Final Report

Federal R&D Agenda for Net Zero Energy, High-Performance Green Buildings

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About the National Science and Technology Council
The National Science and Technology Council (NSTC) is the principal means by which the Executive Branch coordinates science and technology policy across the diverse entities that make up the Federal research and development (R&D) enterprise. A primary objective of the NSTC is to establish clear national goals for Federal science and technology investments. The NSTC prepares R&D strategies that are coordinated across Federal agencies to form investment packages aimed at accomplishing multiple national goals. The work of the NSTC is organized under four committees: Science, Technology, Environment and Natural Resources, and Homeland and National Security. Each committee oversees subcommittees and working groups that focus on different aspects of science and technology. More information is available at www.ostp.gov/nstc.

About the Buildings Technology Research and Development Subcommittee
The Buildings Technology Research and Development (BTRD) Subcommittee is the interagency body responsible for coordination of Federal program activities in support of the research, development, and demonstration of building technologies and related infrastructure. The BTRD Subcommittee coordinates interagency buildings technology R&D activities by providing guidance aimed at supporting advances in buildings technology and related infrastructure, with a particular focus on enabling the energy-efficient, automated operation of buildings and building systems and the sustainable renewal of the nation's physical infrastructure. The Subcommittee collaborates with Federal agencies that own, construct, lease, or provide financial assistance for facilities to identify their buildings technology R&D needs.

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The Office of Science and Technology Policy (OSTP) was established by the National Science and Technology Policy, Organization, and Focus areas Act of 1976. OSTP's responsibilities include advising the President in policy formulation and budget development on questions in which science and technology are important elements; articulating the President's science and technology policy and programs; and fostering strong partnerships among Federal, state, and local governments, and the scientific communities in industry and academia. The Director of OSTP also manages the NSTC. More information is available at www.ostp.gov.

About This Document
This document defines a research agenda for Net Zero Energy, high-performance green buildings. It describes the BTRD goals and R&D objectives by which these goals are to be achieved. The goals and objectives focus on Net Zero Energy, water and materials use, indoor environmental quality, performance measurements and metrics, and barriers to the adoption of these new technologies by the buildings sector. The plan also includes a description of current Federal programs in support of the research agenda.

Cover – High Performance Buildings

Executive Summary

The construction and buildings sector consumes enormous amounts of energy, clean water, and materials. Buildings use about one-third of the world's energy — a proportion that will continue to increase as the population grows and becomes more urban and more affluent (Griffith et al. 2007). In the United States today, the building sector accounts for 40% of the primary energy use, compared to 32% for the industrial sector and 28% for the transportation sector. The use of electric power and heat in the buildings sector also accounts for about 40% of U.S. greenhouse gas emissions (GHGs). If current trends continue, buildings worldwide will become the top energy consumers by 2025, and are likely to use as much energy as industry and transportation combined by 2050 (DOE 2007a).

More effective stewardship of our resources contributes to the security, environmental sustainability, and economic well-being of the nation. Buildings present one of the best opportunities to economically reduce energy consumption and limit GHGs. Improving how buildings are designed, built, operated, renovated, and recycled could significantly alter how buildings use energy and other basic resources. This challenge will require the development of new, cost-effective building technologies, practices, and standards, the revision and revalidation of building requirements, and the holistic design of energy and resource use within the building, building site, campus, and community. These include the new technologies and strategies to achieve Net Zero Energy buildings, which over a set time period (typically a year) produce as much energy as they consume, enabling buildings to be energy self-sufficient.

<<Sidebar>>

Construction and Buildings Sector Annual Costs in 2007
Source: http://www.census.gov/const/C30/total.pdf

<<end sidebar>>

The development and adoption of new Net Zero Energy and high-performance building technologies are at the core of addressing this challenge. Today, the industries that create these technologies across multiple business sectors play an increasingly important role in effective resource use and job growth, both in the domestic and the global economy. Thus improving the global competitiveness of buildings-related industries in the United States will contribute to the economic vitality of our nation.

Federal research and development (R&D) investments, in concert with academic and private sector R&D activities, play a critical role in the development of new, high-performance and energy-efficient "green" buildings. Optimizing these R&D investments requires that they be coordinated across the Federal enterprise and aligned with R&D activities in the private sector and academia through an open and broadly distributed Federal R&D agenda. The Federal R&D agenda presented here is the consensus assessment of 16 Executive Branch Federal agencies, along with the Architect of the Capitol and the Smithsonian Institution. These Federal agencies, through the interagency Buildings Technology Research and Development Subcommittee of the National Science and Technology Council, have defined an R&D vision for the technologies required for buildings of the future (Figure ES-1).

Buildings Technology Research and Development Vision

Enable designs of new buildings and retrofits of existing buildings that over the life cycle:

- Produce as much energy as they consume (Net Zero Energy) and significantly reduce GHGs.
- Double the service life of building materials, products, and systems and minimize life cycle impacts.
- Halve the use of domestic water (e.g., to 50 gal/day/person or less), maximize water recycling and rainwater harvesting, and minimize stormwater runoff.
- Achieve breakthrough improvements in indoor occupant health, productivity, and comfort.

Figure ES-1

This Federal R&D agenda contains six major building technology goals that define the major transformational advances needed for energy, water, and material use for Net Zero Energy, high-performance green buildings. Inspired by the building research and owner communities, the goals address R&D needs as well as implementation barriers associated with technologies that could significantly improve building performance and occupant health and productivity. For each goal, focus areas are identified that represent the tasks that must be undertaken to achieve it (see Table ES-1). At the same time, the R&D agenda addresses the relational interdependencies among the broader goals of improving energy efficiency, increasing renewable energy use, reducing GHGs, providing healthy indoor environments, and enabling sustainability of basic resources.

The R&D focus areas in this agenda reflect the technology advances needed to enable widespread availability of cost-effective Net Zero Energy and high-performance technologies, practices, and protocols. The focus areas also include the research needed to overcome barriers to implementation, including fundamental characteristics of the building sector, obsolete or unnecessarily restrictive building codes and regulations, and structural or regulatory disincentives for builders and building owners to invest in green building technologies.

Table ES-1. Goals for Effective Energy, Water, and Resource Use in Buildings

Goal 1. Develop the enabling measurement science to achieve Net Zero Energy, sustainable high-performance building technologies.

Focus Area a. Develop rigorous metrics that enable high-performance building goals to be predicted, assessed, monitored, and verified and new energy-efficient technologies, products, and practices to be developed.

Focus Area b. Enable widespread adoption of high-performance goals by developing practical tools and processes to address the complex interactions of building components and systems throughout the building life cycle.

Goal 2. Develop Net Zero Energy building technologies and strategies.

Focus Area a. Develop building envelope materials, components, systems, and construction techniques to minimize building energy loads.

Focus Area b. Develop ultra energy-efficient components and subsystems that minimize energy use and satisfy building energy needs.

Focus Area c. Develop supply-side technologies that, when coupled with energy efficiency, can achieve Net Zero Energy buildings and communities.

Goal 3. Develop the scientific and technical bases for significant reductions in water use and improved rainwater retention.

Focus Area a. Reduce water use through more efficient water-saving appliances, fixtures, and water systems.

Focus Area b. Develop analyses and technologies to overcome environmental, health, and technical barriers to widespread water recycling and increased rainwater harvesting.

Focus Area c. Develop low-impact development practices to significantly reduce stormwater runoff.

Goal 4. Develop processes, protocols, and products for building materials that minimize resource utilization, waste, and life cycle environmental impacts.

Focus Area a. Develop processes that minimize waste generation from building construction, renovation, and demolition.

Focus Area b. Expand life cycle inventory data and perform life cycle assessments to identify the full environmental and public health impacts of product and material choices.

Focus Area c. Develop new building materials and products with minimal environmental and public health impacts over their extended life cycles.

Goal 5. Develop the knowledge and associated energy efficiency technologies and practices needed to promote occupant health, comfort, and productivity.

Focus Area a. Develop technologies to improve indoor environmental quality and reduce building energy consumption.

Focus Area b. Develop the knowledge necessary to support scientifically sound and building-specific standards and codes that address the health and comfort of building occupants.

Goal 6. Enable technology transfer for Net Zero Energy, high-performance green buildings.

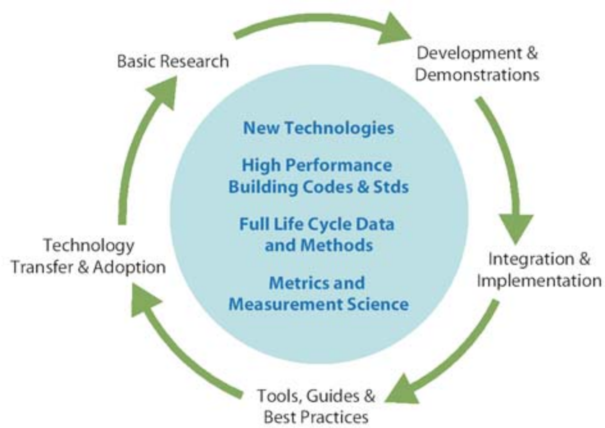
Focus Area a. Develop high-performance building design tools and guidance for urban planners, architects, engineers, contractors, and owner/operators.

Focus Area b. Develop tools and guides that enable the use of modern, adaptive performance-based building codes.

Focus Area c. Analyze cost effectiveness of incentives for adopting and using innovative technologies and practices.

To achieve all the goals identified, the R&D focus areas must be considered in the context of the building as a whole, integrated system. Studies by government and industry researchers have found that using currently available high-performance technologies can reduce a building's energy consumption and CO_2 emissions by 30%–50% (Anderson et al. 2006; Griffith et al. 2007; Levine et al. 2007; USGBC 2007). Furthermore, laboratory studies indicate that new technologies integrated holistically with the building design can reduce energy consumption and CO_2 emissions by as much as 70% (Griffith et al. 2007). With this level of improvement in energy efficiency, on-site renewable energy can in many cases supply the remaining energy needs. To the extent that these technologies become cost effective, they would enable the widespread adoption of Net Zero Energy, high-performance buildings.

Other important considerations for buildings of the future are not addressed in this report. These include improved structural resiliency, the broader environmental and energy impacts of urban planning and siting, and the associated transportation overhead related to occupants' movements to and from their homes and worksites. The scope of this report is limited to the development of new technologies, protocols, and practices at the building site, unless they apply without modification to groups of buildings or communities.



Innovation Cycle

This new Federal R&D agenda is a significant step toward integrating current and new R&D programs that will enable building construction and retrofit to achieve Net Zero Energy, high-performance green buildings goals. The established goals and focus areas represent the shared vision of Federal agencies whose missions include research, development, and demonstration of technologies associated with green buildings. When achieved, these advances in our current knowledge and practice will help define the future of buildings in our nation.

The primary drivers for this report are the Energy Policy Act of 2005 (EPAct 2005, Public Law No. 109-58) and the Energy Independence and Security Act of 2007 (EISAct 2007, Public Law No. 110-140). These two Acts define a broad mandate to develop Federal R&D that will enable residential and commercial buildings to be more efficient and sustainable, and to lower their impacts on the environment while improving occupant health and productivity (see Appendices 9.3 and 9.5 for a detailed summary of these two Acts).

The Zero Net Energy Commercial Buildings Initiative —
The goal of the initiative shall be to develop and disseminate technologies, practices, and policies for the development and establishment of zero net energy commercial buildings for
(1) any commercial building newly constructed in the United States by 2030;
(2) 50 percent of the commercial building stock of the United States by 2040; and
(3) all commercial buildings in the United States by 2050
Source: EISA 2007, Title 4, Subtitle B, Section 422c

The national goal established for commercial buildings outlined in EISAct 2007 provides for a complete transformation of the commercial building sector by 2050.

The following Federal agencies developed the recommendations contained in this report:

- *U.S. Department of Agriculture*
- *U.S. Department of Commerce*
- *U.S. Department of Defense*
- *U.S. Department of Energy*
  - *National Renewable Energy Laboratory*
  - *Oak Ridge National Laboratory*
  - *Lawrence Berkeley National Laboratory*
- *U.S. Department of Health and Human Services*
- *U.S. Department of Homeland Security*
- *U.S. Department of Housing and Urban Development*
- *U.S. Department of the Interior*
- *U.S. Department of Labor*
- *U.S. Department of State*
- *U.S. Department of Veterans Affairs*
- *U.S. Environmental Protection Agency*
- *U.S. General Services Administration*
- *National Aeronautics and Space Administration*
- *National Science Foundation*
- *Executive Office of the President*
- *Office of the Architect of the Capitol*
- *Smithsonian Institution*

0 Introduction

0.1 Background

The need to address the interrelated problems of improving energy efficiency and increasing renewable energy use, maintaining healthy indoor environments, and increasing the sustainability of resources is a global concern. A collection of reports, findings, and policy statements from a broad range of public, private, and nongovernmental organizations highlights this imperative. These include the Zero Net Energy Challenge Conference held in Geneva Switzerland in September 2007, the World Business Council for Sustainable Development (WBCSD) Energy Efficiency in Building Project (www.wbcsd.org), and the North American Commission for Environmental Cooperation's (2008) report, *Green Building in North America: Opportunities and Challenges*. Many also highlight the enormous contribution of commercial and residential buildings to greenhouse gas (GHG) emissions and on the consumption of energy, clean water, materials, and land resources. This report identifies the R&D areas that must be pursued for buildings to substantially reduce energy consumption and to sustain human health, habitation, and environmental resources.

The new technologies and practices arising from these R&D activities will transform how buildings are designed, engineered, constructed, operated and maintained, renovated and reused, and demolished. They will reduce the consumption of energy, potable water, and material resources and the associated emission and pollutant impacts on the building occupants and the environment. High-performance buildings of the future must address the energy and environmental considerations through life cycle assessment (LCA) of buildings and their components, site location, and development impacts.

From an energy perspective alone, high-performance building technologies can already reduce building energy consumption on average by 30-50% (Griffith et al. 2007). New technologies to achieve Net Zero Energy — buildings that over a set time period (typically a year) produce as much energy as they consume — must be developed and integrated holistically into the building design to make buildings more self-sufficient. Other considerations such as conserving water and material resources, improving indoor environmental quality (IEQ), and reducing GHG and other emissions are equally important.

<<Sidebar>>

Characteristics of Commercial Buildings in the United States

U.S. Commercial Buildings (Including Malls), 2003	Number of Buildings (million)	Total Floor Space (billion square feet)	Mean Square Feet per Building (thousand)	Median Square Feet per Building (thousand)
All Buildings	4.9	71.7	14.7	5.0

(Source: DOE Commercial Buildings Energy Consumption Survey 2003)

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Buildings use about one-third of the world's energy — a proportion that will continue to rise as the population grows and becomes more urban and more affluent (Griffith et al. 2007). In the United States today, energy consumption is classified into three sectors: transportation, buildings, and industrial. The building sector accounts for 40% of the primary energy use, compared to 32% for the industrial sector and 28% for the transportation sector (see Figure 1). If current trends continue, buildings worldwide will become the top energy consumers by 2025, and are likely to use as much as industry and transportation combined by 2050 (DOE 2007a).

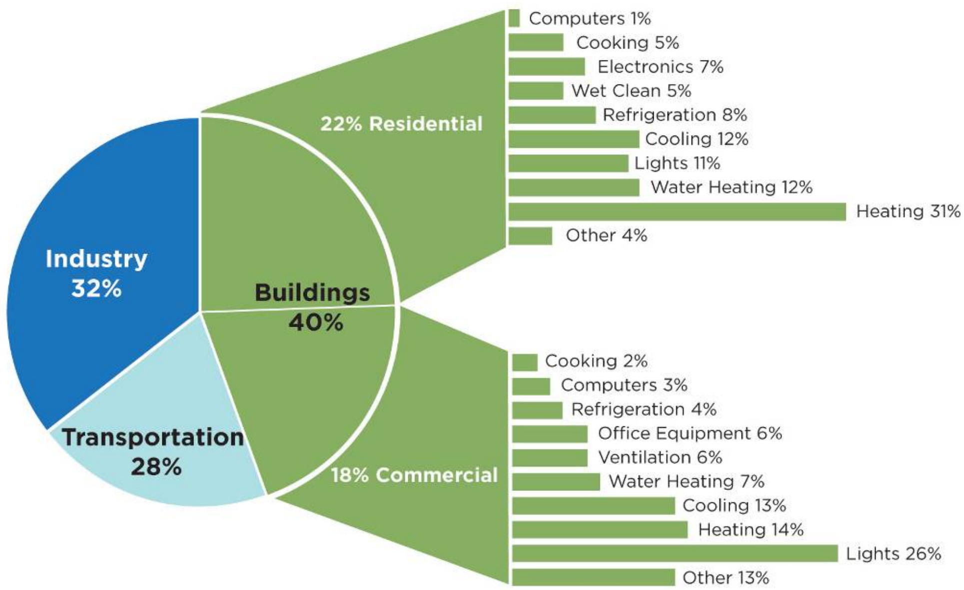

Figure 1. Energy Consumption in the United States
Source: 2007 DOE Buildings Energy Data Book. Tables 1.1.3, 1.2.3, 1.3.3

Energy consumption associated with buildings has a substantial impact on the environment. Within the U.S., buildings account for 40% of total carbon dioxide (CO_2) emissions, 12% of water consumption, 68% of electricity consumption, and 60% of all nonindustrial waste (EPA Green Building Workgroup 2007). Air quality in buildings — where most Americans spend 90% of their time — can be far more polluted than outdoor air because of material emissions, mold growth, and other sources. Buildings must be designed, built, operated, maintained, renovated, and demolished in ways that reduce their environmental footprints to ensure adequate supplies of energy, water, and other resources, to protect human health and safety, and to curtail the projected growth of CO_2 emissions and other pollution and ecosystem disruptions.

McKinsey & Company (2007), working with major industry players such as Shell Oil, Pacific Gas & Electric, and DTE Energy, found that improving energy efficiency in buildings and appliances is the least costly way to reduce a large quantity of carbon emissions (i.e., by an estimated 710 to 870 million metric tons of CO_2 equivalent per year by 2030). To achieve national goals such as Net Zero Energy buildings (NREL 2003), Federal R&D investments must help private companies and nonprofit entities develop advanced products and tools that will be competitive in the building supply market. Once introduced, these new technologies will likely spur new competition, resulting in low-cost products for a wider range of consumers.

