Journal of Engineering Research and Applied Science
Available at www.journaleras.com
Volume 12 (2), December 2023, pp 2337-2347
ISSN 2147-3471 © 2023

Green Buildings for Decarbonization and Air Conditioning

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Accepted 16 August 2023

Abstract

Green buildings are energy efficient and environmentally responsible for sustainable human health development. Their design, construction and operational practices that consider sustainability will minimize their negative impact on the environment and people, while taking into consideration the financial impacts. Although solid energy policy architecture is in place, sustainable energy targets are weak, government support is limited, and bureaucratic hurdles for energy investment still frustrate potential investors. Most importantly, many top policymakers do not seem to be ready to play a productive role in designing a forward-looking, sustainable energy policy. The building construction sector has a great potential to reduce total energy consumption through sustainable projects. All over the world policy-makers have already realized the potential and begun setting some governmental goals. This paper discusses the green building concept for sustainable energy development.

Keywords: *Green building concept; Sustainable energy development; Building environment*

1. Introduction

Climate change and its disastrous consequences are stimulating the transformation towards a sustainable development, with its increasing economic efficiency, protection and restoration of ecological systems and improvement of human well-being [1]. The maintenance of natural resources is a subject that often appears when sustainable development is considered. In addition, with increasing world population and economic development, the strain on resources is increasing. As economic development and the environment are linked, the realization has set in to conserve energy and natural resources [2]. The increased use of resources that cause pollution and emissions need to save and conserve energy for sustainable development. In engineering, sustainable building design is a design ideology, which harbors the notion of sustainable human development [3]. Sustainable development can be defined in various ways. Every individual will approach the issue of sustainability differently depending upon various factors, such as sustainability goals, background, awareness, and economic conditions [4].

Sustainability is providing opportunities of development to the future generation, in terms of resources [5]. One of the key aspects in sustainability is sustainable construction. Sustainable construction practices are such that they are based on ecological principles, with no environmental impacts, have a closed material loop, and have full integration into the landscape after the service life of the structure is over [6]. The concept of green buildings is the measure of our efforts in attaining idealistic sustainable construction practices [7]. Green Building is the "practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building life-cycle from siting to design, construction, operation, maintenance, renovation, and deconstruction". This definition has evolved over the years. "Green Buildings" is an ever-evolving, dynamic term. Green Building is the status of our efforts in attaining sustainability in construction practices [8-14].

In order to be able to move towards our objective of sustainability, we should have a clear definition of what is called as a green and sustainable building, as it is defined by the US. Environmental Protection Agency (EPA) [5], "Green building is the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction. This practice expands and complements the classical building design

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concerns of economy, utility, durability, and comfort. Green building is also known as a sustainable building [15-20].

2. Low-carbon energy transition

2.1. Energy structure and climate change

The current energy structure is still dominated by fossil fuels such as coal, oil, and natural gas. According to the International Energy Agency (IEA) statistics, the global energy supply in 2018 reached 14,279,569 Ktoe, with coal, oil and natural gas accounting for 26.88%, 31.49% and 22.84%, respectively [13]. As illustrated in Fig. 1, the global energy supply demonstrates an overall increasing pattern. It is apparent that the increase was mostly driven by fossil fuels before 2015, however, after 2015, fossil fuel supply has flattened out while the supply of renewable energy sources such as biofuels, waste, wind, solar and hydro has begun to increase noticeably. Figure 2 shows the global power capacity by source in the Stated Policies Scenario. Figure 3 also shows the share of renewables in total capacity additions by region and scenario.

