an efficient option if you have access to a well. In this system, well water is used as the heat transfer fluid. The water is pumped from the well through the heat pump where heat exchange occurs, and then it is returned to the ground through a discharge well. This system can be very cost-effective and energy-efficient, as it leverages the constant temperature of the well water.

3.4.4 Pond or lake loop system

If there is an available access to a body of water like a pond or lake, a pond or lake loop system can be a low-cost and energy-efficient option. In this system, pipes are run from the heat pump to the body of water, where they are coiled and sunk to the bottom. The water serves as the heat exchange medium with the heat pump. This system can be very efficient, as water conducts heat better than air or soil.

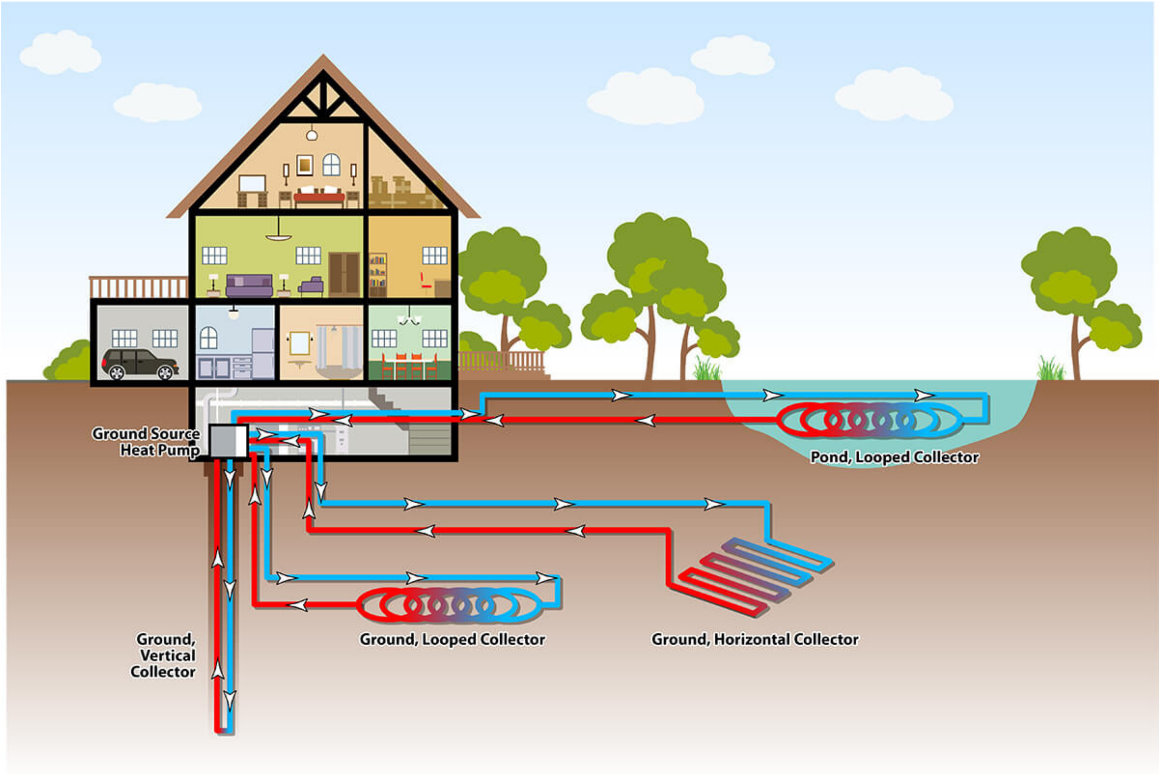

Figure 5. This figure shows a simple geothermal system with a heat source, a reservoir, a production well, a power plant, an injection well, and a reinjection zone.[41] Picture Credit: www.hollidayheating.com.