The Intergovernmental Panel on Climate Change (IPCC 2007a) stated that the largest energy and carbon savings potential by 2030 is in retrofitting or renovating buildings over the whole building stock (rather than in new buildings alone), because of their slow turnover. In 2005, the U.S. stock of residential and commercial buildings consumed almost 40 quadrillion Btu of energy (DOE 2007a). Yet new construction is also extremely important: projections indicate 34 million new homes and a 48% increase in commercial building floor space (73 to 108 billion square feet) will be constructed between 2005 and 2030 (McKinsey & Company 2007). Any significant improvement in the aggregated energy efficiency of buildings must therefore address both new and existing buildings.

<<Sidebar>>

Characteristics of Residential Buildings in the United States

U.S. Housing Unit Characteristics 2001 (in millions of units)	Total Number of Housing Units, including Seasonal	Single Family Housing	Multifamily Housing	Manufactured Housing
All Buildings	124.4	84.7	31.0	8.6

(Source: Table 1A-1, American Housing Survey for the United States: 2005, HUD and DOC)

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The scope of this report goes beyond current technologies and identifies a range of new technologies that will enable Net Zero Energy, high-performance green buildings. This report includes discussion of R&D needs for commercial and residential buildings, and identifies goals in Federal R&D needed to achieve significant improvements in energy efficiency and resource sustainability. These goals provide the basis for Federal R&D investments into future high-performance buildings research. The conclusions contained in this report are intended to complement recent findings by the U.S. Green Building Council's National Green Building Research Agenda (USGBC 2007), the United Nations Environmental Programme — Sustainable Buildings and Construction Initiative (2007), the IPCC (2007b), and other recent publications.

To achieve the goals outlined in this and other reports, the scope of the R&D must address the interrelated issues of enhanced energy efficiency and increased renewable energy use, improved occupant health and productivity, and sustainability of basic resources. These goals represent technology advances that must be pursued through an integrated, systematic approach for the entire building system.

The anticipated outcomes of this research agenda will be a suite of evaluated technologies, tools, and practices that, when optimally applied, will enable high-performance building technologies to be cost-effectively deployed across a wide range of new and existing buildings (see Figure 2). The goal is that all buildings will be designed and retrofitted by using tools and guidelines that can minimize their consumption of energy, potable water, and natural resources, reduce emissions and other pollutants, and ensure that all design performance standards are met. With these tools, building designers, owners, and operators will be able to evaluate alternatives for renovating and repurposing these structures to make informed decisions based on intended use, performance and design goals, and total life cycle cost.

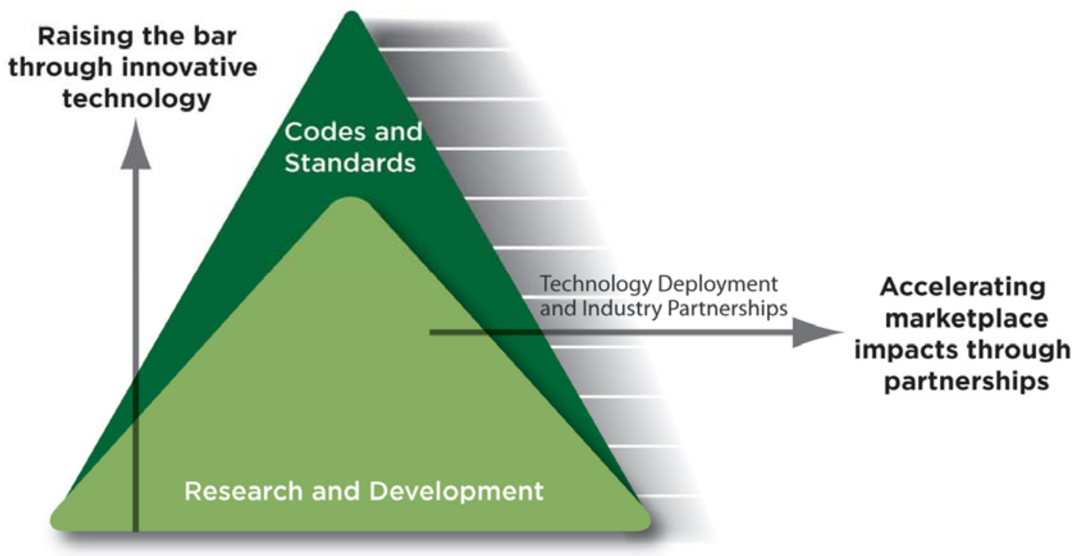

Figure 2. R&D Agenda Outcomes

Future building codes and regulatory and building permitting requirements based on sound scientific data will facilitate the adoption of resource-saving building designs and improve the indoor environment for the occupants. The aggregated costs of making these improvements will be clearly and demonstrably offset by resource savings over the estimated life cycle of the buildings. And, just as important, building resources will be conserved and emissions and other pollutants will be reduced or eliminated.

To achieve these goals, new technologies arising from federally sponsored R&D must become readily available to the entire construction industry — from multinational construction firms to "mom and pop" companies or do-it-yourself homeowners. Standards, tools, and guidance must be developed that focus on every facet of the building sector — residential, commercial, and institutional — and include new construction and retrofit technologies. This will be a major challenge, but the projected benefits will have significant impacts on global energy and resource supplies and occupant health and productivity for years to come.

<<Sidebar>>

Characteristics of U.S. Government Real Assets Worldwide (2006)

Total Federal Assets	Total Building Assets	Total Land Records	Total Area of Building Assets
1,253,821	505,559	239,899	3.87 billion square feet

(Source: GSA Federal Real Property Council (FRPC) 2007,
http://www.gsa.gov/gsa/cm_attachments/GSA_DOCUMENT/FRPP112007_R2-tI3-v_0Z5RDZ-i34K-pR.pdf
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0.2 Federal Research, Development, and Deployment Activities

Federal agencies have a long and successful history of activities related to resource use, energy efficiency, and renewable energy technologies for buildings and facilities. This includes R&D and the deployment of state-of-the-art technologies (see Table 1).

Table 1. Select Federal Building Programs

Federal Agency	**Deployment Activities**
U.S. Environmental Protection Agency	ENERGY STAR® Green Infrastructure Environmentally Preferable Purchasing Smart Growth
U.S. Department of Energy	Builder's Challenge Building Energy Codes Commercial Building Energy Alliances ENERGY STAR®
U.S. General Services Administration	Energy Center of Expertise Program High-Performance Green Federal Buildings Program
U.S. Department of Health and Human Services	Energy Management Program Sustainable Buildings Program
U.S. Department of Housing and Urban Development	Partnership for Advancing Technology in Housing Program Healthy Homes Demonstration Program
U.S. Department of State	Natural Hazards Program Energy & Sustainable Design Program
U.S. Department of Veterans Affairs	Sustainable Design & Energy Reduction
	Research and Development Activities
National Institute of Standards and Technology	Healthy and Sustainable Buildings Program Cybernetic Building Systems Program Prediction & Optimization of Concrete Performance Program Service Life of High-Performance Polymeric Materials Program
National Science Foundation	Energy Efficient Materials and Efficient Material Use Energy for Sustainability/Efficient Energy Supply Partnership for Advancing Technology in Housing Program Partnership on Environmental Technologies and Systems
Smithsonian Institution	Smithsonian Environmental Research Center Smithsonian Tropical Research Institute
U.S. Department of Agriculture	Advanced Housing Research Center Program Moisture Management in Energy Efficient Housing Sustainable Design and Building Deconstruction Rainwater Harvesting Research Program

0.3 Research, Development, and Demonstration Recommendations

The R&D agenda presented in this report supports the high-level goals and focused R&D that are needed to improve the energy, water, and resource efficiency of buildings, reduce their emissions of pollutants, and improve IEQ. The research, development, and demonstration recommendations respond to the needs of commercial, residential, and institutional building owners for economically viable and deployable high-performance building technologies. The overall goal of this effort is that scientists and engineers in the public and private sectors will identify with these goals and focus areas, coordinate their activities, and work synergistically to overcome technological and institutional barriers to achieving Net Zero Energy, high-performance green buildings. The scope of the goals and focus areas covers all commercial, institutional, and residential buildings.

Developing a Federal R&D agenda to realize these goals is a significant step toward developing Federal R&D programs that will overcome technical and institutional barriers to Net Zero Energy, high-performance green buildings. The R&D goals and focus areas described in this report represent the collective vision of all Federal agencies whose missions include the research, measurement science, development, demonstration, and adoption of energy efficiency technologies.

Section 1 of this report addresses the tools, metrics, and measurement science needed for integrated, performance-based building design and operation. Section 2 addresses the key R&D focus areas needed to achieve Net Zero Energy buildings. Section 3 summarizes R&D focus areas for reducing water use and rainwater retention, Section 4 addresses material use and waste reduction, and Section 5 discusses occupant health and IEQ. Section 6 includes a discussion of advances needed to overcome barriers to implementing new technologies, protocols, and practices that will result in Net Zero Energy, high-performance green buildings. Sections 7 and 8 review the collection, analysis, and dissemination of these research results and provide conclusions and next steps.

1 Integrated, Performance-Based Design, Construction, and Operation

Goal 1: Develop the enabling measurement science to achieve Net Zero Energy, sustainable, high-performance building technologies.

R&D Focus Area 1a

Develop rigorous metrics that enable high-performance building goals to be predicted, assessed, monitored, and verified and new energy-efficient technologies, products, and practices to be developed.

In its report, *A National Green Building Research Agenda*, USGBC (2007) notes the need for integrated, transformational solutions to reach Net Zero Energy buildings:

> "…to achieve Net Zero Energy buildings, prescriptive, independent measures will no longer suffice. Leaps forward in building performance require design that fully integrates building systems…"

There is a limit to the overall energy savings potential of mainstream approaches for reducing energy use in new buildings. Major national studies agree that this limit ranges from 30% to 50% (Anderson et al. 2006; Griffith et al. 2007; Levine et al. 2007; USGBC 2007). Integrating technologies with the building design (form) to create a building that delivers efficiency as a single system, however, can raise savings to 70% of building energy use compared with conventional new building design (Griffith et al. 2007). With these dramatic reductions, renewable energy could provide the remaining energy needs and enable the widespread adoption of Net Zero Energy buildings (see Figure 3 using solar power or other renewable resources).

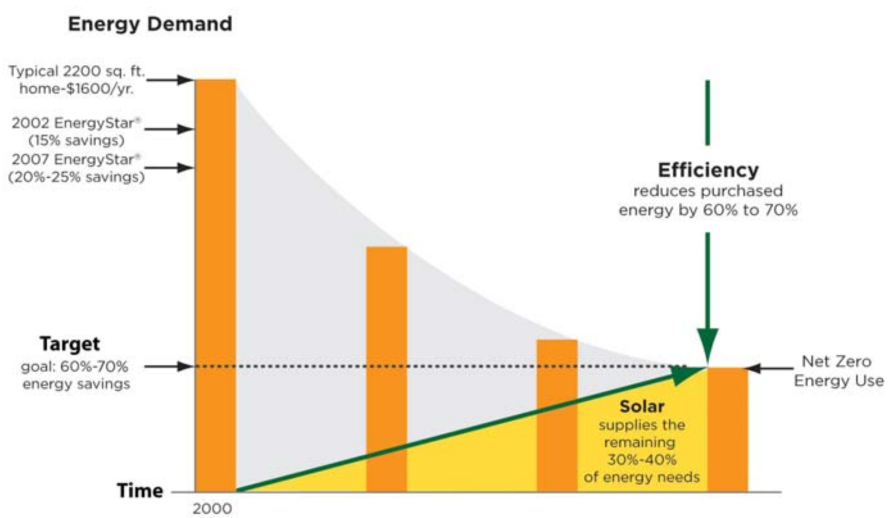

Figure 3. Approach for Achieving Net Zero Energy Buildings

New construction offers the greatest energy savings potential on a building-by-building basis, but the greatest potential on an overall, national basis lies with improvements to existing buildings (North American Commission for Environmental Cooperation 2008) because of their slow turnover (~1%/yr). Integrated, performance-based retrofits and renovations have reportedly led to operational savings of 40% to 75%, respectively (Adelaar et al. 2008).

To enable a transformation to performance-based design and operation of the nation's buildings, next-generation metrics, methods, and tools must be developed that permit a building's energy use to be seamlessly predicted, monitored, controlled, and minimized across the dimensions of performance, scale, and time. To achieve this, a building needs to be evaluated as a single, durable good. Its complex component systems are integrated during design and perform as a whole throughout its life cycle, including construction, operation and use, renovation, and waste management. The technical and nontechnical barriers that prevent this transformation are enormous, but so are the opportunities for significant, cost-effective energy and carbon reductions. Indeed, in 2007, the Nobel prize-winning Intergovernmental Panel on Climate Change identified the building sector as having the highest GHG emissions, but also the best potential for dramatic emission reductions (IPCC 2007a), such as those from Net Zero Energy buildings.

1.1 Performance Metric Integration

Many international governments, organizations, and industry sectors realize the importance of developing and harmonizing credible, science-based environmental performance metrics.

International activities have been organized by numerous organizations: the United Nations Environmental Programme and Society for Environmental Toxicology and Chemistry (UNEP/SETAC Life Cycle Initiative); the Organization for Economic Cooperation and Development (Evaluation of Green and Other Sustainability Indices for the Biobased Economy); European Union Joint Research Center (program to establish in a transparent and objective manner, a consensual well-to-wheels energy use and greenhouse gas emissions assessment of a wide range of automotive fuels and power trains relevant to Europe in 2010 and beyond); and the Secretariat of the Global Bioenergy Partnership (GBEP), launched May 2006 at the 14th Session of the UN Commission for Sustainable to promote the use of bioenergy (http://www.globalbioenergy.org/).

National activities have been organized by USGBC (LCA into LEED program); the American Society of Civil Engineers (17-member alliance, Practice, Education, and Research for Sustainable Infrastructure); and the State of California (protocols for measuring the life cycle carbon intensity of transportation fuels). The European Union carbon trading systems are also attracting considerable attention (Buck 2007). International standards have been developed for eco-labeling, which rates environmental performance across a comprehensive range of environmental concerns and life cycle stages such as production, use, and waste management (International Organization for Standardization 2006).

Throughout its November 2007 report, *A National Green Building Research Agenda*, USGBC (2007) stresses the need for performance metrics and tools. With reference to programs related to climate change, the report states: "The 2030 Challenge, Zero Carbon,

Carbon Neutral, Zero Impact, The One Liter House, and others are examples of challenges posed to the research and design community for standardizing metrics and benchmarks." Noting that a key barrier to widespread adoption of green building technologies is the question of how much benefit is obtained and at what cost, the report cites the need for basic research to "develop protocols for measurement and an integrated database of measured performance at various project scales."

To address these national needs, R&D geared at developing new measurement science for building energy technologies is needed. Measurement science in this context includes the following:

- Performance metrics and measurement methods
- Tools to predict performance
- Protocols to achieve desired performance
- Evaluation and assessment of the performance of technologies, systems, and practices
- Performance-based standards and practices.

Specifically, the nation needs measurement science for evaluating and integrating the life cycle energy, environmental, and economic performance of buildings.

Energy Performance

Building energy consumption can be reduced by about 30%–50% by using a broad array of currently accessible and cost-effective technologies. The remaining reduction can be achieved only with innovative building technologies that are enabled by measurement science. Measurement science is needed to quantify the installed energy performance of building components and systems, optimize control system performance, detect and respond to performance degradations, and provide metrics and standards to assess the performance of emerging building energy technologies. Specifically, the following three areas of measurement science need to be addressed to develop credible measures of the technical performance of carbon-intensive technologies:

Achieve energy use reductions in buildings through in-situ performance measurements. The energy performance of buildings frequently fails to meet design goals. Typically only the total energy consumed within a building, measured by a single electricity or gas meter, is available to building owners and occupants. Providing a new measurement system that enables owners and occupants to see real-time energy consumption segregated by end uses, such as plug loads, lighting, and major appliances, will lead to informed energy use decisions and practices. Additionally, advanced nondestructive measurement systems are needed to identify construction defects such as insulation voids as a tool to improve the quality of construction practices. Research resulting in the development of sensors that enable such informed energy use decisions and constructions practices must be implemented in user-friendly displays.

Achieve building energy use reductions through embedded intelligence. Building systems almost never achieve their design efficiencies during building operation, and their performance typically degrades over time. Case studies indicate that energy consumption for heating, ventilation, and air-conditioning can be reduced 20% just by detecting mechanical faults and ensuring that systems are operating correctly (TIAX LLC 2005). The key to realizing these improvements is to combine new measurement technology and performance metrics with analysis techniques that can be implemented in building automation and control products. The resulting systems have a distributed, embedded intelligence that automatically detects and responds to faults, operational errors, and inefficiencies (see also Section 2.2).

Develop measurement science for emerging building energy technologies. Energy and energy efficiency, like many other environmental and health impacts of buildings, are invisible attributes. Potential users of building technologies require actual, as opposed to advertised or rated, performance measures before making capital investments. Credible performance measures, combined with tools, performance data, and design guidelines, will create market demand for emerging building energy technologies, economies of scale, and reduced capital costs. To facilitate the development and commercialization of these technologies, measurement science is needed in the areas of distributed energy sources, such as improved power measurement methods for photovoltaics (PV), location-sensitive performance prediction tools for fuel cells, measurements and standards for solid-state lighting, three-dimensional performance metrics for advanced insulation systems, and performance prediction tools for innovative building materials.

Environmental and Economic Performance

Proponents of green buildings seek significant reductions in the industry's life cycle environmental impacts, but environmental science and economic reality suggest that this goal may not be easily achieved. For the foreseeable future, the greatest national energy saving potential lies with improvements to existing buildings. Promising R&D opportunities may not be adequately researched and commercialized if their environmental and economic outcomes are uncertain. Addressing the following R&D needs will help directly link building energy technology innovation to long-term environmental and economic benefits and costs the following R&D needs must be addressed:

Develop next-generation environmental impact assessment methods. Measurement science must be developed that rigorously tracks building energy performance. Performance must be measured throughout the entire life cycle of building systems, components, and materials, from raw materials acquisition through manufacturing, transportation, installation, use, and ultimately, end-of-life waste management. Yet these metrics cannot be developed in a vacuum. To avoid the possibility that energy reductions are achieved at the cost of exacerbating other environmental and public health concerns, companion metrics must be developed to quantify and integrate all these concerns. This will require measurement science and performance metrics for issues such as IEQ, material and land use, and water use (see also Sections 3, 4, and 5).

