RAND

Summary of Federal Construction, Building, and Housing Related Research & Development in FY1999

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Department of Housing & Urban Development and
the National Institute of Standards & Technology

Science and Technology Policy Institute

Preface

This Analysis

This publication presents the results of a search of the "Research and Development in the United States" (RaDiUS) database. The search sought to identify all federally funded research and development (R&D) activities related to the fields of construction, building, and housing in fiscal year 1999.

This search was jointly requested by the National Science and Technology Council's (NSTC) Subcommittee on Construction and Building (C&B) and the Partnership for Advancing Technology in Housing (PATH).

This report and the corresponding data file transmitted to the C&B Subcommittee and PATH are intended to increase understanding of the federal governments' R&D portfolio related to construction and building, as well as the subset of R&D related to housing. This information should help:

- public and private sector R&D sponsors manage their portfolios,
- researchers and businesses find and learn about federal R&D,
- increase the coordination and leveraging of public and private R&D efforts.

This report should be of interest to government managers, the private sector, and academic researchers.

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- helps improve understanding in both the public and private sectors of the ways in which science and technology can better serve national objectives.

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Glossary, List of Symbols, etc.

Symbol	Definition
USDA	Department of Agriculture
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of Interior
DOT	Department of Transportation
DVA	Department of Veterans Affairs
EPA	Environmental Protection Agency
HHS	Department of Health & Human Services
HUD	Department of Housing & Urban Development
NASA	National Aeronautics and Space Administration
NSF	National Science Foundation

Executive Summary

Project Scope

This publication presents the results of a search of the "Research and Development in the United States" (RaDiUS) database. The search sought to identify all federally funded research and development (R&D) activities related to the fields of construction, building, and housing in fiscal year 1999.

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Motivation

Investments in new construction and building typically represent 8 to 10 percent of the nation's GDP, with more than 40 percent of this investment being for new housing. (BEA, 2001). These new investments combined with the nation's existing facilities and infrastructure, provide the nation with its homes, workplaces, roadways, electricity, and sewers, etc. Despite the importance of these investments and the limited funds typically available to design, build, operate, and maintain them, this industry is generally believed to invest less than 0.5 percent of the value of its sales in R&D, whereas the national average is close to 3 percent (NIBS, 1996; NSB, 1998).

This report and the corresponding data file transmitted to the C&B Subcommittee and PATH are intended to increase awareness and understanding of the federal governments' R&D portfolio for construction, building, and housing. This information should help:

- public and private sector R&D sponsors manage their portfolios,
- researchers and businesses find and learn about federal R&D,

- increase the coordination and leveraging of public and private R&D efforts.

This report should be of interest to government managers, the private sector, and academic researchers.

Results

The overall results of this study were that in FY99, the federal government funded more than 1,600 projects representing roughly $545 million in construction and building related R&D. Energy supply and transportation-related infrastructure represented just under 50 percent of the total dollar investment. Of the total, more than 500 projects representing roughly $236 million were potentially relevant to housing. Of housing-related R&D investments, energy supply and energy efficiency represented roughly 65 percent of this funding

These activities were performed by nine departments and three independent agencies. For the broader construction and building portfolio, the Departments of Energy and Transportation together represented roughly 64 percent of the dollar investment. Of the R&D related to housing, the Department of Energy represented 71 percent of the total.

Other departments sponsoring R&D for construction, building, and housing-related research included Agriculture, Commerce, Defense, Health and Human Services, Housing and Urban Development, Interior, and Veterans Affairs. The independent agencies funding relevant R&D included the Environmental Protection Agency, the National Aeronautics and Space Administration, and the National Science Foundation.

1. Introduction

1.1 The Role of Construction & Building in the Economy

In 1999, the nation invested roughly $860 billion—more than 9 percent of the nation's GDP—for the building and construction of new facilities and infrastructure. Roughly 47 percent of this investment was for residential structures (e.g., single family homes, multi-family apartments), 33 percent was invested by the private sector in non-residential structures (e.g., commercial buildings, factories, utilities, farms), and 20 percent was invested by governments in public facilities and infrastructure (e.g., public buildings, highways, sewers, etc.) (BEA, 2001). While the specific percentages and component breakdowns vary annually, investments in new construction and building typically represent 8 to 10 percent of the nation's GDP, with more than 40 percent of this investment being for new housing.

This new construction, along with the nation's existing facilities provide Americans with their homes, workplaces, and the infrastructure needed to support our quality of life and allow our economy to function. Yet, as new construction is built, operating and maintaining these facilities and infrastructure gets progressively more expensive. To provide just one example of the costs involved in operating and maintaining facilities, the federal government—the nation's largest owner and operator of buildings—spends more than $3 billion annually on electricity for the 420,000 buildings that it owns and the 88,000 buildings that it leases (FEMP, 2000; GSA, 2000a; GSA 2000b). Given the importance of these facilities and infrastructure to the nation's economy and quality of life, becoming more effective at designing, building, operating, and maintaining our new and existing facilities will continue to be an important component of our economy as well as an investment in the future.

1.2 The Role of R&D in Improving Construction, Building, and Housing

While the size of this industry makes it important in its own right, that fact that financial resources for facilities and infrastructure are scarce in both the public and private sectors suggests that learning to design, build, operate, and maintain

our infrastructure "smarter" is a good idea. However, it is generally believed that the construction and building industry invests less than 0.5 percent of the value of its sales in R&D, whereas the national average is close to 3 percent (NIBS, 1996; NSB, 1998).

In response to this apparent under-investment in R&D, the National Science & Technology Council's[1] Construction and Building Subcommittee developed the National Construction Goals in the mid-1990s. These goals were then endorsed by industry and led to several efforts to improve coordination among the industry's diverse stakeholders. These efforts included the Partnership for Advancing Technology in Housing (PATH), the Partnership for the Advancement of Infrastructure and its Renewal (PAIR), and an effort to streamline the nation's building regulatory system. Together these efforts work toward improving the affordability, performance, safety, durability, and other characteristics of the built environment.

1.3 This Report's Contribution to Understanding the Federal Government's R&D on Construction, Building, and Housing

One of the primary ways by which the federal government can improve the value of its R&D investment is to improve the coordination and leveraging of public and private sector funds by making its activities and their results more accessible to the public.

To assist in these efforts and provide precisely this type of information, the NSTC's Construction & Building Subcommittee and PATH jointly asked RAND to conduct two related searches of RAND's database on "Research & Development in the United States" (RaDiUS) for Fiscal Year 1999 (FY99).

