Green Building Research Funding:
An Assessment of Current Activity in the United States

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Acknowledgements

Material in this report comes from a large number of sources, including agency and research organizations' websites, personal knowledge of the U.S. Green Building Council (USGBC) Research Committee members and other individuals. The Research Committee guided the development of this report, performed several rounds of review and revision, and approved its final content.

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About the U.S. Green Building Council

The U.S. Green Building Council is the nation's foremost coalition of leaders from across the building industry working to promote buildings that are environmentally responsible, profitable and healthy places to live and work. It is a 501c3 nonprofit entity with more than 8,000 member organizations, and a vision that buildings and communities will regenerate and sustain the health and vitality of all life within a generation. USGBC's membership includes private corporations, federal agencies, state and local governments, industry and professional associations, and nonprofit organizations; and encompasses 70 local chapters and affiliates nationwide.

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Executive summary

Background

This report is intended to aid the U.S. Green Building Council (USGBC) Research Committee's effort to create a national green building research agenda identifying critical gaps in scientific and technical information needed to drive market transformation towards the adoption and evolution of sustainable building design, construction and operations practices in the United States. It outlines recent green building research and tracks federal, state and trade association contributions to green building research funding.

The built environment, including buildings and other development, plays a substantial role in environmental health, human welfare and economic stability. Building operation accounts for 40% of U.S. energy use[1]; this number increases to an estimated 48% when the energy required to make building materials and construct buildings are included.[2] Building operations alone contribute over 38% of the U.S.'s carbon dioxide emissions and over 12% of its water consumption. Waste from demolition, construction and remodeling makes up over 35% of all non-industrial waste (1996).

Buildings also have a significant impact on human health. Indoor air typically contains between 2 and 5—and occasionally greater than 100—times more pollutants than outdoor air. As a result, poor indoor air quality in buildings has been linked to significant health problems such as cancers, asthma, Legionnaires' disease and hypersensitivity pneumonitis.

Building industries—including architecture, engineering, manufacturing, construction and operations—employ over 1.7 million people and make up a significant part of the gross domestic product (GDP); an estimated $1 trillion per year. In addition, the effect of buildings on the productivity, health and well-being of people who work indoors impacts other sectors of the economy.

Scope

Generally, green building research includes any environmental, technical, social or business research on the negative environmental or public health impacts of buildings, on approaches to reducing or eliminating those impacts, and on promotion of the design, construction, and operation of man-made (built) environments in harmony with natural (ecological) systems. For the purpose of this report, the definition of green building research includes applied research, economic and market research, and technology transfer work. The latter represents the development—but not implementation—of relevant case studies, standards and other resources. This definition of research excludes technical assistance to projects; construction or renovation work; conferences, trainings or outreach; topics that primarily affect areas outside of the building site boundary; security and disaster issues; research funded or executed internationally; basic science, basic social science and other research with potential or indirect applications in green building; and proprietary, self-funded work underway by private companies.[3] Green building is also known as "sustainable" and "high-performance" building.

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[1] Annual Energy Review 2005. DOE/EIA-0384 (2005). Energy Information Administration, U.S. Department of Energy. July 2006.
[2] This figure includes primary energy for building operation plus the fabrication of building materials and construction of buildings. See the body of the report for references.
[3] Some of these realms may contribute to a greater body of green building research. However, they were excluded in order to more clearly define the scope of this report.

Data Collection and Analysis

Information in this report was collected from two primary sources: internet sites and personal interviews, with a focus on organizations that fund green building research at levels of at least $1 million per year. Internet research provided research project descriptions and, in some cases, detailed funding information. Personal interviews augmented data for those organizations that do not post detailed information online. Funding data was compiled and analyzed by funding organization, by year (2002-2006), and by topic area. [4] Topic areas included: energy and atmosphere, materials and resources, indoor environmental quality, sustainable sites, water efficiency, technology transfer, economic research or comprehensive green building research.[5] For this analysis, projects that overlap two topic areas were categorized based on the focus of the organization providing funding and/or conducting research. It should be understood, however, that these categories are somewhat fluid and overlapping. In addition, green building research funding was compared against the total research dollars spent by each organization.

The dollar amounts presented in this report are approximate and intended to provide general insight into the relative orders of magnitude of research funding, not precise values to the dollar. Furthermore, the latter level of detail is not necessary to understand the implications of the current level of green building research funding in comparison with funding levels in other engineering or science related fields.

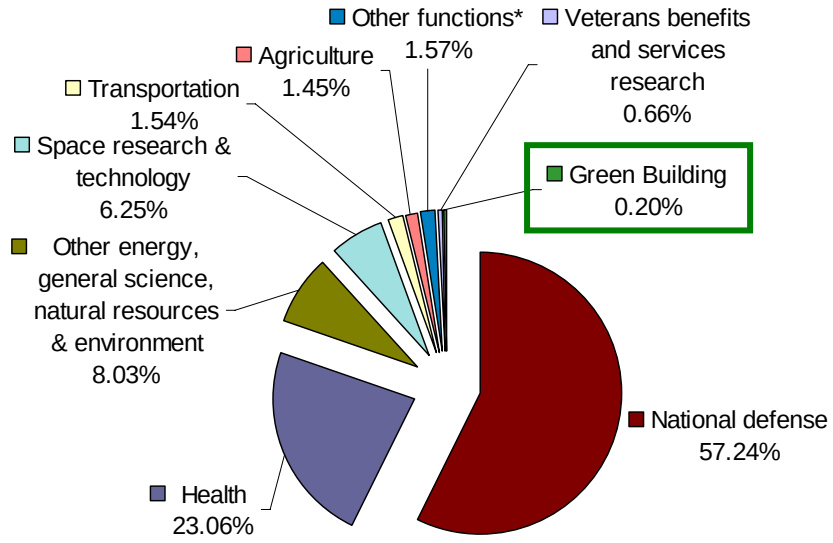
Findings

Between 2002 and 2004, federal green building research accounted for approximately 0.2% of all Federally funded research – a percentage that appears disproportionate to the benefits that can be gained by improving the efficiency and the health and environmental quality of buildings.

[4] Data was not available for all organizations for all five years. Some individuals were not willing to provide funding information, and some individuals with appropriate funding knowledge were not available for comment.

[5] Technology transfer includes the development codes, standards, metrics, databases, curricula, software, case studies and other tools. Economic research includes market research, cost/benefit analyses and other projects broadly related to economics, real estate and finance. Comprehensive green building research includes projects that study issues across more than two of the topic areas.

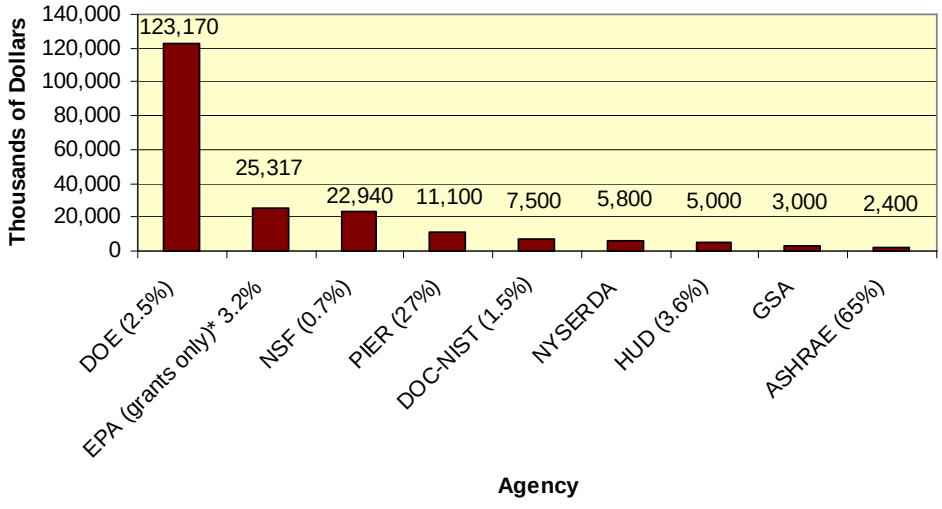
Chart 1. Federal R&D Budget Authority, by Budget Function FY2003-2005.



** Other functions include education, training, employment, and social services; income security; and commerce. Green building data was compiled from agencies and the Office of Management and Budget (OMB); baseline federal R&D budget data comes from the National Science Foundation (NSF). The 0.2% funding toward green building does not include money from the Department of Defense.*

About a half dozen federal organizations; two state organizations; and one professional organization all fund green building research at levels of at least $1 million per year. Additional federal, state and municipal agencies, foundations, utilities, professional organizations and corporations provide smaller levels of funding. Major consortia fund research in building performance at several universities; their budgets of $1-2 million per year typically come from a combination of public and private sources. Many of the organizations discussed here also contribute additional funding, not addressed in this report, to technical and other project assistance, education and outreach.

Chart 2. Average Annual Green Building Research Funding by Organization, 2003-2005, with Green Building Research Funding as a Percentage of Total Agency Research Allocations

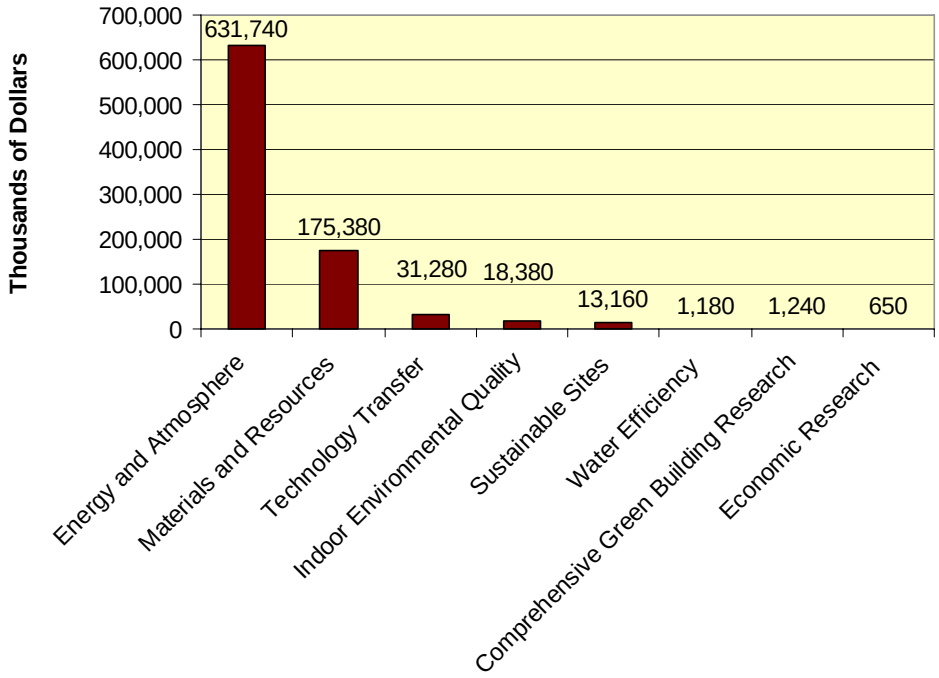


**Most of EPA green building research funds are distributed through grants; there is, however, a smaller additional amount of funding for intramural research.*

Green building research is being conducted by national laboratories, federal laboratories, private companies, industry-academic collaboratives, university research centers and individual university faculty and students. Broadly, the green building topics with the highest amount of dedicated research are very specific, finite and clearly associable with a single agency. Nearly all of the research identified in this report supports new strategies and technologies, though it also includes some building evaluations, "business case" research and technology transfer work – mostly on methods, models and protocols.

