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Infrastructure: Green Building Overview and Issues

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Summary

Buildings, whether residential, commercial, government, or special-use, are core components of the nation's infrastructure. Their construction, operation, and demolition are increasingly recognized as major sources of environmental impact. Without significant transformation of building construction and operations, that impact is expected to increase with population growth and changes in other demographic and economic factors. One strategy for achieving that transformation is most widely known by the term green building. However, the term is used differently by various proponents and practitioners, denoting a continuum of practices, from those differing minimally from standard practices, to those aimed at providing buildings with a minimum of environmental impact.

In general, *green building* can be characterized as integrated building practices that significantly reduce the environmental footprint of a building in comparison to standard practices. Descriptions of green building generally focus on a number of common elements, especially siting, energy, water, materials, waste, and health. Serviceability or utility is also an explicit design element for a class of green buildings known as high-performance buildings.

One of the most salient features of green building is integration of the various elements. Although individual elements can be addressed separately, the green building approach is more comprehensive, focusing on the environmental footprint of a building over its life cycle, from initial design and construction to operations during the building's useful life, through eventual demolition and its aftermath.

The desire to integrate the various elements of green building has led to the development of rating and certification systems to assess how well a building project meets a specified set of green criteria. The best-known system is Leadership in Energy and Environmental Design (LEED). Developed by the U.S. Green Building Council, it focuses on site, water, energy, materials, and indoor environment. Recently, green building practices have found their way into building model codes and technical standards.

Green building has received substantial attention from government, industry, and public interest groups. Several federal laws and executive orders have provisions relating to green building. Among these are the energy policy acts (EPACTs) of 1992 and 2005 (P.L. 102-486 and P.L. 109-58), the Energy Independence and Security Act of 2007 (EISA, P.L. 110-140), and Executive Order 13693. EISA and other policy instruments require all federal agencies to implement green building practices. However, several agencies have programs and activities that have a focus that goes beyond reducing the environmental impacts of the facilities used by that agency—for example, by performing research or facilitating the green-building activities of nonfederal entities. Among those agencies are the General Services Administration, the Environmental Protection Agency, the Office of Federal Sustainability, the National Institute of Standards and Technology, and the Departments of Defense, Energy, and Housing and Urban Development.

Green building raises issues relating to performance, cost, market penetration, and the approach itself. Among the questions Congress may face with respect to such issues are the following: How well are current green building programs working? How effective are current methods for coordinating the green building activities of different agencies? To what extent and by what means should Congress extend its efforts to facilitate and support the adoption and effective implementation of green building measures? What priorities should Congress give to the different elements of green building? What actions should Congress do to facilitate the growth of the scientific and technical knowledge base relating to green building?

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Introduction

The environmental impacts of human activity have been a source of controversy and concern for many years. Much of the focus over that time has been on impacts such as pollution and the destruction or degradation of wildlife habitats and ecosystems. Over the past few decades, however, concerns have increased greatly about greenhouse gases, resource depletion, and degradation of ecological services such as water supply. Over that time, the impacts of buildings have come under increasing scrutiny.

There are many different kinds of buildings—residential, commercial, government, and those with special uses such as schools and hospitals—and they form a large and core component of the nation's infrastructure. The construction, characteristics, operation, and demolition of buildings are now recognized as a major source of environmental impact, including direct effects on the humans who use them. U.S. buildings consume vast amounts of resources annually in the form of electricity for lighting and temperature control, drinkable water for indoor and outdoor use, and construction materials with diverse supply chains and manufacturing processes; they also produce substantial waste streams throughout their lifecycles, from construction to daily operations to demolition. Such resource use can impose high environmental and financial costs. For example, buildings account for about 40% of energy consumption in the United States, producing approximately 40% of anthropogenic greenhouse gas emissions, and costing consumers more than $430 billion a year in energy bills.[1]

A building's location and interaction with its surrounding environment also influences its ecological and human health impacts. Buildings create impermeable surfaces that can have substantial effects on stormwater management and associated health and environmental impacts. A building's proximity to public transportation affects the energy required to transport occupants to and from the premises. If an office is not accessible by walking or public transit, for example, occupants may need to commute by car, contributing to traffic delays, smog, and greenhouse gas emissions. Occupant health and productivity is also affected by building features that determine indoor air quality. Most people spend far more time indoors than outside, and the air in buildings often has substantially higher concentrations of pollutants than the air outside, contributing in extreme cases to a phenomenon known as "sick building syndrome."[2]

These and other undesirable environmental and health impacts can be addressed for construction, renovation, and operations of both new and existing buildings. *Green building* is a tool for transforming the ways in which buildings are designed, built, operated, and demolished that has generated substantial interest in recent decades. Since emerging as a relatively novel concept in the 1990s, green building has grown into what many consider a respected approach to building, with an increasing number of stakeholders. They include, among others, private construction firms, building owners and occupants, green building certification and standards-developing organizations, federal and state lawmakers, local code officials, and a variety of government agencies.

This report discusses the concept of green building, major federal policies and programs relating to it, and associated issues. Topics covered include how green building is defined, what it consists of, the major areas of environmental impact it seeks to address, an overview of the tools available

[1] Department of Energy, Energy Information Administration, "Annual Energy Outlook 2015," DOE/EIA-0383(2015), April 2015, https://www.eia.gov/outlooks/aeo/pdf/0383(2015).pdf.

[2] Environmental Protection Agency, "The Inside Story: A Guide to Indoor Air Quality," Overviews and Factsheets, *EPA*, August 28, 2014, https://www.epa.gov/indoor-air-quality-iaq/inside-story-guide-indoor-air-quality.

for ensuring that a building conforms to green criteria, outstanding issues in the implementation of green building, an overview of the major statutory and executive authorities that address it, and programs in federal agencies that involve one or more elements related to it.

What Is Green Building?

Environmentally sensitive building is not a particularly recent phenomenon,[3] but the modern practice of green building began emerging in the 1990s. One milestone in the United States was the formation in 1990 of the Committee on the Environment within the American Institute of Architects (AIA),[4] followed within a few years by the founding of the U.S. Green Building Council (USGBC)[5] and other organizations. The most prominent federal green building project in that decade was the "Greening of the White House."[6] From those beginnings, the concept of green building has expanded to encompass both the movement to promote environmentally conscious design principles and the set of practices and strategies by which builders seek to reduce harmful impacts of the built environment.

There is no single consensus definition of green building; efforts exist along a design and performance continuum. What some call green building is barely distinguishable from standard building practices. At the extreme, the term can be used in an almost meaningless way, purely as a marketing tool. Such practices are sometimes called "greenwashing."[7]

In contrast, some practitioners aim to provide buildings with environmental impacts that are greatly reduced from those of typical buildings. Examples include the so-called "zero-impact" building, which is intended to have no net environmental impact, including but not limited to net-zero energy use; and the "minus-impact" building, which would provide a net environmental benefit (see "Net-Zero Buildings," below). Most green building efforts have less ambitious reduction goals.

In general, *green building* might best be characterized as an integrated approach to building design, construction, and operations that significantly reduces the environmental footprint of buildings in comparison to standard practices. The *environmental footprint* is the overall impact of a structure or activity on the environment, including the human environment.[8]

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[3] For a brief history, see, for example, Robert Cassidy, ed., "White Paper on Sustainability," *Building Design and Construction* Supplement, November 2003, 48 p., https://www.bdcnetwork.com/sites/default/files/BD%2BC%202003%20White%20Paper%20on%20Sustainability.pdf; Osman Attmann, *Green Architecture: Advanced Technologies and Materials*, McGraw-Hill's GreenSource Series (New York: McGraw-Hill, 2010).

[4] American Institute of Architects, "AIA/COTE: A History Within a Movement," 2008, https://network.aia.org/committeeontheenvironment/home/cotehistory.

[5] The U.S. Green Building Council (http://www.usgbc.org) is a U.S. nonprofit cross-sector organization (including representatives of industry, government, and academia) founded in 1993. The Sustainable Buildings Industry Council (https://www.nibs.org/?page=sbic), a trade association, also became involved in green building in the 1990s. The international World Green Building Council (http://www.worldgbc.org) was founded several years later, in 1999. That organization and others, such as the International Initiative for a Sustainable Built Environment (http://www.iisbe.org) may be especially important for green building in China, India, and other developing nations.

[6] See The White House, "Greening of the White House," November 1999, http://clinton4.nara.gov/Initiatives/Climate/WHgreening.html.

[7] Greenwashing refers to the false or exaggerated promotion of a product as green or sustainable.

[8] See, for example, Commission for Environmental Cooperation, "Green Building in North America," 2008, http://www3.cec.org/islandora/en/item/2335-green-building-in-north-america-opportunities-and-challenges-en.pdf. Related terms include *ecological footprint*, which refers to impacts on ecosystems, often measured as the acreage required to absorb the impact; see for example, Aaron Best et al., "Potential of the Ecological Footprint for Monitoring (continued...)

This characterization captures two common features of the various meanings given to the term. First, green is a relative concept—a green building is one that is greener than average. Second, it is not limited to only one factor, such as energy consumption, but involves integration across several, as is discussed below. The green building approach can be applied to any class of building: large or small, commercial or residential.

Green builders seek to achieve improvements in environmental performance through a variety of techniques and strategies, from the implementation of innovative technologies (such as energy-efficient heating and cooling systems) to design features intended to influence occupant behavior (such as placing stairways prominently to encourage their use). Some of these techniques will be discussed in more detail below. Decisions about which of these techniques will be used are often made in the design and planning phase, but can impact the environmental footprint of a building throughout its lifecycle. As a result, green building techniques are most often applied to new construction, through there is a growing incidence of green renovation and retrofit projects.

The term *green building* is often used interchangeably with others such as *sustainable building*, and that practice is followed in this report. However, the terms may also be used in ways that are not exactly synonymous. For example, sustainable building may be described as a form of green building, but with a more stringent goal of indefinitely maintaining environmental footprints that are small enough that they will not impede future human activity and the functioning of ecosystems.[9]

Another term often used interchangeably with green building is *high-performance building*. However, high-performance building usually involves other factors such as security in addition to environmental ones. There are two federal statutory definitions:

> a building that integrates and optimizes all major high-performance building attributes, including energy efficiency, durability, life-cycle performance, and occupant productivity,[10]

and

> a building that integrates and optimizes on a life cycle basis all major high performance attributes, including energy conservation, environment, safety, security, durability, accessibility, cost-benefit, productivity, sustainability, functionality, and operational considerations.[11]

(...continued)

Environmental Impacts from Natural Resource Use" (European Commission, DG Environment, May 2008), http://ec.europa.eu/environment/archives/natres/pdf/footprint.pdf; and Global Footprint Network, "Ecological Footprint," 2017, http://www.footprintnetwork.org/our-work/ecological-footprint/. Another term is *carbon footprint*, which can be characterized as the net amount of greenhouse gases being produced as a result of an activity (see, for example, James Morton Turner, "Counting Carbon: The Politics of Carbon Footprints and Climate Governance from the Individual to the Global," *Global Environmental Politics* 14, no. 1 [2014]: 59–78, http://repository.wellesley.edu/cgi/viewcontent.cgi?article=1084&context=scholarship).

[9] These characterizations draw most heavily on descriptions in some documents from the Building Science Corporation (http://www.buildingscience.com/index_html). Some observers may argue for other characterizations of "sustainable building," such as "zero-impact." See discussion on "Approach and Implementation."

[10] 2 U.S.C. §16194(a).

[11] 2 U.S.C. §17061(12).

Definitions of Green Building

"Green," "sustainable," and "high-performance" are among the terms used to denote building practices that reduce the environmental impacts of components of the built environment. Descriptions and definitions vary among organizations, as illustrated by the language quoted below:

P.L. 110-140, Energy Independence and Security Act of 2007 (42 U.S.C. §17061(13))

The term "high-performance green building" means a high-performance building that, during its life-cycle, as compared with similar buildings (as measured by Commercial Buildings Energy Consumption Survey or Residential Energy Consumption Survey data from the Energy Information Agency)—

(A) reduces energy, water, and material resource use;
(B) improves indoor environmental quality, including reducing indoor pollution, improving thermal comfort, and improving lighting and acoustic environments that affect occupant health and productivity;
(C) reduces negative impacts on the environment throughout the life-cycle of the building, including air and water pollution and waste generation;
(D) increases the use of environmentally preferable products, including biobased, recycled content, and nontoxic products with lower life-cycle impacts;
(E) increases reuse and recycling opportunities;
(F) integrates systems in the building;
(G) reduces the environmental and energy impacts of transportation through building location and site design that support a full range of transportation choices for users of the building; and
(H) considers indoor and outdoor effects of the building on human health and the environment, including—

(i) improvements in worker productivity;
(ii) the life-cycle impacts of building materials and operations; and
(iii) other factors that the Federal Director or the Commercial Director consider to be appropriate.

Environmental Protection Agency

Green building is the use of approaches that create buildings and development that are environmentally responsible and resource-efficient throughout a building's life cycle, from site selection to demolition or reuse.

General Services Administration

Sustainable design seeks to reduce negative impacts on the environment, and the health and comfort of building occupants, thereby improving building performance. The basic objectives of sustainability are to reduce consumption of nonrenewable resources, minimize waste, and create healthy, productive environments.

Green buildings exhibit environmentally responsible intent and perform in a resource efficient manner. They meet the needs of the occupants that live and work in them in a way that minimizes demand for natural resources and reduces or eliminates waste. Green buildings save energy, water, materials, protect the indoor environment and are designed to evolve as occupant needs change. Such buildings are generally more comfortable, healthy, durable and adaptable over time.

U.S. Green Building Council

Green building is a holistic concept that starts with the understanding that the built environment can have profound effects, both positive and negative, on the natural environment, as well as the people who inhabit buildings every day. Green building is an effort to amplify the positive and mitigate the negative of these effects throughout the entire life cycle of a building.

World Green Building Council

A "green" building is a building that, in its design, construction or operation, reduces or eliminates negative impacts, and can create positive impacts, on our climate and natural environment. Green buildings preserve precious natural resources and improve our quality of life.

Sources: Environmental Protection Agency, "Location and Green Building," March 29, 2017, https://www.epa.gov/smartgrowth/location-and-green-building; General Services Administration, "Sustainable Design," May 22, 2017, https://www.gsa.gov/portal/content/104462; General Services Administration Sustainable Facilities Tool, "What Is Sustainability," 2017, https://sftool.gov/learn/about/41/sustainability; Jacob Kriss, "What Is Green Building?" (U.S. Green Building Council, August 6, 2014), https://www.usgbc.org/articles/what-green-building; World Green Building Council, "What Is Green Building?" 2017, http://www.worldgbc.org/what-green-building.

Additional objectives may also be considered in the design of high-performance buildings, including aesthetics and historical preservation.[12]

The "Energy Independence and Security Act of 2007" (EISA) further refined the concept by establishing a detailed definition for *high-performance green buildings* (see "Definitions of Green Building," above).

Elements of Green Building

Descriptions of green building generally focus on specified elements, which in various documents may also be referred to by other terms such as attributes, life-cycle parameters, performance areas, or impact categories. Commonly cited elements are energy, water, materials, waste, and health.[13] Another is siting, particularly with respect to transportation, ecology, and smart growth.[14] The siting element has increased in prominence over the last several years as more attention has focused on the built environment beyond the building itself.

Most descriptions do not explicitly include a serviceability, productivity, or functionality element, but that may be because those would be commonly expected to be integral elements of any building design. However, they are included explicitly among the objectives for high-performance buildings, which may also consider such others as disaster and climate resilience. These objectives have risen in prominence in the wake of a number of high-profile natural disasters, including Hurricanes Katrina and Sandy, and the 2011 earthquake and tsunami that initiated the Fukushima Daiichi nuclear meltdown.[15]

The goals of a given green building project may vary depending on the needs of the stakeholders, including a building's expected occupants. As a result, different elements may be prioritized in different projects (see "Net-Zero Buildings," below). Local factors such as climate zone and flood risk may influence the design process in ways that affect the relative emphasis placed on the various elements discussed below.

[12] Dan Prowler and Stephanie Vierra, "Whole Building Design," *Whole Building Design Guide*, August 17, 2017, http://www.wbdg.org/resources/whole-building-design.

[13] Different sources may emphasize different factors. For example, the Environmental Protection Agency (EPA) lists the following components: energy efficiency and renewable energy, water efficiency, environmentally preferable building materials and specifications, waste and toxics reduction, indoor air quality, and smart growth and sustainable development (Environmental Protection Agency, "Components of Green Building," February 20, 2016, https://archive.epa.gov/greenbuilding/web/html/components.html). The Living Future Institute has developed the "Living Building Certification" with seven "performance areas": place, energy, materials, water, health and happiness, equity, and beauty (International Living Future Institute, "Living Building Challenge," 2017, https://living-future.org/lbc/).

[14] Smart growth is defined differently by different organizations, but the various definitions have in common a set of planning strategies aimed at managing growth to improve livability and economic viability while reducing environmental impact. For a detailed discussion, see Environmental Protection Agency, "Our Built and Natural Environments, A Technical Review of the Interactions Among Land Use, Transportation, and Environmental Quality, Second Edition," June 2013, https://www.epa.gov/smartgrowth/our-built-and-natural-environments.

[15] PwC, "Rebuilding for Resilience: Fortifying Infrastructure to Withstand Disaster," September 2013, https://www.pwc.com/gx/en/psrc/publications/assets/pwc-rebuilding-for-resilience-fortifying-infrastructure-to-withstand-disaster.pdf.