The first search was to be broad and capture the full scope of the construction and building industry. The second search was to focus on federal R&D related to housing. Since housing was to be a component of the broader search, the second search was to be a subset of the first.

RAND was also asked to produce a published report documenting the search results and to develop an electronic database of those results. This document is

[1] The National Science and Technology Council (NSTC) is a Cabinet-level Council that provides the President with a way to coordinate science and technology issues across the diverse parts of the Federal research and development enterprise.

the final report and the database has been provided to both the C&B Subcommittee and PATH for public access and distribution.

1.4 What is RaDiUS?

RaDiUS—an acronym for "Research and Development in the United States"—was developed by RAND, in cooperation with the National Science Foundation, to better support the White House Office of Science and Technology Policy (OSTP) and the National Science and Technology Council (NSTC).

RaDiUS is a web-based search engine and database of all unclassified federally-funded R&D activities. The database contains detailed project and funding information on the 450,000+ projects and roughly $80 billion in R&D funded by the federal government each year.

The data contained in RaDiUS originates directly from the President's budget as well as information submitted by individual federal agencies to RAND. The information is then organized hierarchically based on Congressional appropriations and Office of Management & Budget (OMB) budget categories.[2] The hierarchical organization makes it possible to track dollars from the agency level down to individual projects.

More information on RaDiUS, how it works, and how to register for an account can be found on the RaDiUS webpage located at www.rand.org/scitech/radius.

1.5 Why is RaDiUS helpful?

Given the size of the federal R&D investment, managing this portfolio to achieve specific goals is difficult to say the least. If one seeks to analyze, understand, or affect change in any part of the portfolio, the first step is likely to be to identify what is currently being funded by the federal government. RaDiUS is the first and only tool that allows one to begin the process by allowing one to search for relevant R&D activities, obtain detailed project information, and aggregate and compare funding levels.

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[2] An important aspect of RaDiUS is that it contains only federally funded activities that are properly coded to reflect the OMB definition of R&D as defined in OMB Circular No. A-11 which can be downloaded from http://www.whitehouse.gov/omb/circulars/.

2. Search Methodology

2.1 Searching the RaDiUS Database

RaDiUS consists of a graphical web-based user interface, a search engine, and a database of federal R&D information. Rather than coding the database for keywords and then searching the database, RaDiUS searches its database by looking at project descriptions and mission statements of the hierarchical organizations located within the database.

This means that effectively searching the database requires one to develop search terms that reflect the full breadth and depth of the topic of interest. This can be challenging since some project descriptions are written in general terms while others are written using highly specialized and precise technical language without discussing the larger context of the research.

For this reason, comprehensive RaDiUS searches can require numerous searches using different sets of terminology. Furthermore, since some of these terms may be used by other scientific and technical communities, additional efforts are often needed to screen out and remove projects that are found by RaDiUS but that are not relevant to the topic of interest. For these reasons, the first step of any RaDiUS search is to develop a search strategy that effectively targets the topics of interest.

2.2 Developing a Search Strategy

A successful search typically consists of combining two different search strategies.

The first strategy consists of identifying initial search terms and testing them by searching the database. One then looks at the results and evaluates each search term's effectiveness. Based on the results, additional search terms can be identified by reading matching project descriptions or by selecting search terms that are suggested by RaDiUS. At the same time, terms uniquely associated with irrelevant projects can be identified and used to screen out irrelevant projects. Finally, ineffective search terms can be excluded all together.

The second strategy which can be pursued roughly in parallel with the first is to identify those agencies, programs, etc. that fund relevant research and to look at the R&D performed by those organizations. In many cases, the second strategy can be done most effectively by looking at the funding sources that are identified in the initial and subsequent phases of the first strategy.

By using these two strategies iteratively, one can search broadly while excluding R&D which is clearly irrelevant.

For this project, the process of identifying initial search terms began by reviewing a number of reports to identify key terms, technologies, and interest areas. While the specific reports are listed in the References chapter, they included NSTC and member agency documents as well as the results of a RaDiUS search of FY94 R&D data (McGaraghan, 1996). Since the FY94 search focused predominantly on buildings and their lifecycle, specific efforts were made to develop a broad list of search terms in the non-building area. In addition, a special effort was made to ensure that all housing-related R&D topics were included.

The specific search terms and sponsoring organizations examined for this project can be found in Appendices A and B of this report.

2.3 Confirmation of Project Relevance

Once the iterative dual strategy process described above was completed, more than 3,500 projects had been identified. The resulting project descriptions were then read by the project team to confirm that the projects were indeed relevant. In those cases where RAND was unsure whether a topic was relevant or not relevant, the C&B Secretariat and/or federal agencies were contacted to seek guidance. (For example, fundamental/basic research on materials was considered to be outside the scope of construction and building, as was large scale power generation). As a result of the confirmation process, the total number of relevant projects was reduced to roughly 1,600.

2.4 Categorizing Search Results

Once the results were complete, the records were skimmed to determine how the results could be organized into meaningful and useful categories that could then be analyzed on an aggregate basis. While the research team had initially hoped to categorize the results according to the National Construction Goals, this format was found to be problematic because some projects could be categorized

under multiple goals while other projects could not be categorized under any of the National Construction Goals. For this reason, the project team used three categories derived from the National Construction Goals as well as new categories developed for this search.[3]

Just as determining search terms was an iterative process, so too was developing the categories. This is because having too many categories was judged to be as unhelpful as too few. In addition, some R&D areas can be easily combined, such as highway and bridge R&D. That said, it is important to realize that any aggregation will disappoint some stakeholders. In developing the categories, the project team sought to devise categories that would be useful to most people most of the time. (Those seeking to disaggregate categories or to create different aggregations should obtain the final electronic data and develop categories that meet their own needs). In addition, it should be stated that some projects could be placed into more than one category. For this search, however, the project team placed projects in the category that seemed most appropriate given the information in the project description.

The final categories are listed in Table 1. To better understand the specific types of research addressed within each category, the reader is referred the category sections of the results chapters where the R&D conducted within each category is explained briefly.

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[3] The categories derived from the National Construction Goals were "Pollution & Waste Reduction", "Reduction in Construction Work Illness & Injuries", and "Reduction in Occupant-related Illness & Injury."