Of the key categories of sustainability established in LEED, energy is by far the best-funded topic within green building, followed by materials and resources, while other major knowledge areas are funded at lower levels.

Chart 3. Total Green Building Research Funding by Topic, 2002-2005



Within energy and atmosphere research, about 45% of the funding supports energy efficiency topics; 54% supports renewable energy technologies; and 1% supports other atmospheric issues. The building-related renewables research is almost entirely on photovoltaics (PVs), though there is also some research on fuel cells in architectural applications. The U.S. Department of Energy (DOE) is, by a factor of ten, the largest funder of building-related energy and atmosphere research.

Materials and resources issues receive the second largest amount of funding of the topic areas. Within this topic area, resource efficiency, waste streams, human health, and embodied energy issues are the best funded aspects of a materials' life cycle. Furthermore, relatively few organizations fund research on the full life cycle of any given material. DOE, the largest funder of green materials research, focuses on reducing the embodied energy of a few major construction materials. The National Science Foundation (NSF), the second largest, funds a broader range of topics.

Within indoor environmental quality (IEQ) research, both the causes and effects of poor IEQ are being studied. Major subtopics under IEQ include indoor air quality (IAQ), daylighting and ventilation/thermal comfort; the latter two often overlap with energy efficiency. Nearly all organizations that fund green building research fund projects that overlap with IEQ issues to some extent.

Although considerable research may be underway on water and site topics at a large scale, little of it falls within the scope of this review. The few site- or building-scale projects that are funded generally cover decentralized water collection, treatment or storage; lawn care, pesticides, and turf issues; and natural stormwater management practices, including green roofs.

Conclusions

Research on green building presently constitutes an estimated 0.2% of all Federally funded research, an average of $193 million per year. This is roughly equivalent to only 0.02% of the estimated value of annual U.S. building construction, despite the fact that the construction industry represents 9% of the U.S. GDP.[6] At the same time, the construction industry reinvests only 0.6% of sales back into research – significantly less than the average for other U.S. industries, and significantly less than private sector construction research investments in other countries.

Thus, despite the major effects of buildings and the built environment on our economy, quality of life and natural environment, funding for research on the built environment is relatively insignificant relative to funding for other research topics. Without a considerable increase and improvement in green building practices, the negative impacts of the built environment on human and environmental health are very likely to increase dramatically in coming decades. Federal and state government organizations should immediately take a proactive approach to addressing these problems in order to reduce the risks and consequences of global warming, water shortages, human health problems, ecosystem destruction, and many others. To do so, relevant funding sources should increase support to research on readily achievable green building strategies while also investing in long-term research programs that would prompt the major shift in design and construction practices necessary to alleviate many challenges critical to the nation's economy, health and well being.

Green building research already makes a difference, but a greater commitment to this research could make an even more profound difference.[7] To do so, however, funding for green building research must be commensurate with that of other streams of research, and commensurate to the severity of the problems that buildings create; the current 0.2% of Federal research dollars will not be adequate to address these critical issues in a timely manner.

[6] The entire construction industry, including heavy construction and public works, represents 14% of the U.S. GDP.
[7] As an example of the impact of green building research, a 2001 National Research Council report indicates that three decades of building energy efficiency research yielded significant benefits, and that its economic value exceeds DOE's investment.

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Introduction

Summary

In January 2006, the U.S. Green Building Council (USGBC) chartered a Research Committee to "be both a resource about existing knowledge and a driver of relevant research."[8] Its first project is the development of a national green building research agenda identifying critical gaps in scientific and technical information needed to drive market transformation towards the adoption and evolution of sustainable building design, construction and operations practices in the United States. This report is intended to aid the project by outlining the nature and extent of green building research currently underway or recently completed.

Background

The built environment, including buildings and other development, plays a substantial role in the environmental health, human welfare and economic stability of the United States. These three issues constitute what economists refer to as the "triple bottom line;" they represent the cornerstones of our well-being as a nation.[9] Buildings are critical to the health of all three. The built environment, including roads, bridges and other civil structures and buildings comprised 6% of the land of the Continental United States in 2003 and is growing annually; there was a 24% increase in developed land between 1992 and 2002.[10] The built environment has a profound impact on the natural environment.[11] Building operations account for 40% of U.S. energy use[12]; this number increases to an estimated 48% when the energy required to make building materials and construct buildings are included in the figure.[13] Building operations alone contribute over 38% of the country's carbon dioxide emissions[14] and over 12% of its water consumption.[15] Waste from demolition, construction and remodeling amount to 136 million tons of landfill additions annually, making up over 35% of all non-industrial waste (1996).[16,17] Construction and remodeling of buildings account for 3 billion tons—40%—of raw material use globally each year.[18] In fact, direct and indirect material investments in the built environment account for 70% of all national physical flows[19].

Buildings also have a significant impact on human health. Americans spend an average of 90% of the day indoors. A significant number of all buildings are associated with sick building syndrome or

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[8] *Charter for the USGBC Research Committee*, January 2006.
[9] Savitz, Andrew W. and Karl Weber. The Triple Bottom Line: How Today's Best-Run Companies Are Achieving Economic, Social and Environmental Success -- and How You Can Too. San Francisco: John Wiley and Sons, 2006.
[10] 2002 National Resources Inventory. National Resources Conservation Service, U.S. Department of Agriculture. http://www.nrcs.usda.gov/technical/land/nri02/nri02lu.html, 18 December 2006.
[11] Many of the following statistics are compiled at U.S. Environmental Protection Agency, *Buildings and the Environment: A Statistical Summary,* http://www.epa.gov/greenbuilding/pubs/gbstats.pdf, December 2004.
[12] Annual Energy Review 2005. DOE/EIA-0384 (2005). Energy Information Administration, U.S. Department of Energy. July 2006.
[13] Mazria, Ed. Architecture 2030 Challenge. http://www.architecture2030.org/building_sector/index.html, 18 December 2006.
[14] Emissions of Greenhouse Gases in the United States 2002. DOE/EIA-0573(2002). Energy Information Administration, U.S. Department of Energy. October 2003. http://www.eia.doe.gov/oiaf/1605/ggrpt/index.html. 18 December 2006.
[15] Estimated Water Use in the United States in 1995. U.S. Geological Survey. http://water.usgs.gov/watuse/pdf1995/html/, 18 December 2006.
[16] Characterization of Building-Related Construction and Demolition Debris in the United States. Office of Solid Waste, U.S. Environmental Protection Agency. July 1998. http://www.epa.gov/epaoswer/hazwaste/sqg/c&d-rpt.pdf, 18 December 2006.
[17] Municipal Solid Waste in the United States: 2001 Facts and Figures. Office of Solid Waste, U.S. Environmental Protection Agency. October 2003. http://www.epa.gov/garbage/pubs/msw2001.pdf, 18 December 2006.
[18] Lenssen and Roodman, 1995, "Worldwatch Paper 124: A Building Revolution: How Ecology and Health Concerns are Transforming Construction," Worldwatch Institute.
[19] Matos, G.R., and Wagner. "Consumption of materials in the United States, 1900–1995." Annual Review of Energy and the Environment 1998, v. 23, p. 107–122.

building related illness; up to 30% new and remodeled buildings may experience acute indoor air quality problems.[20] Indoor air typically contains between 2 and 5—and at times greater than 100—times more pollutants than outdoor air.[21] As a result, poor indoor air quality in buildings has been linked to significant health problems such as cancers, asthma, Legionnaires' disease and hypersensitivity pneumonitis.[22,23]

Building industries—including architecture, engineering, manufacturing, construction and operations—employ over 1.7 million people[24] and make up a significant part of the gross domestic product (GDP); an estimated $1 trillion per year.[25] This represents the largest economic sector in the United States, and the second largest manufacturing sector. [26] The state of our buildings also may profoundly impact other sectors' levels of productivity, particularly in their effects on the health and well being of workers. Several Federal agencies have identified indoor environmental quality issues to be significant enough to warrant building-specific research agendas. For example, The National Institute for Occupational Safety and Health (NIOSH) developed *Improving the Health of Workers in Indoor Environments: Priority Research Needs for a National Occupational Research Agenda* in 2002[27] and the US EPA released *Program Needs for Indoor Environments Research* in 2005. The negative impact of buildings on human health is significant, as described above, and the resulting loss in productivity has a direct impact on our economy. The impact of the building industry on the US GDP is substantial, especially when considering buildings' influence on their occupants' productivity.

Scope

Green building research can be defined very broadly, as a large number of factors contribute to human and ecological health as they relate to the built environment. For the purpose of this report, which focuses on defining current major research projects, the definition of green building research is more limited. Generally, it includes any environmental, technical, social or business research on the negative environmental or public health impacts of buildings, on approaches to reducing or eliminating those impacts, and on promotion of the design, construction, and operation of man-made (built) environments in harmony with natural (ecological) systems. The concept of green building is also known as "sustainable" and "high-performance" building.

Research identified by this report includes applied research, economic and market research, and technology transfer work. The latter represents the development—but not implementation—of relevant case studies, standards and other resources. The report's scope excludes technical assistance to projects, construction/renovation projects, conferences, trainings or outreach.

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[20] Indoor Air Facts No. 4 (revised): Sick Building Syndrome (SBS). U.S. Environmental Protection Agency. http://www.epa.gov/iaq/pubs/sbs.html, 18 December 2006.

[21] The Total Exposure Assessment Methodology (TEAM) Study. EPA 600/S6-87/002. U.S. Environmental Protection Agency. 1987. http://www.epa.gov/ncepihom/.

[22] Indoor Air Facts No. 4 (revised): Sick Building Syndrome (SBS). U.S. Environmental Protection Agency. http://www.epa.gov/iaq/pubs/sbs.html, 18 December 2006.

