Chapter 1

Green Buildings for Climate Mitigation and Sustainable Air Conditioning

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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. 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.

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 environment are linked, the realization has set in to conserve energy and natural resources. The increased use of resources that cause pollution and emissions, highlight the need to save and conserve energy for sustainable development. In

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https://doi.org/10.58830/ozgur.pub389.c1607

engineering, sustainable building design is a design ideology, which harbors the notion of sustainable human development [2]. Sustainable development can be defined in various ways. Every individual will approach the issue of sustainability in a different manner depending upon various factors, such as, sustainability goals, background, awareness, and economic conditions [1-12].

Sustainability is providing opportunity of development to the future generation, in terms of resources [4]. 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 [5]. The concept of green buildings is the measure of our efforts in attaining that idealistic sustainable construction practices. 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 [6, 7].

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 concerns of economy, utility, durability, and comfort. Green building is also known as a sustainable building [7-12].

2. Mitigating Climate Change

The term climate change mitigation refers to strategies or actions that attempt to limit the scale and rate of long-time climate change [8-10]. A wide variety of measures are being attempted, including shifting to low-carbon energy systems represented by wind, solar, and nuclear technologies; designing compact urban areas with high-efficiency mass transit systems; improvements to the efficiencies of motors, appliances, and air-conditioning systems; and investments in bikeways and bicycling infrastructure, to name but a few. The problem, as noted, is that the trajectory of increasing atmospheric CO_2 concentrations is such that it will take a vast coordinated international effort to maintain climate change gas concentrations at levels that will not cause certain catastrophe. We do know that CO_2 has increased by over 60% since the start of the Industrial Age 230 years ago, from 280 to 400 ppm. In just 30 years since 1990, CO_2 levels have increased from 350 to 450 ppm, about 45% of the total. This acceleration in CO_2 levels shows no sign of slowing down, and by 2040, we are likely to reach the critical 450 ppm level, the dividing line between a planet with glaciers, ice-covered poles, and snow-covered mountaintops and one that is ice-free world [11, 12].

A wide variety of possible remedies are associated with climate change mitigation, ranging from nontechnical, behavioral options to highly technical solutions that remove carbon from the atmosphere and store it in rock formations or caverns. This latter approach to handling climate change gases is often referred to as climate engineering. The storage of CO_2, either by natural or climate engineering means, is known as carbon sequestration. The natural sequestration possibilities for the excess carbon being created by human actions include two major planetary environments: terrestrial and ocean [8-12].

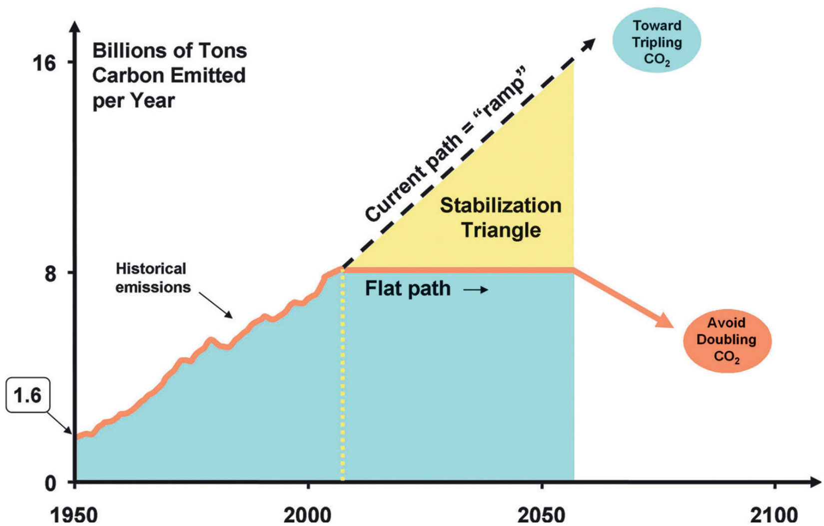

Figure 1. The climate stabilization wedge or triangle represents the amount of carbon must be prevented from entering the atmosphere to prevent the worst effects of climate change [8].

The Carbon Mitigation Institute [8] described eight major carbon mitigation strategies, or stabilization wedges applied together in a comprehensive fashion, do have the potential to reduce CO_2 to 2000 levels by 2060. Each Stabilization Wedge can reduce human carbon emissions by 1.0 Gigaton (Gt) annually. Taken together, they constitute the triangular area in Figures 1 and 2 which represents the additional carbon that will be emitted if nothing is done to mitigate it, about 200 Gt. By 2060, if nothing is done and carbon emissions continue to increase, we can expect triple the atmospheric carbon of the pre-industrial era and an increase from 280 ppm to almost 900 ppm. If, in contrast, carbon emissions could be flattened and emissions would remain constant, the result would the possibility of adapting to climate change without its worst effects. The Stabilization Triangle in these figures represents the quantity of carbon that can possibly minimize planetary scale disruptions, about 1.0 Gt per wedge in the triangle, or 8 billion tons total [8-12].