R&D Categories
Building Design Improvements
Building Process Improvements & Automation
Building Product Improvement
Concrete, Cement, Pavement, & Asphalt
Energy Efficiency
Energy Supply
Forestry
Geotechnical Engineering & Soil/Groundwater Remediation
Land-use Design Improvements
Metals, Composites, & Advanced Materials (Non-wood, Non-concrete)
Other
Pollution & Waste Reduction
Reduction in Construction Work Illness & Injuries
Reduction in Occupant-related Illness & Injury
Structural Engineering & Natural Hazards
Transportation Infrastructure
Unknown
Wood Products & Quality

Table 1. Categories Used to Organize R&D Projects

2.5 Addressing Agency Data Limitations

As described earlier, RaDiUS' data is based on the Presidential budget and information given to RAND by the individual agencies. For many agencies, budget information may come from one office while project information may come from several other offices. Experience has shown that combining these data sources can reveal inconsistencies and errors for several reasons including:

- The data submitted by agencies can be incomplete or inaccurate thereby affecting project descriptions and/or funding-related information.
- RaDiUS tracks federal R&D as defined by OMB Circular No. A-11. This circular defines "Research and Development" as several budget categories with specific R&D code numbers. If agency budget records do

not reflect these codes, those projects are not included in the RaDiUS database.

- While RaDiUS does not include classified R&D, the Departments of Defense and Energy have decided that some aspects of their unclassified R&D portfolio are too sensitive to be completely and readily accessible to all users. Accordingly, access to some project information is restricted by user type.

Each of the above limits RaDiUS' ability to provide a full and complete view of the federal R&D portfolio. This is because awards without project descriptions are essentially impossible to find since the RaDiUS search engine principally matches search terms with project descriptions. Second, projects bearing incorrect budget codes are completely missed. Third, projects that lack funding information underestimate the total federal investment in a given type of R&D.

Fortunately, some of the data limitations can be partially overcome through reasonable approximations. The two main approximation approaches are described below. In addition, agencies can be contacted to request additional information where desired. For further information on the data limitations encountered during these RaDiUS searches and how they were resolved, please see the agency-by-agency breakdown in Appendix C.

2.5.1 Approximating Missing Project Funding Levels

In cases where project funding information was lacking, the funding level was roughly estimated by dividing the sponsor's "Budget Authority" by the total number of projects awarded by that sponsor. ("Budget Authority" refers to the amount of funding the sponsor has been authorized to spend in the Congressionally-approved budget). It should be noted that this form of estimation only works if RaDiUS contains information on the sponsor's Budget Authority.

2.5.2 Accounting for Missing Project Descriptions

As previously stated, the RaDiUS search engine cannot find projects that lack project descriptions. However, a second type of approximation can be used when one is confident that all or most of a sponsor's R&D is relevant. In these cases, it may be better to include the sponsors entire portfolio even though there are no project descriptions. During this search, this approximation was used for the US Army Corps of Engineers as described in Appendix C.

3. Summary of FY99 Federal "Construction & Building" R&D

This chapter presents a quantitative profile of the construction and building-related R&D funded by the federal government during FY99. This profile consists of two different aggregations of R&D projects. The first aggregation is by the R&D categories listed in Table 1. The second aggregation is by the sponsoring agency. In each case, summary data is presented in tabular and graphical format for both the number of projects and the associated funding levels. Finally, each aggregation also contains a more detailed textual description of the R&D areas and their rough funding levels.

3.1 Federal "Construction & Building" R&D by Category

3.1.1 Summary Data

Table 2 presents the results, aggregated by category, of the full search. Figures 1 and 2 present this data graphically for the number of projects as well as for average annual funding.

Category	Number of Awards	Average Annual Funding ($)
Building Design Improvements	18	4,936,738
Building Process Improvements & Automation	26	4,317,629
Building Product Improvement	50	23,147,929
Concrete, Cement, Pavement, & Asphalt	53	15,571,147
Energy Efficiency	90	57,966,181
Energy Supply	97	135,090,635
Forestry	171	21,499,224
Geotechnical Engineering & Soil/Groundwater Remediation	53	30,888,236
Land-use Design Improvements	16	3,780,930
Metals, Composites, & Advanced Materials (Non-wood, Non-concrete)	104	12,353,120
Other	17	4,032,169
Pollution & Waste Reduction	38	15,329,995
Reduction in Construction Work Illness & Injuries	152	15,879,289
Reduction in Occupant-related Illness & Injury	44	4,801,723
Structural Engineering & Natural Hazards	210	27,006,183
Transportation Infrastructure	225	131,343,574
Unknown	117	18,795,819
Wood Products & Quality	136	18,689,907
Total	1,617	545,430,428