[23] Fung, Frederick, MD, MS; William G. Hughson, MD, PhD. "The fundamentals of mold-related illness: when to suspect the environment is making a patient sick." Postgraduate Medicine Online, June 2003. http://www.postgradmed.com/issues/2003/06_03/fung.htm, 18 December 2006.

[24] 2002 Economic Census. Census Bureau, U.S. Department of Commerce. http://www.census.gov/econ/census02/advance/TABLE2.HTM, 18 December 2006.

[25] U.S. Department of Energy. 2006 DOE Buildings Energy Data Book. http://buildingsdatabook.eren.doe.gov, 19 February 2007.

[26] *Ibid*.

[27] Mendell, Mark J. et al. "Improving the Health of Workers in Indoor Environments: Priority Research Needs for a National Occupational Research Agenda." American Journal of Public Health. September 2002. http://www.ajph.org/cgi/content/abstract/92/9/1430?ck=nck, 18 December 2006.

This report focuses on work that is funded and/or executed by public, institutional or non-profit organizations. It does not include proprietary self-funded work underway by private companies to develop products and technologies because of the level of difficulty involved in obtaining this information. Grant-funded research executed by private companies is included.

Because green building is a broad field without exact definition, in some cases the level of research on this topic may be understated or overstated, depending upon where one draws the lines. In order to keep the scope of this report manageable and realistic, it is limited to buildings and their sites. The following areas of research were excluded, even though they may have relevance in the discussion of a green building research agenda:[28]

- Security-focused research;
- Brownfield, smart growth, urban planning, land use and related health research;
- Basic science research with possible indirect implications for green buildings;
- Basic social science research;
- Natural disaster research;
- Mixed mode transportation research;
- Technologies being developed for other industries that may someday have applications in buildings;
- Industrial product development research; and
- Research funded or executed by foreign countries or international organizations.

For the purposes of this report, research topics were divided into eight categories. Five of the eight are similar to those of the LEED® Rating System:[29] Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality, Sustainable Sites, and Water Efficiency; the remaining categories include Economic Research, Comprehensive Green Building Research, and Technology Transfer. Where possible, research projects within each agency were further divided to represent greater detail on the topics covered; e.g., the Energy and Atmosphere category is divided into Energy Efficiency, Renewable Energy, Commissioning and M&V, and Other Atmospheric Issues.

Data Collection and Analysis

The information in this report was collected from two primary sources: internet sites and personal interviews. The first step of this effort began with interviews of USGBC Research Committee members, liaisons, and USGBC support staff for the purpose of identifying the organizations that fund green building research. Those interviews took the form of one-on-one telephone interviews, group conference calls and e-mails. These discussions, coupled with personal knowledge of green building research, contributed to resources used for this report, including referrals to organizations and individuals for additional information. These organizations are discussed in greater detail in the Funder Profiles section; the individuals are listed in the Acknowledgements section.

Initial internet research on federal agency funding focused on OMB budget documents. They provided overall budgets for some specific research sectors, such as research on different building materials in Industrial Technologies Program of the Department of Energy. In most cases, however, OMB documents remain too broad to include detail on topics as specific as green building research.

[28] These exclusions were made to limit the scope of the Ginsberg Fellowship project.
[29] LEED® is the Leadership in Energy and Environmental Design Green Building Rating System. See http://www.usgbc.org/DisplayPage.aspx?CategoryID=19 for more information.

The second step was to identify funding information listed on organizations' websites. Some of the sites, including the EPA and NSF, had a grant database that listed all extramural research funding. These databases were searched for grants related to green building research for the years 2002-2006. Searches were typically limited by a set of key words, such as "energy," "lighting," "indoor," etc.[30] Search results were analyzed grant by grant to identify those related to green building. Some organizations, such as the U.S. Department of Agriculture (USDA)'s Forest Service's Forest Products Laboratory (FPL) and the Center for Disease Control (CDC)'s National Institute for Occupational Safety and Health (NIOSH), publish funding information within the context of individual research programs, not as a part of a larger database. Data was collected from this type of site by examining each page of a site's relevant programs or projects.

The third step was to conduct telephone interviews with individuals in organizations whose funding data was not published online. The goal of these interviews was to identify the amount of funding given to green building research annually between 2002 and 2006, where possible, and to identify the funding allocated to one of 8 different general topic areas: energy and atmosphere, materials and resources, indoor environmental quality, sustainable sites, water efficiency, technology transfer, economic research or comprehensive green building research.

These first three steps comprised data collection and sorting of relevant facts in preparation for the final phase of the process. The fourth step involved the compilation and analysis of all green building research funding amounts for the purpose of comparing these dollar values to amounts devoted to topics other than green building. Where possible, dollar amounts were categorized by year, by funding organization, and under one of the eight general topic areas. This enabled analyses discussed below, such as comparisons of funding by topic and funding by agency. In addition, green building research funding was compared against the total research dollars spent by each organization; the total Federally funded green building research was also compared against other types of Federally funded research, e.g. national defense, agriculture, etc. The National Science Foundation publishes data on total research expenditures by federal agency. Similar values for two state agencies and one professional organization were compiled through personal interviews.

While the methods of data collection outlined above facilitate conclusions to be drawn on the level of magnitude of green building research funding, they are not intended to provide exact dollar amounts. Although the information available online is typically published to a level of detail at least to the $1,000, it is likely that some projects were overlooked, or that some were inadvertently included when they should not have been. In particular, the information provided by interviewees, while likely to be comprehensive, typically involved dollar figures rounded to the $100,000 level. Given these factors, the dollar amounts presented in this report are intended to provide general insight into the relative orders of magnitude of research funding, not precise dollar values. Furthermore, the latter level of detail is not necessary to understand the implications of the current level of green building research funding and comparisons to funding levels in other engineering or science related fields.

It is understood that some research programs and funding efforts oriented to support the science, technology and implementation of green building strategies may have been inadvertently omitted in this report. It has been the intention of the author to provide a comprehensive listing of all major green building research projects but it is possible that isolated programs may have been missed. Alternatively, one could make the case that this report actually overstates the level of green building research currently funded, depending on how strictly one defines the broad concept of green

[30] Search words included buildings, energy efficient, energy, sustainable, air quality, lighting, indoor, plumbing, water, water efficient, water fixtures, stormwater, graywater, blackwater, green, AEC, commissioning, photovoltaic, irrigation, daylighting, and productivity.

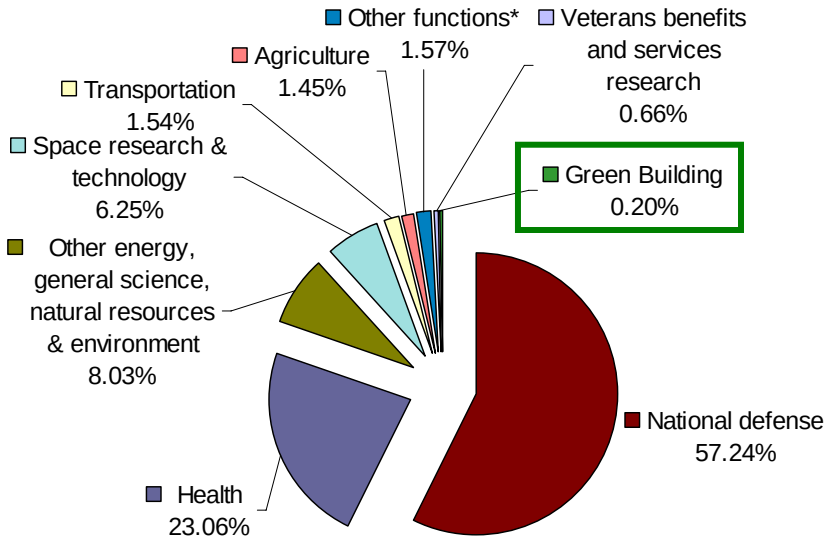
building. Balancing out the possibilities of under-representation and over-representation, this report involved an extensive effort to accurately identify current green building research funding levels.

Funding Streams

Overview

Between 2002 and 2004, green building research accounted for approximately 0.2% of all Federally funded research[31] – a percentage that appears disproportionate to the benefits that can be gained by improving the efficiency and environmental performance of buildings.[32]

Chart 1. Federal R&D Budget Authority, by Budget Function FY2003-2005.



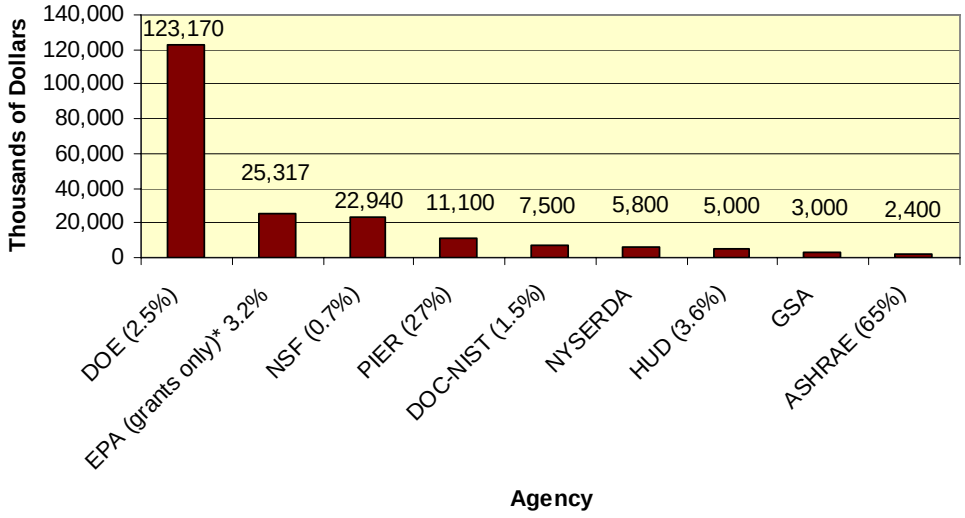
** Other functions include education, training, employment, and social services; income security; and commerce. Green building data was compiled from agencies and the Office of Management and Budget (OMB); baseline federal R&D budget data comes from the National Science Foundation (NSF). The 0.2% funding toward Green Building does not include money from the Department of Defense.*

The largest streams of green building research funding come from about a half dozen federal organizations; two state agencies, the California Energy Commission's Public Interest Energy Research (PIER), the New York State Energy Research and Development Authority (NYSERDA); and one professional organization, the American Society for Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) (Chart 2). Additional federal, state and municipal agencies, foundations, utilities, professional organizations and corporations provide smaller levels of funding. In some cases, these organizations fund laboratories associated with different organizations, e.g., PIER funds research executed at Department of Energy (DOE) National Labs. Many of these organizations contribute more to technical and other project assistance, education and outreach than to research.