Table 5. the diverse and efficient applications of geothermal energy

Active Energy-Based Element	Description
Heating and Cooling Systems	Geothermal energy can be used to power heating and cooling systems in buildings. These systems use the stable temperature of the earth a few meters below the ground to provide heating in the winter and cooling in the summer. This can significantly reduce the energy consumption of a building.
Geothermal Heat Pumps	These are devices that use the heat from the earth to provide heating, cooling, and sometimes hot water for homes and buildings. They are highly efficient and can result in significant energy savings.
Hot Springs	Hot springs are a natural example of geothermal energy use. The hot water from these springs can be used for heating buildings or for therapeutic purposes.
Electricity Generation	Geothermal energy can also be used to generate electricity[1]. This is done by drilling wells into geothermal reservoirs to bring hot water and steam to the surface, which is then used to drive turbines connected to generators.
Snow Melting Systems	Geothermal energy can be piped under roads and sidewalks to melt snow. This can help to improve safety and accessibility in cold climates.

Geothermal systems have many advantages over conventional heating and cooling systems. They are more energy-efficient, environmentally friendly, quiet, durable, and require less maintenance. Geothermal systems can also provide hot water and dehumidification for buildings[31]. Geothermal systems can be further strengthened by utilizing smart technologies, such as IoT-connected sensors and controllers, to better manage energy and control the temperature of a building. By leveraging an integrated system of sensors and controllers, building owners can optimize the use of energy and reduce overuse of energy systems. The environmental benefits of geothermal energy systems can be maximized with the proper implementation and maintenance. For example, the U.S. Department of Energy recommends regular maintenance of geothermal systems to ensure optimal performance and energy efficiency. Geothermal systems have been used for various applications in architecture, such as residential, commercial, institutional, and public buildings[31].

4. Case Studies

Two case studies were selected to verify the connection between the biophilic design and energy-based building elements to improve the energy efficiency and reduce and reduce carbon examining the adaptation of the concluded BEBEs these projects are. (**Figure 6**) shows the use of natural existing material in the building construction and integration with the land which will benfit the energy based building elements.

Figure 6. The use of natural existing material in the building construction and integration with the land.

4.1 The Thermal Baths in Vals, Switzerland.

The Therme Vals, a spa complex in Switzerland, is a testament to the harmonious integration of architecture and nature. Designed by Peter Zumthor, it is a remarkable example of energy-efficient building design. Here’s how it incorporates various elements:

4.1.1 Natural materials

The building is constructed using Valser Quartzite slabs, a material sourced locally. This choice of material not only enhances the aesthetic and sensory experience of the building but also contributes to energy efficiency and carbon reduction. The use of local materials minimizes the carbon emissions associated with transportation. Moreover, stone, with its natural thermal properties, absorbs heat during the day and releases it slowly when temperatures drop, reducing the need for artificial heating and cooling. The design of the Therme Vals, which adapts to the slope of the hills and appears to emerge from the landscape, likely leverages the earth's natural insulation, further enhancing energy efficiency. Interestingly, the Valser Quartzite has been found to release vital minerals such as magnesium and calcium into water, adding to the overall sustainability and health benefits of the spa. These strategies align with broader efforts to reduce the carbon footprint in building construction, which include repurposing existing assets or materials, using lower-emission materials, and incorporating renewable energy sources[34,35].

4.1.2 Daylighting

The design of the baths explores the relationship between water, stone, light, and shadow, creating a unique atmosphere. Daylight pierces through the roof panels in eight-centimeter gaps, allowing daggers of light to illuminate the pools below in geometrical slivers. (**Figure 7**) large floor-to-ceiling windows open into the valley, providing bathers with the sense that they are floating[35].