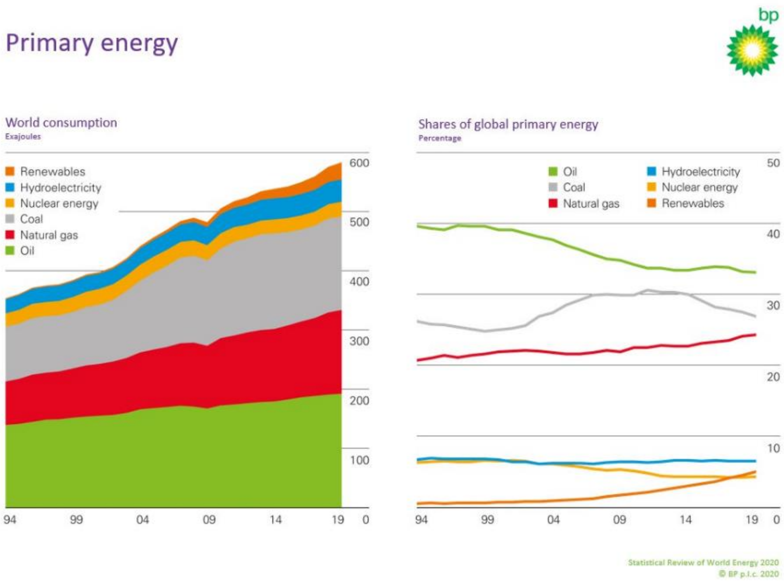

Figure 1. World primary energy consumption by fuels and share [2].

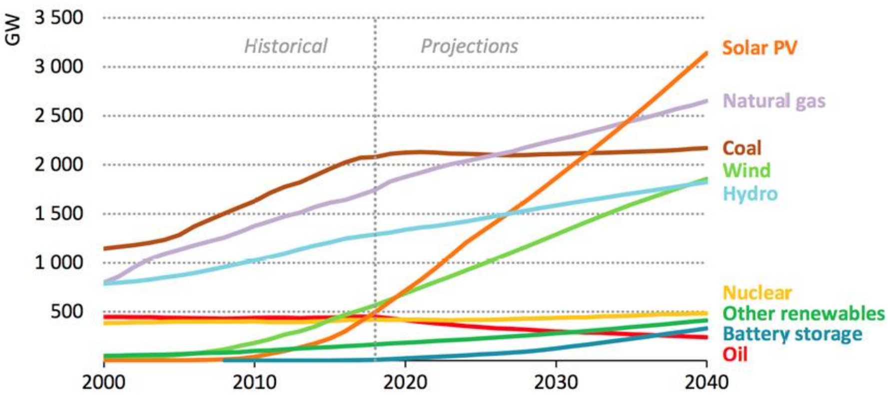

Figure 2. Global Power Capacity by Source in The Stated Policies Scenario [30].

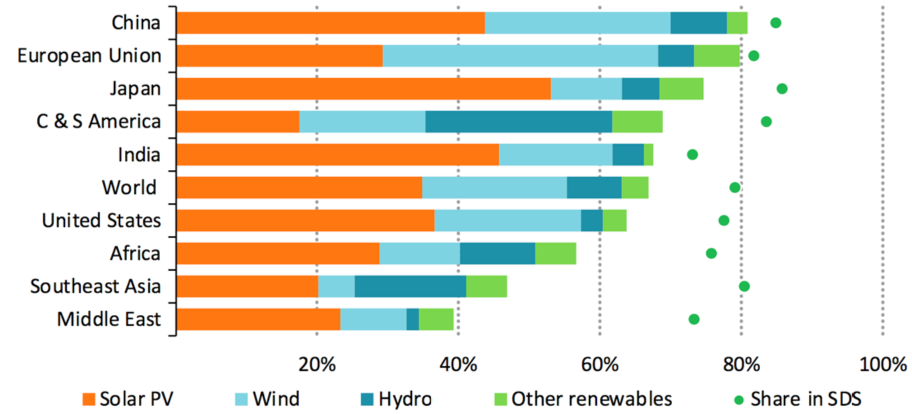

Figure 3. Share of renewables in total capacity additions by region and scenario [30].