Energy

A reduced energy footprint is probably the most widely cited element of green building.[16] Techniques include

- energy efficiency and conservation,[17] through such means as energy-efficient appliances and lighting, weatherization, and daylighting;[18]
- use of alternative, renewable sources of energy, such as solar or geothermal power or combustion of biomass;
- utilization of energy storage technologies, often in combination with on-site renewable energy generation; and
- participation in smart-grid innovations such as demand-response programs.[19]

Energy is widely considered a crucial element because of the economic costs and environmental impacts associated with energy use. A 2010 study by the National Academies found the potential energy savings from widespread deployment of energy efficiency measures to be significantly higher for buildings than for transportation and industry.[20] In a 2015 report on energy technologies, the Department of Energy estimated that buildings using the best available energy efficiency technologies would consume about half as much energy on average as those in the current building stock.[21]

Federal law sets numeric requirements for reductions in energy use by federal buildings.[22] The energy intensity[23] of such buildings declined by more than 22% from 2003 to 2015. Nevertheless, 2015 consumption exceeded the federal goal.[24]

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[16] See, for example, Government Accountability Office, "Green Building: Federal Initiatives for the Nonfederal Sector Could Benefit from More Interagency Collaboration," GAO-12-79, (November 2, 2011), http://www.gao.gov/products/GAO-12-79; Alex Lukachko and Joseph W. Lstiburek, "Towards Sustainability—Green Building, Sustainability Objectives, and Building America Whole House Systems," Research Report (Building Science Corporation, February 8, 2008), https://buildingscience.com/documents/bareports/ba-0801-towards-sustainability-green-building-sustainability-objectives-and-building-america-whole-house-systems-research/view. This report compared the different emphases among several national green building programs for residences. It found that energy efficiency was the only issue that was a primary focus for all, with indoor environmental quality the next most important.

[17] Energy efficiency means using less energy to perform the same function, whereas energy conservation refers to practices that reduce consumption, often by changing behavior. Using a lightbulb that produces the same amount of light with less energy would be an example of energy efficiency, while turning off the light when leaving a room would be an example of energy conservation.

[18] Daylighting refers to the practice of designing windows and skylights to utilize sunlight for indoor lighting needs.

[19] See the textbox on Smart Buildings and the Internet of Things for more on demand-response and building smart-grid integration.

[20] National Research Council, *Real Prospects for Energy Efficiency in the United States* (Washington, DC: National Academies Press, 2010), doi:10.17226/12621.

[21] Department of Energy, "Quadrennial Technology Review: An Assessmnet of Energy Technologies and Research Opportunities," September 2015, https://energy.gov/sites/prod/files/2017/03/f34/quadrennial-technology-review-2015_1.pdf.

[22] See the section on "Legislative and Policy Framework" below.

[23] Building energy intensity is measured in British thermal units (Btu) per gross square foot.

[24] Chris Tremper, "Federal Progress Toward Facility Energy/Sustainability Goals" (Department of Energy, June 30, 2017), https://energy.gov/sites/prod/files/2017/06/f35/fy16_facility_sustainability_goals.pdf. The energy intensity in FY2015 was 98,408 BTU per gross square foot (GSF), compared to a goal of 89,163 BTU per GSF, which would represent a 30% reduction over 2003 levels.

Net-Zero Buildings

A Net-Zero Energy Building (NZEB) meets all of its energy consumption requirements through a combination of energy efficiency and the use of onsite renewable energy sources such as wind, biofuels, and geothermal power. NZEBs may sometimes rely on delivered energy from an energy network such as the electricity grid, but they produce and export enough renewable energy to the network to fully offset what they draw from it. A net-zero performance target is much more stringent than the "better-than-average" or point-based goals of most green building rating systems and standards. An even more ambitious target is net-positive energy, which requires producing more energy on site from renewable energy than is used during the course of a year. Note, however, that an NZEB need not be highly energy-efficient, provided that it produces enough energy to compensate for what it uses,

"Getting to zero" on energy has been a goal of governments, professional organizations, and other stakeholders since the mid-2000s. The Energy Independence and Security Act of 2007 (EISA, P.L. 110-140) directed the Department of Energy to establish an initiative to develop net-zero energy commercial buildings, with the goal of having achieved net-zero energy in all U.S. commercial buildings by 2050. Prominent organizations promoting net-zero building efforts include the Department of Energy (DOE), its National Renewable Energy Laboratory (NREL), the National Institute of Standards and Technology (NIST) of the Department of Commerce, and nongovernmental entities such as ASHRAE, the New Buildings Institute, the National Institute of Building Sciences, and the Living Futures Institute.

The concept of net zero has also been applied to other resource areas, as in net-zero water and net-zero waste buildings. Executive Order 13693 directed federal agencies to design all new buildings greater than 5,000 gross square feet to be net-zero energy, and, where feasible, net-zero water or waste by FY2030. Net-zero water buildings are designed to reduce overall water use; maximize alternative sources of water, such as harvested rainwater, grey water, and reclaimed water; and safely return the balance of all nonalternative water to its original aquafer or watershed. Net-zero waste buildings are designed to reduce, reuse, recycle, compost, or recover waste streams, resulting in zero solid waste sent to landfills.

The overall market for net zero buildings is small but growing. According to reports by the New Buildings Institute, 332 NZEB projects were completed or underway in 2016, up from 60 in 2012. Challenges to implementing net-zero energy include costs, gaps in data and measurement science, and potential trade-offs with indoor air quality associated with some energy-efficiency techniques. A major focus of NIST's Net-Zero Energy Residential Test Facility is demonstrating that extreme energy efficiency can be achieved without compromising indoor air quality as long as both elements are thoughtfully integrated into the building's design. A net-zero building is not necessarily a green building: It may not require environmental design or performance in element areas other than the one specifically being targeted. Over time, zero-performance targets in multiple performance areas may become incorporated into green building criteria.

Sources: General Services Administration, Sustainable Facilities Tool, "Net Zero Energy," 2017, https://sftool.gov/plan/420/net-energy; Department of Energy, "Net Zero Water Building Strategies," 2017, https://energy.gov/eere/femp/net-zero-water-building-strategies; Paul Hernandez, "Net-Zero Energy Residential Test Facility (NZERTF)," NIST, June 1, 2016, https://www.nist.gov/el/net-zero-energy-residential-test-facility; Kent Peterson, Paul Torcellini, and Roger Grant, "A Common Definition for Zero Energy Buildings" (Department of Energy, September 2015), https://energy.gov/sites/prod/files/2015/09/f26/bto_common_definition_zero_energy_buildings_093015.pdf; Berkeley Analytical Associates LLC, Bernheim + Dean, and White + GreenSpec, "High Performance Indoor Air Quality Specification for Net Zero Energy Homes" (National Institute of Standards and Technology, February 2015), http://nvlpubs.nist.gov/nistpubs/gcr/2015/NIST.GCR.14-980.pdf.

Given its importance, energy is sometimes mistakenly treated as the predominant or even the sole element to be considered in green building. However, while a green building almost always addresses the energy element, a building that focuses solely on energy may not be a green building: It could have other environmental impacts that outweigh any benefits from its reduced use of energy.[25]

[25] For an example of other impacts potentially outweighing savings from energy efficiency, see Alex Wilson and Rachel Navaro, "Driving to Green Buildings.," *Environmental Building News* 16, no. 9 (2007): 1–18, http://search.ebscohost.com/login.aspx?direct=true&db=eih&AN=26824144&site=ehost-live.

Some energy-efficiency measures may also negatively impact indoor air quality (see "Net-Zero Buildings").

Water

Reducing water usage in buildings can provide cost savings. It can also aid management of water resources, especially in arid areas and in response to periodic drought elsewhere.[26] Reductions can be achieved through such measures as reduced-flow plumbing fixtures,[27] recycling of wastewater,[28] and landscaping designed to reduce irrigation requirements.

Water management may also include how the building and associated land handle rain, on-site water, and run-off. Development designed to ensure that the way a site handles water is similar to how it did so before development is called *low-impact development,* which "uses natural and engineered infiltration and storage techniques to control stormwater where it is generated."[29] Among the methods used are reduction in impervious surfaces through landscaping, use of porous materials and green roofs, and use of holding ponds, swales, rain gardens, and similar measures. Such techniques for water management are sometimes referred to collectively as *green infrastructure* (see the section on "Environmental Protection Agency").

Materials

The materials used in a building, during both construction and operations, can contribute substantially to the building's environmental footprint. The choice and use of materials affects resource depletion, pollution, embodied energy,[30] and health. "Environmentally preferable" or "green-labelled" products can reduce the impact. Such materials may have significant recycled content, be made from renewable biological resources (so-called "biobased" products), or be created with processes that use low amounts of energy and produce low amounts of pollutants.[31] They may also be designed to reduce health risks such as those from formaldehyde and other volatile organic compounds (VOCs).

There is some debate about what constitutes an environmentally preferable material. The lack of a consistent vocabulary for describing the sustainability attributes of materials, as well as inconsistencies in the measurement methodologies and reporting frameworks used by various

[26] See CRS Report R43407, *Drought in the United States: Causes and Current Understanding*, by (name redacted) and (name redacted).

[27] Federal manufacturing standards for certain plumbing products were established by the Energy Policy Act of 1992 (P.L. 102-486).

[28] Much wastewater from buildings can be reused in other applications on site, although some treatment may be required or preferred. For example, grey water, which is residential wastewater from sources other than kitchens and toilets, can be reused for irrigation and in toilets.

[29] Anne Guillette, "Low Impact Development Technologies," *Whole Building Design Guide*, November 3, 2016, http://www.wbdg.org/resources/low-impact-development-technologies. Low-impact building is sometimes used as a synonym for low-impact development and sometimes as a synonym for green or sustainable building.

[30] *Embodied energy* can be defined as "the sum of the energy requirements associated, directly or indirectly, with the delivery of a good or service."" (Cutler J. Cleveland and Christopher Morris, eds., *Dictionary of Energy*, Second Edition [Amsterdam: Elsevier, 2014]). For a discussion of the term in the context of building construction, see Ben McAlinden, "Embodied Energy and Carbon," *Institution of Civil Engineers (ICE)*, May 15, 2015, https://www.ice.org.uk/knowledge-and-resources/briefing-sheet/embodied-energy-and-carbon.

[31] Some federal agencies have developed guidance for obtaining such products (see, for example, Environmental Protection Agency, "Sustainable Marketplace: Greener Products and Services," March 9, 2017, https://www.epa.gov/greenerproducts; General Services Administration, Sustainable Facilities Tool, "Green Procurement Compilation," 2017, https://sftool.gov/greenprocurement; U.S. Department of Agriculture, "BioPreferred," 2017, https://www.biopreferred.gov/BioPreferred/).

eco-labelling systems, can make it difficult to determine whether a given material is preferable to a substitute.[32]

Waste

The environmental impacts from a building's waste stream over its life cycle can be mitigated by waste-reduction efforts, which fall broadly into four main categories: source reduction, reuse, recycling, and waste-to-energy.[33] The waste from standard demolition and construction processes can be reduced through more efficient use of materials (source reduction) and recycling or reuse of waste products.[34] Landscaping can be planned to reduce or eliminate chemical pollutants from grounds maintenance and to recycle waste such as lawn clippings through mulching and composting. High-efficiency boilers and furnaces can reduce the production of many atmospheric pollutants. Operational solid waste such as paper and foodstuffs can be recycled or otherwise processed to reduce their environmental impact.

Health

Several factors can influence the health impacts of buildings. For some, the health effects are obvious, such as the presence of indoor air pollutants like mold, radon, carbon monoxide, asbestos, and VOCs. Indoor air quality (IAQ) has a significant impact on occupant health, given that most people tend to spend a large percentage of each day indoors. Primary techniques for maintaining high IAQ include ensuring adequate ventilation; providing air filtration; and using materials without heavy metals, VOCs, asbestos,[35] or other potentially toxic substances. Overall indoor environmental quality (IEQ) includes, in addition to IAQ, factors such as lighting, climate control, acoustics, and ergonomic design; those may also have significant impacts on the health of building occupants.[36]

Siting

Where a building is situated can have significant effects on its environmental footprint.[37] For example, siting of buildings near transportation hubs can facilitate the use of public transportation

[32] Jorge L. Contreras, Meghan Lewis, and Hannah Roth, "Toward a Rational Framework for Sustainable Building Materials Standards," *Standards Engineering* 63, no. 5 (September 2011), https://www.researchgate.net/profile/Jorge_Contreras12/publication/228311359_Toward_a_Rational_Framework_for_Sustainable_Building_Materials_Standards/links/576bdd1908aead4e3adcfd2c.pdf. See also "Programs and Activities of Selected Federal Agencies" for a discussion of some of the federal programs aimed at developing standards for, and facilitating the procurement of, environmentally-preferable materials.

[33] Waste-to-energy refers to the recovery of useable forms of energy from waste materials through processes such as combustion, gasification, and others. EPA ranks waste management strategies from most to least preferred as follows: source reduction and reuse, recycling/composting, energy recovery/waste-to-energy, and treatment and disposal (Environmental Protection Agency, "Sustainable Materials Management: Non-Hazardous Materials and Waste Management Hierarchy," August 10, 2017, https://www.epa.gov/smm/sustainable-materials-management-non-hazardous-materials-and-waste-management-hierarchy).

[34] Environmental Protection Agency, "Sustainable Management of Construction and Demolition Materials," June 30, 2017, https://www.epa.gov/smm/sustainable-management-construction-and-demolition-materials.

[35] Asbestos is present in many older buildings and is still used in some construction materials (Environmental Protection Agency, "Learn About Asbestos," December 19, 2016, https://www.epa.gov/asbestos/learn-about-asbestos).

[36] General Services Administration, Sustainable Facilities Tool, "Indoor Environmental Quality (IEQ)," 2017, https://sftool.gov/learn/about/1/indoor-environmental-quality-ieq.

[37] The WBDG Sustainable Committee, "Optimize Site Potential," *Whole Building Design Guide*, May 18, 2017, http://www.wbdg.org/design-objectives/sustainable/optimize-site-potential.

and reduce impacts from private automobiles. Site selection may also take into account the ecological sensitivity of potential sites, to minimize adverse impacts on ecological services[38] and native species of plants and animals. The orientation of building axes and surfaces, and the building's proximity to trees and other plantings, affect its heating and cooling requirements. Climate-related risk factors may also be incorporated into siting decisions. Risks from sea-level rise, flooding, and extreme weather events, all of which may be affected by climate change, are of increasing concern to builders, particularly in coastal areas.[39]

Serviceability

A building that is not useful to its occupants is unlikely to be worth its cost, no matter how small its environmental footprint. Therefore, productivity and other measures of utility comprise an important element of green building that is not always discussed. A large percentage of U.S. workers spend their days in offices, and studies have suggested that IEQ strongly influences worker comfort and productivity.[40]

There is some evidence that green buildings can lead to improved productivity among occupants.[41] However, that is not always the case. For example, poor acoustic performance has been repeatedly observed in certified green buildings, suggesting that trade-offs do sometimes occur between serviceability and other elements. While serviceability is not generally considered as a separate element in green-building design, it is explicitly identified as an objective for high-performance buildings and has received increasing attention in green certification systems.[42]

Resilience

Resistance to hazards such as earthquakes, hurricanes, flooding, subsidence, and forest fires can increase the useful life of a building and permit it to function when services such as transportation and utilities are not available. Approaches to resilience include such practices as resistant construction; locating critical mechanical components on upper levels away from potential flood waters; on-site power generation, such as through photovoltaic and wind-turbine technology; rainwater harvesting; and water recycling capabilities. An increasing emphasis has been placed on climate-resilient design, defined in Executive Order 13693 as assets designed to "prepare for,

[38] Potential sites may provide services before development such as air and water purification, erosion control, recreation, and habitat for beneficial plants, animals, and microorganisms. Site development using standard design and construction practices can severely reduce such services.

[39] For a discussion of how sea-level rise impacts coastal development, see CRS Report R44632, *Sea-Level Rise and U.S. Coasts: Science and Policy Considerations*, by (name redacted) and (name redacted). For a discussion of coastal resilience to flooding, see CRS In Focus IF10225, *Coastal Flood Resilience: Policy, Roles, and Funds*, by (name redacted), (name redacted), and (name redacted). For a discussion of climate-change science and impacts, see CRS Report R43229, *Climate Change Science: Key Points*, by (name redacted).

[40] Yousef Al Horr et al., "Occupant Productivity and Office Indoor Environment Quality: A Review of the Literature," *Building and Environment* 105 (August 2016): 369–89, doi:10.1016/j.buildenv.2016.06.001.

[41] Greg Kats et al., "The Costs and Financial Benefits of Green Buildings: A Report to California's Sustainable Building Task Force" (Sustainable Building Task Force, October 2003), http://evanmills.lbl.gov/pubs/pdf/green_buildings.pdf; and Piers MacNaughton et al., "The Impact of Working in a Green Certified Building on Cognitive Function and Health," *Building and Environment* 114 (March 1, 2017): 178–86, doi:10.1016/j.buildenv.2016.11.041.