Develop protocols and tools for building-scale performance evaluation. To enable consistent, meaningful comparisons of the life cycle environmental performance of building technology alternatives in the whole building context, standard measurement protocols must be developed. Using these protocols, national baseline databases should be compiled to report life cycle environmental performance for a range of existing and future building types, energy technologies, and climate zones. These metrics and protocols, particularly those related to carbon measurement, must be harmonized with those being developed for other industry sectors such as agriculture.

Develop life cycle cost databases. The Office of the Federal Environmental Executive (2003) green building report cites detailed Statutes and Office of Management and Budget guidelines, such as those identified in this report (see Appendix 9.3), calling for life cycle cost-based analyses for Federal capital investments, and notes that despite these mandates, first-cost decisions often prevail and impede more environmentally preferable building opportunities. It cites "increased use of performance-based standards and life cycle costing" as a critical national need. To address this need, databases reporting initial and future costs for a range of building types, energy technologies, and U.S. climate zones — consistent with those developed for environmental performance — should be developed that enable standard building life cycle costing tools to be readily applied.

Integrated Performance Evaluation

On the subject of innovation in its 20-year technology roadmap, *High-performance commercial buildings: a technology roadmap* (DOE 2000), the commercial building industry emphasizes the need for clear, integrated performance metrics:

> Overcoming technology barriers will certainly be vital. Achieving the integrated, "smart" buildings of the future, together with higher levels of energy- and resource-efficiency, will require continued research and development, with a focus on system integration and monitoring, as well as component optimization. Although technology challenges are significant, they are dwarfed by the need for clear performance metrics that make a compelling economic case for and help define high-performance commercial buildings. (See also Figure 4.)

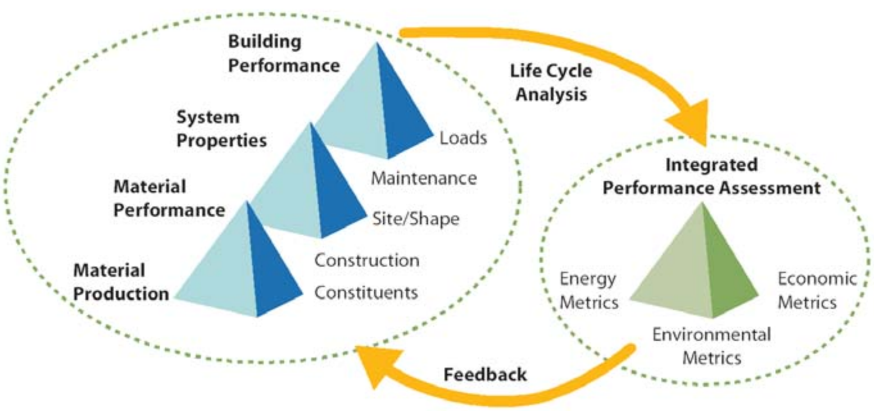

Figure 4. Integrated Performance Evaluation
Adapted from Lepech, M. "A Paradigm for Integrated Structures and Materials Design for Sustainable Transportation Infrastructure" PhD. Thesis, University of Michigan, 2006.

To realize this vision, the following three research needs must be addressed.

Develop integrated performance metrics. To spur investment in sustainable technology development, multidimensional indices must be developed that harmonize and integrate energy, environmental, and economic metrics. These indices would enable comparisons of buildings employing advanced energy technologies with their baseline counterparts on the basis of their business value. A carbon efficiency ratio, for example, would indicate the change in life cycle costs per metric ton of life cycle carbon saved. A more comprehensive eco-efficiency ratio would measure dollars saved per unit improvement in overall life cycle environmental performance. The final form of these integrated performance metrics must be developed with industry input to ensure their sustainability performance measurement needs are met.

Assess trade-offs. Noting the critical nature of environmental challenges in addition to energy and climate change, the North American Commission for Environmental Cooperation (2008) recommends that performance metrics across a full range of environmental impacts be developed and integrated. Yet all environmental impacts are not equally important. A 2006 panel convened by the National Institute of Standards and Technology (NIST) to facilitate the synthesis and comparison of the overall environmental performance of building products judged global warming, weighted at 29%, as the most important impact, yet not so important that decisions can be made solely on its basis. Other important concerns included fossil fuel depletion, air and water pollution, human health, and water and land use (Gloria et al. 2007). To enable integrated, practical environmental performance measurement tools to be developed and standardized, national and regional weight sets must be investigated, developed, and adopted at the State and Federal levels.

Implement building scorecards, rating systems, and labels. Successful implementation of integrated performance metrics requires decision-making tools such as rating systems, scorecards, and eco-labels. The popular EnergyGuide appliance ratings exemplify effective market transformation through performance metrics. Next-generation rating systems and labels that transfer more complex, multidimensional performance measures into readily understood terms will enable widespread recognition and adoption of high-performance goals. Once implemented in regionally-specific databases, communities and governments at all levels will be able to maintain report cards to accurately assess and track their contributions to climate change and other environmental concerns. This in turn will support development of sound uniform carbon trading metrics and environmental scorecards and provide a context for action to further reduce the industry's environmental footprint.

R&D Focus Area 1b

Enable widespread adoption of high-performance goals by developing practical tools and processes to address the complex interactions of building components and systems throughout the building life cycle.

1.2 Design Integration

Building systems, components, and equipment too often are designed and implemented based on independent, prescriptive criteria. Through an integrated design approach, however, all components and subsystems are considered together in an effort to optimize overall building performance. Indeed, case studies have shown building energy savings of 30%–70% for design solutions that integrate dynamic, operable, high-performance “envelope” components and systems — those for roofs, walls, windows, and doors — to manage thermal loads (Griffith et al. 2007). Designing for effective daylighting, ventilation, and passive solar energy management, for example, could yield energy savings approaching 40%, without advances in individual technology efficiencies.

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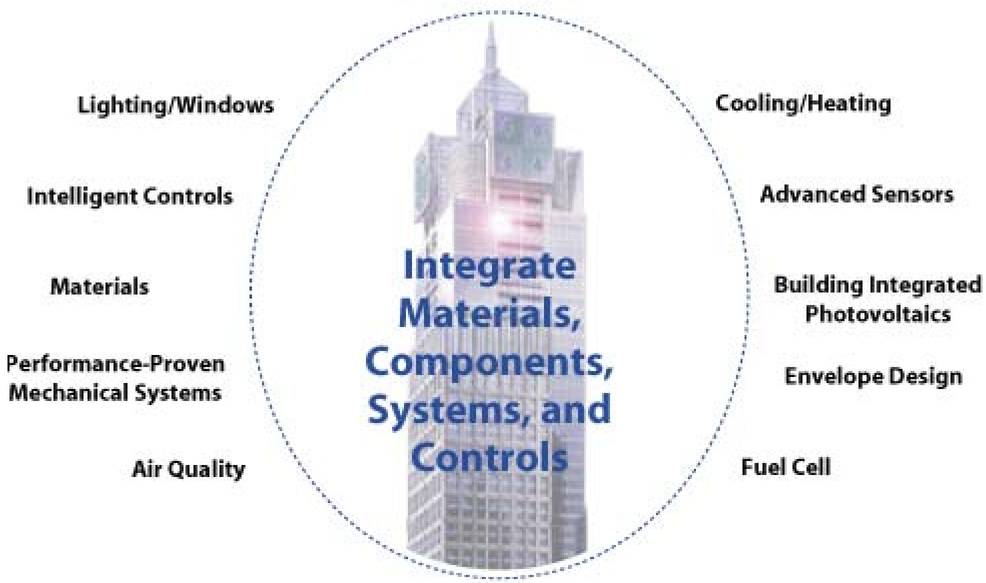

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Develop practical tools and information models. Integrated design for energy-efficient, high-performance buildings begins with the practical application of sound performance metrics. This requires major advances in the capabilities and user friendliness of building information modeling (BIM) and simulation tools for optimizing the design and operation of buildings. These next-generation tools and models will permit integrated energy modeling of advanced technologies, provide the capability to perform “what if” analyses, and help optimize energy-related design parameters and high-performance buildings.

Building energy simulation tools predict the energy performance of specific buildings based on extensive databases of building physics, climatological information, and engineering calculations involving thousands of measurement methods and computations (ANSI/ASHRAE 2007; Torcellini et al. 2006). Fundamental research is needed to validate the results of building energy simulations, to seamlessly integrate simulation results back into the BIM tools, and to develop the digital generation of building energy performance standards that will drive the design and optimization techniques. This, in turn, will enable baseline building databases to be developed that show interactions among technologies and provide a platform for measuring building-level performance, including carbon footprint and other eco-efficiency metrics. For maximum impact, the results of these sophisticated analyses should be disseminated with simple life cycle costing tools to justify energy efficiency investments through future cost savings for the residential and small commercial markets. Together, advanced modeling, tools, and data, combined with practical design and retrofit guidance, will permit the development of solutions that can be readily implemented at different levels of energy efficiency, including solutions that create Net Zero Energy buildings.

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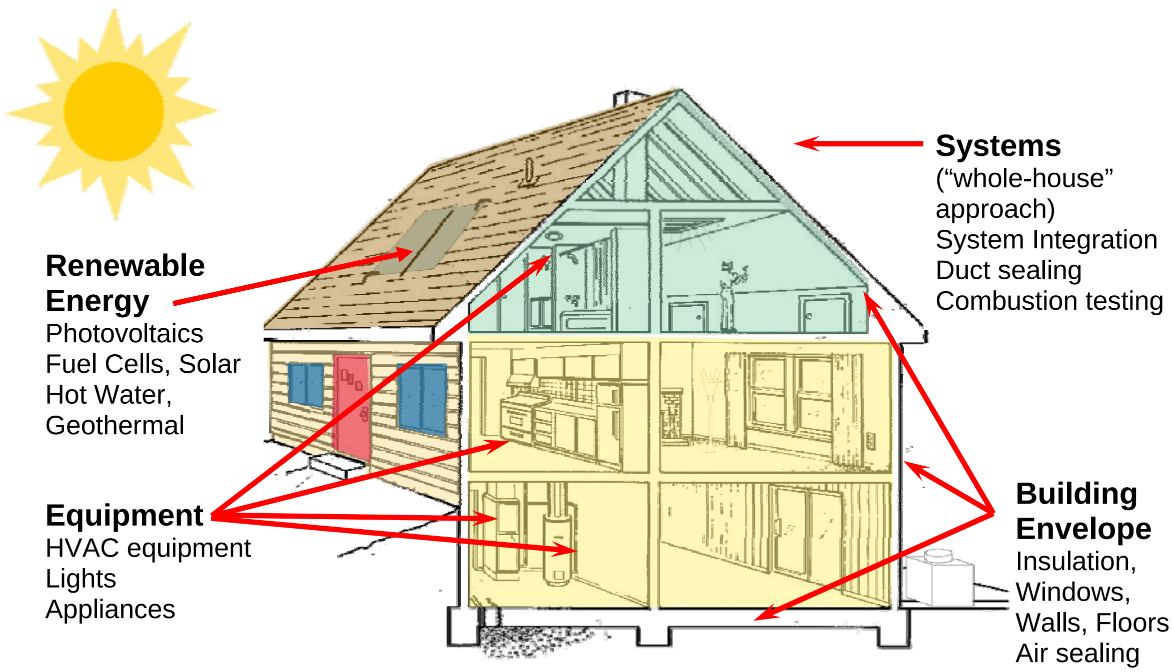

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Integrate the life cycle. Although new energy-efficient components and systems have significantly improved building energy performance over the past 30 years, the life cycle energy savings are often significantly less than projected. Performance deficiencies pervade buildings. The most comprehensive study of building deficiencies to date found an average of 32 deficiencies per building in existing buildings and 67 in new buildings (Mills et al. 2004). U.S. Department of Energy case studies of six high-performance buildings indicate a gap between design intent and construction that results in reduced energy performance (Torcellini et al. 2006). Building energy efficiency is further compromised when materials, systems, and components fail before the end of their expected service lives: producing and installing replacement products more frequently adds to a building's life cycle carbon footprint and other environmental impacts.

To ensure that Net Zero Energy buildings of the future perform as intended, validation test procedures, guidelines, system commissioning, and performance monitoring tools must keep pace with energy technology advances (Haves et al. 2007). Ongoing, reliable verification that ever-advancing component systems are meeting design expectations throughout the building life will require advances in building information modeling that permit the capture of critical design parameters and performance metrics. Research is also needed to enable seamless integration of system components and the creation of distributed, embedded diagnostic tools that monitor individual system components and system-level interactions. These ongoing performance monitoring systems must be integrated with commissioning tools to enable continuous building recommissioning. Implemented in simple tools, the building industry can then evaluate a building as a single, durable product with ongoing, automated monitoring and control processes that can be aggregated to provide a building-level performance evaluation to ensure it operates as intended throughout its life.

2 Net Zero Energy Building Technologies and Strategies

Goal 2: Develop Net Zero Energy building technologies and strategies.

The greenest energy is the energy that is not used. The energy and GHG footprint of new buildings can be reduced on average by 40% by using current technologies for energy efficiency, assuming the challenges of integrated whole-building design, construction, and operation can be overcome, made affordable, and effectively transferred to mainstream practitioners. However, energy-efficient and direct-use renewable energy technologies — in the forms of cost-effective materials, components, subsystems, and construction techniques — still have enormous potential for energy savings at lower cost than acquiring supplies from traditional or renewable power sources. At the same time, renewable power and other supply technologies also have enormous advancement potential.

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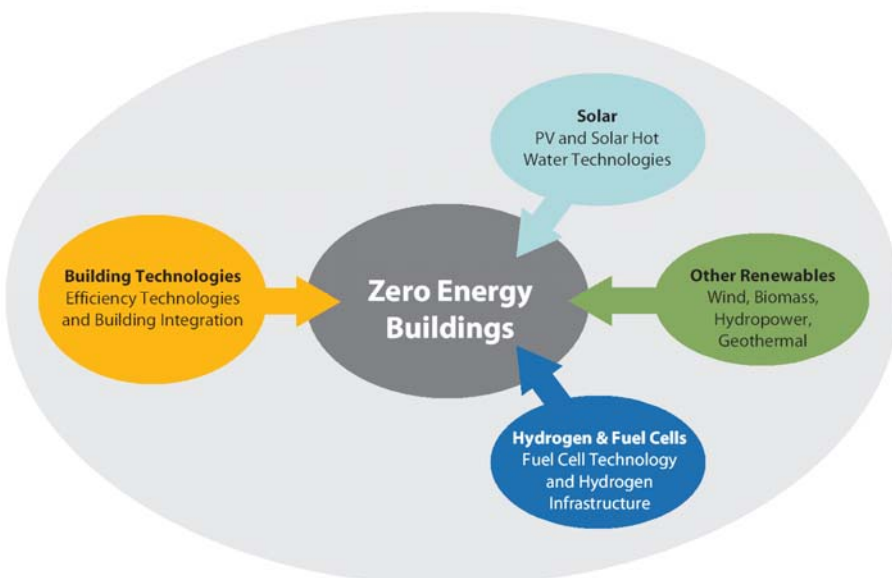

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This section addresses three major issues:

- R&D for advancing efficiency and direct-use renewable technologies that save energy by improving the building envelope (the fabric separating the indoor and outdoor environments) and reducing energy loads (needs).
- R&D for building components and subsystems that are responsible for satisfying the building loads more efficiently.
- Building- and community-scale energy supply-related technologies.

These R&D programs are necessary to keep the pipeline of new cost-effective technologies and practices flowing. The results from these programs will have a major impact on how commonplace integrated whole-building design, construction, and operation becomes, and how far beyond 30–50% savings new buildings can affordably go. These research programs also determine how much energy and GHG can be reduced in existing buildings, by expanding the portfolio of retrofit techniques and technologies and deepening the savings levels achievable.

From an architectural perspective, the building design (form) and siting are necessary considerations for Net Zero Energy, high-performance green buildings. The overall form of the structure, the climate considerations, and its location and orientation to the sun in relation to the immediate environs, including other structures, will all affect the efficiency and effectiveness of the building. Locating a building with convenient access to mass transit or to other efficient modes of transportation may also significantly reduce the indirect energy use over the life of the building. Although building design, location, and siting considerations are important, these factors are generally well understood and require universal implementation rather than significant new R&D.

R&D Focus Area 2a

Develop building envelope materials, components, systems, and construction techniques to minimize building energy loads.

2.1 Envelope Load Reduction

The building envelope is critical for reducing building energy loads. It is the starting point for energy-efficient buildings and the main determinant of the amount of energy required to heat, cool, and ventilate. It can also significantly influence lighting energy needs in areas that are accessible to sunlight. Specifically, it determines how airtight a building is, how much heat is transmitted through thermal bridges (which breach insulation and allow heat to flow in or out), and how much natural light and ventilation can be used (World Business Council for Sustainable Development 2007).

In 2005 the U.S. stock of residential and commercial buildings consumed almost 40 quads (quadrillion [10^{15}] Btu) and the building envelopes contributed significantly to the amount of energy consumed for heating, cooling, and ventilation, which totaled 57% or nearly 23 quads (DOE 2007a). The largest portion of carbon savings achievable by 2030 in the buildings sector derives from retrofitting inefficient buildings that are already in place (IPCC 2007a). New construction, though, remains extremely important: 34 million new homes and a 48% increase in commercial building floor space (73–108 billion square feet) are projected between 2005 and 2030 (McKinsey & Company 2007).

Energy is used during the five phases of the building's life cycle: (1) manufacture of products and components; (2) transportation of products and components to the construction site; (3) construction; (4) operation; and (5) demolition and recycling (United Nations Environmental Programme 2007). More than 80% of energy use over a building's life typically occurs during the operational phase (World Business Council for Sustainable Development 2007), so the primary R&D focuses on developing affordable, durable, and reliable envelope technologies to reduce operational energy use.