Although the share of fossil fuels in the global energy supply structure has declined, the overall supply still exceeds 80%. The high-carbon energy system has increased carbon emissions. The United Nations Environment Program (UNEP) pointed out in its Emissions Gap Report 2019 that total greenhouse gas (GHG) emissions from energy production and industrial activities reached 37.5 Gt in 2018, with total carbon dioxide emissions increased by as high as 2% [14]. And 65% of the total carbon emissions were from using fossil fuels [15]. Massive GHG emissions have exacerbated global warming, wreaking havoc on human society and the environment [16]. Furthermore, frequent natural calamities such as sea level rise and forest fires have already put people in danger in many regions [16-19].

In the face of climate change, it is crucial to synergize the economy, energy consumption, and climate change so as to achieve sustainable development and carbon neutrality [18, 19]. In 2015, 196 participating parties jointly signed the “Pairs Agreement” to reach an agreement on decarbonization [13]. The agreement aims to keep global warming well below 2 ◦C, ideally 1.5 ◦C, above the pre-industrial temperature level [20, 21]. To achieve this goal, many countries have made active efforts to restructure their energy system. For example, the European Union (EU) announced a 20–20–20 target, that is to improve energy efficiency by 20%, reduce carbon emissions by 20%, and increase the share of renewable energy to 20% by 2020. China set up a “30·60” plan, pledging to peak carbon dioxide emissions by 2030 and achieving carbon neutrality by 2060. Energy transition has emerged as a new battlefield for global leadership on climate change.

2.2. Global energy transition

The growing concern about climate change has shifted people’s attention towards renewable energy globally. A green energy transition is quietly kicking off amid the fourth industrial revolution. The green energy transition aims to replace high-carbon fossil fuels with low-carbon clean energy. Clean energy mainly consists of low-carbon renewable energy sources [22], such as solar, wind, hydro, bioenergy, geothermal, etc. [23-30].

Figs. 1-3 illustrates the proportion of renewable energy consumption in total energy consumption around the world. As shown in the energy consumption map, renewable energy consumption accounted for more than 25% of total energy consumption in Northern Europe and South America in 2017. Europe has the largest renewable energy consumption share globally, with most European countries exceeding 20%. For example, in 2017, renewable energy sources provided 76.7% and 61.2% of the power used in Iceland and Norway, respectively. Approximately 88% of Iceland’s primary energy consumption came from renewable energy sources that year, with wind and solar together contributing up to 66%. Because of its geographical location, Iceland also has abundant hydropower and geothermal resources. Similarly, in 2017, Norway powered up 40% of its primary energy consumption with hydropower [1-4].

In South America, renewable energy consumption, primarily hydro and biofuels, ranked second in the total energy consumption in 2017, with many countries reaching 15% [23]. In Uruguay, for example, renewable energy provided 61% of its energy consumption that year, with biofuels and hydropower contributing 42% and 12%, respectively. Similarly, Brazil had 42.3% of its total energy consumption generated by renewable energy sources in the same year, with biofuels accounting for more than 30%. Figure 4 shows the renewable share of total final energy consumption by country in 2020. Figure 5 also shows the global renewable installed capacity.