Table 2. FY99 Federal C&B R&D by Category

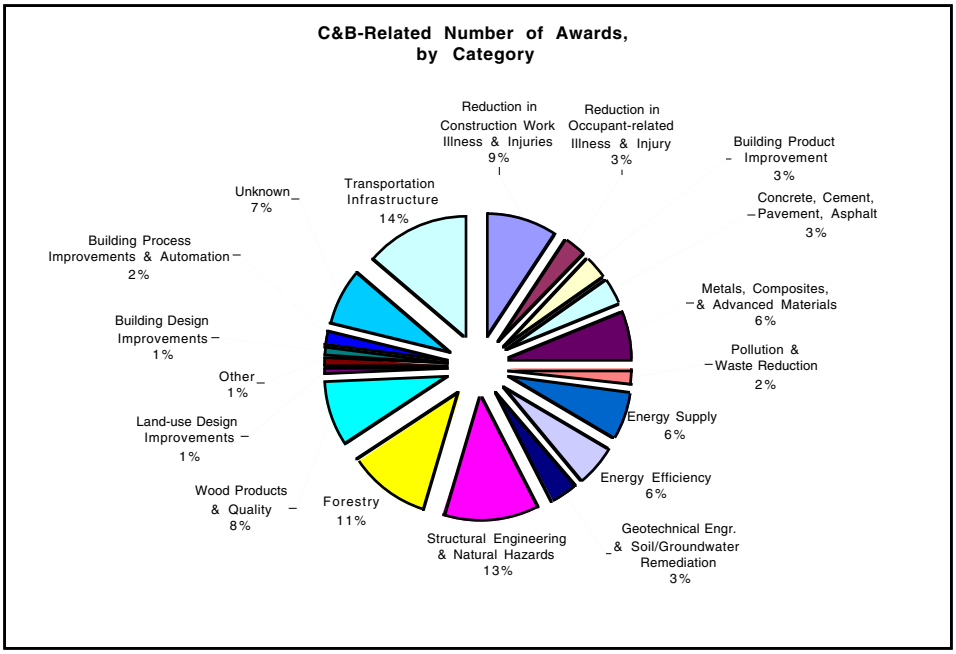

Figure 1. FY99 Federal C&B R&D Number of Project Awards by Category

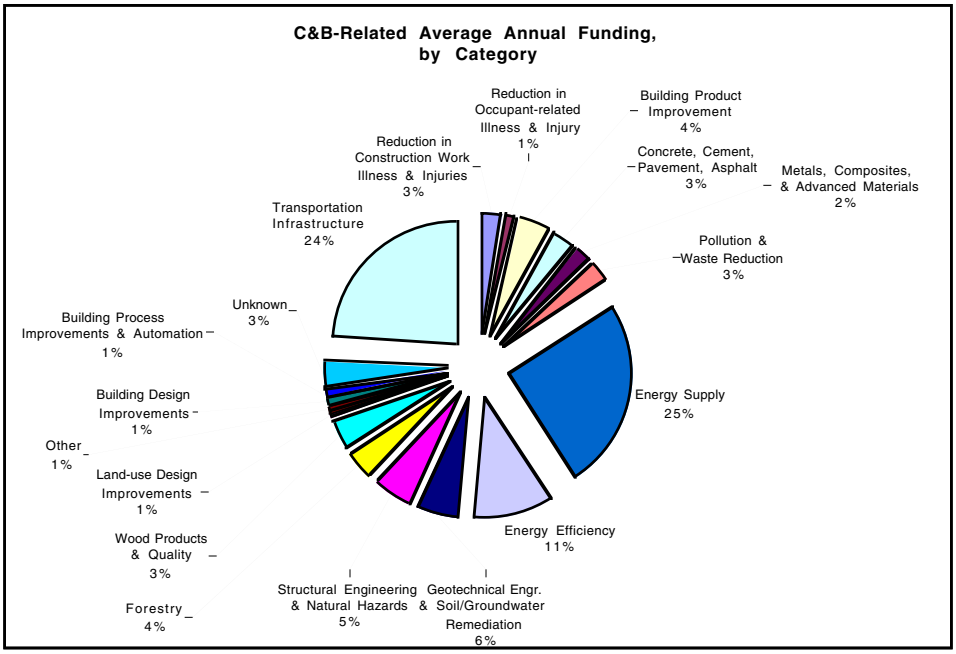

Figure 2. FY99 Federal C&B R&D Average Annual Funding by Category

3.1.2 Description by Category

Building Design Improvements

In FY99, roughly $5 million was invested in efforts to improve building design. This included R&D on energy efficient design, sustainable and green design, affordable housing, and improved building rehabilitation/renovation. It also contained software development efforts aimed at helping architects and others design better buildings.

Building Process Improvements & Automation

Roughly $4 million was invested in improving and automating the building process. This category included R&D related to innovative construction approaches, partial and complete automation of construction and materials handling, simulation of construction operations, new collaborative work methods, new project management and delivery systems, as well as how to use information technologies on the job site and to improve regulatory enforcement.

Building Product Improvement

Approximately $23 million was invested in building product improvement. Roughly half of this was focused on window-related research with the rest distributed among adhesives, alternatives to stick framing, improved foundations, insulation, paint, and roofing.

Concrete, Cement, Pavement, and Asphalt

More than $15 million was invested in areas related to concrete, cement, pavement, and asphalt. Most of the R&D focused on transportation related applications with other efforts addressing general analysis techniques, cement-wood composites, concrete composites, corrosion, fiber-reinforced polymer concrete, and non-destructive evaluation.

Energy Efficiency

Almost $58 million was invested in R&D on energy efficiency. Of this total, slightly more than half was focused on general analytical, technical, and program support. These general work areas included building energy systems, building codes and standards, existing buildings, heat and moisture modeling, and weatherization. In addition, roughly one-third was focused on HVAC, appliances, and motors. Finally, approximately 10 percent was invested in lighting.

Energy Supply

Just over $135 million was invested in energy supply. More than $100 million of this was invested in renewable energy sources, including $90 million for photovoltaics, roughly $8 million for general solar and solar thermal technologies, and more than $8 million for geothermal technologies. On the non-renewable side, roughly $28 million was invested in fossil fueled generation sources (primarily fuel cells at $8 million), energy storage technologies ($3 million), superconductivity ($11 million), and transmission and distribution technologies ($4 million).

Forestry

More than $21 million was invested in areas related to forestry. Nearly $16 million of this was for general forestry research. More than $4 million was focused on pest and fungi. Trade, economics, and policy round out the R&D portfolio.

Geotechnical Engineering & Soil/Groundwater Remediation

Nearly $31 million was invested in this category, however, geotechnical engineering represents only $2 million of the total. Almost $29 million was invested in soil & groundwater remediation with almost all of this being a single DOD groundwater remediation field laboratory.

Land-use Design Improvements

Less than $4 million was invested in R&D on improving land-use planning, policy, and design. These investments included comprehensive land use planning, sustainable development, transportation, brownfield redevelopment, deconstruction/demolition for re-development of urban areas, and urban heat islands. It also included R&D on the application of remote sensing and geographic information systems (GIS) to land-use planning for urban growth, natural resource management, and farmland preservation. Several aspects of this research focused on understanding changes along the edges of urban growth areas.

Metals, Composites, & Advanced Materials (Non-wood, Non-concrete)

More than $12 million was invested in metals, composites, and other advanced materials. (This category does not include composite or advanced materials containing wood or concrete; those materials are listed in their respective categories.) This category contains more than $5 million for metals, alloys, and welding; $3 million for ceramics; and over $2 million for composites. The

category is rounded out with R&D on general analysis, testing, instrumentation, and polymers.

Other

This category represents R&D that could not easily be put into other categories. This was typically because the activities included multiple R&D areas and/or the dissemination of test results to interested parties, including web outreach and other services. This category represented just over $4 million.

Pollution & Waste Reduction

More than $15 million was invested in reducing pollution and waste. Approximately $10 million addressed multiple media (e.g., air, water, solid waste) with the Navy's work on environmental compliance equipment being the bulk of this R&D. The next largest R&D area was improved wood processing, followed by R&D on refrigerants, paint, water, and sludge.

Reduction in Construction Work Illness & Injuries

Almost $16 million was invested in reducing construction-related illness and injuries. This R&D was primarily conducted by the National Institute for Occupational Safety and Health (NIOSH) within the Department of Health and Human Services. Safety studies included surveillance on construction fatalities, intervention studies on fall protection, safer excavation technologies, back injury studies, electrical safety, and mobile equipment related injuries. Construction health projects addressed issues such as asphalt fumes, hearing loss prevention for construction trades, ergonomic interventions, control of silica exposures, tool-related vibration, and lead exposures.