[31] Funding information compiled from agency and Office of Management and Budget websites.
[32] Center of Building Performance and Diagnostics. "NSF Research Needs Workshop: Building Systems Integration for Performance and Environmental Quality Final Report 99, NSF Project #9708399." October 1997.

At times, corporations also fund research projects or provide in-kind donations to third party research projects, though this is sporadic and limited in comparison to the private support for third party research in the IT and pharmaceutical industries. Many companies also dedicate a significant percentage of their operating budgets to internal research related to green building, though this is typically confidential and difficult to track. Major consortia fund research in building performance at several universities; building research organizations at University of California Berkeley, Carnegie Mellon University, Syracuse University and Georgia Tech have substantial budgets of $1-2 million a year. Funding for these typically comes from a combination of public and private sources. These budgets are generally made up of grant funding from industry and the organizations discussed above.

Chart 2. Average Annual Green Building Research Funding by Organization, 2003-2005, with Green Building Research Funding as a Percentage of Total Agency Research Allocations

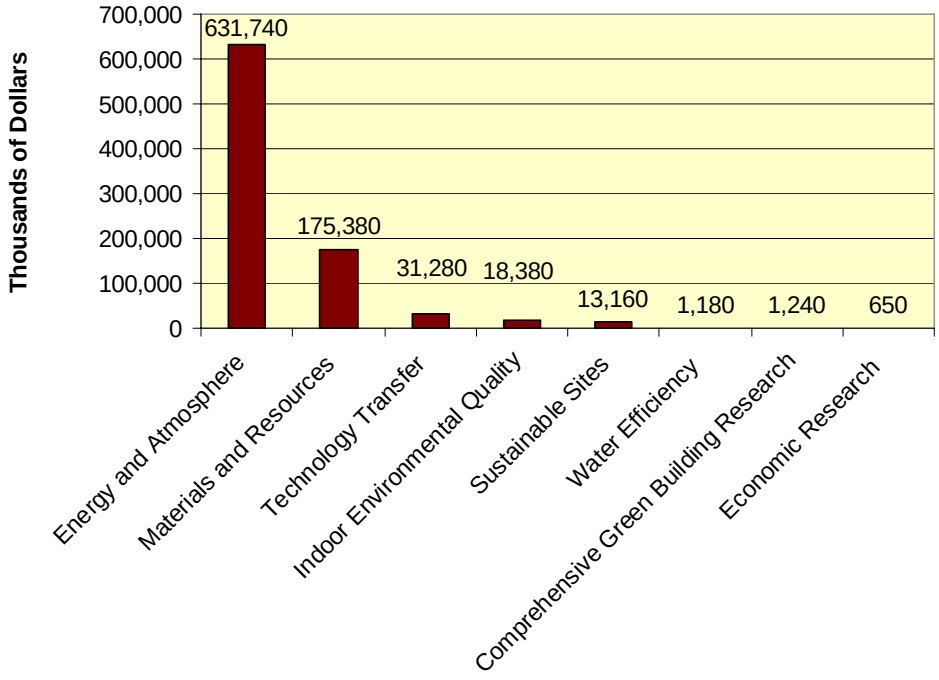


**Most of EPA green building research funds are distributed through grants; there is, however, a smaller additional amount of funding for intramural research.*

Federally funded extramural research includes both competitively selected grants and direct Congressional appropriations known as earmarks. Both contribute significantly to green building research, though the former is far easier to track. The latter are distributed through federal agencies such as DOE or EPA; the agencies are required by Congress to process the funds, but may have some authority to advise and administer the projects. This is true for research across the board, not just in green building.

Of the key sustainability categories within LEED, energy is by far the best-funded topic within green building, followed by materials and resources, while other major knowledge areas are funded at lower levels.

Chart 3. Total Green Building Research Funding by Topic, 2002-2005



Not all research falls within the LEED framework. Looking beyond those, "technology transfer" includes the development of codes, standards, metrics, databases, curricula, software, case studies and other tools. The economic research category also includes market research, cost/benefit analyses and related projects. Comprehensive green building research includes projects that study issues across more than two of the knowledge areas listed in Chart 3. Some research overlaps two different knowledge areas. For example, underfloor air distribution projects can affect both energy efficiency and indoor environmental quality. For this analysis, projects with overlap were categorized based on the focus of the organization providing funding and/or conducting research.

Funder profiles

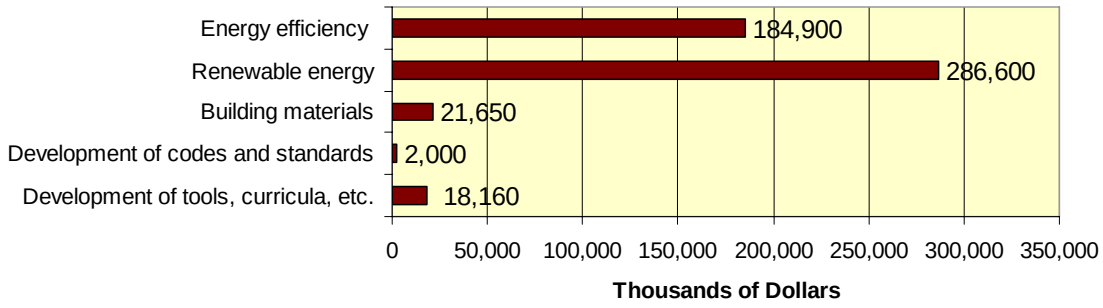
The following list identifies the major federal and state agencies, non-governmental organizations and industry-academic partnerships that fund green building research at greater than approximately one million dollars per year. Organizations are listed in order of the amount of green building funding, from largest to smallest funders, with general approximations made for organizations without specific green building funding information available.

1. U.S. Department of Energy (DOE)

Predictably, most DOE green building research falls within the LEED Energy and Atmosphere category, including some topics that overlap with Indoor Environmental Quality issues. DOE also funds some research on the embodied energy of building materials.[33] Both topics are addressed within the Office of Energy Efficiency and Renewable Energy (EERE); most of the energy and atmosphere research is funded through the Building Technologies and Solar Energy Technologies Programs, while materials and resources research is funded through the Industrial Technologies Program. Although DOE's energy research is far greater than its work in other topic areas, the Industrial Technologies Program is also the single largest U.S. funder of materials research.

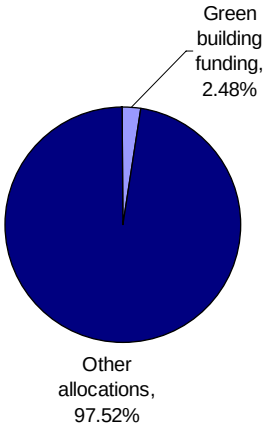
Within EERE, about 60% of green building research funding goes to DOE national laboratories; the remaining 40% is distributed through competitive selection. The Department of Energy funds numerous national laboratories; four do a significant amount of green building related work: Lawrence Berkeley National Laboratory (LBNL), Oak Ridge National Laboratory (ORNL), National Renewable Energy Laboratory (NREL), and Pacific Northwest National Laboratory (PNNL). A number of other national laboratories do a smaller amount or less directly related research on green building topics. Other organizations also fund these labs, but in amounts smaller than DOE. Most of the projects that DOE currently funds through competitive selection are in the Solid State Lighting Portfolio in the Building Technologies Program. EERE's Inventions and Innovations Program also gives grants for research in new green technologies. In addition, DOE's Federal Energy Management Program funds some technology transfer work, although most of its efforts are not research oriented.

Chart 4. DOE Funding by Topic (2002-2004)



[33] Embodied energy is the energy required for extraction or harvesting of raw materials and manufacturing the raw materials into products for buildings. Some definitions of embodied energy also include the energy required for transporting a material to the construction site, but the embodied energy research performed by DOE's, Industrial Technologies Program focuses on extraction and/or manufacturing processes.

Chart 5. DOE Research Funding Allocations, 2002-2004



2. U.S. Environmental Protection Agency (EPA)

EPA funds green building research extramurally through grants and intramurally through research laboratories run by EPA's Office of Research and Development (ORD.) Most of EPA's green building research is on air quality, including research that explicitly addresses indoor air issues, outdoor air research that has a direct impact on indoor air quality issues, or general air quality research that impacts both indoor and outdoor air issues. Generally, the latter represents EPA's most heavily funded green building related projects.

Internally, much of this research is carried out by the Indoor Environment Management Branch (IEMB) of the EPA's National Risk Management Research Laboratory (NRMRL). EPA has been dedicating about 4% of its external grant funding to green building research in a wide range of fields, though air quality (mostly outdoor) is by far the leading topic. In addition, some of EPA's Small Business Innovation Grants and Pollution Prevention (P2) grants go towards green building research.

Chart 6. EPA Green Building Research Grant Funding by Topic, Total 2002-2006

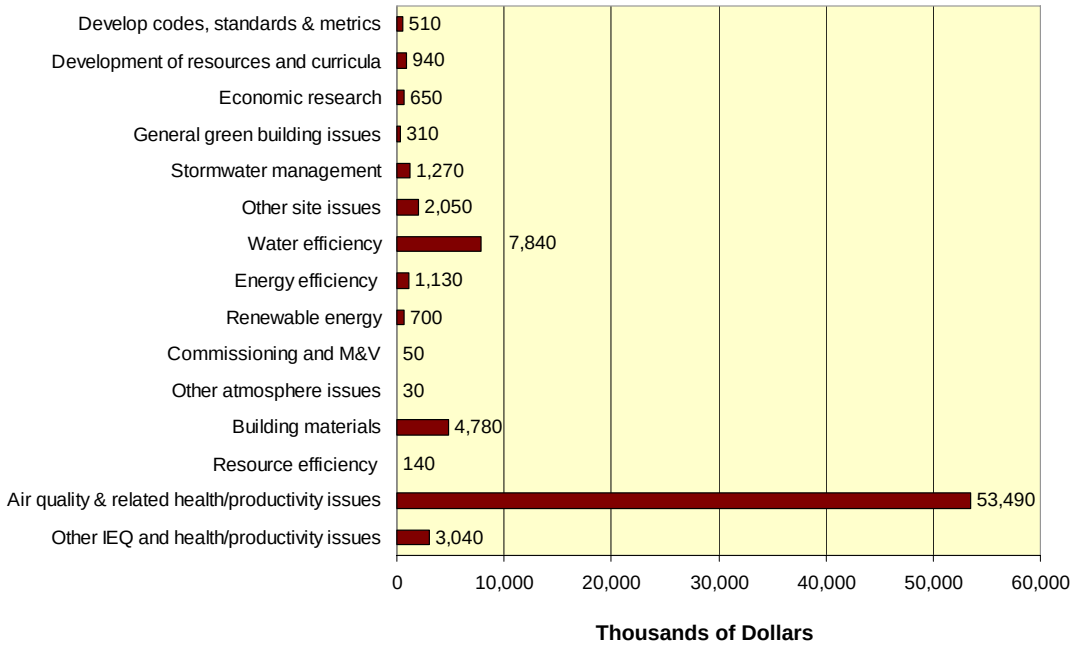
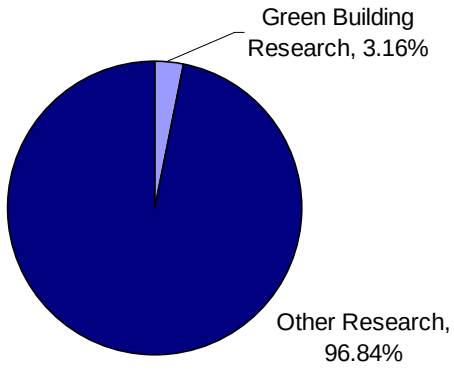