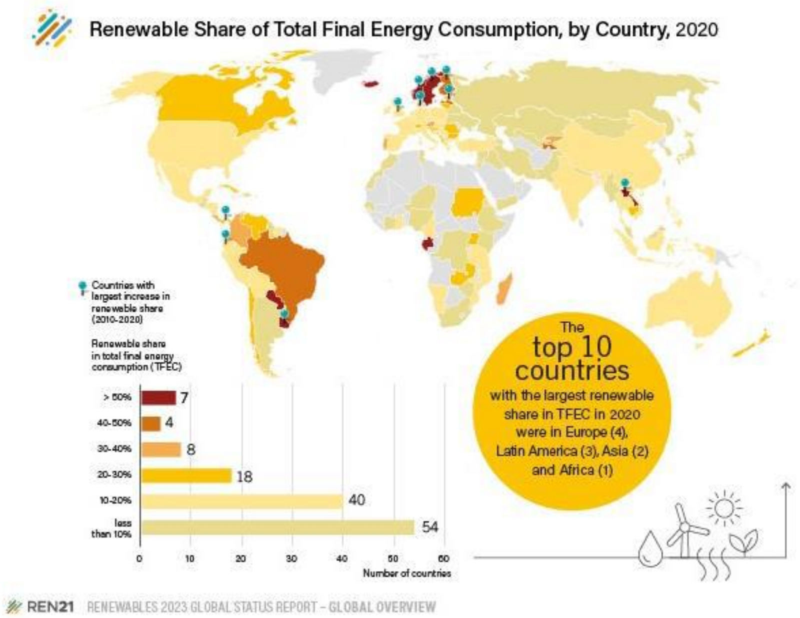

Figure 4. Renewable share of total final energy consumption by country in 2020.

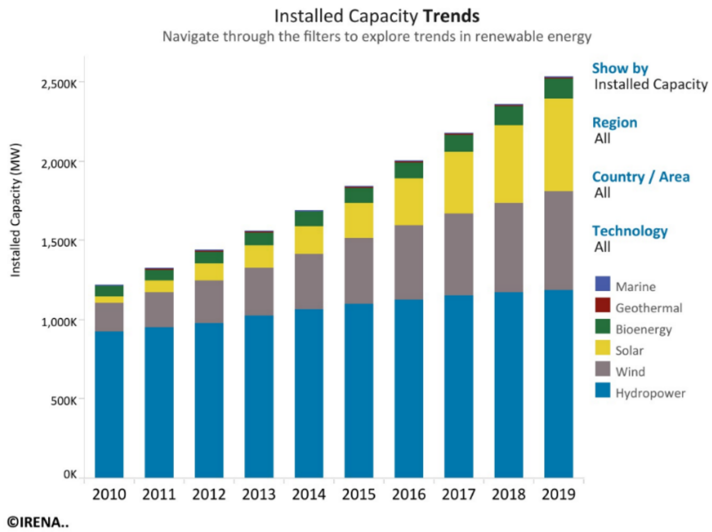

Figure 5. Global renewable installed capacity.

In contrast, the proportion of renewable energy consumption is relatively small in the Asia-Pacific region. The majority of Asia-Pacific countries consumed renewable energy at less than 15% of total energy consumption, with the exception of New Zealand (30.4%), Vietnam (25.7%), North Korea (25.4%), Canada (23.2%) and Sri Lanka (22.8%). Specifically, New Zealand is located at the junction of the Indian Ocean and Pacific Ocean plates with active crustal movement, and so they have abundant geothermal and hydroenergy sources, accounting for 29.1% and 12.8% of total energy consumption, respectively. In Sri Lanka, nearly 40% of the electricity mix is derived from hydropower. Although the share of renewable energy consumption in China and the United States is relatively small, both countries are world leaders in renewable power generation capacity. For example, in China, as power systems become more integrated, they are expected to account for 40% of global renewable power generation before 2024 [24]. In the United States, the power generation capacity of solar and wind energy is increasing year-on-year, and is expected to grow by 50% within a decade [25].

Globally, renewable energy is demonstrating a promising momentum. In 2019, worldwide investment in wind power generation totaled US$138.2 billion and investment in photovoltaic power generation reached US$131.1 billion. In South America, renewable energy investment surged by 54% over the previous year, with Chile and Brazil

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leading the way [26]. The European wind power market has also grown significantly. In 2020, wind power contributed approximately 57%, 32%, and 26.4% of the total energy supply in Denmark, Ireland, and Portugal, respectively [13]. At the same time, in China, the use of fossil fuels such as oil and coal has been declining in recent years, while renewable energy consumption, especially hydropower, solar, and wind, continues to rise [27]. At the end of 2019, China's renewable energy installation capacity has reached 7.94 kW, a 9 % year on year rise. Despite the sound progress of global renewable energy investment, there are still issues awaiting to be solved. First of all, renewable energy projects involve large upfront costs and technical requirements, making them especially challenging for many developing countries [28]. The high cost and technical requirements will largely hinder the energy transition progress [29]. In addition, although the green energy transition has diversified the energy mix, no renewable energy resource has yet possessed a monopolistic power like fossil fuels, leading to a limited proportion of renewable energy in global energy consumption. Renewable energy accounted for barely 14% of the global energy demand [30]. Therefore, it is necessary to explore new opportunities in current changing global economic landscape