[42] See, for example, Taryn Holowka, "Indoor Environmental Quality and LEED V4," *U.S. Green Building Council*, August 15, 2017, https://www.usgbc.org/articles/indoor-environmental-quality-and-leed-v4.

withstand, respond to, or quickly recover from disruptions due to severe weather events and climate change for the intended life of the asset."[43]

Integration

One of the most salient features of green building is integration. The green building approach considers integration across (1) elements, in order to improve performance in multiple impact areas, and (2) stages, in order to minimize environmental impacts throughout the building's lifecycle.[44]

This approach, with its focus on the whole building (see "Whole Building Design Guide," below), can lead to better assessment of the overall environmental impact of a building. It also permits explicit assessment of and balance among potentially competing goals, and it allows planners to examine how different elements and stages interact and to develop an integrated strategy. Integration and performance with respect to several elements can be enhanced by the appropriate use of information technology in building operations (see "Smart Buildings and the Internet of Things," below).[45]

Balance Among Elements

A focus on one element at the expense of others can be counterproductive. For example, energy efficiency can be improved by sealing the building envelope to prevent conditioned air from escaping. But an absence of air exchange can result in increased concentration of pollutants in the building and can impede moisture control, fostering the development of mold and deterioration of building materials.[46] Addressing both energy efficiency and health requires either a compromise or technologies such as active ventilation with heat exchange. A green building approach reduces the risk of unanticipated problems by forcing an examination of how actions affecting each element impact others, so that an overall optimization can be achieved. Nevertheless, in some cases, such as many renovations, only one or a few factors might be feasible to address. In other cases, it may make sense to prioritize certain elements at the expense of others due to cost or feasibility constraints, local environmental factors, or occupant priorities.

Balance Across Stages

A focus on only one stage in the life cycle of a building can lead to savings at that stage but losses at another. For example, in the absence of sufficient data on the environmental impacts of developing, manufacturing, installing, using, and eventually disposing of alternative building materials, a choice that appears to be environmentally sound may in fact not be. Use of concrete walls provides more insulation on average than use of wood, but has much higher net emissions of carbon dioxide over its life cycle.[47] Far more energy is used in operating a building than in

[43] Executive Order 13693, "Planning for Federal Sustainability in the Next Decade," *Federal Register* 80, no. 57 (March 25, 2015): 15871–84, https://www.gpo.gov/fdsys/pkg/FR-2015-03-25/pdf/2015-07016.pdf.

[44] This is called a *cradle-to-grave* approach.

[45] See also, ASHRAE, "An Introduction to Building Information Modeling (BIM): A Guide for ASHRAE Members," November 3, 2009, http://cms.ashrae.biz/bim/pdf/BIMGuide_Rev_110309.pdf.

[46] See, for example, the documents available at Building Science Corporation, "Building Science Digests," 2017, https://buildingscience.com/document-search?term=&field_doc_topic_tid=All&type%5B%5D=7. Note that inadequate sealing of a building envelope may also permit external pollutants to enter a building and may compromise moisture control, depending on climate and other factors.

[47] Tables 1.6.2 and 1.6.3 in Department of Energy, "2011 Buildings Energy Data Book," March 2012, (continued...)

constructing one,[48] however, so choices made during construction may need to be balanced with planning for the postoccupancy stage. A green building approach can reduce such problems by facilitating an assessment of the impact from actions at one stage on all the others.

Smart Buildings and the Internet of Things

Increasingly, green building design is incorporating Internet-connected technologies. The spread of Internet access and falling prices for web-enabled technologies have given rise to what has become known as the "Internet of Things" (IoT). The term refers to networks of "smart" objects that communicate with each other and with computers through the Internet. A smart object is any noncomputer device with a unique identifier and Internet connectivity. The IoT and smart technologies have impacted the operations of sectors, such as manufacturing, transportation, energy, and government services. In a buildings context, IoT has led to the development of a new generation of "smart buildings."

There is no universally agreed-upon definition for a smart building, but such buildings usually incorporate resource monitoring, data analytics, and, in some cases, automation to manage building operations more efficiently. More than 80% of the energy used by a building throughout its life, from construction to demolition, is associated with operations. Examples of smart building technologies that target environmental performance include networked energy and water meters, connected thermostats, and automated leak and fault-detection sensors, all of which can be used in concert to optimize a building's resource use. Building systems may also be networked with the electricity grid, water infrastructure, and waste collection systems to leverage operational efficiencies at the neighborhood or city scale. For instance, buildings can monitor and respond to real-time electricity pricing signals from the grid to shift consumption to periods of low demand and high supply. This is known as demand-response, and it can be used by smart grids to reduce the use of inefficient power plants during periods of peak demand, increasing efficiency and minimizing overall emissions of pollutants.

Integration of the IoT with buildings raises some concerns related to privacy and security. IoT devices are potentially vulnerable to exploitation from hackers, who may use them to access sensitive information through their connection to a building's network, or to influence building operations, such as by turning lights, HVAC, or security systems on or off. From an environmental perspective, IoT devices may also increase the overall number of energy-drawing objects in the building. That increase may reduce or even negate savings from measures to optimize building energy use. Smart building technologies and networked resource management solutions are still evolving, however, and will likely revolutionize building operations in the long run.

Sources: CRS Report R44227, *The Internet of Things: Frequently Asked Questions*, by (name redacted); National Institute of Standards and Technology, "Embedded Intelligence in Buildings Program," July 17, 2017, https://www.nist.gov/programs-projects/embedded-intelligence-buildings-program; Jim Sinopoli, "Smart Controls," Whole Building Design Guide, August 15, 2016, https://www.wbdg.org/resources/smart-controls.

Interdependence

Many elements are also clearly interdependent. For example, use of environmentally preferable products can affect occupant health, which in turn can affect productivity. A building with on-site renewable energy generation may be well-prepared to function during periods when power is unavailable from utilities, such as after a natural disaster. On-site stormwater management can facilitate the provision of ecological services.

(...continued)

http://en.openei.org/doe-opendata/dataset/6aaf0248-bc4e-4a33-9735-2babe4aef2a5/resource/3edf59d2-32be-458b-bd4c-796b3e14bc65/download/2011bedb.pdf. The embodied energy also tends to be higher for concrete.

[48] National Institute of Standards and Technology, "Embedded Intelligence in Buildings Program," July 17, 2017, https://www.nist.gov/programs-projects/embedded-intelligence-buildings-program.

Green Certifications and Standards

Formal systems and tools have been developed over the last few decades that set criteria for green and sustainable buildings and methods for assessing whether new construction or renovation projects meet those criteria. The systems and tools fall into one or more of four main categories: rating systems, certifications, standards, and codes.

Green Rating Systems and Certifications

Given the range and interconnections of elements involved, determining whether a building is green or sustainable is not straightforward—there is no simple metric for determining how well a building meets the desired criteria. To address this problem, in the 1990s, some professional organizations in the building sector developed rating and certification systems that helped to standardize and define green building practices and raised public awareness of them.

The term *rating system* is often used interchangeably with *certification system*, although they refer to somewhat different concepts. Many systems, such as the well-known Leadership in Energy and Environmental Design (LEED), combine both rating and certification into a single system.

Rating systems assign points to buildings for meeting established criteria in various green building design categories. That results in an overall score and, often, assignment to one of a number of ranked tiers indicating the level of rigor of the criteria a building attains.

Certification provides validation that a building meets or exceeds specified design or performance requirements. It is arguably most objective when an independent entity conducts the assessment and awards the certification. Such a *third party* must be independent of the builder, contractor, and designer, as well as the organization that developed the rating system or standard.[49]

A handful of organizations currently offer rating and certification for green buildings. By far the most prevalent certification system within the United States is LEED, developed by the U.S. Green Building Council (USGBC). When it launched in 1998, LEED was among the first voluntary, consensus-based certification systems in the United States. It quickly became widely recognized as a benchmark for green building design.[50] The number of LEED certifications has increased annually since the first certification was awarded in 2000.[51] As of April 2017, more than 37,300 commercial buildings had been certified by LEED worldwide.[52] USGBC has also expanded the categories of building certifications offered to include new commercial construction, existing buildings, building interiors, homes, schools, retail, healthcare, whole neighborhoods, and others (see textbox on "Special-Use Buildings"). Certification is also

[49] Stephanie Vierra, "Green Building Standards and Certification Systems," *Whole Building Design Guide*, December 9, 2016, https://www.wbdg.org/resources/green-building-standards-and-certification-systems; Contreras, Lewis, and Roth, "Toward a Rational Framework for Sustainable Building Materials Standards."

[50] Jenny Richards, "Green Building: A Retrospective History of LEED Certification" (Institute for Environmental Entrepreneurship, November 2012), http://enviroinstitute.org/wp-content/uploads/2012/09/GREEN-BUILDING-A-Retrospective-History-of-LEED-Certification-November-2012.pdf.

[51] U.S. Green Building Council, "Country Market Brief," May 15, 2017, http://www.usgbc.org/advocacy/country-market-brief.

[52] U.S. Green Building Council, "About LEED," July 2017, https://www.usgbc.org/articles/about-leed.

available for operations and maintenance of existing buildings (including buildings first certified when new), with a five-year recertification cycle.[53]

LEED focuses primarily on six green building elements: location and transportation, sustainable sites, water efficiency, energy and atmosphere, materials and resources, and indoor environmental quality.[54] It also has credit categories for innovation and for regional priority, which considers specific factors of importance to sustainability within a specified region.

Special-Use Buildings

Specialized buildings such as schools, hospitals, and data centers have unique mission requirements that pose green-building challenges. They may also have very different resource-use patterns from the average commercial building. As a result, different categories of special-use buildings require green-building design and construction that is tailored to fit their particular needs and priorities.

Hospitals, for example, are complex to design and must meet substantial regulatory requirements, even before sustainability is taken into account. They are among the most resource-intensive buildings, consuming almost three times as much energy per square foot as a typical office building and posing unique challenges to other elements of green building such as air quality. Hospitals thus offer substantial opportunities for environmental performance improvements, but these must be achieved without compromising their primary mission of improving healthcare outcomes for patients. Some green techniques, such as daylighting and the use of nontoxic building materials, have obvious benefits for health and wellbeing that translate readily to a healthcare environment. It is unlikely, however, that a hospital will be able to achieve zero waste, given that hazardous and medical wastes are not as amenable to recycling or composting as the waste streams from most other building types. Furthermore, some energy and water conservation techniques may not be appropriate in a hospital setting, where water heating and flow rates must be tightly controlled for health and safety reasons. Similarly, scientific laboratories and data centers face trade-offs and challenges in implementing energy-saving features without compromising mission-driven building functions that rely on higher-than-average building energy consumption.

In recognition of such challenges, some rating systems and standards include guidance specifically tailored to specialized building types. LEED, for instance, offers new building certification specifically designed for schools, retail stores, healthcare buildings, data centers, hotels, and warehouses and distribution centers. Agencies such as the Environmental Protection Agency (EPA) and the Department of Energy (DOE) also offer programs aimed at integrating green building practices into the design of certain classes of special-use buildings.

Some agencies have reported challenges in complying with federal green building requirements due to the number of special-use buildings in their inventories. Executive Order 13693 requires 15% of existing federal buildings to be brought into compliance with the Guiding Principles by FY2025. DOE's large number of data centers, laboratories, and accelerators; EPA's scientific laboratories; and the VA's hospitals have all proven challenging to bring into compliance with the Guiding Principles.

Sources: Robert F. Carr and WBDG Health Care Subcommittee, "Health Care Facilities," *Whole Building Design Guide*, April 6, 2017, http://wbdg.org/building-types/health-care-facilities; Energy Information Administration, "2012 Commercial Buildings Energy Consumption Survey: Energy Usage Summary," March 18, 2016, https://www.eia.gov/consumption/commercial/reports/2012/energyusage/; World Health Organization, "Healthy Hospitals, Healthy Planet, Healthy People," Discussion Draft, (May 2009), http://www.who.int/globalchange/publications/climatefootprint_report.pdf; Government Accountability Office, "Federal Green Building: Federal Efforts and Third-Party Certification Help Agencies Implement Key Requirements, but Challenges Remain," GAO-15-667, (July 2015), http://www.gao.gov/assets/680/671618.pdf.

To be LEED-certified, a building must meet a set of mandatory basic requirements for most elements and must also receive a designated number of the total points that can be earned within each element from optional items. A building's total score determines its level of certification:

[53] U.S. Green Building Council, "O+M: Initial Certification or Recertification?," June 3, 2014, https://www.usgbc.org/articles/om-initial-certification-or-recertification.

[54] Brendan Owens et al., "LEED v4 Impact Category and Point Allocation Development Process" (U.S. Green Building Council, August 2013), https://www.usgbc.org/sites/default/files/LEED%20v4%20Impact%20Category%20and%20Point%20Allocation%20Process_Overview_0.pdf. These elements are related but not identical to those described in the section on "Elements of Green Building."

Certified, Silver, Gold, or Platinum. While this "checklist" approach has been criticized,[55] it permits comparatively simple assessment of compliance and can facilitate the kind of integrated consideration of elements that many observers regard as a hallmark of green building. The LEED rating system is updated periodically; the most recent version, LEED v4, was released in November of 2013.[56]

Other rating and certification systems in use in the United States include the following:[57]

- The Building Research Establishment Environmental Assessment Method (BREEAM) is a British system developed in 1990. Though BREEAM rating systems have been used internationally since then, only the BREEAM In-Use certification has been introduced in the United States, beginning in 2017.[58] BREEAM In-Use is an online rating system for existing commercial building performance. Unlike LEED, BREEAM In-Use has no prerequisites; any existing building can use it to benchmark performance and certify subsequent improvements. BREEAM ratings are Acceptable, Pass, Good, Very Good, Excellent, and Outstanding, which are signified by between one and six stars.[59] Rating levels are based on a building's score across nine impact categories: management, health and well-being, energy, transport, water, materials, waste, land use, and ecology and pollution. To remain valid, certifications must be renewed annually.
- Green Globes was developed in Canada by the Green Building Initiative. It is based on BREEAM, and has an associated standard (see "Green Building Codes and Standards"). A building may earn between one and four Globes based on the number of points earned out of a possible total of 1000.[60] Points are distributed across six elements—site, energy, water, materials and resources, emissions, and indoor environment—plus project management. Like BREEAM In-Use, Green Globes has no mandatory provisions or prerequisites that must be met before certification can be considered; certification and rating level are based solely on the number of points earned.
- The International Living Future Institute's Living Building Challenge[61] offers three certifications: Living Building Certification, Petal Certification, and Zero Energy Building Certification. Criteria for certification fall into seven performance areas, referred to as "Petals": place, water, energy, health and happiness, materials, equity, and beauty. Living Building Certification requires a building to meet requirements in all seven performance areas. Petal Certification requires compliance with no fewer than three of the seven Petals, one of which

[55] See, for example, Andrew J. Nelson and Ari Frankel, "Building Labels vs. Environmental Performance Metrics: Measuring What's Important about Building Sustainability" (RREEF Real Estate, October 2012), http://realestate.deutscheam.com/content/_media/Research_Sustainability_Metrics_in_the_Real_Estate_Sector-Oct_2012.pdf.

[56] For a list of changes in LEED v4, see U.S. Green Building Council, "LEED v4 User Guide," November 2014, https://kapost-files-prod.s3.amazonaws.com/published/54886ef033efbe406e00012a/ebook-leed-v4-user-guide.pdf.

[57] See also Vierra, "Green Building Standards and Certification Systems."

[58] BREEAM USA, "BREEAM USA Introduces BREEAM In-Use for Existing Buildings," 2017, http://www.breeamusa.com/how-it-works/what-is-breeam/.

[59] BREEAM USA, "Certification," 2017, http://www.breeamusa.com/certification/.

[60] Green Building Initiative, "How to Certify," 2014, https://www.thegbi.org/green-globes-certification/how-to-certify/.

[61] International Living Future Institute, "Living Building Challenge."

must be water, energy, or materials. Zero Energy Certification requires a building to generate all of its energy needs on site without using combustion. Unlike new-building certification under the other ratings systems, which occurs upon completion of construction, certification under the Living Building Challenge also requires a 12-month assessment of actual building performance.

Different ratings systems emphasize different aspects of green building. Therefore, whether one or another is more appropriate may depend on local conditions and priorities. Systems also differ in the types of buildings for which they offer guidelines and certification; some focus primarily on new construction, while others are more geared toward existing buildings.

In addition to the comprehensive green certification systems discussed above, some additional programs exist to certify that a building has taken steps to improve environmental performance for a single element or in a limited number of performance areas. These include Energy Star (energy-efficiency),[62] Indoor airPLUS (indoor air quality),[63] WaterSense (water efficiency),[64] Zero Energy Ready Home (energy and air quality),[65] and Passive House/ PHIUS+ (energy, water, and air quality).[66] In many cases, a building may be separately certified under more than one of those programs.

Energy Star

Energy Star is a voluntary labeling program established by EPA in 1992 under authority from the Clean Air Act. It is now a joint EPA/DOE program. It is designed to overcome market barriers to the adoption of energy-efficient products and services.

Residential: The agencies work with manufacturers to identify appliances and other products that are cost-effective and energy efficient. Products meeting the criteria receive an Energy Star label. The agencies provide information directly to consumers about the thousands of labeled products. Among the product categories included are office equipment, home electronics, heating and cooling (HVAC), appliances, lighting, and windows. The program has also partnered with builders to create Energy Star-qualified homes and with lenders to encourage the use of Energy-Efficient Mortgages and "green loans" to promote energy-efficient housing.

Commercial: More than 20 types of commercial and industrial facilities are eligible to earn an Energy Star label. In addition, EPA offers partnerships to businesses and other organizations that make top-level managerial commitments to adopt superior energy management. Partners continually assess energy use within their organizations and use an integrated approach in upgrading buildings. EPA provides standardized measurement tools and a recognition program to assist and promote these efforts. The Energy Efficiency Improvement Act of 2015 required EPA to develop Tenant Star to recognize commercial building tenants that voluntarily achieve high levels of energy efficiency.

Federal: EPACT 2005 requires federal agencies to purchase either Energy Star products or those designated as energy efficient by the Federal Energy Management Program (FEMP). EISA requires additionally that federal agencies lease only facilities with a recent Energy Star label.

Source: Environmental Protection Agency and Department of Energy, "Energy Star," 2017, https://www.energystar.gov/.