Reduction in Occupant-related Illness & Injury

Nearly $5 million was invested in R&D related to the health and safety of building occupants, with the primary focus being on indoor air quality (IAQ). More than $3 million was invested in general IAQ issues. Smaller sums were invested in specific sectors or technology needs including air quality in residential housing, air quality in the agricultural and livestock industries, air quality sensor development, asbestos, and low solvent adhesives.

Structural Engineering & Natural Hazards

$27 million was invested in structural engineering and natural hazard R&D. Earthquake-related R&D represented more than $8 million of this category, multiple-hazard R&D was another $6.5 million, and fire research was $6 million. Smaller sums were invested in R&D on general structural analysis, dynamic and

passive structural control systems, measurement and instrumentation, wind and flood hazards, as well as dams, hydraulic, and marine structures.

Transportation Infrastructure

More than $130 million was invested in R&D on transportation infrastructure. Nearly all of this was from the Department of Transportation. While a lack of project descriptions made it impossible to further characterize nearly $80 million of this R&D, approximately $46 million was focused on highways and system efficiency. The remaining $4 million was split between bridges, intermodal transportation, and transit and rail R&D.

Unknown

Almost $19 million in potentially relevant R&D could not be categorized due to a lack of project descriptions. However, these projects were included due to the general relevance of the sponsoring agency or based on the terms used in the highly abbreviated project descriptions (e.g., "Construction (Advanced)"). The records included in this category are all DOD records, with roughly $15.5 million from the U.S. Corps of Engineers. The balance of the category comes from the Navy, Air Force, and Army.

Wood Products & Quality

Approximately $20 million was invested in R&D on wood products and wood quality. Less than 50 percent of this was invested in finding new applications for wood and wood scrap/waste ($8 million). Roughly $3 million focused on milling techniques and technologies that reduced waste and improved resource utilization. Other areas receiving between $1 and $2 million each included wood preservatives, wood-containing composites, wood drying, structural properties of wood & wood structures, and adhesives.

3.2 Federal "Construction & Building" R&D by Agency

3.2.1 Summary Data

Table 3 presents the results of the C&B search aggregated by agency. Figures 3 and 4 present this data graphically for the number of projects as well as for average annual funding.

Category	Number of Awards	Average Annual Funding ($)
USDA	356	41,273,032
DOC	48	36,420,761
DOD	167	59,819,822
DOE	204	209,586,725
HHS	166	17,146,260
HUD	45	11,892,694
DOI	1	57,950
DOT	190	140,787,859
DVA	1	14,011
EPA	10	1,617,353
NASA	1	150,000
NSF	428	26,663,961
Total	1,617	545,430,428

Table 3. FY99 Federal C&B R&D by Agency

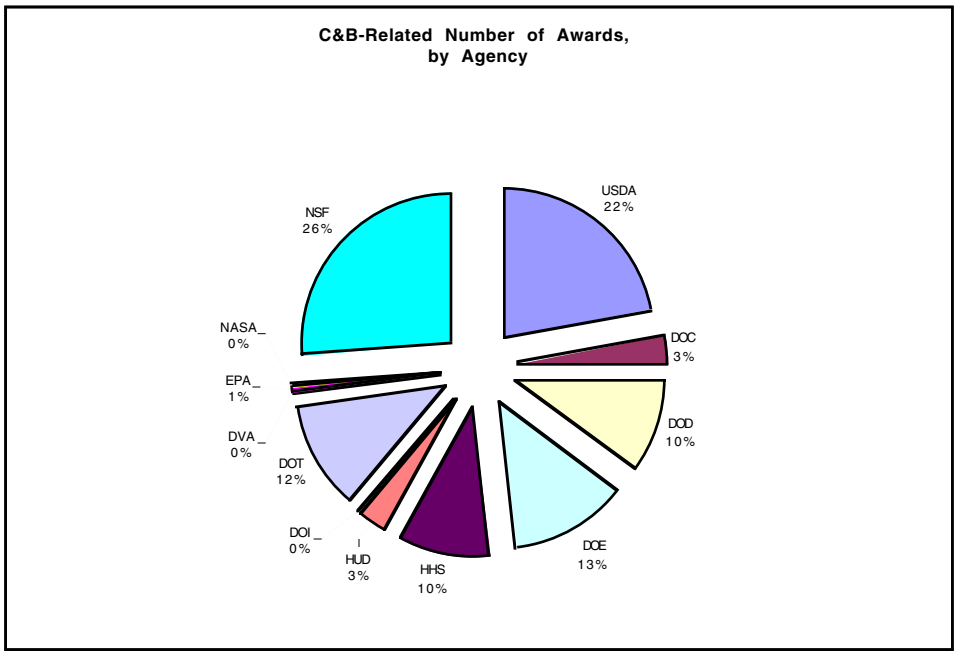

Figure 3. FY99 Federal C&B R&D Number of Project Awards by Agency

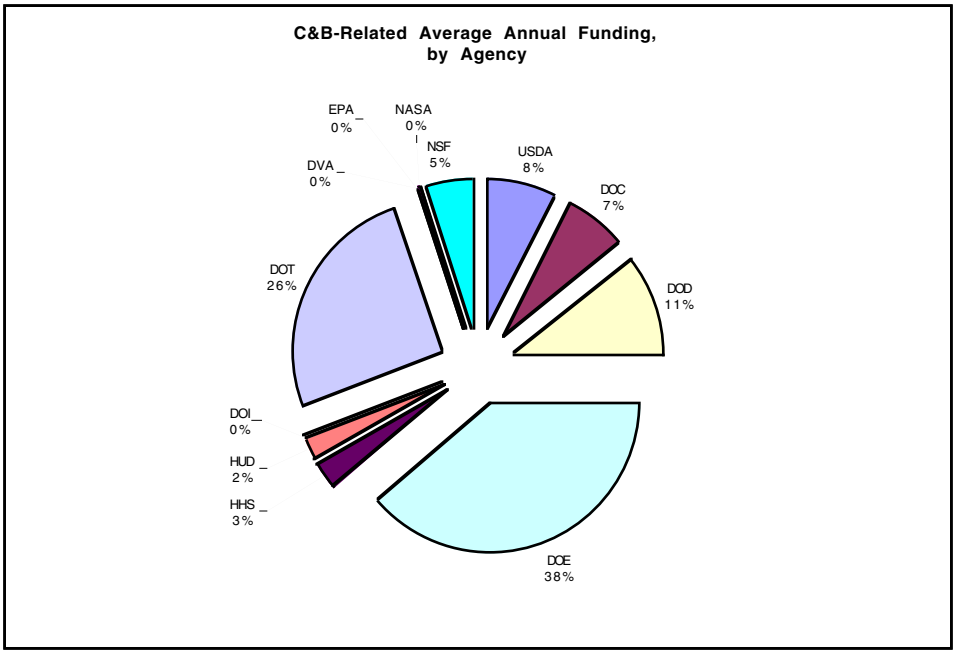

Figure 4. FY99 Federal C&B R&D Average Annual Funding by Agency

3.2.2 Description by Agency

Department of Agriculture

Nearly $41 million was invested by the Dept. of Agriculture with roughly $20 million for forestry, $17 million for wood products and quality, and $2 million for pollution and waste reduction. The remaining $2 million was spent across numerous categories.