A simple strategy for reducing heating and cooling loads is to use appropriate levels of insulation, optimize the glazing area, and minimize the infiltration of outside air to isolate the building from the environment. Advancements in materials, components, and subsystems promise high-performance, climate-optimized use of the building envelope as a filter that selectively accepts or rejects solar radiation and outside air depending on the need for heating, cooling, ventilation, and lighting at that time, and uses the heat capacity of the building structure to shift thermal loads on a time scale of hours to days (IPCC 2007a).

Enhance the use of solar heat and light, energy storage, and natural ventilation. Surface material selection is a critical part of building design in that it has enormous impacts on energy performance, thermal comfort, and glare control. Engineering innovation and subsystems integration research are needed to produce cost-effective window technologies (including strategies for glazing and shading) for effective daylight distribution without glare or unwanted solar heat gain, and to optimize control strategies for a range of climates and orientations. This research should include evaluating improved skylights, tubular daylighting, and other systems for penetrating sunlight more deeply into the core of buildings. Research is also needed to develop surface materials that reduce or increase solar heat gains through opaque roof, wall, and above-grade foundation surfaces.

New systems and materials must be developed that provide reliable, durable solutions for passive storage of thermal energy in buildings to flatten heating and cooling load profiles and to minimize peak energy demands, overheating from solar gain, and mismatches between the need for and availability of recycled energy from traditional waste streams such as graywater and ventilation exhaust. Research is needed to provide reliable, durable solutions that integrate natural ventilation into envelope components to make them self-cooling, self-drying, and contributors to IEQ (see Executive Summary, Goal 5). Activities within this topic would be to develop new technologies and analyze their performance for various climates, orientations, and building types.

Reduce the impact of moisture and air infiltration. In cold climates, uncontrolled exchange of air between the inside and outside of a building can be responsible for up to half of the total heat loss; and in hot-humid climates, air leakage can be a significant source of indoor humidity (United Nations Environmental Programme 2007). Inappropriate moisture levels in building environments can impact occupant health and performance (see also Section 5.1) and moisture, in all its physical forms, is commonly regarded as the single greatest threat to the durability and long-term performance of the housing stock. Excessive exposure to moisture is a common cause of significant damage to many types of building components and materials; it can also lead to unhealthy indoor living environments (Partnership for Advancing Technology in Housing 2004; see also Section 5.1).

The single most important factor in reducing the impact of embodied energy is to design long-lived, durable, and adaptable buildings. Extending the life spans of buildings defers energy and costs associated with demolishing and constructing new buildings (United Nations Environmental Programme 2007). Research is needed to advance the fundamental understanding of the flow of heat, air, and moisture through building envelope materials and assemblies; develop and validate models; and apply models and field research to develop and demonstrate highly insulating, airtight, and moisture-tolerant envelope systems (IPCC 2007a).

Several promising concepts are on the horizon. Coatings and application techniques that use superhydrophobic materials (those that are very difficult to wet) and make building envelope materials immune to mold, mildew, rain, and flood damage would extend building life, save embodied energy, and foster healthier indoor environments. The same is true of envelope membranes whose air and moisture permeability (openness to passage of air and moisture) increases or decreases dynamically in response to surface conditions, advanced insulation materials that may be integrated into air and vapor barriers, and methods to detect envelope breaches.

Develop construction techniques that enable superior technology integration and materials waste reduction, recycling, and reuse. The disparity between the predicted and as-built performance of buildings suggests that today's technologies are far from foolproof in the hands of design practitioners, construction and retrofit laborers and supervisors, code officials, and building operators. For homes and buildings to approach Net Zero Energy and still be affordable, a new level of whole-building design sophistication must be achieved and sustained throughout construction, operation, demolition, and recycling. This includes integrating BIM data into energy modeling tools to evaluate performance during the actual engineering design process (see also Section 1.2). Achieving the full energy savings potential using the technologies described here will require a level of integration precision during the construction phase far beyond the capabilities of conventional practice.

Many technologies are available whose full benefits can be realized only with improved construction techniques. Soffit-to-ridge, above-sheathing natural ventilation does a wonderful job of sweeping solar heat gain off a sloped roof, but only with the correct air gap width between the sheathing and roof surface, which varies with slope and other factors. Walls and roofs can passively self-cool and dry with natural ventilation and, with the help of a solar-cell-powered damper induce air flow for IEQ or free cooling. But reliable and precise construction will be required for such approaches to be successful.

Conventional construction practices waste enormous amounts of materials — construction of a typical single-family home generates 2 to 4 tons of waste (Donnelly 1995; see also Section 4). Conventional construction is also very hazardous — about 400,000 injuries occur annually in the United States and more than 1,200 workers lost their lives in 2004 (Meyer and Pegula 2006). Research is needed to develop cost-effective approaches to greater automation and improved controls in the construction process to reduce materials waste; make greater use of natural and recycled content and biobased materials; reduce injuries; cost and build time; achieve greater durability and longevity; and achieve compatibility with emerging BIM-driven design, engineering, construction, operation, and repurposing life cycle concepts. The energy benefits of the new approaches will be greater realization of the energy savings potential of integrated whole-building design and use of advanced envelope technologies.

R&D Focus Area 2b

Develop ultra energy-efficient components and subsystems that minimize energy use and satisfy building energy needs.

2.2 Component Efficiency

Homes and other buildings encompass a large and diverse set of components and subsystems to satisfy the lighting, comfort, and other needs of their occupants in various climates. There are many energy end uses and a diversity of function (e.g., homes, offices, and restaurants) in buildings, especially those for commercial and institutional use. Because buildings have a slow turnover rate, many vintages of components and subsystems are still in service. Some components and subsystems can be economically renewed during a building's life span to make it more energy efficient. Newly constructed buildings, though, provide the best opportunities to incorporate Net Zero Energy technologies and practices. For new construction and building renovation, more reliable, practical, and affordable energy-efficient components and subsystems must emerge to achieve the savings potentials identified for residential and commercial buildings.

Increase building system intelligence. Buildings consume approximately 70% of the nation's electricity (DOE 2007a). Power consumption by cooling equipment is the single largest load component driving the growth in electric utility peak period loads nationwide. Enormous potential for cost savings in the power utility sector is associated with making buildings or communities of buildings intelligent enough to reduce their power draw, especially during peak periods. By reducing peak loads, the utility sector can defer investment in new electricity supply infrastructure (power plants and transmission and distribution lines) and better use assets.

Efforts are underway to change utility regulations so that cost savings resulting from building improvements (such as making them more intelligent) will be shared through incentives or subsidies between the utility and those paying for the building improvements (EPA 2007a). Intelligent energy-consuming components and subsystems can save energy in many ways. Equipment such as rooftop heating and cooling units, water chillers, and air handlers can detect and diagnose their own faults and request service. Research is needed to develop robust, affordable technologies so that buildings of any vintage perform at least as efficiently as originally designed throughout their entire operational phase.

Buildings retrofitted with intelligent subsystems have the potential to perform more efficiently than originally designed by delivering healthy environments and amenities only when and where needed, and at a level that maximizes productivity and well-being. Research and strong cooperation among stakeholders are needed to develop the necessary measurements and standards to communicate load requirements with utilities and to reduce demand at peak times. Measurements and standards are also needed to enable self-assessment of operating efficiency and faults, and to integrate the control of separate systems to use resources effectively. Usable products will then emerge to continually minimize operating costs and energy use, respond to relieve grid stress and avoid outages, continuously validate commissioning performance levels, and send notifications when service is required.

Enhance the use of ground energy sources and heat sinks. The effective use of ground energy sources and heat sinks offers significant potential for energy savings and peak load reduction for buildings. Ground resources — including the Earth, surface water, recycled graywater, sewage treatment plant effluent, retention basin stormwater, harvested rainwater, and water from a subsurface aquifer — whether alone or in combination with outdoor air in a hybrid configuration, are generally more efficient than outdoor air for equipment heat exchange. Efficiency improves when these sources are cooler than outdoor air in summer and warmer in winter.

These systems can be at a neighborhood or building scale. In many areas the modest remaining heating, cooling, and water heating loads of near Net Zero Energy homes and low-rise commercial buildings can be served with efficient heat pumps coupled to ground loops placed in the construction excavations. Research is needed to develop and validate the necessary design tools and performance prediction models so practitioners can confidently interface equipment in buildings to the most energy-efficient and affordable ground energy sources and heat sinks.

Develop better and more cost-effective components and subsystems. In 2005 lighting consumed 4.5 quads (26%) of energy in commercial buildings, much of it during peak periods, and 2.3 quads (11%) in residences (DOE 2007a). The commercial and residential building sectors dominate the energy used for lighting (see Figure 5).

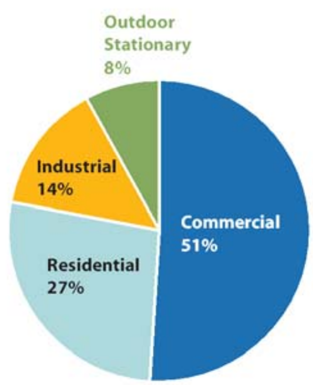

Figure 5. National lighting energy consumption by sector
Source: http://www.eere.energy.gov/buildings/tech/lighting/

Only 10% of the energy used for traditional residential incandescent lighting produces light; the other 90% is wasted as heat. Research is needed to develop the materials, controls, and fixtures for solid-state lighting (SSL) devices. Lighting efficiency is measured in lumens per watt; if successful, SSL (target efficiency in 2015 is 160 lumens per watt) has the potential to leapfrog the efficiency of today's linear fluorescent lamps (80), compact fluorescent lamps (60), and incandescent lamps (15) (DOE 2007b).
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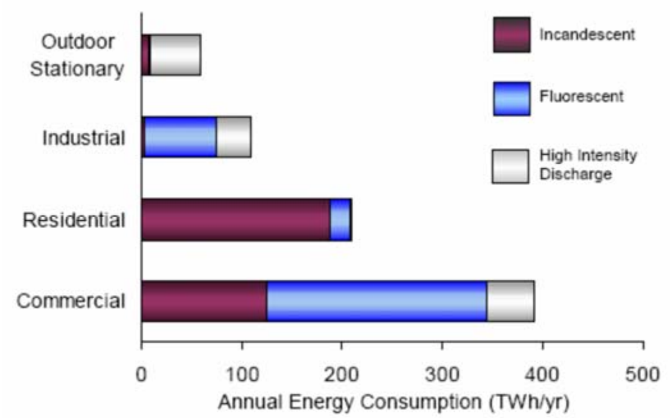

Source: http://www.eere.energy.gov/buildings/tech/lighting/

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Although SSL efficiencies are impressive, other technologies could reduce the large amount of lighting energy consumption that occurs during daylight hours. Subsystems that route visible sunlight throughout the building, including the core, without wasting it on empty spaces will reduce daytime electric lighting requirements. Research is needed on these and more sophisticated subsystems — including those that split the incoming solar energy into visible light and other frequencies; route only visible sunlight into the building where and when needed, to minimize solar heat gain; and divert the rest to PV power generation, and those that capture and reroute visible light from windows with poor solar orientation.

Research is needed to develop more affordable and efficient components and subsystems. These include integrated styles of equipment that recycle heat between end uses, for example, by capturing waste heat from a cooling device to generate hot water. The basic designs of some major household appliances and other equipment need to be revisited. Many advances have been made in model-based design processes, improved materials, components, subsystems, communications, sensors, and controls since their design decades ago. All types of electronic devices need to be revisited to maximize transformer and other component efficiencies and minimize standby losses.

The vast potential of intelligent buildings to conserve energy by responding to occupant movements and preferences can be fully realized only by developing dynamic lighting, space conditioning, and ventilation subsystems that can provide comfortable environments and amenities as needed with minimal standby or auxiliary energy losses.

R&D Focus Area 2c

Develop supply-side technologies that, when coupled with energy efficiency, can achieve Net Zero Energy buildings and communities.

2.3 Energy Supply

With very few exceptions, buildings are grid-connected consumers of purchased energy. Moreover, limited communication between the loads is required by buildings and the utilities that have to supply energy to meet these loads. As a result, buildings strain the utility infrastructure, especially during peak periods driven by building cooling loads. The problem is accentuated by the fact that the electricity grid and buildings have limited ability to store energy, and power generated must be consumed at the moment of generation. Research is required to develop new systems that enable buildings, campuses, neighborhoods, and communities to produce as much energy as they use.

Integrate distributed generation and on-site renewable resources into the electrical power grid. Distributed generation and on-site renewable sources are allowed in small quantities, though widespread deployment is not possible under utility capital investment and infrastructure configurations. Coordination among the energy loads from buildings, their distributed supplies at the building-to-community scale, and the available central supplies from the electric utility requires a better understanding these interactions. This includes R&D for modeling tools to characterize and resolve integration issues and to address load requirements at the grid-interconnection points. To achieve the goal of Net Zero Energy — for buildings and communities with periods of net generation to offset periods of net loads — improved model characterizations and tools must be developed and validated that are similar to the models and tools that have been developed for building-integrated PV (DOE 2007c).

Adopt resource-friendly utility rate structures. Energy providers must adopt utility rate structures that maximize the benefits to customers and the utility, by making it economic for the most resource-friendly energy supplies to be used. R&D is needed to improve the metrics and tools to track and communicate energy production and consumption characteristics so customer operations can maximize efficiency and minimize cost.

Develop energy storage technologies. Research is required to develop energy storage technologies for buildings, communities, and utilities and to evaluate their ability to manage grid resources and maximize the efficiency of the entire grid system. This may involve multiple supply types (utility central station power, wind, solar, and combined heat and power [CHP] from biofuels) and may affect all customers. This crosscutting need could be influenced by onboard energy storage technologies for plug-in hybrid electric vehicles, which will likely be grid-connected at buildings.

R&D is also required to optimize on-site renewable energy supply technologies for use at the buildings-to-community scale. For CHP from biofuels, research is needed to reduce costs, broaden size range, expand biofuels options, reduce emissions, reduce thermal distribution losses, and improve the use of recycled heat.

Additional research is also needed to improve confidence in PV module ratings and to improve methods for testing and evaluating the performance of combined solar PV power and thermal energy collection modules. Measurement techniques and performance metrics need to be developed for CHP systems, which may be based on a variety of generator prime movers (e.g., industrial turbines, microturbines, reciprocating engines), as well as distributed generation systems (having the previously listed generators plus fuel cells). Measurement techniques and performance metrics are needed to rate the energy and noise performance of on-site small wind turbines. All these new technologies must be proven to be cost-effective and easy to maintain.

2.4 Trade-Offs in Gaining Energy Efficiency

Energy use and GHG emissions are two of the major global challenges in the 21st century. Other challenges include using water, land, and material resources efficiently; reducing or eliminating buildings' contributions to air and water pollution and waste generation; and maintaining healthy environments. Like any complex issue, the development of Net Zero Energy technologies for buildings involves careful examination of trade-offs, be they water and material use and recycling; IEQ; or occupant, building, or community needs and preferences. New technologies that maximize building energy efficiency and minimize operational energy use require careful examination of these other key factors. The subsequent sections of this report cover these ancillary requirements for achieving Net Zero Energy, high-performance green buildings: water and materials use, occupant health and performance, and the implementation barriers that must be overcome (see also Section 1.1**).**

3 Water Use and Rainwater Retention

Goal 3: Develop the scientific and technical bases for significant reductions in water use and improved rainwater retention.

Water is a valuable resource and the demand for water for drinking water supplies and to support electrical power generation, agriculture, and industry is increasing. While the U.S. population has nearly doubled between 1950 and 2000, the amount of water used to support municipal, agricultural, and industrial activities has more than tripled over the same time period. And changing climate patterns, including more frequent droughts and severe storms, threaten to disrupt surface and ground water resources.

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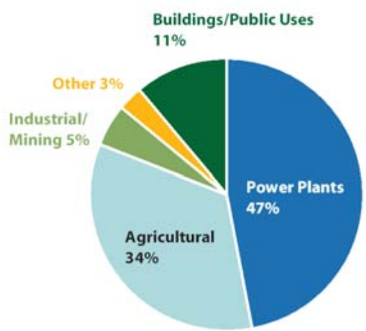

Total Water Use in the United States.
Ref: Hutson et al. 2004

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These trends are not sustainable — a recent U.S. government survey found at least 36 states anticipate local, regional, or statewide water shortages by 2013 (EPA 2008). The financial investment needed to upgrade the water infrastructure is estimated at hundreds of billions of dollars (EPA 2002).

Modern development patterns affect the ability of our water resources to naturally renew themselves, adding to future water and environmental costs. In built environments, much of this impact is a consequence of the extensive use of impervious surfaces — roads, driveways, and structures — that prevent rainwater from infiltrating into the ground, forcing it instead to run offsite at unnaturally high levels or be directed into storm drains and sanitary wastewater treatment systems. Storm runoff and excessive loading to wastewater collection systems (separate or combined) may overload treatment facilities, cause nutrients, metals, organic contaminants, and pathogens to be released into aquatic ecosystems, and affect overall water quality. Runoff from stormwater and overflows from water treatment systems are considered to be the fourth leading source of impairment in rivers, third in lakes, and second in estuaries (EPA 2000), and contribute to the increased cost of producing drinking water from these sources.

Water use also has additional significant energy and GHG impacts. Water heating represents 13% of a residential building's total energy consumption. Energy used to withdraw, treat, and transport drinking water and collect and process wastewater and stormwater has been estimated to account for approximately 3% of total U.S. energy consumption (Electric Power Research Institute 1999). Water and energy resources are also expended in response to recurring leaks spawned by the deteriorating water infrastructure, overflows that result from discrepancies between capacity and loading, pressure requirements to meet fire suppression needs, flushing of lines to remove contamination, and inherent inefficiencies due to pumping water over long distances. Wastewater treatment systems also generate CO_2 and methane, as well as other GHGs such as gaseous nitrogenous and sulfur compounds and volatile organic compounds (EPA 2007b).

Building and site development practices have the potential to reduce the energy consumption and carbon footprint of water by providing a means to use water more efficiently on site. Opportunities for increasing water efficiency include harvesting rainwater for augmenting traditional water supplies, optimizing in-building water use, recycling in-building water, and developing innovative new approaches that reduce water and energy use, operate in closer harmony with the natural water systems and generate less GHGs.