[62] Energy Star, "Buildings and Plants," 2017, https://www.energystar.gov/buildings.

[63] Environmental Protection Agency, "Indoor AirPLUS," June 9, 2017, https://www.epa.gov/indoorairplus.

[64] Environmental Protection Agency, "WaterSense," July 24, 2017, https://www.epa.gov/watersense.

[65] Department of Energy, "Zero Energy Ready Home," 2017, https://energy.gov/eere/buildings/zero-energy-ready-home.

[66] Passive House Alliance, "Passive House Institute US (PHIUS)," 2017, http://www.phius.org/home-page.

Federal Government Use of Certification Systems

Several federal statutes and policies impose green building requirements on federal offices and agencies,[67] and some agencies have been using third-party green building certification systems since the late 1990s. While no certification system meets all of the federal requirements for green buildings, the General Services Administration (GSA) has recommended that agencies use third-party green certification systems,[68] and some federal agencies have found the use of third-party certification systems to have benefits that include simplifying compliance with federal guidelines, reducing the need for additional staff, and providing a recognizable label to communicate sustainability efforts within the agency and to the public.[69] Several agencies have elected to establish internal policies on certification under one of the available rating systems.[70]

EISA required the Secretary of Energy, in consultation with GSA and the Department of Defense (DOD), to identify a third-party certification system and level that the Secretary "determines to be the most likely to encourage a comprehensive and environmentally-sound approach to certification of green buildings" (42 U.S.C. §6834(a)(3)(D)(i)(III)). The Secretary's recommendation is to be reviewed and updated every five years, taking into account the results of a study to be conducted by the Director of GSA's Office of Federal High-Performance Green Buildings, which was also established by EISA (42 U.S.C. §17092). As of 2013, GSA recommended that federal agencies use either LEED or Green Globes,[71] and that agencies using one of these systems should achieve either a LEED Silver rating or Two Globes under the Green Globes system for new construction and major renovation projects.

Instead of specifying a particular rating system, the 2014 Department of Energy rulemaking on green building certification sets out minimum criteria for a rating system to be eligible for use by federal agencies. Those agencies choosing to pursue third-party certification must choose a system that meets those criteria.[72]

In addition to federal policies, many states require green building certification or the equivalent for government buildings, and many cities or counties have such requirements for buildings in the commercial sector. Some jurisdictions also provide grants or tax incentives for some green building certifications.[73]

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[67] See the section on "Legislative and Policy Framework."

[68] Dan Tangherlini, Administrator, General Services Administration, "Letter to Ernest Moniz, Secretary of Energy," October 25, 2013, https://www.gsa.gov/portal/getMediaData?mediaId=180467.

[69] Government Accountability Office, "Federal Green Building: Federal Efforts and Third-Party Certification Help Agencies Implement Key Requirements, but Challenges Remain," GAO-15-667 (July 2015), http://www.gao.gov/assets/680/671618.pdf.

[70] Agencies that have adopted a green rating system include the Department of Defense, the Department of Energy, GSA, the Department of Veterans Affairs, the U.S. Department of Agriculture, and the Environmental Protection Agency. See ibid.; and U.S. Department of Agriculture, "2016 Strategic Sustainability Performance Plan," June 30, 2016, https://www.dm.usda.gov/emd/docs/USDA%202016%20Strategic%20Sustainability%20Performance%20Plan-updated.pdf.

[71] Dan Tangherlini, Administrator, General Services Administration, "Letter to Ernest Moniz, Secretary of Energy," October 25, 2013, https://www.gsa.gov/portal/getMediaData?mediaId=180467.

[72] 10 C.F.R. §433.300.

[73] Daniel C. Matisoff, Douglas S. Noonan, and Mallory E. Flowers, "Policy Monitor—Green Buildings: Economics and Policies," *Review of Environmental Economics and Policy* 10, no. 2 (July 2016): 329–46, doi:10.1093/reep/rew009.

Green Building Codes and Standards

Green building rating and certification systems have served as testbeds for objectives and practices that have subsequently been incorporated into model building codes and standards. Unlike rating and certification systems, building codes are often mandatory. While most standards are not themselves mandatory, they, along with model codes,[74] may be incorporated into mandatory codes or laws.[75] This section discusses comprehensive green building codes and standards that address multiple green building elements. Codes and standards dealing solely with energy efficiency are not discussed.[76]

Building codes specify minimum requirements for building design and construction. Historically, they have focused primarily on health and safety,[77] but they can cover many other aspects of a building's design or construction, from aesthetics to resource use. The "Energy Policy Act of 1992" (EPACT 1992) established a baseline for energy efficiency in building codes.[78] Beyond such federally mandated minimum requirements, it is left to state and local governments to determine the contents of the codes that regulate buildings within their jurisdictions. Rather than create and revise their own codes, however, many state and local jurisdictions adopt or modify national model codes generated by code development organizations.

Green building codes specify additional requirements for environmental design and performance that go beyond, and, in some cases, can be layered on top of existing building codes. They are occasionally referred to as "beyond-code" or "above-code" options, because they exceed minimum building code requirements. Governments adopting green building model codes can choose to make them mandatory or treat them as voluntary measures for meeting green building objectives.

Both model codes and mandatory building codes often incorporate technical standards for specific components or features. Those standards are created by recognized standards development organizations (SDOs). Some such organizations have used the standards-development process to create more general green building standards. The Whole Building Design Guide defines a standard as "a set of guidelines and criteria against which a product can be judged."[79] Just as a building may be certified under a rating system, a building that has achieved a given standard may be certified as having met the criteria of that standard.

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[74] Model codes are building codes prepared by groups of experts that have no legislative or rulemaking authority. Model codes gain the force of law when they are adopted as requirements by a jurisdiction (Melvyn Green, *Building Codes for Existing and Historic Buildings* [Hoboken, N.J: Wiley, 2012]).

[75] For example, the mandatory building code of the District of Columbia for construction, alteration, maintenance, and so forth includes by reference the International Building Code, a model code created by the International Code Council, and technical standards developed by organizations such as the American Society of Mechanical Engineers. See District of Columbia Government, "District of Columbia Construction Codes Supplement of 2013," May 2014, https://dcra.dc.gov/sites/default/files/dc/sites/dcra/publication/attachments/DCMR%2012_ConstructionCodes_2013.pdf.

[76] For more on energy codes, see Department of Energy, "Building Energy Codes Program," 2017, https://www.energycodes.gov/.

[77] The four primary risk areas historically regulated by building codes include fire safety, speed of exit, structural integrity, and general health and safety. See Green, Building Codes.

[78] For a history of the development of ASHRAE energy efficiency standards and their inclusion in U.S. law, see Gordon Holness, "Achieving Energy Performance—Going Beyond Codes and Standards," April 4, 2011, http://newbuildings.org/sites/default/files/Holness_Beyond_codes.pdf.

[79] Dan Prowler and Stephanie Vierra, "Whole Building Design," *Whole Building Design Guide*, August 17, 2017, http://www.wbdg.org/resources/whole-building-design. See text box "Whole Building Design Guide," below, for (continued...)

For both green building codes and standards, specific requirements may be achievable by multiple pathways. Prescriptive pathways specify the precise method of achieving a given requirement, whereas performance pathways allow designers flexibility in their methods provided that the projected or modelled end results meet the necessary requirements. A newer option is outcome-based requirements, which establish a performance target that must be met and verified through measurement and reporting after construction ends.

Green building standards are sometimes described as code-intended, indicating that they are written in mandatory, code-enforceable language, and may be adopted by jurisdictions, either as they are written or with modifications made by the adopting entity. Both codes and standards are developed through a consensus process that involves multiple stakeholders,[80] but SDOs typically require accreditation by a body such as the American National Standards Institute (ANSI), ensuring that their development process adheres to a set of approved procedures.[81] ANSI standards also require that certification be performed by a third party.

Whole Building Design Guide

The Whole Building Design Guide (WBDG) is a web-based portal providing information on an integrated approach to the design, construction, and operation of buildings. It is a collaboration among federal agencies and many private-sector and nonprofit organizations. It is hosted by the National Institute of Building Sciences

The site describes the goals of the approach as follows: "Whole Building Design provides the strategies to achieve a true high-performance building: one that is cost-effective over its entire life cycle, safe, secure, accessible, flexible, aesthetic, productive, and sustainable." The most relevant goal for green building is the last. The guide provides design guidance to federal agencies for all seven goals, as well as a broad range of information and resources to the federal government, the building industry, and the public.

The whole-building approach promoted by the site involves not only integrated design but also integration of the teams of people involved, including architects, owners, contractors, operators, community members, and other stakeholders. The portal provides tools and other resources to promote and facilitate such integration.

Sources: Dan Prowler and Stephanie Vierra, "Whole Building Design," *Whole Building Design Guide*, August 17, 2017, http://www.wbdg.org/resources/whole-building-design; Office of the Federal Environmental Executive, "The Federal Commitment to Green Building," 2003, https://archive.epa.gov/greenbuilding/web/pdf/fedcomm_greenbuild.pdf.

There are two main developers of national green building model codes and standards in the United States: the International Code Council (ICC) and ASHRAE.[82] Their efforts are discussed below.

The ICC is responsible for the development of a comprehensive family of integrated International Codes, covering a number of building sectors.[83] The ICC International Building Code (IBC) is

(...continued)

further information.

[80] The number and types of stakeholders involved in the consensus process differs between code developing organizations and standards setting organizations.

[81] American National Standards Institute, "ANSI Essential Requirements: Due Process Requirements for American National Standards," January 2017, https://share.ansi.org/shared%20documents/Standards%20Activities/American%20National%20Standards/Procedures,%20Guides,%20and%20Forms/2017_ANSI_Essential_Requirements.pdf.

[82] Melissa A. Beutler et al., eds., *Green Building and the Construction Lawyer: A Practical Guide to Transactional and Litigation Issues* (Chicago, Illinois: Forum on Construction Law, 2014). ASHRAE was formerly known as the American Society of Heating, Refrigerating and Air-Conditioning Engineers.

[83] ICC develops building codes through the ICC Governmental Consensus Process, which includes regulators in the code-development process. See International Code Council, "CP28-05—Code Development," December 11, 2015, https://cdn-web.iccsafe.org/wp-content/uploads/CP28-05.pdf.

widely used in the United States. In 2012 the ICC released the International Green Construction Code (IgCC),[84] described as "the first model code to include sustainability measures for the entire construction project and its site."[85]

The IgCC functions as an overlay code, meaning that it is fully compatible, and can be adopted in conjunction with, the full family of ICC codes governing building safety and other features. The most recent revision was released in 2015. Municipalities choosing to adopt the IgCC as an overlay may choose from among various compliance pathways and options in order to make the mandated requirements more or less strict, as well as to account for local climate and other pertinent factors.

The IgCC covers most building types, with the exception of low-rise residential buildings. The IgCC refers low-rise residential builders to the ICC 700 National Green Building Standard (NGBS), an ANSI standard developed in partnership with ASHRAE and the National Association of Homebuilders (NAHB). The NGBS is structured as a rating system, much like LEED, but can be adopted by ordinance, much like a model code.[86]

ASHRAE, USGBC, and the Illuminating Engineering Society of North America (IES) have also jointly released a high-performance green building standard for nonresidential buildings and residential buildings of more than three stories.[87] Known as Standard 189.1, it functions as a code-intended standard and is offered as a compliance option under the IgCC. The standard contains requirements in the following areas: site sustainability, energy efficiency and renewable energy, water-use efficiency, indoor environmental quality, and building impacts on the atmosphere, materials, and resources. Elements of Standard 189.1 have been incorporated into the building requirements for Department of Defense properties.[88]

In 2015, the ICC and ASHRAE announced a partnership to fully integrate Standard 189.1 to serve as the technical content of the 2018 version of the IgCC. The new code will also be aligned with the LEED rating system, providing the market with a streamlined set of beyond-code tools.[89] In addition to such national efforts, several state, local, and tribal authorities have developed their own green building codes.

Legislative and Policy Framework

Several federal laws, executive orders, and other policy instruments have provisions relating to green building. Selected relevant provisions are described below. However, the list presented in

[84] IgCC is developed in cooperation with the American Institute of Architects, ASTM International, ASHRAE, the Illuminating Engineering Society, and USGBC. The ICC has also developed the International Energy Conservation Code focused primarily on encouraging building energy efficiency.

[85] International Code Council, "Overview of the IgCC," 2017, https://www.iccsafe.org/codes-tech-support/codes/2015-i-codes/igcc/.

[86] National Association of Home Builders, "ICC 700 National Green Building Standard," 2017, https://www.nahb.org/en/research/nahb-priorities/green-building-remodeling-and-development/icc-700-national-green-building-standard.aspx.

[87] ASHRAE, "Standard 189.1-2014—Standard for the Design of High-Performance Green Buildings," 2014, http://www.techstreet.com/ashrae/standards/ashrae-189-1-2014?product_id=1886477.

[88] Department of Defense, "United Facilities Criteria: High Performance and Sustainable Building Requirements," UFC 1-200-02, (December 1, 2016), http://www.wbdg.org/FFC/DOD/UFC/ufc_1_200_02_2016.pdf.

[89] International Code Council, "ICC, ASHRAE Outline Roles to Consolidate IgCC and 189.1 in Response to Call from Industry" (Press Release, July 22, 2015), https://www.iccsafe.org/about-icc/periodicals-and-newsroom/icc-ashrae-outline-roles-to-consolidate-igcc-and-189-1-in-response-to-call-from-industry/.

this report is not exhaustive. For example, the Resource Conservation and Recovery Act of 1976 (RCRA), as amended (42 U.S.C. §6901 et seq.), requires agencies to procure products with recycled content. This report also does not include discussion of state and local policies, which have substantial influence on green building efforts within those jurisdictions.

Energy Policy Act of 1992

The Energy Policy Act of 1992 (P.L. 102-486), known as EPACT 1992, contained incentives and requirements relating to efficient use of energy and water in federal, commercial, and residential buildings. It included, among other matters, provisions relating to state building energy codes,[90] energy efficiency in federal buildings and public housing, a pilot program for mortgages for energy-efficient housing, the development of energy-efficient technologies, and energy and water efficiency requirements for appliances, plumbing fixtures, and building materials.

Energy Policy Act of 2005

Among other provisions, the Energy Policy Act of 2005 (P.L. 109-58), known as EPACT 2005, required the development of energy and water conservation programs for congressional buildings and a reduction in energy consumption by federal buildings of 20% (relative to 2003) by 2015;[91] promoted the procurement of energy-efficient products by federal agencies; established a testbed program for advanced building efficiency; set an energy consumption target for new federal buildings of 30% below existing standards; and required the application of sustainable-design principles to new and replacement federal buildings. It also continued authorization of DOE's weatherization assistance program.

The act set an improvement goal of 25% by 2012 from a 1990 base for state energy conservation plans. It also authorized funding for states to administer rebate programs for residential energy-efficient appliances, to assist local governments in improving energy efficiency in public buildings, and for other state activities, including incentives to states to establish building energy-efficiency codes that meet or exceed established standards.

It established the Energy Star labeling program as a joint program of DOE and EPA,[92] and established public information and education programs relating to energy conservation. It also set energy and water conservation standards for various specific products. The act requires agencies to purchase products that either have an Energy Star label or are designated as energy-efficient by the Department of Energy.[93]

EPACT 2005 set energy-efficiency standards for public housing and directed the Department of Housing and Urban Development to develop a strategy for energy conservation and efficiency. The act also provided various tax incentives to businesses and individuals for energy and water efficiency.

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[90] For a summary, see "National Legislation on Building Energy Codes," Table 7.3.5 in Department of Energy, "2008 Buildings Energy Data Book," November 2008, http://web.archive.org/web/20130215004243/http://buildingsdatabook.eren.doe.gov/docs/DataBooks/2008_BEDB_Updated.pdf. Most states now have energy codes, although specific requirements vary.

[91] This was later modified (see below).

[92] EPA began the program in 1992. See "Energy Star" textbox.

[93] The Department of Agriculture also administers a labeling and procurement program, for biobased products (https://www.biopreferred.gov/BioPreferred/). The program was established in the Farm Security and Rural Investment Act of 2002 (P.L. 107-171) and revised in the Food, Conservation and Energy Act of 2008 (P.L. 110-234).

Energy Independence and Security Act of 2007

The Energy Independence and Security Act of 2007 (P.L. 110-140), known as EISA, provided both a general legislative framework for federal green building efforts, including a definition of high-performance green building[94] (see "Definitions of Green Building," above), and specific actions and requirements. Titles III, IV, and V relate most specifically to green building.

Title III set efficiency standards for various appliances and electric lighting. It also required the use of energy-efficient lighting in facilities leased by GSA and further directed that such facilities adhere to energy efficiency and renewable energy requirements to be set by the agency.

Title IV has provisions relating to residential, commercial, federal, and certain other kinds of buildings:

Residential. The act increased funding for DOE's program to provide assistance to low-income families for weatherization of residences, to improve energy efficiency. It required a feasibility study by DOE of the unfunded state rebate programs for energy efficiency and renewable energy that EPACT 2005 had authorized. It also established energy-efficiency standards for manufactured housing such as mobile homes.

Commercial. The act required DOE to create an Office of Commercial High-Performance Green Buildings to facilitate the development of green commercial buildings, including zero-net-energy buildings, in partnership with other federal and with nonfederal entities.[95]

Federal. EISA increased the overall rate of required reduction in total energy consumption of federal buildings in each agency, from 20% (relative to 2003) to 30% by 2015. It set more stringent energy goals for new construction and major renovations, requiring them to reach a 65% reduction by 2015, and zero-net energy use by 2030; and it required the identification and use of a green building certification system for such structures.[96] It also set general water-conservation guidelines and stormwater runoff requirements for property development.