Chart 7. EPA Research Funding Allocations, 2002-2005



3. U.S. Department of Defense (DOD)[34]

The Department of Defense has a number of research initiatives related to green building in each of the armed forces, plus some funding from the central office of DOD. Of organizations within the three forces, the Army Corps of Engineers does the most applied research. The Army Corps' Engineering Research and Development Center has seven laboratories, one of which is the Construction Engineering Research Laboratory (CERL). Within the realm of green building, CERL's work includes technology transfer, such as the Sustainable Project Rating Tool (SPiRiT), and research on construction and demolition waste, construction technologies, energy efficiency and energy production technologies, indoor environmental quality, stormwater management and pollution prevention. DOD R&D budgets do not fund green building work at this time; those funds are directed to military-specific projects. *Chart 1 Federal R&D Budget Authority, by Budget Function FY2003-2005,* above, does not include DOD green building research funds, as they are not taken from Federal R&D budgets. Army green building research funding comes from reimbursable monies; sources include the Army Environmental Command, the Base Realignment and Closure Program, direct Congressional appropriations, the Assistant Chief of Staff of Installation Management, individual installations and others. Individuals and groups who do green building research within the Army have experienced increased difficulty in funding work in recent years; as a result some have begun to seek out new and less conventional sources for funding.

Outside of CERL, most of the green building research work in the Armed Forces is in technology transfer. The U.S. Navy conducts basic and applied research, but it is generally not related to green building; however, the Naval Facilities Engineering Command (NAVFAC) funds technology transfer work. Similarly, the U.S. Air Force Center for Environmental Excellence (AFCEE) provides research and technology transfer services through PROACT, a base-level pollution prevention resource, and The Air Force Technology Transfer Program. As another example of technology transfer, a consortium of federal agencies, including DOD, are funding the development of the Whole Building Design Guide (WBDG), an online tool that includes sustainability as one of eight design objectives.

4. National Science Foundation (NSF)

The National Science Foundation provides funding to a wide range of green building

[34] Most individuals and organizations in the Armed Forces interviewed for this report were not willing or able to provide funding data.

projects, with the largest amount of money going to renewable energy projects. The NSF funds a wide range of organizations, including universities, independent research centers and private companies. Its recent green building grants have ranged from $2,000 to $8,750,000.

Chart 8. NSF Green Building Funding by Category, 2002-2005

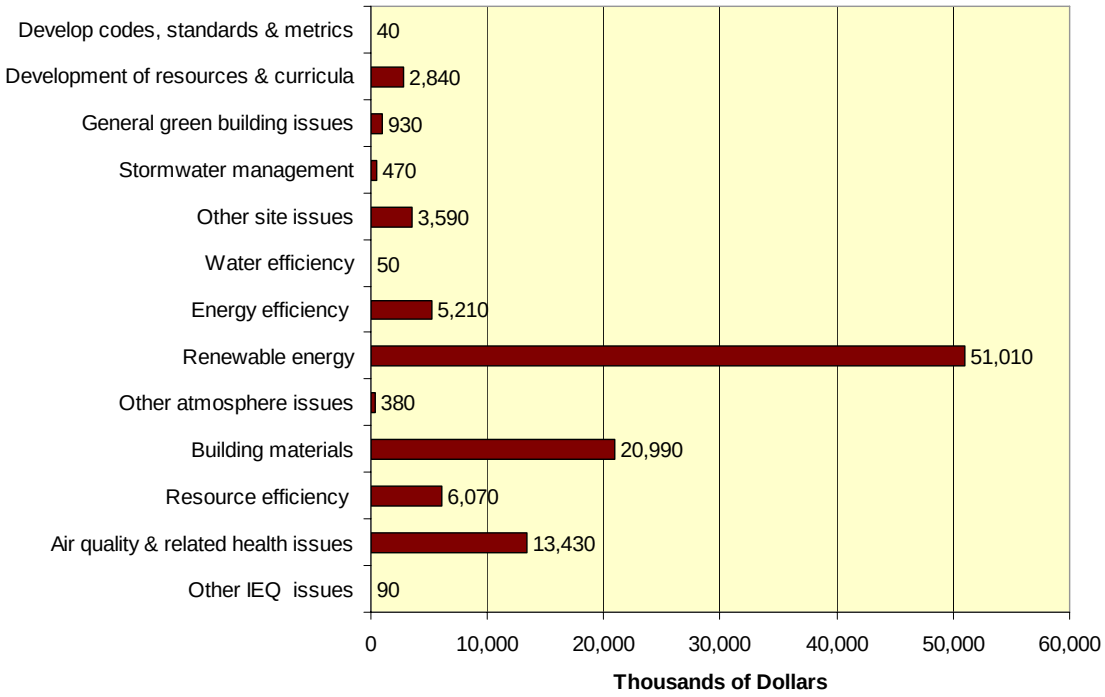
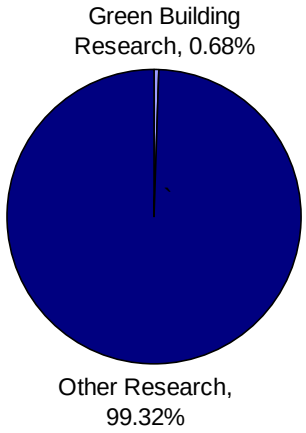


Chart 9. NSF Research Funding Allocations, 2002-2005



5. California Energy Commission (CEC) Public Interest Energy Research (PIER)

PIER "supports energy research, development and demonstration (RD&D) projects that will help improve the quality of life in California."[35] PIER money comes from investor-owned utility ratepayers as a result of 1996 state legislation. Building energy efficiency and renewable energy are two of seven PIER program areas, all of which are required by law to

[35] Public Interest Energy Research < http://www.energy.ca.gov/pier/> 19 August 2006.

focus on "public interest" work. PIER primarily funds applied research, plus some technology transfer executed by individuals, businesses, utilities, and public or private research institutions.

Chart 10. PIER Green Building Funding by Category, 2002-2005

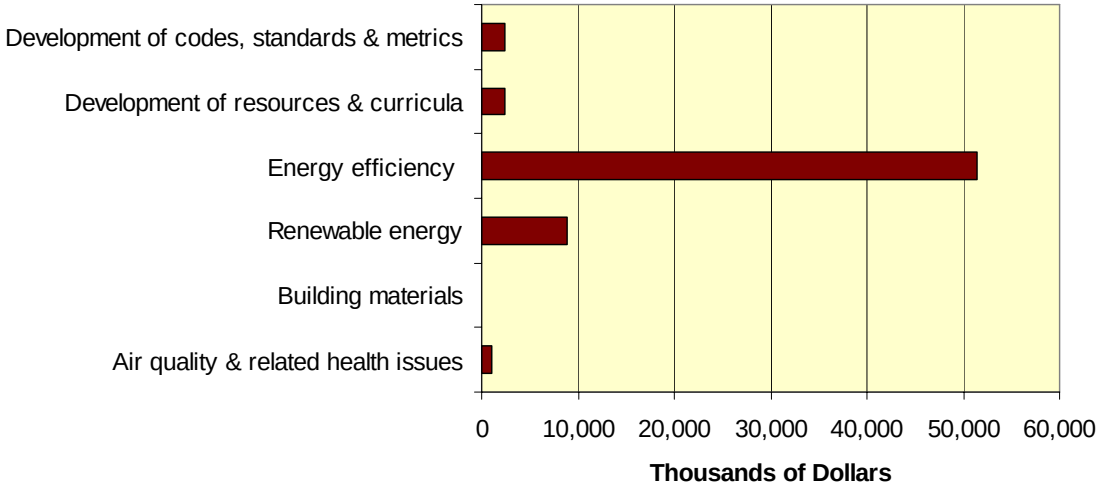
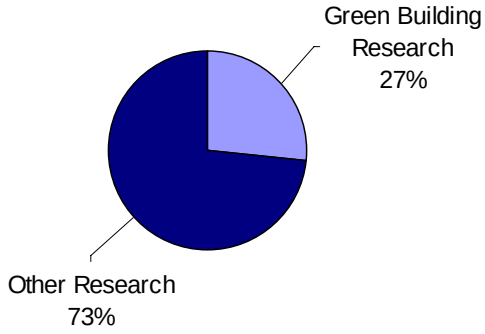


Chart 11. PIER Research Funding Allocations, 2002-2005



6. U.S. Department of Health & Human Services – Center for Disease Control (CDC) National Institute for Occupational Safety and Health (NIOSH)

NIOSH sponsors research on Indoor Environmental Quality, and health issues associated with building material manufacturing and construction; NIOSH also does extensive education and outreach on these topics. NIOSH manages the National Occupational Research Agenda (NORA), which includes over a dozen different research agendas, such as one on indoor environments. NORA priorities are funded through NIOSH grants. Between 2002 and 2004, NIOSH funded an average of nearly $1 million of indoor environment grants per year through NORA and an average of an additional $10 million of grants on related health and air quality issues. NIOSH also funds technology transfer through its Research to Practice program.

7. U.S. Department of Commerce – National Institute of Standards and Technology (NIST) Building Fire and Research Laboratory (BFRL)

NIST provides the majority of the funding for the BFRL, which conducts approximately $7.5 million of green building research per year. Of that, approximately 40% goes to

materials research and 60% goes to building performance research. This represents about 1.5% of research in NIST laboratories, and 0.6% of all Department of Commerce research. Although the Department of Commerce provides primary funding, the BFRL also receives supplementary monies from other sources.