Department of Commerce

Roughly $36 million was invested by the DOC in FY99. Approximately $13 million was focused on structural engineering and natural hazards; almost $6 million on energy supply (primarily fuel cells and photovoltaics); nearly $5 million for metals, composites, and advanced materials; almost $4 million each for energy efficiency and building design improvement, and almost $2 million for building process improvements and automation.

Department of Defense

The DOD invested about $60 million in R&D in FY99. Almost half of this was devoted to soil and groundwater remediation ($28 million). Of the remaining,

roughly $20 million could not be categorized due to a lack of project descriptions. The balance was spread across numerous other R&D categories.

Department of Energy

Out of a total of $210 million, roughly $128 million was devoted to energy supply, $53 million to energy efficiency, and $15 million for building product improvements. The remainder was spread across the other categories.

Department of Health & Human Services

Of the Department's $17 million investment, more than $15 million went to reducing construction-related illnesses and injuries with the remainder focused on reducing occupant-related illness and injury.

Department of Housing & Urban Development

HUD's R&D investment was approximately $12 million, with nearly $10 million of this being specifically for the PATH program. Of the total, $4 million focused on building product improvements, $3 million on multiple-category R&D (classified as "Other"), $1.4 million on building process improvements and automation, and $1 million for building design improvements. The remaining funds are spread across the remaining categories.

Department of Transportation

In FY99, $140 million was invested by DOT. Most all of this was invested in transportation infrastructure R&D ($128 million) with the balance being for research specifically focused on the material aspects of concrete, cement, pavement, and asphalt.

Environmental Protection Agency

The largest component in EPA's $1.6 million investment was focused on reducing occupant-related illness and injury ($600,000). The balance was focused equally on the land management aspects of forestry, brownfield redevelopment, urban air pollution, and pollution and waste reduction.

National Science Foundation

NSF's $26 million was highly distributed among the categories with structural engineering and natural hazards getting the most ($13 million), followed by metals, composites, and advanced materials ($3.5 million); transportation infrastructure ($2.6 million); and geotechnical engineering (almost $2 million). The balance of NSF's investment was spread across the full range of categories.

Other Contributing Agencies

In addition, roughly $200,000 of R&D was performed by the Departments of Interior and Veterans Affairs as well as the National Aeronautics & Space Administration.

4. Summary of FY99 Federal "Housing" R&D

This chapter presents a quantitative profile of the housing-related R&D funded by the federal government during FY99. The data described in this chapter is a subset of the broader construction and building search presented in Chapter 3.

The chapter summary profile consists of two different aggregations of R&D projects. The first aggregation is by the R&D categories listed in Table 1. The second aggregation is by the sponsoring agency. In each case, summary data is presented in tabular and graphical format for both the number of projects and the associated funding levels. Finally, each aggregation also contains a more detailed textual description of the R&D areas and their rough funding levels.

4.1 Federal "Housing" R&D by Category

4.1.1 Summary Data

Table 4 presents the results, aggregated by category, of the housing-related subset. Figures 5 and 6 present this data graphically for the number of projects as well as for average annual funding.

Category	Number of Awards	Average Annual Funding ($)
Building Design Improvements	11	4,194,444
Building Process Improvements & Automation	16	3,140,129
Building Product Improvement	40	21,057,473
Concrete, Cement, Pavement, Asphalt	6	571,639
Energy Efficiency	62	49,462,033
Energy Supply	60	110,515,929
Forestry	2	78,858
Land-use Design Improvements	6	326,509
Metals, Composites, & Advanced Materials (Non-wood, Non-concrete)	5	1,904,876
Other	12	3,704,480
Pollution & Waste Reduction	13	3,969,816
Reduction in Construction Work Illness & Injuries	151	15,857,039
Reduction in Occupant-related Illness & Injury	29	4,159,247
Structural Engineering & Natural Hazards	39	11,455,706
Wood Products & Quality	61	5,917,153
Total	513	236,315,331