Agencies are required to ensure that new building equipment implementing the above measures is commissioned to be operating at design specifications, to plan for operations and maintenance of equipment, and to measure energy and water savings. Agencies were also directed to install advanced metering devices in federal buildings and to record and report energy use data for metered facilities into a building energy benchmarking system.

Federal buildings must undergo regular evaluations of energy and water use, with the Office of Management and Budget (OMB) issuing scorecards twice per year on agency performance in energy management. The life cycle over which energy costs are assessed was extended from 25 to 40 years. Any new major equipment installed must be energy efficient, and the act accelerated the use of energy-efficient lighting and other cost-saving technologies in GSA

[94] EPACT 2005 defined a high-performance building as "a building that integrates and optimizes all major high-performance building attributes, including energy efficiency, durability, life-cycle performance, and occupant productivity" (§914(a)). See also the definition in the "Whole Building Design Guide" textbox.

[95] DOE did not establish an office with that name but performs relevant activities through its Commercial Building Initiative. See Building Technologies Office, "Multi-Year Program Plan" (Department of Energy, January 2016), https://energy.gov/sites/prod/files/2016/02/f29/BTO_MYPP_2016.pdf.

[96] Prior to enactment of the law, the George W. Bush Administration criticized it for, among other things, not including "additional building attributes beyond the energy efficiency and water consumption goals" for high-performance green buildings (The White House, "H.R. 6 – Energy Independence and Security Act of 2007," Statement of Administration Policy.) Only the energy goals in the law are numeric.

facilities. Any buildings leased by a federal agency must have a recently earned Energy Star[97] label.

The act also established an Office of Federal High-Performance Green Buildings within GSA to coordinate and facilitate the development of such buildings in the federal sector. GAO is to perform audits of implementation of these requirements.

Other. The act contains provisions to facilitate the greening of schools, with emphasis on environmental health and energy efficiency. It also authorized energy-efficiency assistance for state and local public facilities and institutions of higher learning. It required the Department of Housing and Urban Development to use updated energy-efficiency standards for public and assisted housing. It also established green building research and demonstration projects through GSA, DOE, and EPA.

Title V contains energy-efficiency provisions relating to the U.S. Capitol complex, and amended provisions in law relating to energy savings performance contracts.[98] It also specified certain actions to promote energy efficiency at executive branch agencies and in the supply of electricity and natural gas by utilities, and for state and local governments to develop and implement strategies for energy efficiency and conservation.

Other relevant provisions in the law include authorization of research and development (R&D) relating to energy efficiency and renewable energy, and loans and other activities to help small businesses improve energy efficiency.

American Recovery and Reinvestment Act of 2009

The American Recovery and Reinvestment Act of 2009 (P.L. 111-5, ARRA) provided $4.5 billion to convert GSA facilities to high-performance green buildings. It also provided $250 million to the Department of Housing and Urban Development (HUD) for green retrofits of housing. It permitted states to use a portion of provided education funds for green renovations of public schools. It also provided funds to various agencies for energy-efficiency improvements to buildings.

Energy Efficiency Improvement Act of 2015

The Energy Efficiency Improvement Act of 2015 (P.L. 114-11) directs GSA to develop model leasing provisions to encourage the implementation of energy and water efficiency measures by tenants in commercial buildings. GSA may use those provisions for leases involving federal agencies, and it must make them available to state and local governments for their own use. The act also amended EISA to add provisions regarding improving energy efficiency in tenant spaces. These include directing DOE to study the feasibility of improving energy efficiency in commercial buildings through the implementation of energy-efficiency measures in discreet spaces within those buildings; directing the DOE's Energy Information Administration to collect additional occupant energy-use information as part of its Commercial Buildings Energy Consumption Surveys; and directing EPA to develop a Tenant Star recognition label as a part of the Energy Star program.

[97] Energy Star is a joint program of EPA and DOE (http://www.energystar.gov; see "Energy Star" textbox).

[98] Department of Energy, "Energy Savings Performance Contracting," 2017, https://energy.gov/eere/slsc/energy-savings-performance-contracting.

The act also contains provisions related to the establishment of energy conservation standards for grid-enabled water heaters used as energy storage or demand-response assets, and energy efficiency benchmarking requirements for federal agencies leasing space in buildings without an Energy Star label. DOE is also directed to study the impact of state and local performance benchmarking policies on commercial and multifamily buildings and maintain a public database of energy-related information on such buildings.

Executive Order 13693

In 2015, President Obama signed Executive Order (E.O.) 13693, *Planning for Federal Sustainability in the Next Decade*.[99] The order revoked and replaced previous Executive Orders 13423 and 13514, which established green building as a key component of federal efforts to reduce environmental impacts, improve resource use efficiency, and lower operating costs at federal facilities.[100] E.O. 13693 expanded upon the sustainability goals of the previous orders and set new targets for federal agencies to achieve by FY2025. Targets include requiring each agency to reduce building energy intensity by 2.5% annually relative to FY2015, reduce potable water consumption intensity by 36% relative to FY2007, produce at minimum 25% of total building electric and thermal energy from clean sources,[101] and ensure that all new buildings with more than 5,000 gross square feet of floorspace are designed to achieve net-zero energy, and, if possible, net-zero water or waste by FY2030. The order also called for the inclusion of climate-resilient design elements in federal buildings, and directed the Chair of the Council on Environmental Quality (CEQ) to issue revised "Guiding Principles for Federal Leadership in High Performance Sustainable Buildings." E.O. 13693 directed agencies to ensure that, for federal buildings of more than 5,000 square feet in area, all new ones and at least 15% (by FY2025) of existing ones comply with the Guiding Principles, with the ultimate goal of achieving compliance in the entire inventory.[102]

According to a GSA analysis, agency efforts to comply with E.O. 13693 led to an 18% increase in the number of federal sustainable buildings between FY2014 and FY2015.[103]

Guiding Principles for Federal Leadership in High Performance Sustainable Buildings

In 2006, representatives of 19 federal agencies and offices[104] signed a memorandum of understanding (MOU) titled "Federal Leadership in High Performance and Sustainable

[99] Executive Order 13693, "Planning for Federal Sustainability in the Next Decade."

[100] Executive Orders 13423 and 13514 were signed by Presidents George W. Bush and Barack Obama respectively. Both directed federal agencies to bring a portion of the federal real estate inventory into compliance with the "Guiding Principles for Federal Leadership in High Performance and Sustainable Building," among other provisions.

[101] Section 19 of E.O. 13693 defines "clean energy" as "renewable electric energy and alternative energy." "Alternative energy" is further defined as "energy generated from technologies and approaches that advance renewable heat sources, including biomass, solar thermal, geothermal, waste heat, and renewable combines heat and power processes; combined heat and power; small modular nuclear reactor technologies; fuel cell energy systems; and energy generation, where active capture and storage of carbon dioxide emissions associated with that energy generation is verified."

[102] E.O. 13693 stipulates that the Guiding Principles be applied where life-cycle cost effective.

[103] General Services Administration, "Summary of Fiscal Year 2015 Federal Real Property Profile Open Data Set," April 2016, https://www.gsa.gov/portal/getMediaData?mediaId=129426.

[104] Those agencies were the Departments of Agriculture, Commerce, Defense, Energy, the Interior, Health and Human Services, Homeland Security, Housing and Urban Development, Justice, Labor, State, Transportation, and Veterans Affairs; and the Council on Environmental Quality, the Environmental Protection Agency, the General Services (continued...)

Buildings."[105] The MOU was developed concurrently with the enactment of EPACT 2005 and contained the first set of five core Guiding Principles for federal high performance and sustainable buildings: employ integrated design principles, optimize energy performance, protect and conserve water, enhance indoor environmental quality, and reduce environmental impact of materials. Subsequent revisions of the Guiding Principles were issued in 2008 and, most recently, in 2016[106] to reflect progress in green building design and to address a broader set of issue areas, including the health and productivity of building occupants. It also added a sixth overarching principle to the list: assess and consider climate change risks. See "Guiding Principles" textbox for more detail.

Guiding Principles

The six Guiding Principles for Federal Leadership in High Performance Sustainable Building are

- **Employ Integrated Design Principles.** This principle includes use of an integrated project team; incorporation of relevant performance goals for "siting, energy, water, materials, and indoor environmental quality"; consideration of the entire life cycle of the building; and methods to verify that performance goals are met.
- **Optimize Energy Performance.** This involves establishment of an energy performance goal for the entire building, including reduction in energy costs of 20%-30% below existing standards; and measures to track performance in comparison to Energy Star benchmarks.
- **Protect and Conserve Water.** This involves reducing indoor use of potable water by 20% and outdoor use by 50% in comparison to baselines, and reducing runoff.
- **Enhance Indoor Environmental Quality.** This principle requires meeting established standards for temperature, humidity, and ventilation; controlling moisture to prevent damage and mold; providing daylight in most spaces that is at least 2% above the amount available directly; using dimming and glare controls; using materials that emit low amounts of pollutants; and taking other steps to protect air quality in the building.
- **Reduce Environmental Impact of Materials.** This involves using materials with recycled and biobased (renewable and sustainable) content that is at or above recommended levels, eliminating ozone-depleting compounds, and recycling at least half of construction waste where possible.
- **Assess and Consider Climate Change Risks.** This principle involves assessing potential impacts and vulnerabilities to both acute weather events and long-term changes in climate during the life of the building, enhancing building resilience through the use of fire-resistant design elements, and avoiding construction in floodplains.

Source: Council on Environmental Quality, "Guiding Principles for Sustainable Federal Buildings and Associated Instructions," February 2016, https://www.fedcenter.gov/_kd/Items/actions.cfm?action=Show&item_id=30813&destination=ShowItem.

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Administration, the National Aeronautics and Space Administration, the Office of Personnel Management, and the Tennessee Valley Authority.

[105] Department of Defense et al., "Federal Leadership in High Performance and Sustainable Buildings Memorandum of Understanding," 2006, http://wbdg.org/FFC/FED/HPSB-MOU.pdf.

[106] Council on Environmental Quality, "Guiding Principles for Sustainable Federal Buildings and Associated Instructions," February 2016, https://www.fedcenter.gov/_kd/Items/actions.cfm?action=Show&item_id=30813&destination=ShowItem.

Programs and Activities of Selected Federal Agencies

The federal government owns or leases about 273,000 buildings in the United States, comprising nearly 3 billion square feet in floorspace (**Table 1**) and costing nearly $6.1 billion in energy bills.[107] EISA and other policy instruments require all federal agencies to implement green building practices for buildings they control. Several federal offices provide guidance and support for the implementation of those requirements.[108] Except for GSA and DOD, which together control three-quarters of all federal building floorspace, this report does not discuss green building within individual agencies, although such efforts may be significant. However, several agencies have programs and activities that have a broader focus than reducing the environmental impacts of the facilities of that agency. This section of the report discusses selected examples.[109]

General Services Administration

The General Services Administration (GSA) manages about 425 million square feet of space in over 8,500 buildings, providing workspace for over 1.2 million federal workers.[110] In 2010, the agency announced that it would require all GSA-owned new construction and major renovation projects to be LEED-certified at the Gold level or above.[111] Properties that GSA leases on behalf of another agency may be either LEED or Green Globes certified at the Silver or Two Globes levels, respectively.[112] By 2020, GSA says that all new buildings will be designed to achieve net-zero energy, water, or waste, exceeding the timeframe and requirements of Executive Order 13693. GSA's Green Proving Ground program conducts evaluations of next-generation building technologies and recommends those that meet agency standards for deployment throughout GSA's property holdings.[113]

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[107] Data on federal property holdings comes from the General Services Administration's *Fiscal Year 2015 Federal Real Property Profile Open Data Set* (see footnote 110). The data set reflects information provided by the executive branch agencies subject to the Chief Financial Officers Act of 1990. The data from FY2015 includes only buildings owned or leased by the federal government in the United States or a U.S. territory. It also excludes properties exempted for national security reasons. Data on the federal government's energy consumption and spending comes from the information for FY2016 in Department of Energy, "Comprehensive Annual Energy Data and Sustainability Performance," 2017, http://ctsedwweb.ee.doe.gov/Annual/Default.aspx?ReturnUrl=%2fAnnual%2fReport%2fReport.aspx.

[108] These include the Council on Environmental Quality (CEQ), Department of Energy (DOE), Environmental Protection Agency (EPA), General Services Administration (GSA), and Office of Management and Budget (OMB). See the appendices in Government Accountability Office, "Federal Green Building: Federal Efforts and Third-Party Certification Help Agencies Implement Key Requirements, but Challenges Remain."

[109] Selection was based on the perceived prominence and influence of those programs on the implementation of green building.

[110] General Services Administration, "FY2015 FRPP Open Data Set," May 2016, https://www.gsa.gov/portal/getMediaData?mediaId=132270; General Services Administration, "Strategic Plan: Fiscal Year 2014-2018," July 2014, https://www.gsa.gov/portal/mediaId/187599/fileName/GSA_FY14-18_GSA_Strategic_Plan.action.

[111] General Services Administration, "GSA Moves to LEED Gold for All New Federal Buildings and Major Renovations" (Press Release, October 28, 2010), https://www.gsa.gov/portal/content/197325.

[112] James C. Wisner, Assistant Commissioner, General Services Administration, "Leasing Alert (LA-FY17-03)—Green Building Rating Certification for New Construction and Tenant Interiors: LEED® and Green Globes," Memorandum to Regional Commissioners, Directors, and Officers, (December 13, 2016), https://www.gsa.gov/portal/getMediaData?mediaId=153842.

[113] General Services Administration, "GPG Program," 7/172017, https://www.gsa.gov/portal/category/102491.

Table 1. Percentages of Total Federal Building Floorspace Under the Jurisdiction of Various Agencies, 2015

Agency	% of Total
Department of Defense	59
General Services Administration	15
Department of Veterans Affairs	6
Department of Energy	4
Department of Interior	4
Other	12

Source: GSA, "FY2015 Federal Real Property Profile Open Data Set," https://www.gsa.gov/portal/content/102880.

Notes: The Federal Real Property Profile data is compiled by the General Services Administration, and is considered the authoritative source for federal property data. However, it is acknowledged to have outstanding issues with reliability and data collection. See Government Accountability Office, "High Risk: Managing Federal Real Property," accessed July 25, 2017, http://www.gao.gov/highrisk/managing_federal_property/why_did_study.

Several offices contribute to GSA green building efforts, including the Energy Program, Environment Program, Leasing Program, Office of Design and Construction, and the Office of Federal High-Performance Green Buildings.[114] EISA required GSA to establish the Office of Federal High-Performance Green Buildings, to coordinate activities relating to such buildings across federal agencies (42 U.S.C. 17092). The office delivers actionable information to improve building performance and conducts assessments on existing green buildings. It created and maintains the Sustainable Facilities Tool (SF Tool), an interactive website supplying green construction, purchasing, and operations resources and information to federal agencies and other interested parties.[115] Much of the research and recommendations generated by the office's other programs are made available on the SF Tool website. The Facility Management Institute is another GSA initiative intended to assist agencies in improving the operations and management of federal buildings.[116]

GSA has several green-building programs and projects that are the result of collaborations with other agencies and offices. EISA (Sections 433 and 436) directed the Director of the Office of Federal High-Performance Green Buildings to provide recommendations to the Secretary of Energy on rating and certification systems that can be used by agencies for meeting federal green building requirements, based on the results of a study to be conducted by the office every five years (42 U.S.C. §6834(a)(3); 42 U.S.C. §17092).[117] The office must also coordinate with the Department of Energy on commercial high-performance green building activities under EISA.

[114] For more on GSA's sustainability programs related to buildings, see General Services Administration, "Sustainable GSA: Buildings," 2017, https://gsa.gov/sustainability/#/buildings.

[115] General Services Administration, "Sustainable Facilities Tool," 2017, https://sftool.gov/.

[116] General Services Administration, "Facility Management Institute," May 31, 2017, https://www.gsa.gov/portal/content/160715.

[117] The act requires the Director to identify a green building certification system that the Director "deems to be most likely to encourage a comprehensive and environmentally sound approach to certification of green buildings." As of 2012, GSA was recommending that agencies choose between USGBC's LEED certification system, and GBI's Green Globes certification system. N. Wang, K.M. Fowler, and R.S. Sullivan, "Green Building Certification System Review," PNNL-20966 (Pacific Northwest National Laboratory, March 2012), http://www.gsa.gov/graphics/ogp/Cert_Sys_Review.pdf.

GSA and DOE cochair the Interagency Sustainable Working Group, which is tasked with reporting on agency progress toward the goals laid out in E.O. 13693. GSA participates in climate adaptation planning for buildings as part of the Agency Adaptation Planning Working Group, which is a subgroup in the Interagency Climate Change Task Force. GSA was also a leader in the interagency effort to develop sustainable design principles for the federal government, culminating in the development of the Whole Building Design Guide.[118]

GSA has also collaborated with the Department of Health and Human Services and New York City agencies to develop FITWEL, a voluntary certification program to promote occupant health and wellness through the design of workplaces.[119]

Department of Energy

Most of the external green building activities of the Department of Energy (DOE) relate to the energy element (see "Elements of Green Building"), through the Building Technologies Office (BTO), the Federal Energy Management Program (FEMP), and the Weatherization and Intergovernmental Programs Office (WIP) of the Office of Energy Efficiency and Renewable Energy (EERE).[120]

BTO sponsors and performs R&D to improve both commercial and residential energy efficiency. It is also involved in the development of energy codes and enforcement of appliance and equipment standards,[121] transfer of relevant technologies to the marketplace, and integrated design of energy-efficient buildings. According to BTO's Multi-Year Program Plan for 2016-2020, the office's long-term goal is to achieve a 50% reduction in energy use intensity in commercial and residential U.S. buildings compared to 2010 levels.[122] A major focus for the program in the next several years will be on enabling the development of cost-effective net-zero energy buildings for the residential and commercial sectors.[123]

BTO has several notable programs, including the following:[124]

- Building America[125] is an R&D program in partnership with the building industry. It focuses on a whole-building, integrated approach to improving energy savings in residential buildings.
- The Commercial Buildings Integration program implements initiatives related to energy savings in commercial buildings, including improving building design,

[118] General Services Administration, "Sustainability Matters," 2008, https://www.gsa.gov/graphics/pbs/Sustainability_Matters_508.pdf. For further information, see the textbox "Whole Building Design Guide."