Chart 12. NIST Building Funding by Category, 2002-2005

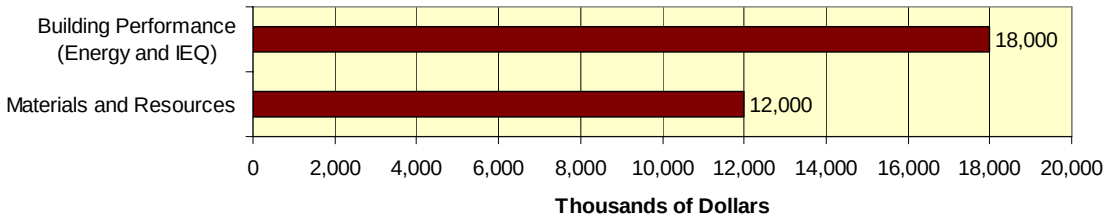
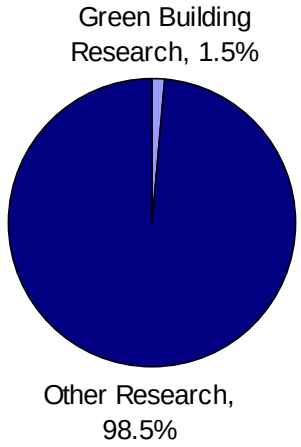


Chart 13. NIST Research Funding Allocations, 2002-2005



8. New York State Energy Research and Development Authority (NYSERDA)

NYSERDA is a public benefit corporation with revenue from state utilities taxes dedicated to energy research by legislation from 1975, though it also receives a smaller amount of federal funding. Over the past four years, NYSERDA has spent an average of $6.3 million on green building research per year, funding work in energy efficiency, renewables and combined heat and power activities. NYSERDA's mission statement is "Use innovation and technology to solve some of New York's most difficult energy and environmental problems in ways that improve the State's economy" – as such, many of its grants focus on local businesses and technology development.[36]

9. U.S. Department of Housing and Urban Development (HUD)

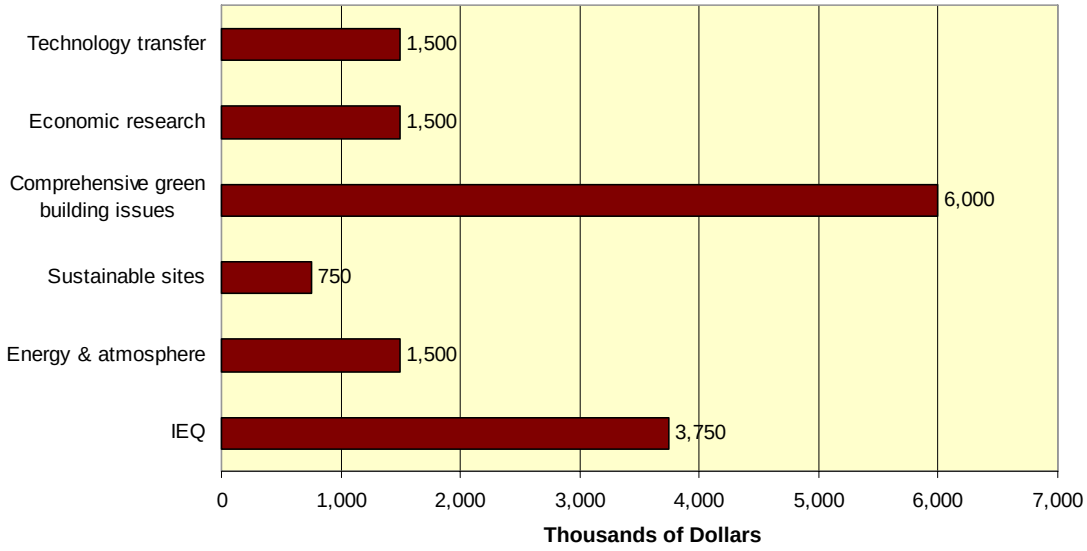
HUD funds a modest amount of research, of which a small percentage goes toward green building issues. The largest venue for this is HUD's Partnership for Advancing Technology in Housing (PATH) Initiative, supported through HUD's Office of Policy Development and Research. PATH receives about $5 million per year through HUD as well as some grant funding through NSF, though this entire amount is not dedicated to research. HUD also sponsors a smaller amount of additional research related to green building, some of which is administered through HUD's Office of Healthy Homes and Lead Hazard Control, covering topics such as construction technologies and lead abatement.

[36] New York State Research and Development Authority. <http://www.nyserda.org/About/about_mission_statement.asp> 12 December 2006.

10. U.S. General Services Administration (GSA)

The U.S. GSA funds internal research that includes green building issues through its Office of Applied Science Research and Expert Services Division. It currently spends about $3,000,000 per year on projects in workplace design, workplace evaluation, building performance and building operation. This research is carried out both internally by GSA staff and through contracts with consultants, national laboratories and universities. The GSA also does related implementation work in its Sustainable Design and Sustainable Development Programs.

Chart 14. GSA Green Building Research Grant Funding by Topic, 2002-2006



11. U.S. Department of Agriculture (USDA) – Forest Service's Forest Products Laboratory (FPL)[37]

The USDA provides primary funding to the Forest Service's Forest Products Laboratory (FPL), which researches more efficient and sustainable use of wood resources. The FPL houses the Advanced Housing Research Center and the Coalition for Advanced Wood Structures. Most of the FPL research relates to Materials and Resources, though work has been done on indoor air quality and energy efficiency of composite wood materials.

12. American Society for Heating, Refrigerating and Air Conditioning Engineers (ASHRAE)

Of professional organizations involved with green building, ASHRAE funds the largest amount of research; about 65% of its $2.4 million annual research budget goes to topics in Energy and Atmosphere, Indoor Environmental Quality and related design tools. Within these areas, research projects are largely selected by ASHRAE's Technical Committees and are implemented by a competitive bid process. Projects are typically funded in the $50-200K range. Co-funding by agencies and other organizations is routinely solicited.

[37] Funding numbers not available at the time this report was written.

Chart 15. ASHRAE Building Funding by Category, 2002-2005

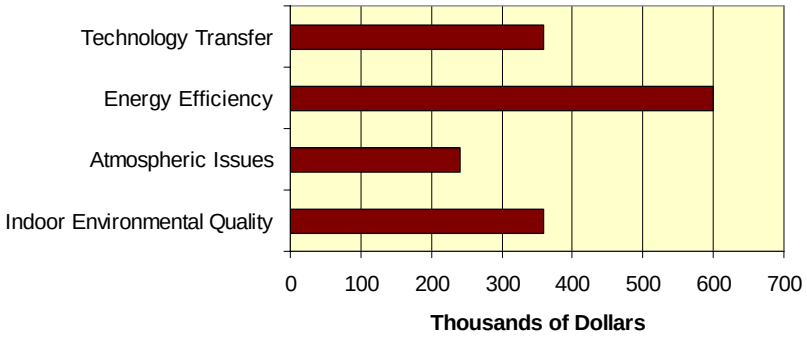
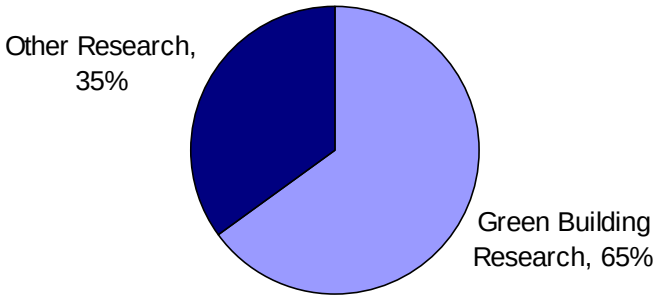


Chart 16. ASHRAE Research Funding Allocations, 2002-2005



13. Public utilities

Many gas, electric and water utilities have significant programs that fund issues related to green building. In most cases, utilities focus on training, implementation and outreach – not actual research. This is not universally true, and many utilities fund a small amount of research in addition to their outreach and implementation efforts. In some cases, the utilities contribute money on behalf of their customers directly to organizations that fund related research. PIER and NYSERDA, discussed above, are two such groups. The Northwest Energy Efficiency Alliance (Alliance) is another; it receives money from electric utilities, public benefits administrators and the Bonneville Power Administration. From 1996-2004, the Alliance's annual budget was $165 million; it increased to $185 million beginning in 2005. The majority of this goes to necessary market transformation tasks, not to research.

14. Industry-Academic Partnerships

The National Science Foundation has formed about 80 Industry/University Collaborative Research Centers (I/UCRCs); two of these deal with green building: UC Berkeley's Center for the Built Environment and Carnegie Mellon University's Advanced Building Systems Integration Consortium (ABSIC). These partnerships receive grant funding from many of the above organizations, however they differ from conventional university research centers in that they also receive significant funding from industry partners, such as product manufacturers and design/engineering firms. Additional industry-academic partnerships formed through other channels also help to facilitate green building research on varying scales. Though both the I/UCRCs and other partnerships generally bring less than $1 million from industry and other non-federal sources to green building research individually, collectively they represent an important contribution to green building research.[38]

[38] Funding numbers from industry partners are confidential.

15. U.S. Department of Education
    The Department of Education's Fund for the Improvement of Postsecondary Education (FIPSE) grants fund some green building topics. They sponsor curriculum development and range from $150,000 to $600,000, typically over a three-year period.

16. National Institute of Health (NIH)
    The NIH, and its National Institute of Environmental Health Sciences (NIEHS) funds both intramural and extramural research that can be linked to green building but that for the most part does not fall within the scope of this report.

Overview of Current Research

Green building research is being done by national laboratories, federal laboratories, private companies, industry-academic collaboratives, university research centers and individual university faculty and students. It spans a wide range of topics, though energy issues are clearly the best represented. Broadly, the green building topics with the highest amount of dedicated research are very specific, finite and clearly associable with a single agency. Integrated, multifaceted and holistic research topics are less prevalent. This is not surprising, given that most funding comes from federal and state agencies with very clear and potentially narrow objectives.

One of the approaches that the Research Committee has suggested for organizing green building research divides it into three categories: 1) performance and impacts of mainstream and green buildings, 2) green building technologies and strategies, and 3) the scientific underpinnings of green building. The first category of research is necessary to test, demonstrate, refute and/or find new means to ensure the effectiveness of green building. The second covers much of the applied research and technology transfer work currently underway. The third represents the basic science that supports the first two categories; this includes scientific discoveries and the development of analytical methods, models and protocols.[39] Almost all of the research identified for this report falls into the second category, though some building evaluations and "business case" research falls into the first category and some research in methods, models and protocols falls into the third. Despite the obvious importance of the basic science research that makes applied green building research possible, such basic research is mostly beyond the scope of this report.