3. Green building concept

The term green building refers to the quality and characteristics of the actual structure created using the principles and methodologies of sustainable construction. Green buildings can be defined as "healthy facilities designed and built in a resource-efficient manner, using ecologically based principles" Similarly, ecological design, ecologically sustainable design, and green design are terms that describe the application of sustainability principles to building design. Despite the prevalent use of these terms, truly sustainable green commercial buildings with renewable energy systems, closed materials loops, and full integration into the landscape are rare to nonexistent. Most existing green buildings feature incremental improvement over, rather than radical departure from, traditional construction methods. Nonetheless, this process of trial and error, along with the gradual incorporation of sustainability principles, continues to advance the industry's evolution toward the ultimate goal of achieving complete sustainability throughout all phases of the built environment's life cycle [9].

High-performance green buildings marry the best features of conventional construction methods with emerging high-performance approaches. Green buildings are achieving rapid penetration in the US construction market for three primary reasons [9]:

a) Sustainable construction provides an ethical and practical response to issues of environmental impact and resource consumption. Sustainability assumptions encompass the entire life cycle of the building and its constituent components, from resource extraction through disposal at the end of the useful life of the materials. Conditions and processes in factories are considered, along with the actual performance of their manufactured products in the completed building. High-performance green building design relies on renewable resources for energy systems; recycling and reuse of water and materials; integration of native and adapted species for landscaping; passive heating, cooling, and ventilation; and other approaches that minimize environmental impact and resource consumption.
b) Green buildings virtually always make economic sense on an LCC basis, although they may be more expensive on a capital, or first-cost, basis. Sophisticated energy-conserving lighting and air- conditioning systems with an exceptional response to interior and exterior climates will cost more than their conventional, code-compliant counterparts. Rainwater harvesting systems that collect and store rainwater for nonpotable uses will require additional piping, pumps, controls, storage tanks, and filtration components. However, most key green building systems will recoup their original investment within a relatively short time. As energy and water prices rise due to increasing demand and diminishing supply, the payback period will decrease.
c) Sustainable design acknowledges the potential effect of the building, including its operation, on the health of its human occupants. A 2012 report from the Global Indoor Health Network suggested that, globally, about 50 percent of all illnesses are caused by indoor air pollution. Estimates peg the direct and indirect costs of building-related illnesses (BRIs), including lost worker productivity, as exceeding $150 billion per year. Conventional construction methods have traditionally paid little attention to sick building syndrome BRI, and multiple chemical sensitivity until prompted by lawsuits. In contrast, green buildings are designed to promote occupant health; they

include measures such as protecting ductwork during installation to avoid contamination during construction; specifying finishes with low to zero volatile organic compounds to prevent potentially hazardous chemical off-gassing; more precise sizing of heating and cooling components to promote dehumidification, thereby reducing mold; and the use of ultraviolet radiation to kill mold and bacteria in ventilation systems.

At the onset of the green building movement, several state and local governments took the initiative in articulating guidelines aimed at facilitating high-performance construction. The Pennsylvania Governor's Green Government Council (GGGC) used mixed but very appropriate terminology in its "Guidelines for Creating High-Performance Green Buildings." The lengthy but instructive definition of high-performance green building (see Table 1) focused as much on the collaborative involvement of the stakeholders as it did on the physical specifications of the structure itself. The issue of resource-conscious design is central to sustainable construction, which ultimately aims to minimize natural resource consumption and the resulting impact on ecological systems. Sustainable construction considers the role and potential interface with ecosystems to provide services in a synergistic fashion. With respect to materials selection, closing materials loops and eliminating solid, liquid, and gaseous emissions are key sustainability objectives [9-12].