Research, including full LCAs, is needed to discover, demonstrate, prove, and evaluate these technologies, and to bring them to practical, cost-effective levels of deployment. Research must be targeted to ensure that water supplies are safe, adequate, sustainable, and energy efficient. Experience and data are needed on the effectiveness of in situ and remote monitoring programs. A key to the success of sustainable water systems is to develop a better understanding of parameters that affect public acceptance. Strategies to improve the public understanding of issues (water, safety, energy, options, and opportunities), including demonstration projects, education, economic incentives, are needed.

R&D Focus Area 3a

Reduce water use through more efficient water-saving appliances, fixtures, and water systems.

3.1 Next-Generation Water Systems and Appliances

The way that water is used in buildings and the amount of water needed to support the building depends on the building function (residential, commercial, office, industrial). On a typical site, water use is divided into potable and nonpotable uses. In general, water that is consumed (directly or indirectly) or comes into direct contact with people is classified as potable (or drinking) water. Nonpotable water for other uses such as fire suppression, toilet flushing, irrigation, cooling water is not required to be of drinking water quality. The water used within the building envelope (in-building water) may include both potable and nonpotable water, while external site water uses include landscape irrigation, cooling water, and other nonpotable water applications.

The in-building water use is dictated by the building function, the types of water systems and appliances in service, and by sociological factors, including consumption behaviors.
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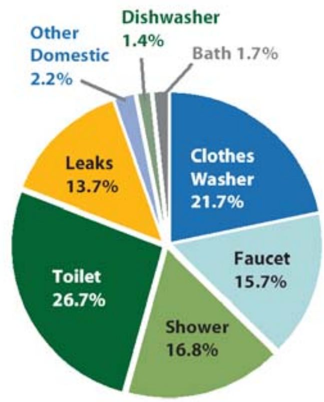

Adapted from "Residential End Uses of Water" by permission,
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The on-site water use depends upon site design, on-site water systems, and geographic and climatic factors. In some cases, on-site use of water can be optimized by taking advantage of natural water availability and landscape design. Other new systems such as water-efficient irrigation systems, water recycling systems using in-building wastewater, capture and recycling of rainwater, and new applications of treated wastewater for nonpotable purposes are needed. Nonpotable water can also be used for replenishing surface water storage systems, cooling water, and other industrial water needs. In all cases, building codes and regulatory frameworks need to function to protect public health and promote efficient water use.

Identify opportunities to improve the efficiency of water use. Research is needed to optimize water use efficiency. Opportunities include separating potable and nonpotable water uses by developing more effective water conveyance and wastewater collection systems. Alternatives to potable water source fire suppression systems hold potential to dramatically reduce energy demands for many water systems. Other opportunities include investigation of decentralized drinking and wastewater systems. For each, ancillary factors of health and safety, security, redundancy, and reliability must be considered in conjunction with reduced energy use and GHG emissions.

New reliable low-flow water appliances such as self-composting, low-flow, or vacuum toilets and cleaning systems (washing machines, dishwashers) are needed. Although considerable development of these systems has occurred over the past decade, consumer confidence and acceptance must be improved through field testing and the investigation of potential consumer incentives (see also Section 6.3). Efficiencies can also be realized by on-site treatment and reuse of water. Many technical questions about the efficacy of new appliances and alternative treatment systems and their associated safety, cost, longevity, maintenance, and ecological considerations, remain unanswered. Next-generation technologies and approaches must be identified, tested, and proven to be cost effective and water efficient. Links between water and energy need to be articulated and communicated to better inform water use and infrastructure decisions.

Develop systems that reduce water consumption. Specific research for the next generation of water-saving and recycling appliances, fixtures, and systems for bathroom and washing use includes whole-building innovations such as hot water distribution systems, building comfort systems, and centralized automatic monitoring systems for managing demand to reduce water consumption. There is a critical need to validate performance data under different conditions and quantify the "true" costs that include GHG emissions and embedded water and energy requirements of materials and infrastructure. Sophisticated occupant surveys and analyses of consumption patterns, credible environmental information sources, and decision making approaches need to be developed that identify social, cultural, institutional, and other barriers to conservation and identify practical strategies to promote adoption.

R&D Focus Area 3b

Develop analyses and technologies to overcome environmental, health, and technical barriers to widespread water recycling and increased rainwater harvesting.

Develop systems that mitigate the negative impacts of water recycling and rainwater harvesting. Research is needed to analyze the potential environmental and health impacts of water recycling and rainwater harvesting and to develop systems that mitigate these impacts. For graywater (the recycling of untreated wastewater from bathroom sinks, showers, bathtubs, and clothes washing machines) research is needed on the potential of entrained constituents (e.g., detergents, salts, lipids, surfactants, and dyes) to harm plants or be transported below the root zone to groundwater during the rainy season or intense storm events. The short- and long-term effects of graywater irrigation on indigenous soil microorganism communities and associated ecosystem functions must also be investigated and evaluated. Assessing health risks to individuals who come in direct contact with graywater will require reference data about microbial and chemical contaminants and routes of exposure (indigestion, inhalation, dermal), and potential health risks. For commercial and industrial buildings, opportunities for collecting, treating, and reusing in-building water needs to be evaluated from a perspective of public health protection, public confidence and acceptance, efficacy, costs, and reliability. Other sources of water that can be harvested and reused include cooling waters and air-conditioning and dehumidifier condensates.

Develop new rainwater harvesting, storage, and distribution systems. New rainwater harvesting systems for residential and commercial drinking water will require that technical capabilities of treatment systems be specified to provide safe, reliable, and cost-effective treatment of pathogens and avoid the short- and long-term health risks of chemical constituents in rainwater and pollutants mobilized or leached from roofing materials, piping, gutters, and other conveyance systems. More research is needed to develop metrics to evaluate the effectiveness of on-site treatment and to determine if different protocols should be used to process graywater and stormwater. The regulatory framework for these decentralized treatment systems should be examined to ensure that treatment and monitoring requirements provide adequate public health and environmental protection.

The efficacy of tailoring treatment requirements to the different water sources (e.g., rainwater, stormwater, or in-building wastewater with separate collection systems from kitchens, laundries, and bathrooms) or uses of water (potable or nonpotable) should also be evaluated. The effectiveness and long-term reliability of on-site facilities for short-term storage of water recovered from different sources (rain, storm, reuse) suitable for their intended uses need to be field tested and verified under different climatic and water use scenarios. Methods for ensuring stored water is used and distributed efficiently for internal and external uses are needed such as automated systems that detect soil moisture requirements and irrigate landscapes using recycled water.

"Real-world" demonstration projects are also needed to evaluate design approaches for drainage systems that have the flexibility and resiliency to manage water captured from storms with varying intensity and duration. In addition, experience is needed to optimize and integrate systems on different spatial scales (site, neighborhood, watershed). Ultimately the success of these systems depends on an integrated approach to water supply, use, and management (drinking water, rainwater, wastewater, stormwater).

R&D Focus Area 3c

Develop low-impact development practices to significantly reduce stormwater runoff.

Improved planning and land use practices. Improved planning and land use practices at the watershed, neighborhood, and site scales can significantly improve the quality and availability of water with concomitant reductions in energy consumption and GHG generation. Environmentally sensitive site design through low-impact development (LID) can significantly reduce water demand and help to maintain or restore natural hydrological conditions (see Figure 6). LID generally refers to systems and practices that use or mimic natural processes to infiltrate, evapotranspirate (return water to the atmosphere either through evaporation or by plants), or reuse rainwater where it is received.

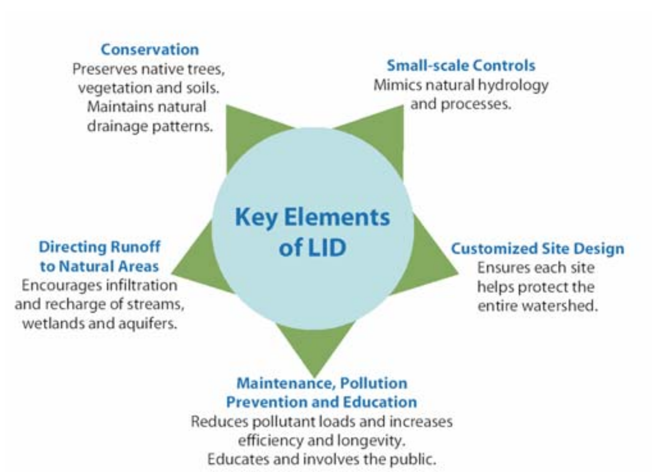

Figure 6. Low-Impact Development
Source: Low Impact Development Center

LID can reduce energy consumption for cooling and heating, ameliorate urban heat island impacts, create habitat, absorb carbon emissions, aesthetically improve communities and sites, and avoid expensive upgrades of traditional hard conveyance infrastructure. Research needs on a larger scale include quantifying the benefits and costs of the widespread use of LID. At the practical level, many questions about the performance, cost, and maintenance requirements of LID practices need to be answered. The performance of LID practices at the site, neighborhood, and watershed scales needs to be analyzed within the LCA framework.

Manage pollutant loadings and runoff volumes. Research on the performance of LID systems in managing pollutant loadings and runoff volumes and rates must be investigated and comparative cost analyses conducted. These will help determine whether LID can partially or wholly replace conventional stormwater management systems, and at what cost or risk to public safety. LCAs must evaluate the performance of green roofs, bio-infiltration systems, permeable pavements, and risk factors such as groundwater contamination. More complex analyses are needed to quantify the benefits and costs of LID practices in abating stormwater runoff and combined sewer overflows, and related impacts on water bodies, drinking water, air quality, public health, energy consumption, and GHG generation.

Use soil-based vegetative infiltration practices. Research is also needed on the value of LID practices to perform bio-infiltration or bio-retention by using soil-based vegetative infiltration practices to filter runoff, reduce surface runoff, and infiltrate water into the ground to trap pollutants in the upper soil horizon and recharge aquifers. LID practices appear to have great promise for reducing pathogen and chemical loadings from land-based sources and improving environmental protection. Research is needed to evaluate the effectiveness of these practices for controlling waterborne contaminants and protecting public health under different site management situations. Particular attention should be directed to ensure pathogen inactivation through design optimization to meet the desired pollutant reduction goals.

4 Material Utilization, Waste, and Life Cycle Environmental Impacts

Goal 4: Develop processes, protocols, and products for building materials that minimize resource utilization, waste, and life cycle environmental impacts.

The United States manufactures and consumes huge quantities and varieties of building materials every day. These activities have major impacts on the economy and the environment. Construction materials (including buildings, roads, and infrastructure supplies) comprise 60% of the total flow of materials (excluding food and fuel) through the U.S. economy (U.S. Geological Survey 1998). Construction, maintenance, renovation, and demolition account for 16% of a building's energy use over its lifetime (see Figure 7).

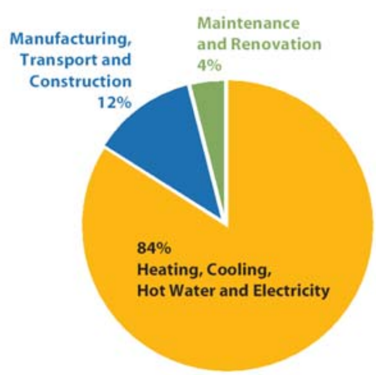

Figure 7. Typical Building Energy Usage
Ref: World Business Council for Sustainable Development 2007

The demand for building materials continues to rise in the United States and abroad. According to projections by the Brookings Institution, to keep up with population growth and needs, by 2030 the nation will need to replace about 82 billion square feet of building space and add 131 billion square feet of new space (Nelson 2004). Meanwhile, the economies of China and other large developing nations are expected to keep expanding and increasing their demand for construction materials.

The extraction, manufacturing, transportation, use, and disposal of building materials have many resource, environmental, and health impacts; all these phases use (and often waste) significant quantities of raw materials, water, and energy. The "embodied energy" (or sum of the energy impacts of a product before it is used) for building materials is estimated to account for 10%–60% of a building's total energy use over a 50-year life cycle (Thormark 2002). The relative percentage of building materials' embodied energy depends on the materials used and the operating efficiency of the building. Thus, as buildings become more energy efficient, the impact materials have on the total life cycle energy consumption of a building will become more significant.

To sustain the nation’s growth and meet the building material needs of future generations, processes, protocols, and products need to be developed that significantly reduce material and other resource use, toxic chemical components and emissions, waste generation, and environmental impacts. To attain this goal, research is needed to develop processes that minimize waste generation from building construction, renovation, and demolition; that incorporate secondary materials, including industrial by-products, in building products; and that reuse and recycle building materials at the end of their useful lives. Additional LCI data are needed to account for the full life cycle environmental and public health impacts of product and material choices. Research is also needed to develop new building materials and products with minimal environmental and public health impacts over their life cycles, including recycled content products.

The Federal government currently maintains several programs to reduce the environmental impacts of its operations, including EPA's Comprehensive Procurement Guidelines for the purchase of recycled content products and USDA’s biobased products procurement program. Coordination of life cycle research with these Federal procurement programs will ensure that future product designations satisfy both the statutory objectives and represent the best product choices from environmental lifecycle, sustainable buildings, and Net Zero Energy building objectives.

R&D Focus Area 4a

Develop processes that minimize waste generation from building construction, renovation, and demolition.

4.1 Building Material Waste Reduction

New processes and techniques are needed to reuse and recycle building materials from existing buildings, as well as to design new buildings for “deconstruction” — the disassembly of a building and the recovery of its materials, often thought of as construction in reverse.

Advance the reuse and recycling of building materials. Almost no buildings have been designed for deconstruction, nor have their materials been designed to perform new services at the end of the buildings’ useful lives. Research is needed to increase the amount of building materials that can be reused or recycled.

Thus far, many people, including contractors and recyclers, have been innovative in determining how to reuse or recycle those materials. Much research has already been completed to study the reuse and recycling of building materials, and many certified green buildings can achieve reuse and recycling rates higher than 50%. Still, more research is needed to help enable buildings to boost those rates to 100%. Materials that currently have low recycling rates across the country include carpet, asphalt shingles, plastics, tile, and insulation. Research is needed to identify new technologies and approaches to boost useful recycling of these materials.

Demolition materials require significant attention, as they may present the greatest potential for risks to human health and the environment. For example, drywall from demolition is often painted with lead-based paint or contaminated with joint compound containing asbestos. Wood recycling faces many challenges from possible contamination from lead-based paint and chemical treatments. The risks associated with wood products and other materials from construction and demolition entering the recycled waste stream and affecting human health and the environment need to be evaluated. Other materials present similar concerns. As new building products are developed, new recycling challenges emerge. Markets and risks for recycling materials from construction, renovation, and demolition should continue to be evaluated to determine the best uses for these materials.

Research new designs for adaptability, disassembly practices, and life cycle impacts. Research is also needed to develop techniques for building adaptability and disassembly. Future buildings should be designed to be flexible to accommodate changing uses during their lifetimes and for disassembly and reuse of their components at the end of their useful lives. Ideally, buildings will be adapted and repurposed; for example, a commercial building might be converted into housing, which extends its lifetime. Buildings may also serve as repositories of materials for future construction. Systems and products that are designed for adaptability and disassembly can prolong the lives of buildings and their components and reduce the amount of materials that buildings consume.

This research should identify the impacts on life cycle of design for adaptability and disassembly practices for various building types. Integrated adaptable designs will allow buildings to be used for different purposes over their lifetimes, which will reduce environmental impacts and costs of demolition, remodeling, and new construction. Research is needed on design options, including optimally placed fixed locations for centralized utility and data access, flexible wall and lighting configurations, modular air diffusers and air exhaust ducts on flexible air chases, and raised floor systems that reduce rewiring and system reconfigurations. Other potential design configurations include simple, exposed connector systems to support building material reuse, standardized grid pattern material sizing, and raised pier and pin foundations.

Develop case studies about building disassembly and relocation. Demonstrating the feasibility of moving and repurposing a building that has been designed for adaptability and documenting its environmental and economic impacts is key to more widespread adoption of these practices. Comparing the materials and transportation costs, time, and energy used to relocate a building to the estimates for new construction will aid in assessing the energy and economic implications of design for adaptability and disassembly.

R&D Focus Area 4b

Expand life cycle inventory data and perform life cycle assessments to identify the full environmental and public health impacts of product and material choices.

4.2 Product and Material Life Cycle Assessment

Building professionals need data, methods, and results to make informed decisions about building materials based on full consideration of their life cycle impacts, including impacts on resources, air, water, land, and human health. To address this priority, LCA data and methods need to be refined, expanded, and applied. The USGBC (2007) has identified this as its top priority for building materials research.

Develop and maintain the U.S. Life Cycle Inventory (LCI) Database. Further development and maintenance of the U.S. LCI Database (NREL and Athena Institute 2008) is needed to make the database more robust and able to support additional product LCAs. This includes expansion of its end-of-life data to include a wider range of waste management options and materials (e.g., hollow and solid core doors, wood cabinets, and windows by type). Because the LCI database is the only centralized source of life-cycle data for products in the United States, its continued development and maintenance are critical to the widespread adoption of LCA-informed building materials.

Refine LCA methods. LCA research needs include improving methods for assessing land and water use impacts. These methods must capture the extent of land disruption, time required for land restoration, and quality of water, soil, and habitat resources associated with the life cycle of building materials (USGBC 2007). Weighting schemes for key LCA performance indicators for building materials need to be refined. Such schemes will help focus R&D for sustainable materials, products, and practices on the highest priority needs. (See also Section 1.1).

Physical safety in using building products as well as the risk to employees manufacturing building products is not currently captured in LCA comparisons of one material to another. For instance, some flooring products are manufactured to reduce the number employee falls per year. While this is certainly a benefit to occupant health and performance (Section 5), this type of information is not captured in the current LCA methods. A new method of evaluating product safety throughout their lifetime should be evaluated and included in all product LCAs.

Perform LCAs for additional building products and address life-cycle options. Consistent, comparable LCAs are needed for many more products to enable LCA-informed building design and renovation. Furthermore, these LCAs must consider various life-cycle scenarios to support sustainable product design, manufacture, transportation, and waste management. These scenarios include consideration of nonhazardous industrial by-product use (e.g., scrap tires, coal ash, steel slag, and foundry sand), energy-efficient processing methods, alternative transportation modes and networks, and end-of-life options (e.g., reuse, recycling, waste-to-energy). These scenario-based LCAs will help policy makers, product manufacturers, and waste generators identify key opportunities to reduce the life-cycle impacts of building products before they occur, rather than after.