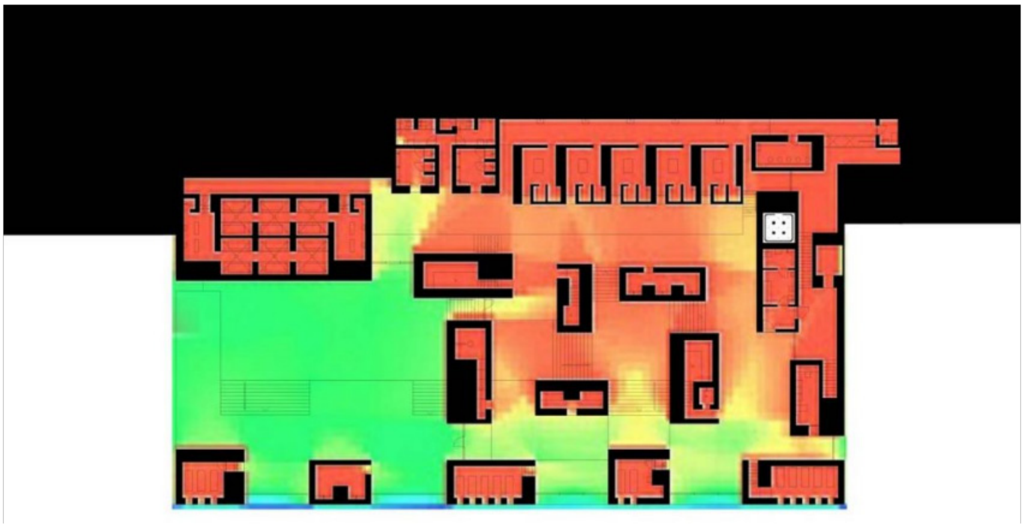

Figure 7. The using natural daylighting inside the building.

4.1.3 Vegetation:

The bathhouse was located below a grass roof, a structure half buried into the hillside. This provision creates an atmosphere of a natural park with artificial plantations but arranged in rectangular shapes. The bathhouse is located below a grass roof, a structure half buried into the hillside. This design not only helps the building blend into the natural landscape but also contributes to its energy efficiency. (**Figure 8**) the green roof provides excellent insulation, reducing the need for artificial heating and cooling. This leads to lower energy consumption and, consequently, a reduction in carbon emissions. The roof is covered with a prairie grass that has a swimming pool for guests. This provision creates an atmosphere of a natural park with artificial plantations but arranged in rectangular shapes. The geometric patterns in the lawn are the only clue to the presence of the structure, further emphasizing its integration with the natural surroundings[35,36].

Figure 8. The integration of green elements with the building design especially the green roof.

4.1.4 Geothermal energy

The Thermal Baths in Vals are built over the only thermal springs in the Graubunden Canton in Switzerland. These hot springs serve as a natural source of geothermal heat for the spa facilities. The thermal springs, known as the St. Peter spring, provide water at a pleasant 30° Celsius. This naturally occurring thermal water is used directly in the spa, reducing the need for artificial heating. By harnessing this geothermal heat, the Thermal Baths in Vals are able to operate more energy-efficiently.

4.2 The Central Taiwan Innovation and Research Park

The project is in Taiwan acts as a public research institute promoting industrial innovations. The project has features of its connection between biophilic design and energy based elements to produce energy-efficient design.

4.2.1 Use of natural materials

In this project the approach in using natural materials was reflected in a double-skin facade system that allows natural ventilation and reduces heat gain. The outer layer of the facade is made of bamboo, which is a local and renewable material that also creates a natural and cultural identity for the building[37].

4.2.2 Daylighting

The design likely incorporates daylighting strategies to reduce the need for artificial lighting, thereby saving energy. The project's core area consists of an exhibition area and a library, which are connected with the laboratories and office area by footbridges. As show in (**Figure 9**), these spaces are designed to be the common areas for the researchers to exchange their creative ideas, and they are illuminated by natural light from the large windows and skylights. The natural light enhances the spatial quality and the visual comfort of the users[38,39].

Figure 9. The maximized use of natural lighting and use of shading devices to prevent the glare.