[119] Kevin Kampschroer, "2016 Strategic Sustainability Performance Plan" (General Services Administration, June 30, 2016), https://gsa.gov/portal/getMediaData?mediaId=151974.

[120] Department of Energy, "Building Technologies Office," 2017, https://energy.gov/eere/buildings/building-technologies-office. See also other programs such as Solar Energy Technologies.

[121] For information on DOE enforcement of equipment standards established by EPACT 2005 and other legislation, see Department of Energy, "Appliance and Equipment Standards Program," 2017, https://energy.gov/eere/buildings/appliance-and-equipment-standards-program.

[122] Building Technologies Office, "Multi-Year Program Plan."

[123] Ibid.

[124] For a full listing of BTO's programs, see Ibid.

[125] Department of Energy, "Building America: Bringing Building Innovations to Market," 2017, https://energy.gov/eere/buildings/building-america-bringing-building-innovations-market.

accelerating market adoption of high-efficiency technologies, and increasing access to building performance data.[126]

- The Better Buildings Alliance is a public-private partnership that promotes energy efficiency in commercial buildings through collaboration with members of the U.S. commercial building community.[127]
- Energy Star is a joint program with EPA that uses voluntary labeling to promote energy-efficient products. Zero Energy Ready Home is a recognition program that builds on the requirements of Energy Star and EPA's Indoor airPLUS program to recognize builders that achieve a minimum energy efficiency improvement of 40% over the average new home.[128]
- The Building Performance Database provides public access to data on the energy performance of commercial buildings.[129]

The Federal Energy Management Program (FEMP)[130] assists federal agencies in implementing energy savings and management, including the designation required by EPACT 2005 of energy-efficient products for purchase by agencies. It provides assistance with procurement, construction, operations, and maintenance. It also chairs, along with the GSA, the Interagency Sustainability Working Group, which is responsible for assisting agencies in implementing sustainable building design, including technical guidance for implementation of the sustainable buildings requirements in E.O. 13693. FEMP collects data and issues reports annually on energy consumption by agencies and on related topics.[131]

Among other DOE entities, the Energy Information Administration (EIA) collects and reports on data relating to energy, including that used by buildings, most notably the residential and commercial energy consumption surveys.[132] Some of DOE's national laboratories also perform R&D relating to green buildings. The Advanced Research Projects Agency-Energy (ARPA-E) funds R&D for early-stage energy-related technologies, including several projects focused on developing innovative, energy-efficient heating and cooling systems for buildings.[133]

[126] Building Technologies Office, "Multi-Year Program Plan."

[127] Better Buildings Initiative, "About the Better Buildings Alliance," *Department of Energy*, 2017, https://betterbuildingssolutioncenter.energy.gov/alliance/about.

[128] Department of Energy, "Guidelines for Participating in the DOE Zero Energy Ready Home," 2017, https://www.energy.gov/eere/buildings/guidelines-participating-doe-zero-energy-ready-home. See also the texbox "Energy Star," above.

[129] Department of Energy, "Building Performance Database," 2017, https://energy.gov/eere/buildings/building-performance-database.

[130] Department of Energy, "Federal Energy Management Program," 2017, https://energy.gov/eere/femp/federal-energy-management-program.

[131] Department of Energy, "Federal Facility Reporting Requirements and Performance Data," 2017, https://energy.gov/eere/femp/federal-facility-reporting-requirements-and-performance-data.

[132] See Energy Information Administration, "Commercial Buildings Energy Consumption Survey (CBECS)," *Department of Energy*, 2017; Energy Information Administration, "Residential Energy Consumption Survey (RECS)," *Department of Energy*, 2017.

[133] Department of Energy, "ARPA-E Programs," 2017, https://arpa-e.energy.gov/?q=program-listing.

Environmental Protection Agency

The Environmental Protection Agency (EPA) has a broad range of programs and activities relating to one or more of the main elements of green building. Notable programs and activities include the following:

- **Energy.** EPA originated the Energy Star program. The Energy Star Portfolio Manager can be used to measure, track, and benchmark building energy use. The agency's Green Power Partnership supports the procurement of power from renewable resources by government and private-sector organizations.
- **Water.** EPA administers WaterSense, a voluntary labeling program established in 2006 to promote water efficiency. Manufacturers may earn WaterSense labels for their products, and landscape-irrigation professionals can be certified under the program. WaterSense-labelled homes and products are independently certified to be at least 20% more water efficient than average.[134] The Green Infrastructure Collaborative and related activities promote community adoption of green infrastructure, a stormwater management approach that uses vegetation, soils, permeable pavements, and other practices to reduce stormwater runoff and maintain or restore natural water filtration and storage in built environments.[135]
- **Materials and Waste.** The Sustainable Materials Management Program (SMM)[136] encourages a life-cycle materials management approach that seeks to reduce environmental and human health impacts associated with materials use, from extraction to disposal. SMM provides resources for governments and businesses on assessing and reducing material use, purchasing recycled materials, and increasing recycling and reuse of construction and demolition materials. SMM programs include WasteWise, a public/private partnership in which participants set goals and report progress on preventing waste, expanding recycling, and increasing purchasing of recycled materials; and the Federal Green Challenge, which encourages government agencies to reduce their waste footprint and water usage, among other goals.

  The Environmentally Preferable Purchasing (EPP) Program[137] assists federal agencies in meeting green purchasing requirements. The Comprehensive Procurement Guideline program identifies recycled products that comply with RCRA requirements.[138]
- **Health.** EPA supports activities such as R&D and awards programs to develop safer and more environmentally friendly chemicals, including "green chemistry" technologies. The Indoor Air Quality Program provides information and tools to ensure the protection of indoor environmental quality in schools, residences, and commercial buildings. Indoor airPLUS is a voluntary partnership and labeling program that specifies minimum air quality design features for homes.

[134] Environmental Protection Agency, "WaterSense."

[135] Environmental Protection Agency, "Green Infrastructure Collaborative," January 13, 2017, https://www.epa.gov/green-infrastructure/green-infrastructure-collaborative.

[136] Environmental Protection Agency, "Sustainable Materials Management," July 25, 2017, https://www.epa.gov/smm.

[137] Environmental Protection Agency, "About the Environmentally Preferable Purchasing Program," March 23, 2017, https://www.epa.gov/greenerproducts/about-environmentally-preferable-purchasing-program.

[138] Environmental Protection Agency, "Comprehensive Procurement Guideline (CPG) Program," 2017, https://www.epa.gov/smm/comprehensive-procurement-guideline-cpg-program.

- **Siting.** The Smart Location Database[139] is a nationwide geographic data resource that measures neighborhood characteristics such as housing density, neighborhood design, and transit accessibility to produce a measurement of a location's siting efficiency.[140] The agency also has a variety of programs and activities relating to smart growth and sustainability.

EPA has also published resources on implementing green building policies for local governments and tribal communities.[141]

Department of Defense

The Department of Defense (DOD) has the largest building footprint in the federal government (**Table 1)**, with a portfolio that contains more than 276,000 buildings covering 2.2 billion square feet and located across thousands of sites worldwide.[142]

DOD issues its own requirements for Department-owned buildings and facilities under the Unified Facilities Criteria (UFC) program.[143] UFC documents contain technical criteria and standards relating to the planning, design, construction, operations, and maintenance of DOD facilities.[144] Two recently issued UFC documents contain requirements relating to green building:

- **UFC 1-200-02** ***High Performance and Sustainable Building Requirements*** (2016) provides guidance toward complying with the minimum building requirements for federal buildings established by EISA, EPACT 2005, the Guiding Principles, and E.O. 13693. All new construction and major renovations must comply with these criteria.
- **UFC 3-210-10** ***Low Impact Development*** (2016) provides guidance for complying with EISA provisions governing stormwater management by using low-impact development (LID) techniques aimed at infiltrating and storing stormwater in order to restore site hydrology and mitigate adverse effects of runoff.[145]

DOD also sets and reports on a variety of goals aligned with green building objectives through the annual publication of its Strategic Sustainability Performance Plan (SSPP). The update for SSPP FY2016 lists department-wide goals for reducing use of facility energy and potable water,

[139] The Smart Location Calculator was developed with assistance from GSA (Kevin Kampschroer, "2016 Strategic Sustainability Performance Plan" (General Services Administration, June 30, 2016), https://gsa.gov/portal/getMediaData?mediaId=151974).

[140] Environmental Protection Agency, "Smart Location Mapping," April 20, 2017, https://www.epa.gov/smartgrowth/smart-location-mapping.

[141] Environmental Protection Agency, "Location and Green Building," March 29, 2017, https://www.epa.gov/smartgrowth/location-and-green-building.

[142] Department of Defense, "Base Structure Report Fiscal Year 2015 Baseline," September 2016, http://www.acq.osd.mil/eie/Downloads/BSI/Base%20Structure%20Report%20FY15.pdf.

[143] John Conger, Acting Deputy Under Secretary of Defense, "Department of Defense Sustainable Buildings Policy," Memorandum to Assistant Secretaries and Directors, (November 10, 2013), http://www.usace.army.mil/Portals/2/docs/Sustainability/Hydrology_LID/DoD_Sustainable_Buildings_Policy_(10%20Nov%202013).pdf.

[144] Whole Building Design Guide, "Department of Defense: Unified Facilities Criteria Program," 2017, https://www.wbdg.org/ffc/dod/.

[145] Department of Defense, "United Facilities Criteria (UFC): Low Impact Development," UFC 3 210-10, (February 1, 2016), https://www.wbdg.org/FFC/DOD/UFC/ufc_3_210_10_2015_c1.pdf.

stormwater management, solid waste diversion, construction and demolition debris diversion, and increasing the percentage of high performance sustainable buildings.[146]

Some of the service branches of DOD have created their own branch-wide green building goals and initiatives. The Army issued a directive in 2014, expanding a Net Zero Installations pilot project into an Army-wide initiative.[147] The Air Force uses Sustainability Development Indicators to ensure that installation development plans consider a wide range of environmental impact areas and performance elements.[148]

In December of 2016, DOD and EPA signed a Memorandum of Understanding listing, among others, goals to work together to implement sustainable and resilient military installations, promote a sustainable and resilient natural and built infrastructure, and to engage DOD installations as test beds for innovative technologies.[149]

Office of Federal Sustainability

The position of Federal Chief Sustainability Officer was originally established under the title of the Federal Environmental Executive in 1993 by Executive Order 12873. Executive Orders 13423 and 13693 broadened that position to include an Office of the Federal Environmental Executive, later renamed the Office of the Chief Sustainability Officer, and extended the duties to include assisting and monitoring the implementation by agencies of the order, including its green building requirements, and advising the Council on Environmental Quality.[150]

National Institute of Standards and Technology

The green building efforts of the National Institute of Standards and Technology (NIST) are housed in NIST's Engineering Laboratory.[151] The Sustainable and Energy-Efficient Manufacturing, Materials, and Infrastructure Program focuses on improvements in measurement science and data relating especially to intelligent building systems, sustainably engineered materials, and achieving net-zero energy buildings with high indoor air quality.

A component of this program is the Net-Zero Energy High-Performance Buildings Program, which is focused on developing building metrics for overall building sustainability and reducing building energy usage through improvements in specific component areas.[152] The Net-Zero

[146] Department of Defense, "Strategic Sustainability Performance Plan FY2016," September 7, 2016, http://www.denix.osd.mil/sustainability/dod-sspp/unassigned/department-of-defense-strategic-sustainability-performance-plan-fy-2016/.

[147] John M. McHugh, Secretary of the Army, "Army Directive 2014-02 (Net Zero Installations Policy)," Memorandum for SEE Distribution, (January 28, 2014), http://www.asaie.army.mil/Public/ES/doc/Army%20Directive%202014-02%20(NZ%20Policy).pdf.

[148] Department of Defense, "Strategic Sustainability Performance Plan FY2016."

[149] Department of Defense and Environmental Protection Agency, "Memorandum of Understanding Between the Office of the Assistant Secretary of Defense for Energy, Installations and Environment and the U.S. Environmental Protection Agency Office of Research and Development, Office of Policy," February 2017, http://www.denix.osd.mil/sustainability/home/success/epa-and-dod-sign-mou/.

[150] Council on Environmental Quality, "The Office of Federal Sustainability," 2017, https://sustainability.gov/home.html.

[151] National Institute of Standards and Technology, "About EL," *NIST*, September 26, 2016, https://www.nist.gov/el/about-el.

[152] National Institute of Standards and Technology, "Net-Zero Energy, High-Performance Buildings Program," July 17, 2017, https://www.nist.gov/programs-projects/net-zero-energy-high-performance-buildings-program.

Energy Residential Test Facility (NZERTF), developed under this program, is a laboratory and demonstration facility dedicated to the development of measurement science needed to achieve net-zero energy homes.[153] NIST has also developed Building for Environmental and Economic Sustainability (BEES),[154] a software tool that uses life-cycle assessment methods to facilitate the selection of environmentally preferable building products.

NIST has also helped to add resources on climate resiliency for buildings to the U.S. Climate Resilience Toolkit,[155] through participation in the Community Resilience Panel for Buildings and Infrastructure Systems, which it cosponsors.[156]

Department of Housing and Urban Development

The Department of Housing and Urban Development (HUD) administers several mortgage insurance and home-financing programs that contain provisions intended to encourage the adoption of green building elements in public housing. The Mark-to-Market program is an initiative that restructures HUD-insured mortgages for multifamily housing projects. A component of the program offers financial incentives for green building measures to be incorporated into eligible housing projects.[157] The Federal Housing Administration (FHA) administers the Energy Efficient Mortgage Program, a program intended to enable homeowners and buyers to finance the cost of energy-efficiency improvements through their FHA-insured mortgage.[158] The Public Housing Capital Fund and the Public Housing Operating Fund provide funding to Public Housing Agencies that may be used to make energy and water efficiency improvements.[159]

HUD also administers the Lead Hazard Control and Healthy Homes Program, which conducts research and provides grants to reduce home health hazards relating to lead-based paint, exposure to mold, moisture, poor indoor air quality, pesticides, dust, and other substances that contribute to poor health outcomes.[160]

[153] National Institute of Standards and Technology, "Net-Zero Energy Residential Test Facility," July 23, 2013, https://www.nist.gov/sites/default/files/documents/2017/04/28/netzerofinal.pdf; National Institute of Standards and Technology, "Net-Zero Energy Residential Test Facility (NZERTF)," June 1, 2016, https://www.nist.gov/el/net-zero-energy-residential-test-facility.

[154] National Institute of Standards and Technology, "BEES," December 23, 2016, https://www.nist.gov/services-resources/software/bees.

[155] United States Global Change Research Program, "U.S. Climate Resilience Toolkit," May 17, 2015, https://toolkit.climate.gov/content/about.

[156] Other cosponsors include EPA, HUD's Office of Economic Resilience, FEMA, and the Office of Infrastructure Protection of the Department of Homeland Security.

[157] Department of Housing and Urban Development, "Programs of HUD: Major Mortgage, Grant, Assistance, and Regulatory Programs," 2016, https://www.huduser.gov/portal/sites/default/files/pdf/Programs-of-HUD-2016.pdf.

[158] Department of Housing and Urban Development, "Energy Efficient Mortgage Program," 2017, https://portal.hud.gov/hudportal/HUD?src=/program_offices/housing/sfh/eem/energy-r.

[159] See Department of Housing and Urban Development, "Public Housing Programs," 2017, https://portal.hud.gov/hudportal/HUD?src=/program_offices/public_indian_housing/programs/ph/programs.

[160] Department of Housing and Urban Development, "Office of Lead Hazard Control and Healthy Homes (OLHCHH)," 2017, https://portal.hud.gov/hudportal/HUD?src=/program_offices/healthy_homes.

Assessing Green Building Efforts

The rise in prominence of green building since the 1990s has raised questions about its impacts. Those questions cover a broad range of issues, including market penetration, cost, actual building performance, the underlying measurement science, the extent to which legislative goals are being met, and the general approach and implementation of green building. Those issues are discussed below.

Market Penetration

The building industry is a substantial component of the U.S. economy. In 2016, the total value of construction and renovation work in the United States exceeded $1 trillion and accounted for more than 6% of U.S. gross domestic product (GDP).[161] The percentage of the overall construction market devoted to green building has grown substantially in recent years, spurred by a variety of factors, from government requirements to the prospect of attractive investment returns to increasing concerns about environmental degradation and quality of life. In 2005, according to one analysis, only 2% of new residential and commercial construction in the United States consisted of green building. By 2013, that percentage was estimated to have grown to 20%.[162]

Green construction spending in the United States has been growing faster than general construction spending as a whole.[163] Spending on green construction more than tripled from $39 billion in 2008 to $129 billion in 2014.[164] One analysis projected that green building activities will generate $303.4 billion in GDP between 2015 and 2018.[165] New institutional construction is expected to be a large future driver of green building growth in the United States, primarily due to certification requirements for public buildings and schools.[166]

The percentage of certified-green floorspace may also be on the rise among existing buildings, although estimates vary significantly. The National Green Building Adoption Index has reported a rise in the percentage of office space that has been certified by LEED or Energy Star from 5% in 2005 to 38% in 2016 for the 30 largest U.S. office markets.[167] Nevertheless, there remains a large portion of the U.S. residential and commercial building stock that was not constructed

[161] U.S. Census Bureau, "US Census Bureau Construction Spending Survey," June 2017, https://www.census.gov/construction/c30/c30index.html.