Table 1. High-performance green building project

- A project created via cooperation among building owners, facility managers, users, designers, and construction professionals through a collaborative team approach.
- A project that engages the local and regional communities in all stages of the process, including design, construction, and occupancy.
- A project that conceptualizes a number of systems that, when integrated, can bring efficiencies to mechanical operation and human performance.
- A project that considers the true costs of a building's impact on the local and regional environment.
- A project that considers the life-cycle costs of a product or system. These are costs associated with its manufacture, operation, maintenance, and disposal.
- A building that creates opportunities for interaction with the natural environment and defers to contextual issues such as climate, orientation, and other influences.
- A building that uses resources efficiently and maximizes use of local building materials.
- A project that minimizes demolition and construction wastes and uses products that minimize waste in their production or disposal.
- A building that is energy- and resource-efficient.
- A building that can be easily reconfigured and reused.
- A building with healthy indoor environments.
- A project that uses appropriate technologies, including natural and low-tech products and systems, before applying complex or resource-intensive solutions.
- A building that includes an environmentally sound operations and maintenance regimen.
- A project that educates building occupants and users to the philosophies, strategies, and controls included in the design, construction, and maintenance of the project

Green and sustainable building refers to a structure and using process that is environmentally responsible and resource-efficient throughout a building's life-cycle: from siting to design, construction, operation, maintenance, renovation, and demolition. This practice expands and complements the classical building design concerns of economy, utility, durability, and comfort [1-12]. Figure 6 shows six design photographs for the green building concept.

Figure 6. There are six design concepts for green buildings.

Although new technologies are constantly being developed to complement current practices in creating greener structures, the common objective is that green buildings are designed to reduce the overall impact of the built environment on human health and the natural environment by [4]:

- Efficiently using energy, water, and other resources,
- Protecting occupant health and improving employee productivity,
- Reducing waste, pollution and environmental degradation.

Green building brings together a vast array of practices and techniques to reduce and ultimately eliminate the impacts of new buildings on the environment and human health. It often emphasizes taking advantage of renewable resources, e.g., using sunlight through passive solar, active solar, and photovoltaic techniques and using plants and trees through green roofs, rain gardens, and for reduction of rainwater run-off. Many other techniques, such as using packed gravel or permeable concrete instead of conventional concrete or asphalt to enhance replenishment of ground water, are used as well [1-7].

Green buildings often include measures to reduce energy use. To increase the efficiency of the building envelope, they may use high-efficiency windows and insulation in walls, ceilings, and floors [1-3]. Another strategy, passive solar building design, is often implemented in low-energy homes. Designers orient windows and walls and place awnings, porches, and trees to shade windows and roofs during the summer while maximizing solar gain in the winter. In addition, effective window placement (daylighting) can provide more natural light and lessen the need for electric lighting during the day. Solar water heating further reduces energy loads. Reducing water consumption and protecting water quality are key objectives in sustainable building. One critical issue of water consumption is that in many areas, the demands on the

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supplying aquifer exceed its ability to replenish itself. To the maximum extent feasible, facilities should increase their dependence on water that is collected, used, purified, and reused on-site [4, 6, 7].

Building materials typically considered to be 'green' include (Expanded polystyrene) rapidly renewable plant materials like bamboo (because bamboo grows quickly) and straw, lumber from forests certified to be sustainably managed, insulated concrete forms, dimension stone, recycled stone, recycled metal, and other products that are non-toxic, reusable, renewable, and/or recyclable. The US Environmental Protection Agency (USEPA) also suggests using recycled industrial goods, such as coal combustion products, foundry sand, and demolition debris in construction projects [5].

4. Green building economics

The market for green buildings in the world continues to increase both in size and in market share. It is reported that the market size of green construction, including both residential and nonresidential buildings, had jumped fourfold in just three years, from $100 billion in 2010 to $190 billion in 2022 and was expected to range between $255 billion and $371 billion in 2030. In 2020, it was estimated that new nonresidential green construction represented 35 to 45% of total construction volume. The three sectors with the greatest rate of market growth and penetration are education, health care, and office buildings. Green building data from MHC indicate that there are several major trends in the ongoing shift to green buildings [9].