4.2.3 Vegetation

The use of vegetation in the project is used by incorporating vegetation in building design which contributes to energy efficiency by providing natural shading and cooling, improving air quality, and enhancing the building's aesthetic appeal. The project incorporates local visual landscape components, green facade and metal-framed curtain wall, to create a connection between the indoor and outdoor environments. The curtain wall is composed of perforated louver panels with green elements that create rhythmic patterns with their curvature and density, allowing natural light to filter through and create dynamic shadows[39]. The semi-outdoor platform at the rooftop is collocated with trees and plantation to act as green roof, as well as a canopy formed by solar panels[39]. This provides more insulation for the building. (**Figure 10**) shows the integration between building design and the landscape to provide a green roof.

Figure 10. The integration between building design and the landscape to provide a green roof.

5. Results

Combining energy-based building elements with biophilic design can result in reduced energy consumption and decreases the carbon emission for the building. The analysis has shown that incorporating natural elements such as plants, daylighting, natural ventilation, and views of nature into building design reduces the energy consumption and decrease the carbon emission combining energy-based building elements and biophilic design are summarized in the following;

Natural Materials as Passive BEBE: The use of natural materials such as wood, stone, and wool can contribute to the energy efficiency of a building by reducing the need for active heating and cooling systems, thereby saving energy and reducing carbon emissions.

Daylighting as Passive BEBE: Daylighting is a passive energy strategy that maximizes the use and distribution of natural diffused daylight throughout a building's interior to reduce the need for artificial electric lighting. This can significantly reduce energy consumption and carbon emissions.

Vegetation and Green Structures as Passive BEBE: Using vegetation and green elements in buildings can reduce carbon emissions by harnessing natural solar and wind energy. This can be done through green roofs, green walls, and green facades.

Geothermal Systems as Active BEBE: Geothermal systems use the earth's constant temperature as a source or sink of heat, providing a renewable, reliable, and efficient energy source that can significantly reduce a building's carbon footprint.

6. Conclusion

The conclusion succinctly emphasizes the innovative value of the study, highlighting the novel approach of integrating passive and active energy-based elements with biophilic design to enhance energy efficiency and reduce carbon emissions in buildings. This unique combination of strategies, such as large windows, skylights, light shelves, and light tubes, along with the use of vegetation and green structures, represents a pioneering attempt to address the research gaps in practical application of natural elements in building design for achieving sustainability goals. The research underscores the significant role of daylighting in reducing a building's energy consumption. By minimizing the reliance on mechanical systems and artificial lighting, these strategies not only decrease energy use but also thermal comfort. By demonstrating the significant impact of incorporating these elements, the conclusion reinforces the importance of this novel approach in effectively reducing energy consumption and carbon emissions. The study also highlights the value of green roofs, green walls, and green facades in providing natural insulation and shading for buildings. These features contribute to reducing heat gain in summer and heat loss in winter. Green walls offer air filtration, noise absorption, and contribute to a pleasant indoor environment. Green facades, however, augment a building's aesthetic appeal and social interaction. The integration of these living infrastructure systems into architecture through biophilic design brings nature indoors and fosters a sense of connection with the surrounding environment.

Lastly, the research emphasizes the importance of renewable energy sources, such as geothermal systems. These systems provide clean and sustainable power to buildings, reducing their dependence on fossil fuels and greenhouse gas emissions. Geothermal systems, which leverage the stable temperatures of the earth, can provide efficient heating and cooling solutions. This not only enhances the energy efficiency of buildings but also increases their resilience and adaptability to climate change and extreme weather events. Biophilic design can incorporate these renewable energy sources into the design in a way that is harmonious with nature and human needs. This study is not only necessary but also timely. It provides a fresh perspective on sustainable construction practices, offering valuable insights for architects, designers, and policymakers in the field. The methods used and the results obtained could pave the way for more energy-efficient and environmentally friendly building designs in the future.

Authors' contributions

Passaint M. Massoud: Conceptualization, Methodology, Investigation, Data curation, Visualization, Writing - original draft, Writing - review & editing.

Availability of data and material

The datasets used in this research study are available upon request. The specific methods and tools used for computational integration and analysis will be described in the manuscript.

Conflict of Interest

The authors declare no competing interests in relation to this research study. There are no financial or personal research findings.

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