R&D Focus Area 4c

Develop new building materials and products with minimal environmental and public health impacts over their extended life cycle

Research and develop new building materials with minimal environmental and public health impacts. One way life cycle information can be used is to guide the development of new products with fewer negative environmental impacts. Research needs include sustainable product development protocols and laboratories to guide discovery and synthesis of materials and products that have fewer overall negative impacts and a greater useful life over a wide range of criteria. Pilot demonstrations of sustainable building products, such as those containing recycled industrial materials and biobased materials, are needed to test their practical performance, and economic research on market obstacles is necessary to commercialize more promising sustainable materials and products.

Assess risks for new building materials. Research also needs to stay current with emerging materials and product technologies, such as nanotechnology, that may be used in buildings to determine the extent to which these represent more environmentally sustainable choices. This will require toxicologists, chemists, biochemists, engineers, and experts in other disciplines such as safety, to work together to understand the risks to humans and the environment from novel substances throughout a product's manufacturing supply chain, in-service use, and disposal or reuse.

5 Occupant Health and Performance

Goal 5: Develop the knowledge and associated energy efficiency technologies and practices needed to promote occupant health, comfort, and productivity.

A primary function of buildings is to provide places for people to live, work, and learn, and in some cases to heal. Advances in energy efficiency need to maintain conditions in buildings such that they can continue to serve these functions and improve the health, comfort, and productivity of the occupants. Many building attributes can affect the occupants' health and their ability to function productively. In the context of high-performance green buildings, the indoor environmental conditions are the most relevant.

R&D Focus Area 5a

Develop technology to improve indoor environmental quality and reduce building energy consumption.

5.1 Indoor Environmental Quality

IEQ directly affects occupant health, comfort, and productivity. Well-established and serious health impacts resulting from poor indoor air quality (IAQ) include Legionnaire's disease, heart disease and lung cancer from secondhand smoke, and carbon monoxide poisoning. More widespread health concerns include increased allergies and asthma from exposure to indoor pollutants (particularly those associated with building dampness and mold), colds and other infectious diseases that are transmitted through the air, and sick building syndrome symptoms caused by elevated indoor pollutant levels.

These illnesses affect many building occupants and result in significant healthcare expenses, sick leave, and lost productivity. Fisk (2002) estimates IAQ improvements could reduce U.S. healthcare costs (estimated at more than $2 trillion for 2006) (U.S. Department of Health and Human Services 2008) by $6–$14 billion by reducing colds and influenza, $1–$4 billion by reducing symptoms of allergy and asthma, and $10–$30 billion by reducing sick building syndrome symptoms. Several strategies, such as increased use of natural ventilation, improved moisture control, low-emitting materials and furnishings, and daylighting can improve human health and productivity. The research needs identified in this section are intended to support the beneficial outcomes of good IEQ in a manner that is consistent with the efficient use of energy. Many of these research areas have been previously identified by the EPA (2001, 2005).

Efforts to make buildings more energy efficient need to maintain the expected level of service, which includes acceptable IEQ. Given the cost of energy consumption relative to occupant salaries, the costs associated with small decreases in occupant productivity resulting from degradation in IEQ will dwarf the energy cost savings (Seppanen and Fisk 2006). Student performance has also been shown to increase with improved IEQ in schools

(Wargocki and Wyon 2007), a long-term economic and social value that again overwhelms the benefits of any short-term energy savings. Improved knowledge, technologies, and practices will provide more cost-effective, energy-efficient buildings without compromising IEQ.

New Indoor Environmental Quality Technologies and Designs

As technologies and practices are implemented to increase energy efficiency, acceptable IEQ must be maintained. Several options such as system commissioning and demand-controlled ventilation can simultaneously improve IEQ and reduce building energy use, but more options are needed to cover the full range of building and system types. More R&D is needed to fill these gaps and to accelerate the adoption of these new concepts by the building and HVAC industries. The unique features of different building types, locations, and occupancies result in different options being more or less applicable in a given situation. Building- and climate-specific issues must be addressed to provide the tools and guidelines needed to implement these technologies, along with building performance data to characterize current IEQ conditions over the range of building types, systems, and climates.

Investigate new technologies for measuring and controlling ventilation rates. Outdoor air ventilation rates determine the energy required to heat or cool the outdoor air and indoor pollutant levels. For ventilation to be effective, rates need to be controlled to reduce indoor pollutant levels without consuming excessive energy. Given the difficulties in measuring ventilation rates in buildings, new methods and technologies are needed to perform such measurements with improved accuracy at a reasonable cost.

Advance particle filtration systems and air cleaning technologies. Cost-effective filtration and air-cleaning technologies, particularly for volatile organic compounds and ozone, offer the potential to improve IAQ and lower outdoor air ventilation rates, which reduce energy consumption. High operational costs, resistance to airflow, and more reliable and predictable performance of these technologies must be addressed through new R&D. Equally important, test methods and rating systems have limited use because they notably lack gaseous air cleaning.

Explore ultraviolet germicidal irradiation (UVGI). Ultraviolet radiation of cooling coils and drain pans may effectively control microbial growth in air handling systems. This technology offers the potential to control microbial growth at low cost and with low airflow resistance. UVGI system design, effectiveness, and maintenance results are needed before this technology can be put to general practice.

Research cost-effective mechanical ventilation systems for residences. New ventilation systems for single-family homes and multifamily residences are being designed and developed with little understanding of their IAQ and energy performance impacts. Residential buildings are of particular interest, given that mechanical ventilation is a more recent addition to these building types and that significant growth is anticipated in the housing sector. Field testing and computer simulations will provide insight into the reliability of different ventilation approaches, as well as their impacts on IAQ and energy consumption. Also required are the economic analyses and ratings of the initial investment costs and longer term operating costs associated with these approaches.

Investigate natural or hybrid ventilation designs. Current natural or hybrid (combinations of mechanical and natural approaches) ventilation may improve IAQ and reduce energy consumption, but also present many design challenges. These systems and designs must address concerns about physical security, unacceptable ambient noise levels and outdoor air pollution, and acceptable levels of indoor temperature and humidity. Design solutions and demonstrations are necessary to allow more widespread application of these promising approaches.

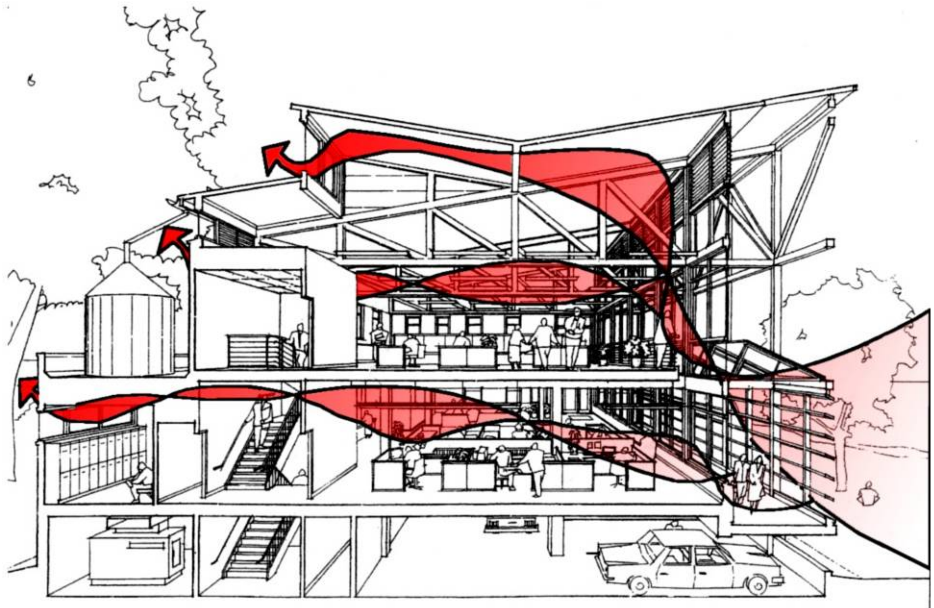

Figure 8. Hybrid Ventilation System
Ref: Griffith et al. 2005, used with permission from the SmithGroup

Study the IEQ effects of air-conditioning. Cooling accounts for about 15% of the primary energy load in commercial buildings (DOE 2007a). However, air-conditioning in offices and homes increases the risk of respiratory health symptoms (Seppanen and Fisk 2002). The scientific basis for these increased adverse health symptoms is not well understood, and mitigation techniques must be further developed and explored.

Understand the IEQ effects of material emissions. A key strategy for energy-efficient IEQ is source control; that is, reducing indoor pollutant generation so less outdoor air ventilation is needed. Materials and products with reduced emission rates need to be developed along with reliable test methods to measure these emission rates (see also Section 4).

Explore operations and maintenance (O&M) procedures. As mentioned in Section 1.1, most buildings never achieve the service levels for which they were designed. Technologies such as sensors, intelligent building controls, practical operational guides, codes, and standards are needed, as are improved education and training of O&M staff (see also Section 6.1). Improved O&M strategies must be developed that maintain both IEQ and energy efficiency and their benefits formally documented. Additionally, consideration of environmentally preferable products and practices used within the building and the surrounding site should be included in occupant health and environmental performance requirements.

Develop and validate airflow and IAQ models. Because field measurements are expensive and time consuming, building simulation will play a key role in this research. Improved building airflow and IAQ models must be developed and validated to accurately predict the impacts of new energy efficiency IEQ technologies and practices.

R&D Focus Area 5b

Develop the knowledge necessary to support scientifically sound and building-specific standards and codes that address the health and comfort of building occupants.

Building Codes and Standards

Develop new requirements and recommendations for ventilation and IAQ standards. Building energy consumption associated with IEQ is driven primarily by ventilation rates, thermal conditions, and the types of activities performed. The corresponding requirements and recommendations in current ventilation and IAQ standards, building codes, and sustainable building rating systems are based on limited scientific information and practical experience. Because many aspects of IAQ are poorly understood, more scientifically sound and building-specific standards and codes have not been developed to comprehensively address occupant health and comfort. The results of these research efforts will help standards writing bodies such as the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), model code development organizations, states, high-performance building raters, and others update their ventilation standards, regulations, and voluntary programs.

A key concern is the specific sources of indoor pollutants and their health-related impacts. Many pollutants have been studied, but knowledge of the sources of specific indoor pollutants, their associated exposure and health effects, and safe indoor levels is quite limited. New methods to measure human performance are needed to formalize the relationship between IAQ and occupant health and productivity (EPA 2005).

Human Health

Determine the impact of indoor pollutant exposures on human health and performance. Practices, standards and codes, and rating programs rely heavily on building ventilation to control indoor pollutant levels. Ventilation rates used in building standards and codes are critical to IAQ and energy efficiency. Scientific analyses are needed to understand chronic health risks (cancer and heart disease, for example) of indoor pollutant exposures, as they correspond to different ventilation rates. Similarly, the relationships between ventilation rates and acute health outcomes such as common colds and influenza, absence rates from work and school, and work performance metrics need to be quantified, as these factors have significant economic costs.

Research the effects of dampness on human health and energy consumption. Standards, recommended practices, and guidance information focus on thermal conditions in buildings; moisture is especially important to energy consumption and IEQ. Damp conditions in buildings are associated with increased respiratory and other health effects, which are likely due to dampness-related biological activity and chemical emissions (Institute of Medicine 2004). Dampness also reduces the service life of building materials, and indoor humidity and dampness control measures substantially affect building energy consumption. The sources of building moisture problems need to be studied to determine how improvements in building design and O&M can reduce their occurrence.

The link between building dampness and occupant health is well established, but the specific pollutants that form this link are not. Pollutants associated with these health effects must be identified so that the most effective measures to control these exposures can be developed. Building dampness is often caused by construction defects that allow water to enter from the outdoors. R&D is needed to develop low-cost, easily constructed, energy-efficient envelope designs and materials and improve construction practices, guidelines, and tools to reduce dampness (see also Section 2.1).

Research ways to reduce airborne disease transmission. The activities and processes in certain types of buildings have major impacts on energy consumption and require special attention to IEQ. Of particular note are the issues associated with airborne disease transmission in healthcare facilities, public spaces, and many other building types. The relative importance of airborne and other disease transmission mechanisms is not fully understood, but airborne transmission is clearly significant for a range of respiratory diseases (Li et al. 2007). Airborne disease transmission in healthcare facilities is of particular concern, as these facilities use vast amounts of energy to care for sick and immunocompromised patients, and because they respond to major medical emergencies. However, suppressing airborne disease transmission is important in all types of high-occupancy buildings, and if better building systems can efficiently reduce infection rates even incrementally, the combined healthcare and energy-related cost savings will be dramatic.

A better understanding of the sizes and transport behaviors of airborne particles that carry infectious agents is needed to reduce airborne disease transmission, particularly for those associated with hospital-acquired infections. Many approaches are being proposed as potential control strategies, but this research is not yet adequate to judge their effectiveness. More information is needed about the exposure reductions, health benefits, and energy impacts of interventions such as increased ventilation, improved filtration, UV germicidal air treatment, and measures such as automatic doors and faucets that reduce indirect contacts. In particular, the trade-offs between improved filtration and use of outdoor air for infection control is not well understood, and energy savings opportunities will present themselves if filtration can be used to decrease outdoor air ventilation rates.

6 Overcoming Barriers to Implementation

Goal 6: Enable technology transfer for Net Zero Energy, high-performance green buildings.

Many real or perceived barriers must be overcome to achieve Net Zero Energy, high-performance green buildings on a nationwide scale. These include the lack of practical information guides, general absence of financial incentives, regulatory and cultural barriers in the building sector, and misconceptions about the impacts of buildings on resource consumption. These barriers may present themselves differently with different types of buildings. Ultimately, overcoming these barriers will decrease related costs to society through improved economy and performance. These include developing tax, insurance, and other financial incentives (such as graduated utility rates that encourage conservation, expedited permitting, priority plan review, or higher housing density allowances for those seeking to use new resource-saving technologies).

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According to a recent study, key players in the building sector misjudge the costs and benefits of green buildings and create a major barrier to the adoption of energy efficiency technologies in the building sector. In this survey, 1400 developers, agents, professional landlords, and corporate tenants respondents grossly underestimated the GHG emissions of buildings (19% versus 40%) and incorrectly placed the additional cost of building green at 17% above conventional construction; more than triple the true cost difference of about 5%. These respondents also saw their role in green buildings as adopting incremental changes once they are tested and demonstrated to be effective or they become an industry standard (57%) or once clients or regulations require it (31%), but very few(12%) saw their role as leading the move to green building.

Source: Energy Efficiency in Buildings: Business Realities and Opportunities, World Business Council for Sustainable Development, August 7, 2007.

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R&D Focus Area 6a

Develop high-performance building design tools and guidance for urban planners, architects, engineers, contractors, and owner/operators.

6.1 Effective Technology Transfer

As described in *Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?* (McKinsey & Company 2005), barriers to implementing new technologies include the cost of the technology, the visibility of the true cost of power, the dynamic nature of building ownership, education about available energy efficiency technologies, and the absence of tools and guides to help the practitioner make sound choices. According to the National Research Council of the National Academies publication (2002), *Promoting Innovation:*

2002 Assessment of the Partnership for Advancing Technology in Housing, barriers to innovation include the cyclical nature of construction, lack of industry integration, the heavy reliance on subcontractors, diverse building codes with local peculiarities in details and administration, lack of access to information about new products, and inadequate training on products, materials, installation, and O&M. Liability and integration costs associated with the introduction of new products or procedures present a significant barrier to innovation in the building sector.

Some of the greatest challenges are how to diffuse, communicate, and promote the adoption of new resource-efficient technologies; in fact, effective technology transfer is as important as innovative R&D. Building innovations that use new technologies or approaches must be demonstrated, documented, shared, discussed, and applied repeatedly, if they are to influence industry practice and product quality. Adequate information and communication flows (along with their noncommercial nature and reliability) are critical to achieving energy and resource goals. Substantial technology transfer efforts will be required to penetrate all facets of the building and construction sectors.

Disseminate technologies to all industries in the sector. The building industry consists of multiple subsectors. Broad subsectors include architecture, construction, remodeling, O&M, and demolition. There are also many narrower subsectors and specialized trades. The construction industry can be categorized as residential, commercial, institutional, public works, and industrial, although the divisions between these are not always clear. Each category operates independently of the others, and each has discrete players, workers, standards, expectations, and often suppliers. Tools and approaches used for large commercial buildings differ from those used on smaller buildings (including residential). The largest construction firms are often integrators and program managers; they rely heavily on specialty subcontractors who perform the construction, and use high-end tools and software. Smaller firms may use a diverse set of subcontractors and only limited design, integration, and performance tools. Disseminating the technologies identified in this plan will require parallel efforts that address the needs of specific uses such as educational, healthcare, institutional, residential, and commercial buildings.

Use integrated design processes. To enable a future where truly integrated design is the rule, rather than the exception, the process by which buildings are planned, designed, constructed, operated, and demolished requires a radical cultural change. Increased collaboration is needed between all building stakeholders, including building professionals, owners, financiers, managers, and operators. Integrated teams must construct and renovate buildings to ensure that building performance is addressed throughout the entire process. The collaboration begins with agreement about the building's energy, environmental, and economic performance targets, and continues throughout the design process to make the holistic evaluations and trade-offs that lead to optimal solutions.

Widespread adoption of integrated design processes will require new communication channels, tools, and methodologies for collaborative decision making across these disciplines. In its 20-year technology roadmap, the commercial building industry recommends a strategy for realizing process change that includes developing and piloting new models of integrated design and development, creating implementation guidelines for applying them, and establishing the tools and professional education programs needed to support the integrated design and renovation of new and existing buildings (DOE 2000).

Figure 9
Adapted from Mattar, S.G. "Buildability and Building Envelope Design." Proceedings, Second Canadian Conference on Building Science and Technology, Waterloo, Nov. 1983.

Standards, tools, and guidance will need to be developed that respond to the needs and requirements of the entire industry, for all types of buildings, and for new construction and retrofit applications.