First, the bigger the building project, the more likely it is to be a high-performance building. Because health care projects tend to be larger, the number of green health care projects is growing very rapidly. Over 80% of projects at least $80 million in size are including the US Green Building Council (USGBC) Leadership in Energy and Environmental Design (LEED) building rating system in their specifications. Second, throughout the United States, schools at all levels from K-12 to university are high-performance green buildings, and green building activity in the educational sector was between $23 billion and $32 billion in 2020. This rapid growth rate is likely being propelled by a combination of state and local mandates that require schools to be certified as green buildings. Third, a significant number of federal, state, and local governments are requiring that publicly owned buildings be high-performance green buildings [9].

Understanding building economics is important for any construction project, but it is especially important for high-performance green buildings because justifying this approach can involve somewhat more complex analysis than for conventional construction. High-performance buildings can produce benefits for their owners in a diverse range of categories: energy, water, wastewater, health and productivity, operations and maintenance (O&M), maintainability, and emissions, to name a few. To address the scope of benefits, the building team must be able either to quantify the effects of their decisions by using simulation tools or to rely on the best available research and evidence gathered from other projects [9].

An analysis of the financial benefits of high-performance green buildings concluded that significant benefits could be attributed to this type of delivery system and that there was a correlation between the LEED-NC rating and the financial return. Table 2 indicates that for a typical high-performance building, the total net present value (TNPV) of the energy savings over a 20-year life cycle is $5.79 per square foot, with other notable per square foot savings from reduced emissions ($1.18), water ($0.51), and O&M savings resulting from building commissioning ($8.47). Table 2 also shows productivity and health savings per square foot of $36.89 for LEED certified and silver buildings and $55.33 for LEED gold and platinum buildings. The 20-year TNPV per square foot in the table represents the sum of the annual net present values for comparison with the investment in green attributes. Clearly, the productivity and health benefits of high-performance green buildings dominate this discussion, and for gold and platinum buildings, the claim is that the savings are almost 10 times greater than the energy savings. It is important to point out, however, that although these claims are generally accepted by high-performance building practitioners, most of those made for productivity and health improvements are based on anecdotal information, not scientific research. The 20-year TNPV is $67 for certified and silver buildings and $771 for gold and silver buildings. The magnitude of these benefits is very impressive when considering that, on average, the incremental construction cost ranges from about $2.50 per square foot for LEED-certified buildings to about $9.50 per square foot for LEED platinum buildings.

Table 2. Value of Various Categories of Savings for Buildings Certified by the USGBC

Category	20-Year TNPV/ft^{2},*
Energy value	$6.86
Emission value	$1.64
Water value	$1.24
Waste value-construction only, 1 year	$0.08
Commissioning O&M** value	$9.64
Productivity and health value (certified and silver)	$47.86
Productivity and health value (gold and platinum)	$67.88
Less green cost premium	($6.00)
Total 20-year NPV (certified and silver)	$59.67
Total 20-year NPV (gold and platinum)	$78.64

*Net present value (NPV) is the net savings for each year, taking into account the discount rate (time value of money). The 20-year TNPV is the sum of the NPVs for all 20 years and represents the total life-cycle savings

**O&M commissioning ensures that the building is built and operated according to the design and results in substantially lower O&M costs [9].

A side-by-side analysis of two prototype buildings by the US Department of Energy's Pacific Northwest National Laboratory and the National Renewable Energy Laboratory (NREL) compared the costs and benefits of investing in high-performance buildings. A base two-story, 20,000-ft^2 (1858-m^2) building with a cost of $2.4 million meeting the requirements of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers' (ASHRAE) Standard 90.1-1999 was modeled using two energy simulation programs, DOE-2.1e and Energy-10, and compared to a high-performance building that added $47,210 in construction costs, or about 2 percent, for its energy-saving features. Table 3 summarizes the results of this study. The features listed in the table are those for which an additional investment was made to produce the high-performance version of the NREL prototype building:

- Building commissioning, as noted previously, can produce significant savings by ensuring that the mechanical systems are functioning as designed.
- Natural landscaping and storm-water management produce savings due to the elimination of infrastructure and the use of easily maintainable native plants.
- Raised floors and movable walls produce savings by improving the flexibility of a building, reducing renovation costs.