[162] Alex Herceg and Aditya Ranade, "Cash Is King: Assessing the Financial Performance of Green Buildings," ACEEE Summer Study on Energy Efficiency in Industry (July 14, 2015), http://aceee.org/files/proceedings/2015/data/papers/2-138.pdf.

[163] Booz Allen Hamilton, "Green Building Economic Impact Study" (U.S. Green Building Council, September 2015), https://kapost-files-prod.s3.amazonaws.com/published/56438d353dab34e8a1000061/green-building-economic-impact-study.pdf?kui=ntZxSELuij0YNSwkwEO_Kw.

[164] Ibid.

[165] Ibid.

[166] Dodge Data and Analytics, "World Green Building Trends 2016: Developing Markets Accelerate Global Green Growth," SmartMarket Report, (2016), http://images.marketing.construction.com/Web/McGrawHillConstruction/%7B9cae5ab2-4ea8-429d-915d-49bc72212ebc%7D_World_Green_Building_Trends_2016_SmartMarket_Report_FINAL.PDF.

[167] CBRE, "Real Green Research Challenge," 2017, https://www.cbre.com/about/corporate-responsibility/environmental-sustainability/real-green-research-challenge.

according to green building criteria and for which rapid retrofitting or replacement to meet those criteria does not seem feasible.[168]

Cost

Green building efforts can impact the financial performance of a building by affecting initial construction costs, operating expenses, rental rates, and property values, among other factors. Actual and perceived costs of implementing green building measures have a strong bearing on design and construction decisions. However, information on true costs is not always easy to obtain, and such informational barriers can distort perceptions about the economic benefits of green building. Moreover, researchers have noted that the flexibility inherent in designing individual green buildings makes generalizing about the cost performance of the market segment as a whole difficult.[169] As a result, empirical evidence of the financial performance of green building investments is limited.

It is widely believed that the initial costs of green buildings are higher than for conventional buildings. A survey of construction industry professionals found that higher perceived initial cost was among the top three obstacles for green building in the United States.[170] Such higher costs can result from several sources. Not only can many features, such as high-efficiency appliances and high-performance windows, be more expensive than conventional approaches, but design costs may be higher, and if the building is to be certified, the process may be time-consuming and expensive in its own right.

There is some evidence, however, that the costs for constructing green buildings are not substantially higher than those of standard construction. A DOE review of the existing literature on green-certified buildings concluded that the available evidence shows construction costs for green buildings to be comparable to those of conventional buildings.[171] The use of integrated design may also result in some reductions in initial costs,[172] and some evidence supports that claim.[173]

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[168] According to one 2008 estimate, about 3% of the building stock (more than 300 billion square feet) in the United States is built new or renovated each year, with a growth rate in the stock of about 1% per year, and a projection that about three-quarters of the stock will be new or renovated by 2035 (Steven Winter, "Green Residential Building in North America: A Perspective from the United States," Background Paper [Commission for Environmental Cooperation, 2008], http://www3.cec.org/islandora/en/item/2333-paper-4b-residential-green-building-in-north-america-en.pdf). In 2012, commercial buildings had a median age of 32 years. Approximately half of such buildings had been built before 1980, and 12% since 2003 (Energy Information Administration, "A Look at the U.S. Commercial Building Stock: Results from EIA's 2012 Commercial Buildings Energy Consumption Survey (CBECS)," March 4, 2015, https://www.eia.gov/consumption/commercial/reports/2012/buildstock/).

[169] Daniel C. Matisoff, Douglas S. Noonan, and Mallory E. Flowers, "Policy Monitor—Green Buildings: Economics and Policies," *Review of Environmental Economics and Policy* 10, no. 2 (July 2016): 329–46, doi:10.1093/reep/rew009.

[170] Dodge Data and Analytics, "World Green Building Trends 2016: Developing Markets Accelerate Global Green Growth."

[171] Waypoint and JDM Associates, "Energy Efficiency and Financial Performance: A Review of Studies in the Market" (Department of Energy, December 2015), https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/Energy%20Efficiency%20and%20Financial%20Performance_12_2015.pdf.

[172] Robert Cassidy, ed., "White Paper on Sustainability," *Building Design and Construction* Supplement, November 2003, 48 p., https://www.bdcnetwork.com/sites/default/files/BD%2BC%202003%20White%20Paper%20on%20Sustainability.pdf.

[173] Greg Kats et al., "The Costs and Financial Benefits of Green Buildings: A Report to California's Sustainable Building Task Force" (Sustainable Building Task Force, October 2003), http://evanmills.lbl.gov/pubs/pdf/green_buildings.pdf.

Proponents of green building assert that operational cost savings will eventually recoup any initially higher investment. One way green buildings can create operational cost savings is by reducing usage of utility resources, and, in some cases, through selling site-generated renewable energy back to the grid. GSA, for instance, claims to have saved over $340 million in energy and water costs between FY2008 and FY2015 from efficiency improvements.[174] More than two dozen studies support the contention that green certification is associated with reduced utility expenses.[175] However, utility costs, such as electricity, gas, and water bills, only make up approximately 19% of a commercial building's operating costs,[176] and evidence is mixed on whether green certification reduces overall operating expenses.[177] There is also evidence to suggest that green-labeled buildings command price premiums on the real estate market, both in the amount that renters are willing to pay to use the space, and in terms of overall market value.[178]

Some features of real estate markets can, however, reduce incentives for investments in green building. For example, building owners, especially homeowners, often move after a few years,[179] reducing the time they would require for a return on their initial investment through potential utility savings. The problem can be exacerbated if the building is rented or leased. The financial return on green building investments made by owners would depend on how much of a premium they could charge current or new tenants. The return for investments by tenants would depend on the length of their tenure—only long-term tenants would be likely to benefit from making such an investment.[180] This is sometimes called the principal/agent or split-incentive problem.[181]

Finally, many potential beneficiaries of green building renovations may be limited by constraints on the availability of capital for such investments, even outside the residential sector. Such constraints are reported to be a problem with respect to such significant users of energy as educational institutions, hospitals, and municipalities.[182]

Cost barriers to the use of green building may continue to decrease as the practice becomes more widespread and economies of scale lower the initial cost differential. Also, financial incentives, offered by some states and municipalities, may help to defray higher initial costs, making green building investments more financially attractive. Some observers argue that costs beyond simple

[174] Kevin Kampschroer, "2016 Strategic Sustainability Performance Plan" (General Services Administration, June 30, 2016), https://gsa.gov/portal/getMediaData?mediaId=151974.

[175] Waypoint and JDM Associates, "Energy Efficiency and Financial Performance: A Review of Studies in the Market" (Department of Energy, December 2015), https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/Energy%20Efficiency%20and%20Financial%20Performance_12_2015.pdf.

[176] Alex Herceg and Aditya Ranade, "Cash Is King: Assessing the Financial Performance of Green Buildings," ACEEE Summer Study on Energy Efficiency in Industry (July 14, 2015), http://aceee.org/files/proceedings/2015/data/papers/2-138.pdf.

[177] Waypoint and JDM Associates, "Energy Efficiency and Financial Performance: A Review of Studies in the Market" (Department of Energy, December 2015), https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/Energy%20Efficiency%20and%20Financial%20Performance_12_2015.pdf.

[178] Ibid.

[179] Between 11 and 13% of Americans move every year (U.S. Census Bureau, "U.S. Mover Rate Remains Stable at About 12 Percent Since 2008," *The United States Census Bureau*, March 18, 2015, https://www.census.gov/newsroom/press-releases/2015/cb15-47.html).

[180] Such arguments about cost problems are often cited as a barrier to wider implementation of green building. See, for example, Building Technologies Office, "Multi-Year Program Plan."

[181] Florian Bressard et al., "Curbing Global Energy Demand Growth: The Energy Productivity Opportunity" (McKinsey Global Institute, May 2007), http://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/curbing-global-energy-demand-growth.

[182] Ibid.

monetary expenditures should be considered. Such thinking has led to the use of concepts such as the "triple bottom line"[183] in literature on green building. The term refers to the inclusion of social and environmental returns, in addition to financial ones, in assessing business performance.

Performance

In evaluating the efficacy of green building efforts, it is necessary to distinguish between design and performance. Much of the focus of green building, including rating systems such as LEED, has been on design and construction specifications. Historically, actual environmental performance of green buildings was not incorporated into certification requirements for most rating systems.

Factors Affecting Performance

There are, however, many factors that can affect operations and potentially degrade the performance of a building after it has received its green rating. Such factors include inadequate maintenance of systems, alterations to prescribed building controls, and unintended changes in building use and occupancy. Consequently, it is not certain that a nominally green building, even one for which the design and construction are certified, will perform in a manner that is significantly better or worse than a conventional building. Indeed, there are well-publicized examples of certified green buildings that have been shown to be extremely resource-intensive postoccupancy.[184]

Studies that have evaluated actual green building performance are discussed later in this section. However, even where greater resource-use efficiency can be demonstrated, savings may be offset by other factors. For example, green building efforts and related energy-efficiency initiatives appear to have helped reduce energy-use intensity (see "Measurement") in U.S. homes built since 2000. Yet, those homes use more total energy on average because they are 30% larger than older ones and have more electronic appliances and other devices.[185]

The energy performance of green buildings has received the most scrutiny. Researchers have shown that there is often a significant difference between the predicted or modelled energy use of a building and its measured performance. This difference is sometimes referred to as a "performance gap." Closing that gap is a topic of ongoing interest and concern to the construction industry.

In response to such concerns, rating system developers have placed increasing emphasis on postoccupancy performance assessment. Recent revisions of the LEED rating system have sought to address critiques centered on the one-time assessment nature of certification by requiring installation of building-level energy and water meters, the data from which are to be compiled and reported to USGBC for the first five years following certification. Other systems, such as BREEAM In-Use and the Living Building Certification, explicitly include performance parameters within the criteria for certification (see "Green Rating Systems and Certifications").

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[183] John Elkington, *Cannibals with Forks: The Triple Bottom Line of 21st Century Business*, Conscientious Commerce (Gabriola Island, BC: New Society Publishers, 1998).

[184] Richard Conniff, "Why Don't Green Buildings Live Up to Hype on Energy Efficiency?," *Yale E360*, August 25, 2017, http://e360.yale.edu/features/why-dont-green-buildings-live-up-to-hype-on-energy-efficiency; Sam Roudman, "Bank of America's Toxic Tower," *The New Republic*, July 29, 2013, https://newrepublic.com/article/113942/bank-america-tower-and-leed-ratings-racket.

[185] Energy Information Administration, "Newer U.S. Homes Are 30% Larger but Consume About as Much Energy as Older Homes," February 12, 2013, https://www.eia.gov/todayinenergy/detail.php?id=9951.

Building codes are also moving toward incorporating performance outcomes into requirements: the 2015 IgCC included an outcome-based compliance pathway for energy usage, allowing builders to meet requirements through actual performance.[186]

Building systems may also be commissioned—that is, independently assessed to ensure they are designed, installed, tested, and capable of being operated as planned.[187] Available data support the contention that commissioning improves environmental performance, especially for energy use.[188] The process can be used not only for new buildings, but also existing ones, either during retrofitting or continuing operations.

In addition to certification and commissioning, an organization can develop an environmental management system (EMS), for which international standards are available.[189] To be certified under the standards, an organization must have an explicit environmental policy that includes commitments to conform to relevant environmental requirements, continuously improve environmental performance, and prevent pollution, among other things. Such commitments are arguably far easier to meet if the EMS includes performance measurement.[190]

Networked building monitoring and diagnostic tools are becoming increasingly prevalent. Such tools can allow early fault detection in critical building equipment as well as providing resource use analytics, allowing building managers to more effectively respond to changing use patterns in real time. (See textbox "Smart Buildings and the Internet of Things," above.) For example, GSAlink, a GSA-developed building diagnostic tool, has been used to identify over 33,000 instances of sub-optimal equipment performance within GSA holdings alone.[191]

Selected Studies

Many studies have attempted to measure and evaluate green building performance. However, a lack of consensus on the criteria for defining green building, as well as on the outcomes to be measured, has made it difficult to compare results between studies.[192] Generally, the evidence that green buildings perform significantly better than conventional buildings is mixed. Recent studies have shown green buildings to exhibit a wide range of measured energy performance, with some buildings performing far below design expectations.[193] The selected studies discussed below

[186] Institute for Market Transformation, "Outcome-Based Pathway Is Voted into the 2015 IgCC" (Press Release, November 20, 2014), http://www.imt.org/news/the-current/outcome-based-pathway-is-voted-into-the-2015-igcc.

[187] Whole Building Design Guide, "Building Commissioning," November 12, 2016, http://www.wbdg.org/building-commissioning.

[188] See, for example, Evan Mills, "Building Commissioning: A Golden Opportunity for Reducing Energy Costs and Greenhouse Gas Emissions in the United States," *Energy Efficiency* 4, no. 2 (May 1, 2011): 145–73, doi:10.1007/s12053-011-9116-8.

[189] The standard is ISO 14001. See International Organization for Standardization, "ISO 14001 Family—Environmental Management," August 21, 2017, https://www.iso.org/iso-14001-environmental-management.html. EPA has promoted testing and adoption of this standard by local governments and nonprofit organizations Environmental Protection Agency, "Frequent Questions About Environmental Managment Systems," Overviews and Factsheets, (January 23, 2017), https://www.epa.gov/ems/frequent-questions-about-environmental-managment-systems.

[190] For more information on ensuring buildings meet performance objectives, see WBDG Functional/Operational Committee, "Meet Performance Objectives," *Whole Building Design Guide*, October 25, 2016, http://wbdg.org/design-objectives/functional-operational/meet-performance-objectives.

[191] Kevin Kampschroer, "2016 Strategic Sustainability Performance Plan" (General Services Administration, June 30, 2016), https://gsa.gov/portal/getMediaData?mediaId=151974.

[192] Melissa A. Beutler et al., eds., *Green Building and the Construction Lawyer: A Practical Guide to Transactional and Litigation Issues* (Chicago, Illinois: Forum on Construction Law, 2014).

[193] New Buildings Institute, "High Performance Buildings Measured Performance and Key Performance Indicators," (continued...)

primarily use LEED ratings as the criteria for inclusion. Because other rating systems are not as prevalent in the United States, little information is available on the performance of buildings constructed under those systems in the U.S. market.

A study of energy use by more than 100 LEED-certified buildings found that, on average, they performed 24% better than other buildings.[194] However, about one in seven performed worse than average. This study was criticized as misleading because of purported sample bias, inappropriate baselines for comparison, and other concerns.[195] A follow-up assessment using the same data concluded that primary energy savings from LEED certification were nonexistent for lower levels of certification and 13% better than average for Gold and Platinum-certified buildings.[196]

A GSA study of 22 green federal buildings, most of which had received LEED certification, found that, on average, the buildings studied performed better than the national average in all measured performance areas, including energy use, water use, operating costs, occupant satisfaction, and carbon emissions.[197] Some buildings performed worse than the national average in certain areas, however.

A study of the energy consumption of 11 LEED-certified Navy buildings found that 9 of the 11 buildings did not meet the federal requirement at the time of the study (30% electricity savings over the benchmark).[198] Furthermore, the majority consumed more electricity than the national average.

An assessment of Arizona's LEED-certified new construction buildings supported the existence of the energy performance gap, as the majority of the sample underperformed both the design and the baseline energy-use simulations, highlighting a disconnection between the efficacy of the strategies employed and the modeling results.[199]

Taken together, the findings in those studies do not appear to provide sufficient evidence of improvements in performance with LEED certification to conclude that such certification consistently reduces building energy consumption. However, sample sizes were small and may not be representative of the overall performance of green-certified buildings. Performance data is

(...continued)

CEC-500-08-049 (March 2013), http://newbuildings.org/wp-content/uploads/2015/11/HPBldgsFinalResearchSummary1.pdf.

[194] Cathy Turner and Mark Frankel, "Energy Performance of LEED for New Construction Buildings" (New Building Institute, March 4, 2008), https://www.usgbc.org/ShowFile.aspx?DocumentID=3930.

[195] Joseph W. Lstiburek, "Prioritizing Green—It's the Energy Stupid," BSI-007, Insights (Building Science Corporation, November 2008), https://buildingscience.com/documents/insights/bsi-007-prioritizing-green-it-s-the-energy-stupid. Another report found discrepancies between LEED ratings and the results of modeling that examined impacts expected over the entire life of the building (Chris W. Scheuer and Gregory A. Keoleian, "Evaluation of LEED Using Life Cycle Assessment Methods," NIST GCR 02-836 [National Institute of Standards and Technology, September 2002], http://www.fire.nist.gov/bfrlpubs/build02/PDF/b02170.pdf).

[196] John Scofield, "A Re-Examination of the NBI LEED Building Energy Consumption Study" (2009 International Energy Program Evaluation Conference, Portland, OR, 2009), https://www.researchgate.net/publication/267793718_A_Re-examination_of_the_NBI_LEED_Building_Energy_Consumption_Study.