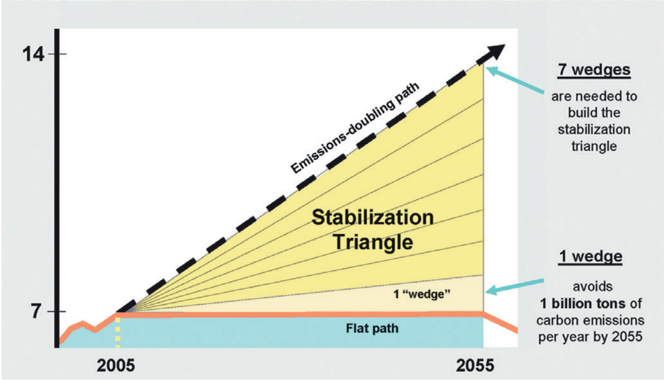

Figure 2. The stabilization triangle has 8 wedges, each of which represents the prevention of 1 gigaton of carbon from entering the atmosphere [8].

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 (Kats 2003).

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 3 shows six photographs for the green building concept.

Figure 3. 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 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. Solar energy systems in green buildings

Developments in solar energy are accelerating so rapidly it's hard even for experts to keep up. Technologies coming out of the lab only a couple of years ago are already having an effect on the designer's choices and on the marketplace. We can expect future advancements in solar buildings to be rapid and profound [9]. We may not be able to predict the future, but we can perceive some of the characteristics of what must be over the horizon. It must be carbon neutral in this climate changing world. Now we realize that we can't put all our eggs in one basket, and whatever energy picture we evolve to is going to incorporate a lot more diversity of supply than it does now. It's going to have to be efficient. It's going to have to involve local jobs. It's going to have to have a low impact on the environment, on the facilities, and on the infrastructure of the facilities where it's installed. It's going to have to be affordable, and it's going to have to be secure [9-12].

Let's discuss the solar energy technologies within the context of these characteristics. Energy is an issue at the intersection of security, economics, and the environment, where there are certainly risks and vulnerabilities, but also opportunities. The ability of solar energy to solve problems in one of these sectors may alleviate problems in some of the other sectors. Life on Earth has always depended on energy from the sun. Our food energy comes from photosynthesis caused by the sun in plants. The fossil fuels that we currently rely on are solar energy, captured and saved by plants over the span of 50 to 450 million years. We have been using that stored fuel at a rapid rate for more than 100 years, and, in the process, moving carbon from the lithosphere to the atmosphere [9].

Even before fossil fuels run out—which they inevitably will—we may be forced to consider alternatives because of the environmental consequences of burning them. One alternative, solar energy, has long been used in buildings; Socrates made reference to it thousands of years ago. A recent reawakening interest in the health and comfort benefits of natural systems has caused its revival for use in building design. Principal ways of using solar energy in buildings include the following:

- Daylighting
- Passive solar heating
- Solar water heating
- Photovoltaics (electricity)
- Solar ventilation air preheating

New technologies, such as photovoltaics that convert solar energy cleanly and silently into electricity and super-insulated windows that admit visible light while screening out ultraviolet and infrared rays, provide today's designer with powerful new tools in the utilization of solar energy. It is now technically feasible to provide all of a building's energy needs with solar energy. Solar is even the least costly option in areas where delivery of fossil fuels or provision of electric power is expensive. Many solar energy applications are cost-effective already, and, as the price of conventional utilities continues to rise, more and more solar energy features will fi nd their way into green buildings [8-12].

The sun is a nuclear reactor 93,000,000 miles from Earth, streaming radiant energy out into space. The intensity on a sunny day is around 1,000 watts/m^2, a value respected by anyone who has been sunburned or momentarily blinded by the brightness. Enough solar energy reaches the Earth to power the world economy 13,000 times over. In fact, 20 days worth of solar radiation is equal to the capacity of all our stored fossil fuel from gas, coal, and oil resources. There is no question that solar energy is of adequate quantity to meet our energy needs. The emphasis is rather on how it can be integrated into building design, given the distributed and intermittent nature of the solar resource.

5. Green building economics

The market for green buildings in the word 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	$6,900	$5,100
management	$60	$48,000
Raised floors, movable walls	$698	$58,420
Waterless urinals	$65,160	$121,420
Total		

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].

6. Conclusions

It was concluded that the sustainability can minimize the harmful impact of the conventional buildings on environment, economy and people in using green materials, technologies. “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, rainwater system, and improve air flow 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.

Acknowledgement-The author acknowledged to Turkish Academy of Sciences for financial support of this study.

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