Table 4. FY99 Federal Housing R&D by Category

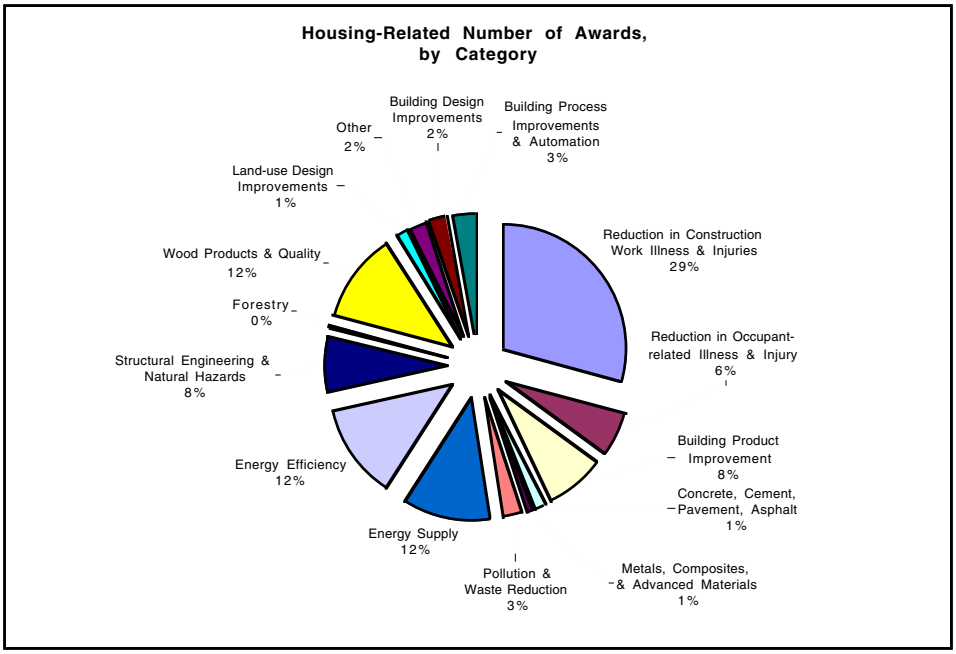

Figure 5. FY99 Federal Housing R&D Number of Project Awards by Category

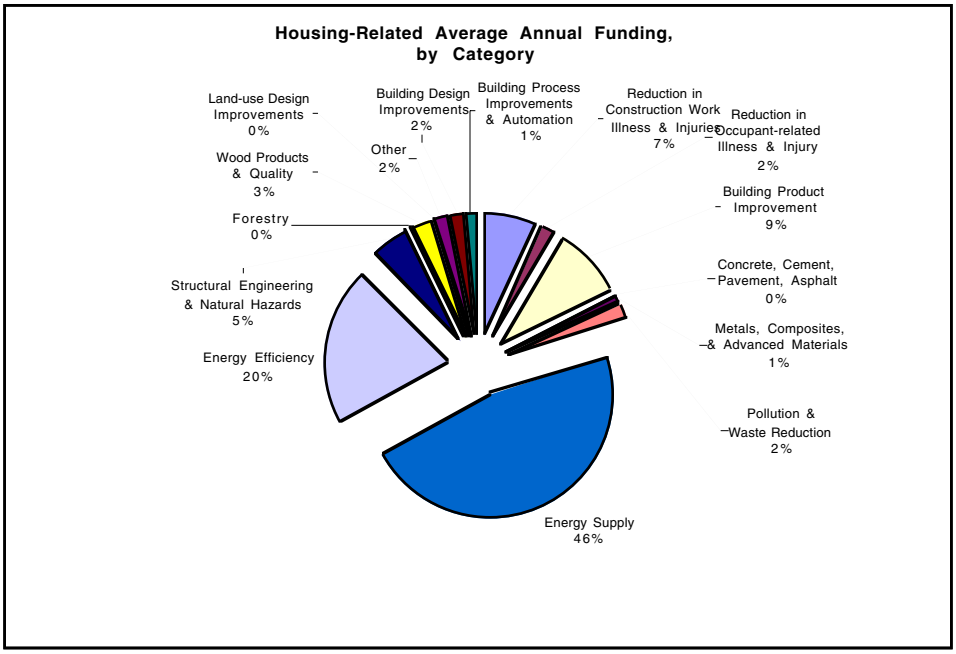

Figure 6. FY99 Federal Housing R&D Average Annual Funding by Category

4.1.2 Description by Category

Building Design Improvements

Just over $4 million was invested in efforts that could help improve residential design. This included R&D on sustainable and green design, affordable housing, and improved building rehabilitation/renovation.

Building Process Improvements & Automation

More than $3 million was invested in R&D potentially relevant to improving the home building process. This included R&D on traditional process improvements as well as information technology developments and how those technologies can be transferred to home building industry.

Building Product Improvement

Approximately $21 million was invested in building product improvements. Of this total, about $12 million was for window-related research. The balance of the category was devoted to general R&D (nearly $6 million), insulation ($1 million), developing alternatives to stick framing ($1 million), as well as improved foundations, insulation, paint, roofing, and windows.

Concrete, Cement, Pavement, and Asphalt

Slightly more than $500,000 was invested in cement-wood composite materials.

Energy Efficiency

More than $49 million in energy efficiency R&D was potentially relevant to housing. Of this total, more than $28 million was focused on general analytical, technical, and program support. This general work addressed building energy systems, building codes and standards, existing buildings, heat and moisture modeling, and weatherization. Roughly $16 million in R&D on HVAC, appliances, and motors was also potentially relevant. Finally, nearly $5 million was invested in lighting.

Energy Supply

More than $110 million of energy supply R&D is potentially relevant to housing. This includes more than $100 million invested in renewable energy sources with photovoltaics representing $90 million, roughly $6 million for general solar and solar thermal technologies, and nearly $8 million for geothermal technologies. On the non-renewable side of C&B relevant R&D, almost $7 million was invested in fuel cells.

Forestry

Roughly $100,000 of R&D examined the role of residential housing as a major component of demand for wood, the economic trade-offs associated with conservation, and the impact of forest and riparian forest buffers on residential development.

Land-use Design Improvements

Approximately $300,000 was focused on demolition/deconstruction for redevelopment of urban areas, impact of natural resource conservation on rural subdivision developments, sustainable development, and transportation issues.

Metals, Composites, & Advanced Materials (Non-wood, Non-concrete)

Nearly $2 million was invested in metals and composites including thermoplastic composites for structural applications, steel applications, and analysis of hybrid/composite structural walls and steel frame systems.

Other

Almost $4 million in multi-category R&D and R&D results dissemination/outreach was conducted.

Pollution & Waste Reduction

Nearly $4 million was invested in reducing pollution and waste. Refrigerant R&D represented more than $2 million of the total while wood processing represented another $1.7 million. The balance addressed water and multi-pollutant issues.

Reduction in Construction Work Illness & Injuries

Since specific project descriptions were not available for NIOSH, it was not possible to determine which portion of their construction-related illness and injury R&D was potentially relevant to housing. Out of a desire to err toward inclusion, NIOSH's full portfolio of almost $16 million was included. However, conversations with NIOSH prior to publication determined that 10 studies representing roughly $1 million dollars were specifically targeted at residential housing though some portions of the larger R&D portfolio were felt to have spill-over benefits to housing.

Reduction in Occupant-related Illness & Injury

Just over $4 million was invested in R&D related to the health and safety of building occupants, with the primary focus being on indoor air quality (IAQ).

Most of this research addressed IAQ generally ($3.1 million), though $600,000 was focused exclusively on residential air quality. Other targeted efforts addressed sensor development and low solvent adhesives.

Structural Engineering & Natural Hazards

More than $11 million was invested in structural engineering and natural hazard R&D. R&D addressing multiple hazards amounted to almost $6 million, with housing-related fire research representing another $3.7 million. Both earthquake and wind-related R&D represented about $1 million each. Smaller investments were made for structural R&D as well as measurement and instrumentation.

Wood Products & Quality

Approximately $6 million was invested in housing-related R&D on wood products and wood quality. Slightly less than half of this was invested in finding new applications for wood and wood scrap/waste ($2.7M). Just over $1 million focused on the structural properties of wood and wood structures as well as adhesives. Other target areas receiving smaller investments included wood-containing composites ($600,000), wood drying ($350,000), and wood preservatives ($110k).

4.2 Federal "Housing" R&D by Agency

4.2.1 Summary Data

Table 5 presents the results, aggregated by agency, of the housing-related R&D subset. Figures 7 and 8 present this data graphically for the number of projects as well as for average annual funding.