Table 3. Comparison of Costs and Savings for NREL Prototype Buildings

Feature	Added cost	Annual Savings
Energy efficiency measures	$51,000	$6,400
Commissioning	$6,400	$3,500
Natural landscaping, storm-water management	$6,900	$5,100
Raised floors, movable walls	$60	$48,000
Waterless urinals	$698	$58,420
Total	$65,160	$121,420

Source [9]

The results of this comparison are remarkable: They indicate that the annual savings produced by the high-performance version are about equal to the added construction cost, producing a simple payback in just over one year. The additional capital costs often associated with high-performance buildings are a function of several factors. First, these buildings often incorporate systems that are not typically present in conventional buildings, such as rainwater harvesting infrastructure, daylight-integrated lighting controls, and energy recovery ventilators.

Second, green building certification (fees, compilation of information, preparation of documents, cost of consultants) can add markedly to the costs of a project. And, finally, many green building products cost more than their counterparts, often because they are new to the marketplace and demand is only in the process of developing. In this last category are many nontoxic materials, such as paints, adhesives, floor coverings, linoleum, and pressed strawboard used in millwork, to name but a few of the many new green building products emerging to serve the high-performance building market. Conversely, cost reductions for some building systems are achievable in green buildings—for example, in heating, ventilation, and air conditioning (HVAC) systems— that can be downsized as a consequence of improved building envelope design [7, 9].

However, additional energy-saving components such as energy recovery ventilators, premium high-efficiency motors, variable-frequency drives for variable air volume systems, carbon dioxide sensors, and many others all add to the front-end capital cost. As for every other type of project, understanding the economics of the situation and including them in the decision-making process is of crucial importance. As described earlier, the classical approach used in assessing high-performance building economics is life-cycle costing (LCC), which includes a consideration of both first cost [7, 9].

These two major cost factors are combined in a cost model that takes into account the time value of money, the cost of borrowed money, inflation, and other financial factors. They are then combined into a single value, the TNPV of the annual costs, and the selection of alternatives is based on an evaluation of this quantity. In some cases, due to legislated requirements, only the capital cost is considered [7]. For example, the state of Florida allows decisions on building procurement to be made solely on the basis of capital costs, whereas the US government requires that an LCC approach be used. Producing a high-performance public sector building in Florida can be very challenging; therefore, finding creative mechanisms for investing in higher-quality construction is imperative. One potential mechanism is the creation of a revolving fund from which building owners or users can borrow and that can be repaid through savings over time [9].

5. Conclusions

It was concluded that sustainability can minimize the harmful impact of conventional buildings on the environment, economy and people in using green materials. Also, "Sustainable" or "green" buildings use key resources like energy, water, and materials more efficiently than conventional (non-sustainable) buildings. Furthermore, sustainable buildings increase natural light, incorporate high-performance systems, and rainwater systems, and improve airflow for occupants. Accordingly, if sustainable principles can be used in building projects, then numerous benefits of green buildings may be achieved, as follows:

- *Environmental benefits:* Enhance and protect biodiversity and ecosystems; Improve air and water quality; Reduce waste streams, and; Conserve and restore natural resources.
- *Economic benefits:* Reduce operating costs; Improve occupant productivity, and; Optimize life-cycle economic performance.
- *Social benefits:* Enhance occupant health and comfort; Improve indoor air quality; Minimize strain on local utility infrastructure, and; Improve overall quality of life.

6.Acknowledgement

The authors acknowledged to Turkish Academy of Sciences for financial support of this study.

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