Research by LEED Category

Energy and Atmosphere

Across both federal and state funding sources, over 70% of the identified green building research is devoted to energy and atmosphere issues; this represents about 0.15% of all Federally funded research. Within energy and atmosphere research, about 45% is on energy efficiency; 54% is on renewable energy technologies; and 1% is on other atmospheric issues. The building-related renewables research is almost entirely on photovoltaics (PV), though there is also some on fuel cells in architectural applications.[40] The PV research covers a wide range of issues, including product development, research to facilitate market transformation, and applications in both residential and commercial buildings.

[39] These three categories were developed by Ken Sandler, U.S. EPA liaison to the Research Committee.
[40] Wind, biomass and other renewable technologies not intrinsically connected to a building are not in the scope of this report.

Within energy efficiency topics, the following receive the most attention: performance of glazing and windows; energy efficient lighting for both indoor and outdoor applications; demand response technologies; building information modeling, controls and management systems; commissioning and retrocommissioning methods; mechanical and ventilation systems that provide both thermal comfort and energy efficiency. Within HVAC systems, underfloor air distribution, displacement ventilation and alternative cooling systems receive significant attention. In comparison with all-mechanical systems, less research is underway on natural ventilation and mixed mode mechanical cooling/natural ventilation systems. In addition to this applied research, much of the technology transfer work is being done for energy efficiency technologies and strategies. Most of this is in the development of codes, standards, software, and commissioning tools.

Though not included in this report, additional fundamental research is currently underway that will likely support renewable technologies in the future. There is also a significant amount of research underway on fuel cells, though almost all of it is currently directed to the automobile industry. As such, it is not included in this analysis, but if successful it may someday be transferred to buildings.

Materials and Resources

Materials and resources issues receive the second most funding of green building knowledge areas across the studied funding sources – about 0.4% of all Federally funded research. Some specific aspects of the life cycle of building materials receive greater attention than others, especially those that overlap with different streams of research such as resource efficiency, waste streams, health of construction workers and building occupants, and embodied energy. Green materials research appears to some extent in nearly all the funding agencies listed above; ASHRAE, NYSERDA and PIER are the only exceptions. There is relatively little overlap, however, as each organization has interest in different parts of material life cycles. Likewise, while many organizations address one or two parts of a given material's life cycle, relatively few study the full life cycle. Most research is being performed on materials used on a large scale, such as wood/paper products, steel, glass and concrete. Aluminum, bio-based materials and composite systems are also receiving attention from a number of different agencies and research organizations.

Indoor Environmental Quality, Health, and Productivity

Indoor environmental quality (IEQ) research currently underway mirrors the complexity and diversity of the field. Both the causes and effects of poor IEQ are being studied. There are an enormous number of factors originating both inside and outside of buildings that can impact indoor air quality and overall indoor environmental quality. In parallel, indoor environmental quality has a wide array of impacts on human health. A number of projects focus on developing methods and models for testing and understanding IEQ problems and how the problems relate to human health. This is more the case for IEQ issues than it is for other knowledge areas, because of the challenge of tracing the pathways from pollutants to exposures to health effects.

Major subtopics under IEQ research include indoor air quality (IAQ), daylighting and ventilation/thermal comfort – the latter two often overlapping with energy efficiency. Of issues that fall only under the realm of IEQ, IAQ is the largest sector of the modestly funded IEQ research. Research streams include particulate matter; diseases and health impacts related to air quality, such as asthma or cancer; building materials' emissions – testing, monitoring and low-emitting product development; mold and moisture management; effective vacuuming and cleaning methods; and models and procedures for air quality testing and monitoring.

Sustainable Sites and Water Efficiency

Most research on both site and water topics is beyond the scope of this review, including significant research on brownfield and Superfund sites, municipal-scale water treatment and efficiency issues, block- and district-scale stormwater management, and land use issues. Within water efficiency, the few projects that are funded generally cover decentralized, site-scale water collection, treatment or storage. Site-related research is broader, but in comparison to other knowledge areas, there are few research projects clustered around any one topic. The topics that are receiving the most attention include lawn care (pesticides, turf) and natural stormwater management practices, including green roofs. Though there is more research recently completed or underway on these topics than others within the sites category, they still may receive less attention than topics in other knowledge areas.

Table 1. Specific Research Streams. As discussed above, the following green building topics appear to receive attention from a number of different projects, organizations or agencies, and/or a large amount of attention from a single group. A topic's presence on this list does not necessarily mean that the research is effective in achieving the research goals, or adequate to address a larger problem.

Energy

- Photovoltaics, including building integrated photovoltaics;
- Cogeneration;
- Solid state lighting;
- Daylighting: design strategies and impacts on productivity (overlap with IEQ);
- Energy efficient lighting: both indoor and outdoor;
- Demand response technologies;
- Commissioning and retrocommissioning methods and tools;
- Building information modeling, controls and management systems;
- Mechanical and ventilation systems that provide both thermal comfort and energy efficiency, including underfloor air distribution/displacement ventilation and alternative cooling systems, but not natural ventilation or mixed mode mechanical cooling/natural ventilation systems;

Materials

- Wood products: material efficiency, product design, post-industrial and post-consumer recycling;
- Concrete: reduction of embodied energy, including use of flyash; improved strength and performance;
- Reduction of embodied energy of steel;
- Glazing and windows: reduction of embodied energy, recycling and performance;
- Bio-based materials, primarily agricultural byproducts and bio-based polymers

Technology transfer

- Software development for improving energy efficiency;
- Some specific building type- and location-specific resources and design guides, such as the Collaborative for High Performance Schools and Minnesota's Buildings, Benchmarks and Beyond (B3) project;

Indoor Environmental Quality

- Particulate matter and air quality;
- Diseases and health impacts related to air quality;
- Building materials' emissions: testing, monitoring and low-emitting product development;
- Mold and moisture management;
- Effective vacuuming and cleaning methods;
- Models and procedures for air quality testing and monitoring;
- Lead: dust transfer, health impacts, and abatement;

Sustainable Sites

- Lawn care/pesticides;
- Natural stormwater management practices, including green roofs.

Parallel Initiatives in Setting Research Agendas

A number of other organizations have recently undertaken parallel initiatives to define critical directions for future research related to one or more aspect of green building. In general, these research agendas and roadmaps are more limited in scope than that of the USGBC's proposed green building research agenda. Nearly all of the initiatives identified in this report focus on energy and indoor environmental quality issues. Considerable efforts have gone into these initiatives, however, and they can be used to inform and complement the USGBC's agenda. In addition, the USGBC is currently in the process of establishing a continuous improvement program for LEED; this process parallels the development of a research agenda as research will be necessary to support this and future versions of LEED. Following are recent and current research agendas:

1. U.S. Department of Energy Building Technology Roadmaps
   DOE worked with industry, academia and research organizations to develop a set of roadmaps intended to "align government resources with the high-priority needs identified by industry."[41] DOE Roadmaps provide a long-term vision intended to direct future research in the Building Technologies Program. The following roadmaps are currently available:
   a. *Vision 2020: The Lighting Technology Roadmap*
   b. *The Promise of Solid-State Lighting for General Illumination: Light Emitting Diodes and Organic Light Emitting Diodes*
   c. *High Performance Commercial Buildings: A Technology Roadmap*
   d. *Building Envelope Technology Roadmap*
   e. *Window Industry Technology Roadmap*
   f. *Heating, Ventilation, Air-Conditioning, and Refrigeration Technology Roadmap*

   Reference: http://www.eere.energy.gov/buildings/tech/roadmaps.html

2. Partnership for Advancing Technology in Housing (PATH) Roadmaps.
   Parallel to the DOE Roadmaps, PATH has created a set of documents that prioritize its research needs:
   a. *Technology Roadmap: Whole House Building Process Redesign*
   b. *Technology Roadmap for Manufactured Housing*
   c. *Technology Roadmap: Advanced Panelized Construction*
   d. *Technology Roadmap: Information Technology to Accelerate and Streamline the Home Building Process*
   e. *Volume 3: Prioritized Action Plan* summarizes the above sets of research needs.

   Reference: http://www.pathnet.org/sp.asp?id=1711

3. U.S. Environmental Protection Agency Strategic Planning Documents.
   EPA's Office of Research and Development periodically publishes a series of strategic planning documents to guide its research. The following documents recently have been released for public review:
   a. *Sustainability Research Strategy,* 2006
   b. Draft *Science and Technology for Sustainability Multi-Year Plan (STS MYP),* 2006

   The Sustainability Research Strategy includes specific research objectives for sustainability, how the Office of Research and Development will organize its research activities, and strategies for their implementation. The Multi-Year Plan focuses on execution, including a prioritization of research needs. In addition, the EPA has released the *Office of Research and Development Strategic Plan*, 2001 and *Program Needs for Indoor Environments Research (PNIER)*, 2005. The former frames all of the EPA's intramural research, while the latter establishes

[41] <http://www.eere.energy.gov/buildings/tech/roadmaps.html> 26 August 2006.

criteria for defining indoor environments research needs and presents a detailed outline of those needs. References: http://epa.gov/sustainability/releasepubcommt.html, http://www.epa.gov/ord/htm/researchstrategies.htm and http://epa.gov/iaq/pubs/pnier.pdf

4. *ASHRAE Research Strategic Plan 2005-2010: Navigation for a Sustainable Future*, 2005.
   The ASHRAE Strategic Research Plan presents a research vision and a list of research needs around sustainability in the HVAC&R industries. Issues are grouped into categories: Energy and Resources, Indoor Environmental Quality, Tools and Applications, Equipment, Components and Materials, and Education and Outreach. Each category includes a set of goals and possible research projects. The plan was developed over three years with the help of two workshops. Reference: http://www.ashrae.org/technology/page/39.

5. Air-Conditioning and Refrigeration Technology Institute, Inc. (ARTI) *"Positioning For The Future" Strategic Planning for the HVAC Industry Report II – Research Recommendations*, 2001.
   ARTI's long range strategic planning process included specific research recommendations for the North American HVACR industry for the residential buildings, commercial buildings, and commercial refrigeration sectors. Energy and indoor environmental quality issues were listed as two of a larger set of critical issues. The report includes 112 research recommendations that came out of an industry workshop. Its audience is HVACR researchers. Reference: http://www.arti-21cr.org/21crstra/

6. National Center for Energy Management and Building Technologies (NCEMBT) *Developing an Applied Research Driven Road Map to Energy Efficient Buildings,* July 2006.
   NCEMBT hosted an interactive seminar with participants from the energy industry, including major suppliers and consumers, to develop a road map to achieve improved overall building energy efficiency by 70% and create new business opportunities for private companies. The white paper, *"Developing an Applied Research Portfolio for Energy Efficient Buildings*," provided supporting information on current research and seminar goals. Results of this seminar are not yet available online.