Provide training and education. As new technologies are introduced, building systems will become increasingly complex. Professional and trade associations, accreditation institutions, and industry groups must develop new educational programs and training materials for the building sector workforce. These programs and materials must address key elements needed to design, construct, operate, and maintain new high-performance building systems and help develop and promote the adoption of new tools and guidelines. Future "green collar" workforce including engineers, practitioners, and technologies require training and educational knowledge-based tools and guides to serve this rapidly growing workforce segment.

How the building is operated and maintained has an enormous effect on its overall life cycle performance. Comprehensive education and certification programs must be available to train building O&M staff on the increasingly complex building system components. New operational capabilities such as real-time performance monitoring and continuous recommissioning rely on well-trained O&M staff familiar with high-performance systems, analysis tools, and software. Single-family residential homeowners have a significant influence on overall home building performance and rely upon easy to follow guides and online resources.

Similarly, occupant behavior studies will provide insights into more effective intelligent building controls (see also Section 2.2) and the effects of the human-technology interaction on technology use and utility. Combined with educational programs and strategies for changing occupant behavior and improving technology interfaces, the life cycle building performance can be improved.

Improve tools and guides. Regulatory requirements have become more prevalent as communities have sought to limit the impact of population growth and sprawl. Regulatory mechanisms such as restrictive zoning, impact fees, growth controls, inefficient and outdated building and rehabilitation codes, multifamily housing restrictions, and stringent subdivision requirements have been in use for decades. These frameworks may, particularly when poorly planned or inefficiently implemented, form barriers to the construction of Net Zero Energy, high-performance green buildings. The result is a regulatory framework that makes building a diverse range of products increasingly difficult.

Standard index ratings and evaluation tools and guides for materials and products will simplify the design and selection processes and empower urban planners with design and planning tools that will facilitate the introduction of innovative energy-efficient, high-performance green technologies into our communities. These tools must be developed for new construction and for retrofits and renovations.

For the residential market, a comprehensive nationwide labeling program for green buildings, materials, and products will enable resource-friendly products to be consumed directly. New product labeling that effectively transfers practical technical and product application information will help promote the use of energy-efficient, high-performance green technologies. Public awareness and education will help stimulate demand for new approaches and technologies for the residential housing market by using simplified product performance guides that are derived from the more in-depth technical documents and performance data.

R&D Focus Area 6b

Develop tools and guides that enable use of modern, adaptive performance-based building codes.

Building codes protect the public, but they may also form barriers to innovation in the construction industry. Even with the near universal adoption of a unified building code, regulatory streamlining across localities and regions remains to be achieved. This is the result of local building regulations, codes, and amendments being adopted piecemeal to address local preferences and regulations that are administered inefficiently or prescriptively. Slow and burdensome permitting and approval systems, obsolete building and rehabilitation regulations, and difficulties associated with infill development are important impediments to innovative development in urban areas.

Many building code and standards organizations are committed to developing the next-generation requirements that integrate adaptive performance-based specifications for improved building efficiency and resource use. Federal R&D activities support the development of performance-based model codes, standards, and sustainable and efficient designs and technologies through technical support, advice, and recommendations to these code writing bodies. Once developed, these new codes and standards must be broadly integrated into local building regulations, codes, and amendments over time. Other approaches are needed to improve building efficiency and accelerate the adoption of new high-performance building technologies and procedures.

Alternative approaches undertaken in parallel with the code and standards process are needed to improve building efficiency and accelerate the adoption of new high-performance building technologies and procedures.

Update codes and standards. Codes, standards, and recommended specifications for residential, commercial, and healthcare facilities may be outdated, obsolete, or in some cases incorrect, and result in lower building performance and efficiency. These requirements (illumination standards, hospital ventilation refresh rates, and other long-standing codified specifications) should be reviewed, updated, and revalidated.

Provide code-based tools and guides. New tools and guides for building performance design with code-checking capability are needed. These tools and guides will help regulatory officials and designers create high-performance buildings, maintain service levels for IEQ, and use performance-based codes and standards that assess compliance based on the desired system performance rather than on prescriptive designs and products. To be useful, these tools should be easy to use and flexible in application. Training materials and educational programs will be needed for regulatory officials and practitioners to successfully implement these tools. Building operation and continuous commissioning-related performance requirements should be investigated as a component to future code-based software tools and guides.

With the adoption of more progressive model building codes and standards, the uptake of new energy efficiency technologies will begin to transform building market dynamics, speed their adoption, and ultimately lower their costs.

R&D Focus Area 6c

Research and develop effective incentives for adopting and using innovative technologies and practices.

6.2 Tools and Metrics for Increased Technology Adoption

Because many design and retrofit decisions are based on the initial cost of the project, materials or designs that may result in lower life cycle operating costs are often rejected because of the initial cost. As a result, high-performance design and operation are often subordinated to the initial cost conundrum. Analytical economic-based analysis methodologies should be developed in conjunction with LCA metrics to evaluate the impact of incentives on the acceptance of technological innovation and the financing supply chain. Standard guidance needs to be developed to help practitioners and owners make educated choices about how to renovate or retrofit buildings.

Develop market-based building valuation metrics and tools. Building, owners, occupants, appraisers, inspectors, realtors, financiers and lenders, insurers, and the public collectively determine whether innovations add "value" to a building. This determination considers changes in building life-cycle cost, technical performance, occupant environments, and market demand for "green" building technologies and approaches. Economic performance metrics and evaluation tools that justify higher market values for high-performance, net zero energy buildings must be integrated with traditional market valuation models to provide market-based incentives for adopting new technologies in buildings.

6.3 Analysis of Financial and Regulatory Incentives

Policymakers may use a variety of incentives and policy tools to promote the accelerated adoption of new, more efficient building technologies. These incentives include increased building valuation, reduced financing fees, lower taxes and insurance premiums, and special considerations in the permitting and review process. Cost-benefit analyses of these policy tools could support policymakers as they consider the most cost-effective ways to achieve energy efficiency goals.

Analyze financial incentives. Financial incentives for adopting innovative technologies may help to overcome the historical decision criteria of minimal initial cost in retrofits and new construction. The costs and benefits of legal instruments such as Energy Saving Performance Contracts should be examined and documented. Other direct external mechanisms should be evaluated along with indirect financial incentives such as leased building systems and components with guaranteed performance requirements and accelerated equipment depreciation schedules. Each of these incentives must be demonstrated to result in an effective business case for investment, long-term savings, and higher resale values.

Investigate tax incentives. State and local governments and utility service providers have experience in the use of incentives for building renovation and new construction. The effectiveness of reduced taxes and fees or implementing graduated service rates that encourage adoption of new these technologies should be evaluated and formally documented. New policies and incentives, such as solar incentive programs, may affect grid energy consumption and help stimulate economic growth in some industries. Cost-benefit analyses of tax credits should be performed to quantitatively evaluate the benefits (energy and associated cost savings, emissions reductions) relative to the costs.

Analyze regulatory incentives. Builders and building owners may be motivated to invest in new resource-efficient technologies if cost-saving regulatory incentives are available. These could include an expedited permitting process and priority plan review for high-density energy-efficient housing for those seeking to employ new resource-saving technologies. Analyses should be performed to understand how benefits compare to costs of various regulatory incentives.

7 Collection, Analysis, and Dissemination of Research Results

The Federal R&D focus areas identified in this report define a rich technical R&D agenda for buildings. To be successful, this technical agenda must be broadly disseminated, reviewed, and discussed by Federal agencies, national and international code and standards organizations, universities, and private sector partners. R&D programs must be developed and coordinated across the Federal enterprise in concert with activities in the private sector activities.

As these R&D programs advance, comprehensive and well-documented research will be performed on the full range of technology areas for new and existing buildings, and practices and protocols needed for development and demonstration will be identified. R&D and demonstrations will form the basis for future research. New technologies, practices, and protocols will document information sources, clearly and completely describe R&D results, and validate and verify methods.

This scientific, technical, and engineering information will be published and shared broadly within the scientific community, so long as it is not proprietary, classified, or restricted by Federal statute and has been technically reviewed and approved for release. Consistent with Federal administrative requirements, distribution outside the U.S. Government may include:

- Public speeches, news releases and advisories, news conferences, broadcast appearances, and interviews or discussions with journalists
- Public writings, such as articles or papers in publications or other writings distributed through mass mailing, e-mail, or posting on a website
- Public educational instruction, lectures, conferences, and seminars
- Public distribution of audiovisual works, including without limitation slide sets, PowerPoint presentations, multimedia (any combination of two or more media productions), and exhibits

Effective transfer of these results will stimulate commercial technology development in the private sector and will help code and standard organizations develop resource-efficient adaptive recommendations and requirements (see Table 2). Tools and guides will be made freely available to building owners and operators, contractors, architects, and other stakeholders.

<<Sidebar>>

In 2007, the energy technologies sector received globally $3 billion in venture capital investment, a 43% increase over 2006, according to Dow Jones VentureSource. U.S. venture capital funds poured $2.5 billion into clean energy enterprises, a 79% increase over 2006. Such enterprises, which only six years ago received less than 1% of all venture capital, attracted 12% last year.

Source: http://useu.usmission.gov, “Venture Capitalists Boost Clean-Energy Technology,” March 5, 2008

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Table 2. Energy-Efficiency, Green, and Sustainability Interest Groups

Codes and Standards Organizations/Professional Societies/Trade Associations
Air-Conditioning, Heating and Refrigeration Institute (AHRI) Alliance to Save Energy (ASE) American Council for an Energy Efficient Economy (ACEEE) American Council of Engineering Companies (ACEC) American Society of Civil Engineers Practice(ASCE) American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) American Society of Mechanical Engineers (ASME) American Solar Energy Society (ASES) Architecture 2030 – American Institute of Architects (AIA) ASCE Member Alliance: Education and Research for Sustainable Infrastructure (PERSI) ASTM International - originally known as the American Society for Testing and Materials Building Owners and Managers Association (BOMA) Continental Automated Buildings Association (CABA) Electric Power Research Institute (EPRI) Energy Efficient Builders Association (EEBA) Green Building Initiative (GBI) International Code Council (ICC) Joint Commission on Accreditation of Healthcare Organizations (JCAHO) National Governors Association (NGA) National Society of Professional Engineers (NSPE) National Association of Home Builders (NAHB) U.S. Combined Heat and Power Association (USCHPA) U.S. Green Buildings Council (USGBC) See also greenjobs www.greenjobs.com/Public/GreenDirectory/associations.htm
International
Commission for Environmental Cooperation (created under Article 13 of the North American Agreement on Environmental Cooperation) International Energy Agency (IEA) International Ground-Source Heat Pump Association (IGSHPA) Sustainable Buildings and Construction Initiative United Nations Environmental Program: Intergovernmental Program on Climate Change and World Business Council for Sustainable Development (WBCSD)
Federal and Governmental
Federal Facilities Council – National Academy of Science (NAS) Federal Network for Sustainability - voluntary, collaborative network of Federal agencies in the Western United States Federal Real Property Council – General Services Administration (GSA) Interagency Energy Management Task Force - Department of Energy's Federal Energy Interagency Sustainability Working Group – DOE Federal Energy Management Program (FEMP) Partnership for Advancing Technology in Housing (PATH) Sustainable Acquisition and Materials Management Practices Workgroup – Office of the Federal Environmental Executive (OFEE)

8 Conclusions and Next Steps

Federal-level R&D and support are needed to address the energy and environmental challenges identified for buildings. The Federal R&D focus areas identified in this report define the future technologies, practices, and protocols needed to transform the energy and resource utilization trends of the building sector. These focus areas are the constituent components to six major goals that enable Net Zero Energy buildings and that reduce energy and resource consumption (see Table 3).

Table 3. Goals for Net Zero Energy, High Performance Green Buildings

Goal 1.	Develop the enabling measurement science to achieve Net Zero Energy, sustainable, high-performance building technologies.
Goal 2.	Develop Net Zero Energy building technologies and strategies.
Goal 3.	Develop the scientific and technical bases for significant reductions in water use and improved rainwater retention.
Goal 4.	Develop processes, protocols, and products for building materials that minimize resource utilization, waste, and life cycle environmental impacts.
Goal 5.	Develop the knowledge and associated energy efficiency technologies and practices needed to promote occupant health, comfort, and productivity.
Goal 6.	Enable technology transfer for Net Zero Energy, high-performance green buildings.

Achieving these goals will take a sustained commitment by Federal agencies, private sector organizations, and academia. The following steps are necessary for the nation to embark on the path to Net Zero Energy, high performance green buildings:

1. Create a detailed roadmap for each R&D goal in partnership with key stakeholder organizations.
2. Engage the key stakeholders — universities, research institutions, standard and code development organizations, professional societies, and private sector companies — to implement the R&D agenda.
3. Publicize the Federal performance requirements for purchases and procurements.
4. Evaluate successes and lessons learned.
5. Organize follow-on workshops, conferences, and planning fora
6. Refine the research agenda.

The role of the Federal government in ensuring the buildings sector's effective use of energy and natural resources is multifaceted. Federal R&D is essential for the basic research needed to develop new building technologies that will achieve Net Zero Energy buildings and to enable the use of high-performance green technologies and practices. Federal departments such as the Department of Defense (DOD), General Services Administration (GSA), and

Department of Veterans Affairs that operate large building programs can lead in the adoption of new technologies in major renovation and construction and all Federal building owners can promote the use of these technologies. Professional societies and research institutions such as universities and research organizations working with their Federal counterparts will develop the ideas into working models. Finally, the public and private sector partnerships will create the products and industry alliances that will ultimately influence the marketplace.

<<Sidebar>>

According to the USGBC in "Green Building Research Funding: An Assessment of Current Activity in the United States", research on green building presently constitutes an estimated 0.2% of all federally funded research, an average of $193 million per year.

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The Federal government is the country's largest building owner — GSA alone owns or leases more than 342 million square feet of space in more than 2,100 communities nationwide. Executive Orders and statutes require that Federal buildings be more energy efficient and green (see Appendices 9.3 and 9.5). GSA and other Federal agencies have promoted and applied new technologies such as BIM and LCA to make buildings and campuses more resource efficient. This leadership role of the Federal government is essential to advancing the knowledge and practice available to the building sector as a whole.

Recognizing that the U.S. building sector consumes more fossil-fuel energy than any other sector is the necessary first step to reducing the nation's consumption of energy. The second is for building owners, architects, contractors, code officials, and others to become more aware of their responsibility to reduce their energy and resource consumption, and of the availability of tools and technologies to initiate this change. This responsibility includes a leadership role in disseminating and implementing the resource-efficient technologies and practices for all types of buildings.

"Knowing is not enough; we must apply.
Willing is not enough; we must do."
-Wolfgang Johann von Goethe

For the building sector to significantly improve its energy and resource efficiency, current technologies must be incorporated into present-day construction and renovation projects. As new building technologies are developed to achieve Net Zero Energy buildings, the private sector must have the tools, guides, and technologies to facilitate their adoption. R&D recommendations provided in this report will also identify incentives for the private sector to accelerate commercialization of energy technologies that have the potential to dramatically alter buildings and their supporting infrastructure on a national and a global scale.

9 Appendices

9.1 Appendix A: Definition of Key Terms

HIGH-PERFORMANCE BUILDING – 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. (Ref: P.L. 110-140)

HIGH-PERFORMANCE GREEN BUILDING – A high-performance building that, during its life cycle, compared with similar buildings (as measured by the Commercial Buildings Energy Consumption Survey or Residential Energy Consumption Survey data from the Energy Information Administration)

- Reduces energy, water, and material resource use
- Improves IEQ by reducing indoor pollution, improving thermal comfort, and improving lighting and acoustic environments that affect occupant health and productivity
- Reduces negative impacts on the environment, including air and water pollution and waste generation, throughout its life cycle
- Increases the use of environmentally preferable products, including bio-based, recycled content, and nontoxic products with lower life cycle impacts
- Increases reuse and recycling opportunities
- Integrates systems
- Reduces the environmental and energy impacts of transportation through building location and site design by supporting a full range of transportation choices for occupants
- Considers its indoor and outdoor effects on human health and the environment, including: 1) improvements in worker productivity, 2) the life cycle impacts of materials and operations, and 3) other factors that the Federal Director or the Commercial Director consider to be appropriate. (Ref: P.L. 110-140)

LIFE CYCLE – The term *life cycle*, with respect to a high-performance green building, means all stages of the building's useful life (including components, equipment, systems, and controls) beginning at conception of a high-performance green building project and continuing through site selection, design, construction, landscaping, commissioning, operation, maintenance, renovation, deconstruction or demolition, removal, and recycling. (Ref: P.L. 110-140)

LIFE CYCLE ASSESSMENT – The term *life cycle assessment* means a comprehensive system approach for measuring the environmental performance of a product or service over the life of the product or service, beginning at raw materials acquisition and continuing through manufacturing, transportation, installation, use, reuse, and end-of-life waste management. (Ref: P.L. 110-140)

LIFE CYCLE COSTING – The term *life-cycle costing*, with respect to a high-performance green building, means a technique of economic evaluation that sums, over a given study period, the costs of initial investment (less resale value), replacements, operations (including energy use), and maintenance and repair of an investment decision. It is expressed (i) in present value terms, in the case of a study period equivalent to the longest useful life of the building, determined by taking into consideration the typical life of such a building in the area in which the building is to be located; or (ii) in annual value terms, in the case of any other study period. (Ref: P.L. 110-140)

MEASUREMENT SCIENCE – This term includes performance metrics, measurement methods, predictive tools, and protocols, as well as reference materials, data, and artifacts; the conduct of intercomparison studies and calibrations; the evaluation and assessment of technologies, systems, and practices; and the development of technical guidelines and bases for standards, codes, and practices via test beds, consortia, and other partnerships with the private sector.