[197] General Services Administration, "Green Building Performance: A Post Occupancy Evaluation of 22 GSA Buildings," August 2011, https://www.gsa.gov/portal/getMediaData?mediaId=214295.

[198] Carol Menassa et al., "Energy Consumption Evaluation of U.S. Navy LEED-Certified Buildings," *Journal of Performance of Constructed Facilities* 26, no. 1 (February 2012): 46–53, doi:10.1061/(ASCE)CF.1943-5509.0000218.

[199] Dixon Oates and Kenneth T. Sullivan, "Postoccupancy Energy Consumption Survey of Arizona's LEED New Construction Population," *Journal of Construction Engineering and Management* 138, no. 6 (June 2012): 742–50, doi:10.1061/(ASCE)CO.1943-7862.0000478.

often proprietary and therefore often inaccessible to researchers conducting evaluations. Greater access to building performance data is frequently cited as a prerequisite to more comprehensive performance assessments.[200]

Measurement

As the discussion above shows, performance measurement is important for ensuring that green buildings meet the environmental targets claimed for them and to assess ways to improve those targets. However, methods for measuring the performance of green buildings are not yet well-developed for most elements. Some, such as energy and water use, are comparatively easy to measure quantitatively, for example through metering. Others may be difficult to quantify and may be possible to evaluate only on the basis of the presence or absence of certain features or through other more qualitative measures.[201] Even for elements that are relatively simple to measure, such as energy usage, there may be disagreement about which of several possible metrics captures the most relevant information. For instance, energy use intensity (EUI), which is the primary metric used to evaluate federal building performance, has traditionally been defined as the amount of energy used per square foot. GSA's Green Building Advisory Committee has recently proposed two additional methodologies for measuring EUI: energy use per occupant and area-based EUI measuring energy used in commuter transportation to and from the building.[202] As the Advisory Committee notes in its report, a building's energy use patterns may appear to vary based on which metric is used. However, a study by Pacific Northwest National Laboratory cautioned that a lack of accurate building occupancy data could complicate efforts to calculate occupancy-adjusted EUI.[203] Furthermore, there is some evidence that commonly accepted metrics, such as an Energy Star score, are not highly correlated with the outcomes they are intended to measure.[204]

Given the life expectancy of buildings—in most cases far longer than occupancy by any given resident—measurement of performance is important not only initially but over the building's entire lifespan. In the absence of such regular measurement and adjustment, environmental performance is likely to deteriorate over time for many elements. Eventually, some form of standard life-cycle assessment may be feasible for whole buildings.[205]

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[200] John H. Scofield, "Do Green Buildings Really Save Energy? A Look at the Facts," Text, *GreenBiz*, (September 21, 2016), https://www.greenbiz.com/article/do-green-buildings-really-save-energy-look-facts.

[201] Grace Ding, "Sustainable Construction—The Role of Environmental Assessment Tools," *Journal of Environmental Management* 86 (February 2008): 451–64, https://www.researchgate.net/publication/6516125_Sustainable_Construction_-_the_Role_of_Environmental_Assessment_Tools; Andrew J. Nelson and Ari Frankel, "Building Labels vs. Environmental Performance Metrics: Measuring What's Important about Building Sustainability" (RREEF Real Estate, October 2012), http://realestate.deutscheam.com/content/_media/Research_Sustainability_Metrics_in_the_Real_Estate_Sector-Oct_2012.pdf.

[202] EUI Task Force, "Expanding the Concept of Energy Use Intensity (EUI): A Proposal to GSA's Green Building Advisory Committee" (General Services Administration, January 17, 2017), https://www.gsa.gov/portal/getMediaData?mediaId=154598.

[203] A. Selvacanabady and K. Judd, "The Influence of Occupancy on Building Energy Use Intensity and the Utility of an Occupancy-Adjusted Performance Metric," PNNL-26019 (Pacific Northwest National Laboratory, January 2017), http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-26019.pdf.

[204] New Buildings Institute, "High Performance Buildings Measured Performance and Key Performance Indicators."

[205] A life cycle assessment is a method for analyzing the environmental impacts of something throughout its lifespan, from initial creation through destruction or disposal—a "cradle-to-grave" evaluation. For one approach involving buildings, see National Institute of Standards and Technology, "Metrics and Tools for Sustainable Buildings Project," *NIST*, July 13, 2017, https://www.nist.gov/programs-projects/metrics-and-tools-sustainable-buildings-project.

EISA requires that federal agencies measure the performance of their buildings against specified targets, especially with respect to energy use. Targets are more stringent for new construction than existing stock. Energy performance is to be measured against a baseline of consumption levels in 2005. Determination of an accurate baseline may be difficult in the absence of adequate measurement of energy use.

Despite the recognized importance of measurement and the availability of options and resources for its application, uncertainties and gaps exist that can make effective application challenging. Consensus may not exist on specific measurement goals or metrics. Reliable and consistent data are often difficult to obtain.[206] Measurement science relating to green building is an active area of research. In 2008, the National Science and Technology Council listed the development of appropriate measurement science as the top research need for progress in green building.[207] Developing metrics and tools for measuring building sustainability is a priority of the National Institute of Standards and Technology.[208]

Progress Toward Federal Goals

Agency progress toward meeting federally mandated green building goals varies widely. In the Obama Administration, OMB released annual sustainability and energy scorecards for each agency with sustainability reporting requirements. Scorecards reported on agency progress toward federal sustainability goals in the following areas: Scope 1 and 2 GHG Emission Reductions, Scope 3 GHG Emission Reductions, Reduction in Energy Intensity, Use of Renewable Energy, Reduction in Potable Water Intensity, Reduction in Fleet Petroleum Use, and Green Buildings. Scorecards included both numeric reports of agency progress, in the form of percentage reductions in target areas, as well as a color score of green, yellow, or red. The precise meaning of a score color differed slightly for each target area. Generally, however, a green score indicated that an agency had met or was on track to meet the target; yellow indicated that some progress has been made toward a target; and red indicated that the agency was neither on track to achieving a given target nor demonstrating significant progress.

Federal progress toward three buildings-related goals is discussed below. See **Table 2** for information on the reported progress of selected agencies toward those goals.

Green Building Goal: E.O. 13693 directed federal agencies to ensure that at least 15% of agency buildings with more than 5,000 square feet of floorspace comply with the Guiding Principles by FY2025. Some agencies have already surpassed this target, while others are making progress. At least three agencies have achieved compliance in fewer than 2% of buildings, however. Several more have received a red score in the green buildings category from OMB for FY2015.

Energy Intensity Goal: EISA set a goal for federal facilities to reduce energy intensity by 30% from 2003 levels by 2015. Many agencies did not meet this goal. Government-wide energy intensity declined only 22% during this period. E.O. 13693 directs agencies for reduce energy intensity by 2.5% per year relative to 2015. Progress on this goal will be reported starting for FY2016.

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[206] For more on the challenges surrounding building performance measurements, see Joel Ann Todd, "Measuring Performance of Sustainable Buildings," *Whole Building Design Guide*, December 8, 2016, http://wbdg.org/resources/measuring-performance-sustainable-buildings.

[207] National Science and Technology Council, "Federal R&D Agenda for Net-Zero Energy, High-Performance Green Buildings," October 2008, http://www.bfrl.nist.gov/buildingtechnology/documents/FederalRDAgendaforNetZeroEnergyHighPerformanceGreenBuildings.pdf.

[208] National Institute of Standards and Technology, "Metrics and Tools for Sustainable Buildings Project."

Potable Water Intensity Goal: E.O. 13514 set a goal for a 26% reduction in potable water intensity between 2007 and 2020. E.O. 13693 replaced that goal in 2015 with a 36% reduction from 2007 levels by 2025. OMB scorecards for 2015 scored agencies on the basis of their progress toward achieving the earlier goal from E.O. 13514. Many agencies have already achieved the earlier goal, with several making substantive progress toward the 36% reduction required for 2025.

Approach and Implementation

Although green building is widely considered a positive development, some observers have expressed concerns about the approach. Some of those criticisms have been directed at rating and certification systems, for the reasons described above and others. The certification process is more rigorous for some systems than for others, and critics have pointed out that many systems do not set caps on performance metrics such as energy use, making claims to sustainability relative. Some argue that the design criteria are not sufficiently integrative—they do not provide sufficient integration across elements or stages in the building's life cycle—or that they are too incremental in scope.[209]

Table 2. Agency Progress Toward Select Green Building Goals as of FY2015

	Building Sq. Ft. Meeting Guiding Principles (Goal: 15%)		Reduction in Energy Intensity from 2003 (Goal: 30%)		Reduction in Potable Water Intensity from 2007	
Agency	**Percent**	**Score**	**Percent**	**Score**	**Percent**	**Score**
Department of Defense	1.4	Red	20.0	Red	22.0	Green
General Services Administration	18.3	Green	30.0	Green	29.0	Green
Department of Energy	7.6	Red	30.0	Green	35.0	Green
Department of the Interior	4.7	Red	33.0	Green	9.0	Red
Department of Justice	4.1	Red	44.0	Green	2.0	Red
Department of Agriculture	18.7	Green	30.0	Green	17%	Green
Department of Homeland Security	10.7	Red	26.0	Red	30.0	Green
National Aeronautics and Space Administration	19.8	Yellow	27.0	Yellow	36.0	Green
Department of Health and Human Services	1.0	Red	28.0	Yellow	12.0	Red

[209] Anya Kamenetz, "The Green Standard?," *Fast Company*, December 19, 2007, http://www.fastcompany.com/magazine/119/the-green-standard.html; and Andrew J. Nelson and Ari Frankel, "Building Labels vs. Environmental Performance Metrics: Measuring What's Important about Building Sustainability" (RREEF Real Estate, October 2012), http://realestate.deutscheam.com/content/_media/Research_Sustainability_Metrics_in_the_Real_Estate_Sector-Oct_2012.pdf.

Department of Transportation	2.0	Red	16.0	Red	20.0	Green
Department of Labor	5.3	Red	29.0	Yellow	25.0	Green
Environmental Protection Agency	15.7	Green	33.0	Green	42.0	Green

Source: January 2016 OMB Scorecards on Sustainability/Energy, available from the websites of specified agencies. Agencies included in this chart were selected from the reporting agencies on the basis of amount of floorspace owned and leased (see **Table 1**), with the exception of EPA, which is included due its substantial green building activities, despite its small spatial footprint. Agencies are ordered by the size of their property holdings. Scorecards were not available for the Department of Veterans Affairs.

Others have argued that mere mitigation of environmental impacts is not sustainable, and that new approaches are preferable, for example based on maintenance or even enhancement of ecosystem services.[210] Such approaches would arguably need to go beyond individual buildings and include other components of the built environment.[211]

Some observers worry that builders new to green building may fail to appreciate the importance of taking a forward-thinking, integrative approach to green building design. Instead, some may regard green building measures as items that can simply be tacked on to a construction project, rather than being an integral part of the project from its inception onward.

The scientific and technological knowledge base for green building is also limited, which is not surprising given the recent origin of the discipline. These limitations make it difficult to identify the most appropriate approaches. Substantial research is considered by many as needed to improve the knowledge base relating to all elements of green building.[212]

Such issues can be compounded by differences in goals and perspectives among different proponents of green building.[213] Identifying objective, rather than subjective, criteria and approaches may also be difficult, especially for elements of green building, such as siting, that are not as amenable to quantitative evaluation as others, such as energy.

Issues for Congress

Four of the questions Congress may expect to face with respect to green building are

- How well are current federal green building programs working? How effective are current methods for coordinating the green building activities of different agencies?

[210] Sarah Nugent et al., "Living, Regenerative, and Adaptive Buildings," Whole Building Design Guide, August 5, 2016, https://www.wbdg.org/resources/living-regenerative-and-adaptive-buildings; Victor Olgyay and Julee Herdt, "The Application of Ecosystems Services Criteria for Green Building Assessment," *Solar Energy* 77 (February 26, 2004): 389–98, https://www.researchgate.net/publication/222033669_The_application_of_ecosystems_services_criteria_for_green_building_assessment.

[211] For example, LEED has developed a Neighborhood Development rating system to assess sustainability of the built environment at the neighborhood scale.

[212] See, for example, Mara Baum, "Green Building Research Funding: An Assessment of Current Activity in the United States" (U.S. Green Building Council, 2007), https://www.usgbc.org/sites/default/files/Green-Building-Research-Funding.pdf; Building Technologies Office, "Multi-Year Program Plan"; National Science and Technology Council, "Federal R&D Agenda for Green Buildings."

[213] For example, environmental groups are likely to have different goals and perspectives than builders or occupants.

- To what extent and by what means should Congress extend federal efforts to facilitate and support adoption and implementation of green building measures throughout the United States?
- What priorities should Congress give to the different elements of green building, especially those such as siting that have received less attention in the past?
- What actions should Congress take to facilitate the growth of scientific and technical knowledge relating to green building?

If Congress wishes to take additional action on such questions, it could do so through appropriations, new statutory requirements, and tax law. It could also review current and proposed agency programs, regulations, and policies.

Oversight of Federal Green Building Programs

GAO has released several reports over the last decade addressing various federal efforts relating to green building. One of those reports identified 94 initiatives across 11 agencies relating to green building in the nonfederal sector.[214] However, few of those initiatives focused on green building in the integrative sense it is discussed in this report, but rather focused on specific elements such as energy, IEQ, or water. GAO recommended that agencies coordinate to assess the relative performance of the initiatives.

Congress may wish to examine how well—in terms of both performance and efficiency—federal agencies are implementing green building programs, and what impacts those efforts are having on the adoption of green building practices both within the federal government and nationwide. In addition to oversight of the activities of individual agencies, it may also be useful to examine how well agency efforts are being coordinated.

Adoption and Implementation of Green Building

In addition to programs and activities such as those described above, some federal agencies such as the Federal Housing Administration and the Department of Veterans Affairs also support the availability of mortgages that promote energy efficiency. Lenders who provide such mortgages may also become Energy Star partners.

If Congress finds that such measures are not adequate, it could consider such steps as providing stronger mortgage and tax incentives, broadening the scope of mortgage and tax incentives to include elements of green building in addition to energy, funding the rebate program authorized by EPACT 2005,[215] and specific appropriations to speed adoption of green building in areas where market penetration has been lagging, such as residential renovation. Congress could also consider regulatory actions, although such efforts might be complicated by federalism issues and differences in regional requirements relating to climate and other variables.

[214] Government Accountability Office, "Green Building: Federal Initiatives for the Nonfederal Sector Could Benefit from More Interagency Collaboration," GAO-12-79, (November 9, 2011), http://www.gao.gov/new.items/d1279.pdf. Agencies whose programs were examined by GAO but are not discussed in the section in this report on "Programs and Activities of Selected Federal Agencies" were the Departments of Agriculture, Education, Health and Human Services, Transportation, and Treasury, as well as the Small Business Administration.

[215] Some observers argue that incentive programs can be several times more effective in stimulating energy efficiency than increases in energy prices (see Florian Bressard et al., "Curbing Global Energy Demand Growth: The Energy Productivity Opportunity" (McKinsey Global Institute, May 2007), http://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/curbing-global-energy-demand-growth).

Congress could consider identifying ways in which current green building efforts in federal agencies could be further enhanced. In addition to accelerating green building for new and existing stock, Congress might consider whether programs and activities are sufficiently integrated within agencies such as EPA and DOE, and whether activities across agencies are sufficiently harmonized, such as through participation in the WBDG (see the text box "Whole Building Design Guide," above).

Priorities Among Elements of Green Building

Among the elements of green building discussed in this report, energy has received far more attention than any other. This priority is not surprising, given concerns about fossil fuel imports, strategic vulnerability, negative effects of climate change,[216] and the high and inefficient levels of use of energy by most of the current building stock in the United States. Nevertheless, Congress may wish to examine whether federal efforts in green building are effectively balanced among the component elements. If they are not, existing programs relating to particular elements could be strengthened or new ones established.

In addition, Congress may wish to explore whether the incremental approach embodied in most green building activities is sufficient to address national needs, or if some modification or acceleration of efforts would be preferable.

Knowledge Base

Development of the scientific and technological knowledge base for green building is supported by R&D funded by both federal and private-sector sources. Levels of funding from both sources may be suboptimal to address the needs currently identified.

According to a 2007 study, green building received less than 0.5% of total funding for federal nondefense R&D.[217] Also, a 2003 study found that despite its economic importance, construction sector investment in R&D was at a much lower rate than the industry average.[218]

Funding for R&D relating to the different elements of green building has also varied, with some elements such as energy being a much higher priority than others. That may well be considered appropriate by most observers, but given the range of green building elements and the need for improved knowledge about them, as well as the accepted importance of integration and economics to successful green building efforts, Congress may wish to consider whether federal funding levels and priorities should be modified, and whether to create incentives for increasing private-sector R&D funding. In addition, Congress may wish to consider whether the availability of training and education relating to relevant areas of expertise is sufficient to ensure a knowledgeable workforce for construction, certification, and operation of both federal green buildings and others, such as schools and hospitals (see the textbox "Special-Use Buildings," above).

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[216] See footnote 39.

[217] Mara Baum, "Green Building Research Funding: An Assessment of Current Activity in the United States" (U.S. Green Building Council, 2007), https://www.usgbc.org/sites/default/files/Green-Building-Research-Funding.pdf. More recent information on funding for green-building research per se was not available for this report.

[218] Estimates vary from 10% to 40% of the industry average as a percentage of sales (Robert Cassidy, ed., "White Paper on Sustainability," *Building Design and Construction* Supplement, November 2003, 48 p., https://www.bdcnetwork.com/sites/default/files/BD%2BC%202003%20White%20Paper%20on%20Sustainability.pdf).

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