7. Lawrence Berkeley National Laboratory's *A Priority Agenda for Energy-Related Indoor Environmental Quality Research,* 2002.
   This research agenda proposes a set of ten high priority energy-related IEQ research goals and 34 high priority project areas connected to these goals.
   Reference: http://eetd.lbl.gov/ied/pdf/LBNL-50612.pdf

8. National Institute for Occupational Safety and Health (NIOSH) National Occupational Research Agenda (NORA).
   NORA includes over a dozen different research agendas, including one on indoor environments: *Improving the Health of Workers in Indoor Environments: Priority Research Needs for a National Occupational Research Agenda*, 2002. This research agenda outlines priority research topics, data suggesting the connection between improved indoor environments and improved human health, and the potential economic benefits of research on relevant topics. The NORA website indicates that it funds research projects on indoor environmental issues based on the priorities put forth in this report.
   Reference: http://www.ajph.org/cgi/content/abstract/92/9/1430

9. Surgeon General's Workshop on Healthy Indoor Environment, January 12, 2005.
   The Surgeon General's workshop goals were: "First, identify the relevant scientific data related to indoor environments. Second, summarize the evidence and potential research needs. And perhaps most importantly - build collaborations around the common goal of improving our indoor environments."[42]
   The workshop reported on research needs related to public health and the indoor environment, worker health, adverse exposures, and energy issues. Reference: http://www.surgeongeneral.gov/topics/indoorenv/

10. Alliance to Save Energy (ASE) Budget Analyses, 2006.
    ASE conducted a set of analyses on federal funding to energy efficiency research that support a push for funding of energy efficiency programs at levels authorized by The Energy Policy Act of 2005 (P.L. 109-58). Though this is not a research agenda, it does make a strong case for funding the energy efficiency related research in other organizations' research agendas.
    Reference: http://www.ase.org/section/_audience/policymakers/fedbudget

11. NSF Workshop *Construction and the Environment: Research Foci for a Sustainable Future.*
    The NSF sponsored a workshop January 13-14, 2005 with government, industry and academic leaders to develop a set of research foci that would engage the social, physical and applied sciences and engineering communities, the construction industry, government agencies and regulatory committees. The foci included data collection and monitoring, development of materials with improved life cycle impacts and decision making tools and models. Reference: Haselbach, Liv M. and Christine M. Fiori. "Construction and the Environment: Research Foci for a Sustainable Future." *Journal of Green Building* Winter 06: 148-157. http://www.ce.sc.edu/NSFWorkshop/NSFWorkshop-FINAL_REPORT_8-23-05.pdf.

[42] Carmona, Richard H. Opening Remarks. Surgeon General's Workshop on Healthy Indoor Environment. Bethesda, MD, January 12, 2005. < http://www.hhs.gov/surgeongeneral/news/speeches/01122005.html> 27 August 2006.

Conclusions

Research on green building presently constitutes an estimated 0.2% of all Federally funded research, an average of $193 million per year. This is roughly equivalent to only 0.02% of the estimated $1 trillion value of annual U.S. buildings construction, despite the fact that the building construction industry represents 9% of the U.S. GDP.[43] At the same time, the construction industry reinvests only 0.6% of sales back into research – significantly less than the average for other U.S. industries, and significantly less than private sector construction research investments in other countries.[44]

Buildings substantially contribute to environmental problems in the U.S. Building operation accounts for 38% of U.S. carbon dioxide emissions, 71% of electricity use and 40% of total energy use[45]; this number increases to an estimated 48% when the energy required to make building materials and construct buildings are included.[46] Buildings consume 12% of the country's water[47] and rapidly increasing quantities of land.[48] Waste from demolition, construction and remodeling amount to 136 million tons of landfill additions annually, making up over 35% of all non-industrial waste (1996).[49] Construction and remodeling of buildings account for 3 billion tons—40%—of raw material use globally each year.[50] They also cause negative impacts on human health; up to 30% of new and remodeled buildings may experience acute indoor air quality problems.[51] Indoor air pollutants are at concentrations typically between 2 and 5—and occasionally greater than 100—times greater than those of outdoor air.[52]

Thus, despite the major effects of buildings and the built environment on our economy, quality of life and natural environment, funding for relevant research is relatively insignificant compared to funding for other research topics. Without a significant increase and improvement in green building practices, the negative impacts of the built environment on human and environmental health are very likely to increase dramatically in coming decades.

Significant and immediate improvements to health and environmental quality can be made with a modest increase in investment of short term research and technology transfer work. The Federal government and other relevant funding sources should increase support to these readily achievable strategies while also investing in long-term research programs to prompt the major shift in design and construction practices necessary to support requisite large scale improvements to health and environmental conditions.

To cite one important example, the impact of carbon emissions on global warming has recently become a focus of national attention, resulting in part in the AIA, USGBC, ASHRAE, Construction Specifications Institute, and the U.S. Conference of Mayors' collective adoption of the 2030

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[43] Department of Energy. 2006 DOE Buildings Energy Data Book. 19 February 2007. <http://buildingsdatabook.eren.doe.gov/>
[44] *Ibid*.
[45] *Ibid*.
[46] Mazria, Ed. Architecture 2030 Challenge. http://www.architecture2030.org/building_sector/index.html 18 December 2006.
[47] Estimated Water Use in the United States in 1995. U.S. Geological Survey. http://water.usgs.gov/watuse/pdf1995/html/ 18 December 2006.
[48] Estimated Water Use in the United States in 1995. U.S. Geological Survey. http://water.usgs.gov/watuse/pdf1995/html/ 18 December 2006.
[49] Municipal Solid Waste in the United States: 2001 Facts and Figures. Office of Solid Waste, U.S. Environmental Protection Agency. October 2003. http://www.epa.gov/garbage/pubs/msw2001.pdf 18 December 2006.
[50] Lenssen and Roodman, 1995, "Worldwatch Paper 124: A Building Revolution: How Ecology and Health Concerns are Transforming Construction," Worldwatch Institute.
[51] Indoor Air Facts No. 4 (revised): Sick Building Syndrome (SBS). U.S. Environmental Protection Agency. http://www.epa.gov/iaq/pubs/sbs.html 18 December 2006.
[52] The Total Exposure Assessment Methodology (TEAM) Study. EPA 600/S6-87/002. U.S. Environmental Protection Agency. 1987. http://www.epa.gov/ncepihom/.

Challenge, a series of goals intended to ensure that all new construction will have net zero carbon emissions by the year 2030, and that an equivalent amount of existing square footage will be renovated to use half of its previous energy use.[53] The goals of the 2030 Challenge are aggressive; studies today indicate that net zero energy use is simply not possible in some parts of the country for some building types with existing technology.[54] Yet the construction, operation and demolition of buildings contribute to nearly half of the United States' greenhouse gas emissions – the building industry's ability to meet the 2030 Challenge could have a profound impact on global conditions.[55] A March 2007 UN report reaffirms buildings' role in global warming; according to Achim Steiner, UN Under-Secretary General and UNEP Executive Director, "Energy efficiency, along with cleaner and renewable forms of energy generation, is one of the pillars upon which a de-carbonized world will stand or fall… By some conservative estimates, the building sector world-wide could deliver emission reductions of 1.8 billion tonnes of $C0_2$. A more aggressive energy efficiency policy might deliver over two billion tonnes or close to three times the amount scheduled to be reduced under the Kyoto Protocol."[56] The maximum impact, however, and the ability to meet the 2030 Challenge, will not be possible without a significant change in our fundamental knowledge of building energy issues.

Funding green building research is a wise investment. In 2001, the National Research Council released a report assessing the benefits of DOE's energy efficiency and other research over the prior 2+ decades. It states, "The committee found that DOE's RD&D programs in… energy efficiency have yielded significant benefits (economic, environmental, and national security-related), important technological options for potential application in a different (but possible) economic, political, and/or environmental setting, and important additions to the stock of engineering and scientific knowledge in a number of fields."[57] The report states that not only do the benefits of building energy efficiency research significantly outweighing the investment, but that energy savings in the building sector is—by an order of magnitude—one of the largest benefits of all DOE research programs studied.[58] Despite the benefits of energy research and development—including but not limited to green building work—federal energy research funding has decreased significantly over the last few decades; when accounting for inflation, it is now less than half of what it was 25 years ago.[59] In contrast, federal support for medical and military research has increased by 400% and 260% respectively.[60]

To put forth just one illustration of the important impacts of green building research, R&D by DOE's National Renewable Energy Lab (NREL) and other organizations helped drive the costs of photovoltaic modules down dramatically – from $30 U.S. dollars per peak Watt in 1975 to just under $5 U.S. dollars per peak Watt in the late 1980's and 1990's, at which point the costs reached a plateau.[61] Yet these costs still need to go lower in order for solar electricity to be fully competitive when access to grid power is available.

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[53] Building Sector Unites to Confront Global Climate Change. Architecture 2030, December 4, 2006. http://www.architecture2030.org/news/Press%20Release%20-%2005Dec06.doc 18 December 2006.
[54] Gonchar, Joann. " In Search of the Zero-Energy Holy Grail." Architectural Record, 2006. http://archrecord.construction.com/features/digital/archives/0612casestudy-2.asp 19 December 2006.
[55] Mazria, Ed. Architecture 2030 Challenge. http://www.architecture2030.org/building_sector/index.html 18 December 2006.
[56] United Nations Environment Programme. " Buildings Can Play a Key Role in Combating Climate Change." Oslo, March 29, 2007. < http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=502&ArticleID=5545&l=en%20>
[57] Committee on Benefits of DOE R&D on Energy Efficiency and Fossil Energy, Board on Energy and Environmental Systems, Division on Engineering and Physical Sciences, National Research Council. "Energy Research at DOE: Was It Worth It? Energy Efficiency and Fossil Energy Research 1978 to 2000." 23 February 2007. <http://www.nap.edu/catalog/10165.html>
[58] *Ibid*.
[59] Revkin, Andrew C. "Budgets Falling in Race to Fight Global Warming." New York Times, Oct. 30, 2006.
[60] *Ibid*.
[61] Renewable Energy 2000: Issues and Trends. 2001. United States Department of Energy, Energy Information Administration. www.eia.doe.gov/cneaf/solar.renewables/rea_issues/contents.html#contents

As this example demonstrates, green building research makes a difference, but a greater commitment to this research could make an even more profound difference – at a time when social, environmental and economic trends demand that major changes be made in the built environment. Increased green building research can enable design and construction practices to help alleviate many challenges critical to the nation's economy, health and well being – including global warming, water shortages, occupational health problems, ecosystem destruction, and many more. To do so, however, funding for green building research must be commensurate with that of other streams of research, and commensurate to the severity of the problems that buildings create – the current 0.2% of Federal research dollars will not be adequate to address these critical issues in a timely manner.