NET ZERO ENERGY (COMMERCIAL) BUILDING – A high-performance commercial building that is designed, constructed, and operated to require a greatly reduced quantity of energy to operate; meets the balance of energy needs from sources of energy that will result in no net GHG emissions; and is economically viable. (Ref: P.L. 110-140)

9.2 Appendix B: Acronyms and Abbreviations

AOC	Architect of the Capitol
ASTM	ASTM International (originally American Society for Testing and Materials)
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BIM	building information modeling
BTRD	Buildings Technology Research and Development
Btu	British thermal unit, a basic measure of thermal (heat) energy
CHP	combined heat and power
CO_2	carbon dioxide
DOC	U.S. Department of Commerce
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
DOS	U.S. Department of State
EPA	U.S. Environmental Protection Agency
GBI	Green Building Initiative
GHG	greenhouse gas
GSA	General Services Administration
HHS	U.S. Department of Health and Human Services
HUD	U.S. Department of Housing and Urban Development
HVAC	heating, ventilating, and air-conditioning
IAQ	indoor air quality
IEQ	indoor environmental quality
LCA	life cycle assessment
LCI	life cycle inventory
LEED	Leadership in Energy and Environmental Design
LID	low-impact development
NASA	National Aeronautical and Space Administration
NIST	National Institute for Standards and Technology
NREL	National Renewable Energy Laboratory
NSF	National Science Foundation
NSTC	National Science and Technology Council

OFEE	Office of the Federal Environmental Executive
OMB	Office of Management and Budget
O&M	operations and maintenance
OSTP	Office of Science and Technology Policy
PV	photovoltaic
Quad	quadrillion, one thousand million million or 10^{15}
R&D	research and development
SI	Smithsonian Institution
SSL	solid-state lighting
USDA	U.S. Department of Agriculture
USGBC	U.S. Green Building Council
VA	U.S. Department of Veterans Affairs

9.3 Appendix C: Legislative Authorities and Supporting Documents

Legislative Mandates

The primary drivers for this report are the Energy Policy Act of 2005 (EPAct 2005, Public Law No: 109-58) and the Energy Independence and Security Act of 2007 (EISAct 2007, Public Law No: 110-140). These two Acts define a broad mandate to develop Federal R&D that will enable buildings to be more efficient and sustainable, to lower their impacts on the environment, and to improve occupant health and productivity.

Energy Policy Act of 2005. EPAct 2005 was passed by the U.S. Congress on July 29, 2005, and signed into law by President Bush on August 8, 2005. This Act was the first comprehensive energy legislation signed into law in more than a decade. Section 913 of EPAct 2005 (Title IX: Research and Development, Subtitle A) instructs the Director of the Office of Science and Technology Policy (OSTP) to establish an interagency group to develop, in coordination with an advisory committee, a National Building Performance Initiative to integrate Federal, State, and voluntary private sector efforts to reduce the costs of construction, O&M, and renovation of commercial, industrial, institutional, and residential buildings.

<<Sidebar>>

EPAct 2005 Requirements

- Research, develop, demonstrate, and apply energy technology systems and materials for new commercial construction and retrofit relating to the building envelope and building system components.
- Research, develop, demonstrate, and apply energy technology and infrastructure to enable the energy-efficient, automated operation of commercial buildings and building equipment.
- Collect, analyze, and disseminate research results and other pertinent information about enhancing building performance to industry, government entities, and the public.

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Energy Independence and Security Act of 2007. More recent activities have underscored the necessity for developing Federal R&D for energy-efficient buildings. EISAct 2007 was signed into public law on December 19, 2007 and focuses on a number of areas that directly affect the energy performance of buildings.

<Sidebar>>

EISAct 2007 Requirements

- Create an Office of Federal High-Performance Green Buildings at the U.S. General Services Administration, to be advised by a Federal Green Building Advisory Committee.
- Create an Office of Commercial High-Performance Green Buildings and a Consortium on Zero Net Energy Commercial Buildings Initiative, and authorize demonstration projects, at the U.S. Department of Energy.
- Authorize grants for healthy, high-performance schools and for a demonstration program at local government buildings, as well as a study of the interactions of sustainable building features and IAQ in schools, at the EPA.
- Upgrade Federal energy, IAQ, and stormwater runoff control provisions.
- Upgrade energy standards for appliances, equipment, and light bulbs.

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R&D is central to attaining the energy efficiency goals outlined in EPAct2005, EISAct 2007, and Presidential Executive Orders. These Acts and Executive Orders recognize the U.S. leadership role in technology development and that Federal and private sector investments in new building technologies will allow the nation to become the world's leader in resource-efficient technologies and conservation.

Supporting Documents

A wide range of Presidential Executive Orders, bipartisan Congressional actions, and governmental reports support the scope of Section 913 of EPAct 2005, EISAct 2007, and this Federal R&D agenda for energy-efficient, sustainable, high-performance buildings. These documents include:

Presidential Executive Orders: Presidential Executive Order 13423 "Strengthening Federal Environmental, Energy, and Transportation Management" signed by President Bush on January 24, 2007. This order sets goals for Federal facilities about energy efficiency, acquisition, renewable energy, toxics reductions, recycling, sustainable buildings, electronics stewardship, fleets, and water conservation.

White House Reports, Memoranda, and Circulars: Reports from President Bush's Council of Advisors on Science and Technology, *The Energy Imperative – Technology and the Role of Emerging Companies* (November 2006) and the *Report to the President on Federal Energy Research and Development for the Challenges of the Twenty-First Century* from President Clinton's Committee of Advisors on Science and Technology in November 1997 provided valuable perspectives about energy efficiency for the building sector.

The Office of Management and Budget (OMB) revised Circular A-11, Section 55 *Energy and Transportation Efficiency Management* to encourage Federal agencies to incorporate ENERGY STAR and the USGBC's LEED Green Building Rating System into upfront design concepts for new construction and building renovations. Defining the Federal R&D agenda, the annual OSTP/OMB Research and Development Budget Priorities memorandum highlight the Administration's R&D priorities. Over the past three years these energy-related priorities have included enabling the development of energy efficiency technologies, diversifying energy sources for American homes and businesses, and advancing technologies for renewable, zero emission, and alternative energy sources.

U.S. Public Law: EISAct 2007, passed (Public Law No: 110-140) on December 19, 2007, focuses on a broad range of topic areas, including buildings technology. The complementary EPAct 2005 was signed into law on August 8, 2005 (Public Law No: 109-58). The precursor to EPAct 2005 was EPAct 1992, which, along with its amendments to the National Energy Conservation Policy Act, formed the statutory basis for Federal energy and water use activities.

Other Governmental and Nongovernmental Reports: Other key reports include the U.S. Climate Change Technology Program (CCTP) *Strategic Plan,* (September 2006) and the Office of the Federal Environmental Executive (2003) report, *The Federal Commitment to Green Building: Experiences and Expectations.* Most recently the USGBC's Research Committee released "A National Green Building Research Agenda" describing the priority research, development, and demonstration areas required for making a transformative leap in building performance and sustainability.

International Efforts: The United Nations Environmental Programme — Sustainable Buildings and Construction Initiative reports on *Buildings and Climate Change* (IPCC 2007), *Climate Change 2007*, and the *Energy Efficiency in Buildings* report (World Business Council for Sustainable Development 2007) represent the more widely recognized international reports on energy efficiency for buildings. Most recently, the Commission for Environmental Cooperation released *Green Building in North America: Opportunities and Challenges*, a Secretariat Report under Article 13 of the North American Agreement on Environmental Cooperation.

Federal Interagency Forum: This report was developed through the Buildings Technology Research and Development Subcommittee of the National Science and Technology Council (NSTC). This Federal interagency group consists of 16 Executive Branch agency members and is co-chaired by officials of DOE and DOC, which led the Subcommittee and the development of this report. Two other Federal organizations, the Architect of the Capitol and the Smithsonian Institution, voluntarily participate on the Subcommittee and in the development of this report. This Subcommittee is chartered by the NSTC to address a broad range of R&D issues that include the activities outlined in Section 913 of EPAct 2005.

9.4 Appendix D: Federal Agency Roles and Mission Areas

Legend	
● Lead Agency Role	○ Supporting Agency Role

	Goal	USDA	DOC	DOD	DOE	DHS	HHS	HUD	DOI	DOS	VA	EPA	GSA	NASA	NSF	SI	AOC
Goal 1	**Metrics and Measurement Science**		● ○		● ○	○	○	○	○			○			○		
Goal 2	**Net Zero Energy Buildings**		○	○	● ○							○	○	○	○	○	○
Goal 3	**Reduced Water Use**		○		○			○	○	○		● ○	○	○	○	○	
Goal 4	**Reduced Material Use**	● ○	○		○			○	○	○		● ○	○	○	○		
Goal 5	**Occupant Health and Performance**	○	○	○	○	○	● ○	○	○	○	● ○	○	○	○	○	○	○
Goal 6	**Implementation and Adoption**	○	● ○	● ○	● ○					○	○	● ○	● ○	○	○	○	○

	USDA	DOC	DOD	DOE	HHS	DHS	HUD	DOI	DOS	VA	EPA	GSA	NASA	NSF	SI	AOC
Basic and Applied Research	○	● ○		● ○	○	● ○	○	○			● ○			● ○	○	
Measurement Science		●		● ○							○			○	○	
Development		● ○		● ○	○	○	○	○			● ○		○	● ○		
Demonstration	○		● ○	● ○			● ○	○			○	○				
Implementation	○	○	● ○	● ○					○	○	○	● ○	○		○	○

9.5 Appendix E: Details of Recent Legislative Acts, Memorandums of Understanding, and Executive Orders

Energy Policy Act of 2005 (EPACT 2005 – July 29, 2005, P.L.109-58)

- TITLE I—ENERGY EFFICIENCY
  - Subtitle A—Federal Programs. Requires federal agencies to reduce building energy intensity 20% by 2015 from 2003 baseline, meter electricity at building level, design new residential and non-residential buildings to 30% less energy than 2004 IECC and ASHRAE 90.1-2004. Also, extends energy savings performance contracting authority to 10/1/2016.
  - Subtitle B—Energy Assistance and State Programs. Authorizes building energy use state programs including low-income home energy assistance program, weatherization assistance, state energy programs, state building energy efficiency codes incentives and others.
  - Subtitle C—Energy Efficient Products. Institutionalizes ENERGY STAR at EPA and DOE; authorizes buildings and other education programs, additional product energy conservation standards, and improved and expanded energy efficiency consumer product labeling.
  - Subtitle D—Public Housing. Extends HUD energy savings performance contracts to 20 years, with public and assisted housing rehabilitation and new construction funded by HOPE VI revitalization grants to reference 2003 IECC and ASHRAE 90.1-1989 and HUD to develop an energy strategy for public and assisted housing.
- TITLE II—RENEWABLE ENERGY.
  - Subtitle A—General Provisions. Requires federal agencies' electricity to include renewable sources ≥ 3% 2007-09, ≥ 5% 2010-12, and ≥ 7.5% 2013; authorizes GSA new and existing public building PV commercialization program of ≥ 150 MW (peak), DOE weatherization assistance, financial assistance, and rebates for renewable energy systems.
- TITLE V—INDIAN ENERGY. Requires HUD to promote energy conservation in housing on Indian land and assisted with Federal resources.
- TITLE IX—RESEARCH AND DEVELOPMENT
  - Subtitle A—Energy Efficiency. DOE to conduct programs of energy efficiency RD&D, and commercial application for new construction and retrofit including onsite renewable energy generation. Calls for OSTP report to Congress on the Federal role in high-performance building R&D; NIBS to assess current voluntary consensus standards and rating systems; authorizes DOE to establish network of Advanced Energy Efficiency Technology Transfer Centers.
  - Subtitle B—Distributed Energy and Electric Energy Systems. Authorizes DOE to develop micro-cogeneration technology for residential applications and to provide financial assistance to demonstrate distributed energy technologies in high-energy intensive commercial applications.
  - Subtitle C—Renewable Energy. Authorizes DOE to establish a program for the demonstration of innovative technologies for solar and other renewable energy sources in buildings owned or operated by a State or local government.

- Subtitle G—Science. Authorizes DOE's Office of Science to conduct a program of fundamental research on solid state lighting in support of EERE's applied program.

- TITLE XIII—ENERGY POLICY TAX INCENTIVES.
  - Subtitle C—Conservation and Energy Efficiency Provisions. Authorizes federal tax incentives to promote energy efficiency and renewable energy use in buildings including commercial building deduction, a builder credit for new homes, taxpayer credits for improvements, PV, solar and fuel cells; also, credit for appliance manufacturers and business credit for fuel cells and microturbines.
- TITLE XVII—INCENTIVES FOR INNOVATIVE TECHNOLOGIES. Authorizes DOE loan guarantees for significantly improved technologies that reduce or sequester pollutants or greenhouse gases.

Multi-Agency MOU on Federal Leadership in High Performance and Sustainable Buildings: Guiding Principles – March 2006 (http://www.energystar.gov/ia/business/Guiding_Principles.pdf)

- Employ Integrated Design Principles—Establish energy performance goals and employ commissioning.
- Optimize Energy Performance—Establish whole building performance target; earn ENERGY STAR rating: for new buildings--energy cost budget 30% lower than ASHRAE 90.1-2004; for major renovations--energy cost budget 20% lower than 2003 baseline (same building); meter buildings.
- Protect and Conserve Water—Indoor water: 20% less than building baseline; outdoor water: 50% less than conventional strategies and reduce runoff pollution.
- Enhance Indoor Environmental Quality—IAQ construction management plan for ventilation, thermal comfort, moisture control, daylighting, low emitting materials, and IAQ.
- Reduce Environmental Impact of Materials—Use recycled and biobased content; minimize construction waste; avoid ozone depleting compounds.

E.O. 13423 – January 24, 2007 (http://www.archives.gov/federal-register/executive-orders/2007.html)

- Requires Federal agencies to reduce building energy intensity 30% by 2015 from 2003 baseline, with half of renewable energy required by EPACT 2005 from new sources, and reduce water use 16% by 2015 from a 2007 baseline. Acquisitions required to emphasize biobased, environmentally preferable, energy-efficient, water-efficient and recycled-content products. Agencies directed to reduce toxic and hazardous chemicals and materials; increase diversion of solid waste; and maintain waste prevention and recycling programs. New buildings and major renovations required to comply with Multi-Agency MOU on Federal Leadership in High-Performance and Sustainable Buildings: Guiding Principles, with 15% of the federal building stock required to comply with these guiding principals by 2015.

Energy Independence and Security Act of 2007 (EISA– December 19, 2007, P.L.110-140)

    - TITLE III—ENERGY SAVINGS THROUGH IMPROVED STANDARDS FOR APPLIANCE AND LIGHTING. Upgrades energy standards for appliances, equipment, and lighting. Authorizes more stringent regional standards for furnaces, central air conditioners, and heat pumps. For new federal buildings, major renovations, or leases subject to GSA prospectus rules, prospectus must include future energy performance estimates and describe EE and RE systems, and GSA must set energy efficient lighting requirements.
- TITLE IV—ENERGY SAVINGS IN BUILDINGS AND INDUSTRY
    - Subtitle A—Residential Building Efficiency. Reauthorizes Weatherization Assistance Program; DOE to establish standards for energy efficient manufactured housing.
    - Subtitle B—High-Performance Commercial Buildings. Requires DOE to establish Office of Commercial High-Performance Green Buildings and Zero Net Energy Commercial Buildings Initiative. DOE to competitively select public-private consortium (consortia) to represent private sector; coordinate with the Office of Federal High-Performance Green Buildings (see Subtitle C) to jointly establish national high-performance green building clearinghouse for outreach, education, and technical assistance.
    - Subtitle C—High-Performance Federal Buildings. Requires federal agencies to reduce building energy intensity 30% by 2015 from 2003 baseline; to audit 25% of facilities each year including commissioning or retro-commissioning; to identify and implement energy saving measures within 2 years if LCC-effective; and to measure and verify savings. Also, requires OMB to issue semiannual energy management scorecards on each agency. Also, new federal buildings and major renovations to reduce fossil-generated energy use 55% by 2010, and 100% by 2030, with respect to CBECS and RECS baselines. Agencies must meter natural gas and steam at building level. Leased buildings must achieve ENERGY STAR. Establishes Office of Federal High-Performance Green Buildings at GSA, coordinated with Office of Commercial High-Performance Green Buildings, to coordinate high-performance green building information and activities throughout the federal government. Requires federal building projects greater than 5,000 ft^2 to manage storm water to pre-developed conditions. Directs GSA to accelerate use of cost-effective technologies in GSA facilities. Public building life redefined as 40 years for LCC.
    - Subtitle E—Healthy High-Performance Schools. Authorizes grants for healthy, high-performance schools and local government building demonstration program.
    - Subtitle F—Institutional Entities. Authorizes technical assistance, grants, and loans for energy efficiency improvements and sustainable energy infrastructure in institutions of higher education, public school districts, local governments, and municipal utilities.
    - Subtitle G—Public and Assisted Housing. Rehabilitation and new construction funded by HOPE VI revitalization grants to reference 2006 IECC and ASHRAE 90.1-2004.
    - Subtitle H—General Provisions. Authorizes high-performance green building technology demonstrations and R&D by the DOE's Office of Commercial High-Performance Green Buildings and the GSA's Office of Federal High-Performance

Green Buildings; creates the Green Building Advisory Committee to advise GSA, and the Advisory Committee on Energy Efficiency Finance to advise DOE.

- TITLE V—ENERGY SAVINGS IN GOVERNMENT AND PUBLIC INSTITUTIONS. Energy Savings Performance Contracting authority made permanent. Prohibits purchase or installation of incandescent light bulbs in Coast Guard buildings; requires new federal buildings and major renovations to meet 30% of their hot water demand with solar if LCC-effective; requires eligible products to have minimal standby power use if LCC-effective; requires annual agency reports to OMB on compliance status of initiatives and savings.
- TITLE VI—ACCELERATED RESEARCH AND DEVELOPMENT. Authorizes DOE to demonstrate direct solar energy for lighting and advanced insulation for refrigeration units, conduct R&D on solar-powered air conditioning, and provide grants to States to demonstrate advanced photovoltaic technology.
- TITLE VIII—IMPROVED MANAGEMENT OF ENERGY POLICY. Authorizes DOE to develop and conduct national media campaign to increase energy efficiency throughout US, including the buildings sector.
- TITLE X—GREEN JOBS. Authorizes DOL to establish energy efficiency and renewable energy worker training program including building, construction, and retrofit industries; energy efficiency assessment industry; deconstruction and materials reuse industries; and manufacturers of products using environmentally sustainable processes and materials.

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