Category	Number of Awards	Average Annual Funding ($)
USDA	89	8,319,175
DOC	29	27,253,127
DOD	2	0
DOE	130	167,622,313
HHS	166	17,146,260
HUD	45	11,892,694
DOI	1	57,950
DVA	1	14,011
EPA	3	606,800
NSF	47	3,403,002
Total	513	236,315,332

Table 5. FY99 Federal Housing R&D by Agency

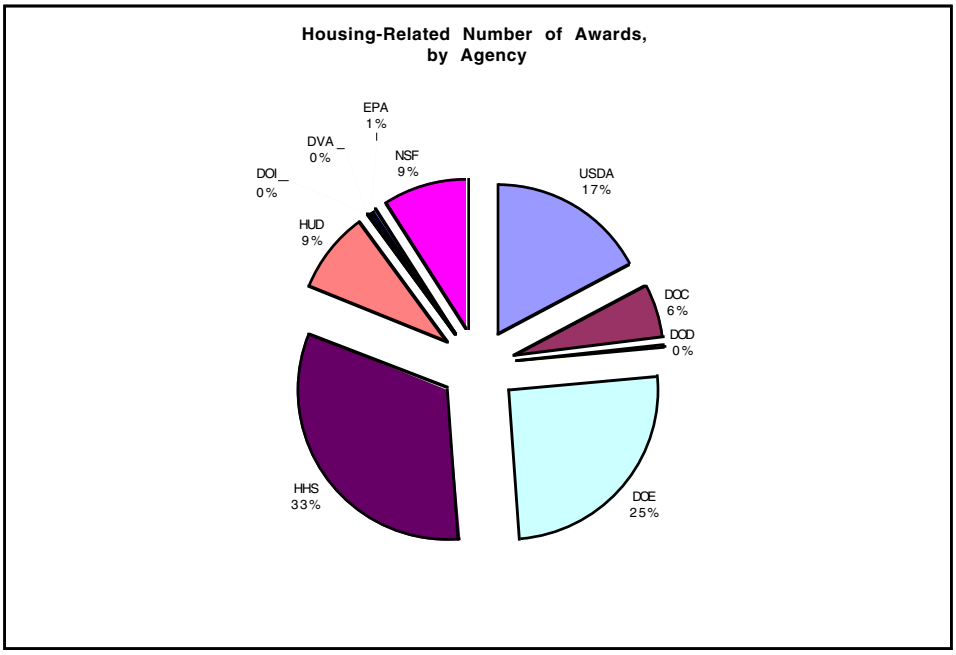

Figure 7. FY99 Federal Housing R&D Number of Project Awards by Agency

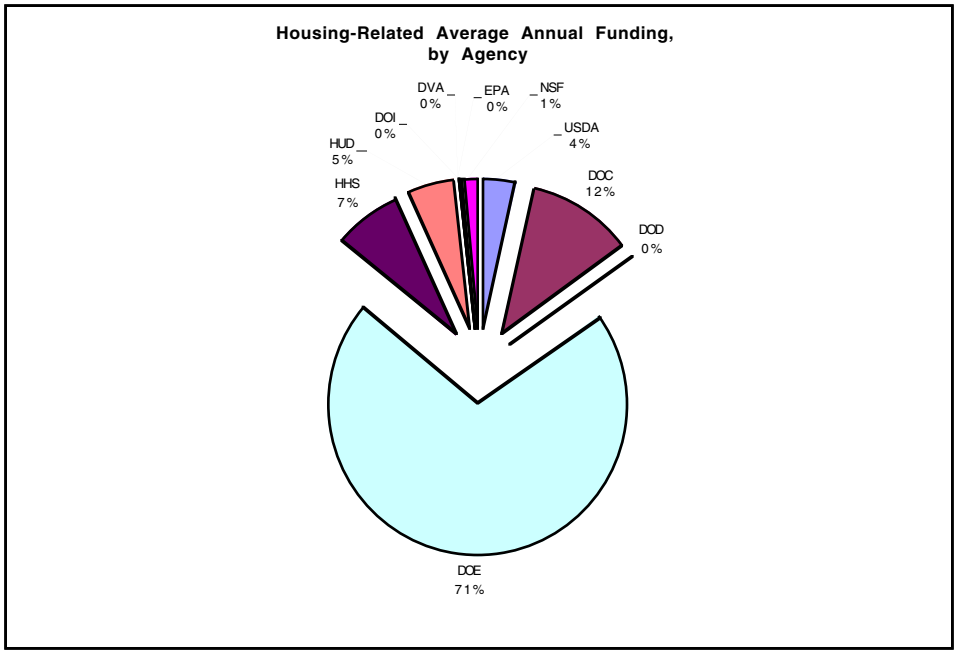

Figure 8. FY99 Federal Housing R&D Average Annual Funding by Agency

4.2.2 Description by Agency

Department of Agriculture

More than $8 million was invested by the Dept. of Agriculture with almost $5 million for wood products and wood quality and $2 million for pollution and waste reduction. Additional R&D addressed cement-wood composites, better building products, improved construction systems, structural engineering and natural hazards, and several other categories.

Department of Commerce

DOC invested roughly $27 million in R&D that was potentially relevant to housing. Most focused on structural engineering and natural hazards ($9 million), with lesser amounts for energy supply ($5 million), energy efficiency (close to $4 million), building design improvements ($3 million), as well as a number of other categories.

Department of Energy

Of nearly $170 million invested by DOE, roughly $105 million was devoted to energy supply, nearly $45 million to energy efficiency, and $15 million for

building product improvements. The remainder was spread across the other categories with reducing occupant-related illness and injury and reducing pollution and waste being the largest components of the remainder.

Department of Health & Human Services

Of the Department's $17 million, more than $15 million went to reducing construction-related illnesses and injuries. The remainder focused on reducing occupant-related illness and injury, primarily due to indoor air quality issues.

Department of Housing & Urban Development

HUD's R&D investment was approximately $12 million, with approximately $10 million of this being housing-related funds. Of the total, $4 million was used for building product improvements, $3 million for multiple-category R&D (classified as "Other"), $1.4 million for building process improvements and automation, and $1 million for building design improvements. The remaining funds are spread across the remaining categories.

Environmental Protection Agency

EPA's investment in potentially relevant R&D amounted to $600,000 and was focused on reducing occupant-related illness and injury, especially indoor air quality and low-solvent adhesives.

National Science Foundation

Roughly $3.4 million of NSF's R&D investment was potentially relevant to housing. More than half of this was focused on structural engineering and natural hazards ($1.7 million) with the balance spread across the full range of categories.

Other Contributing Agencies

Three other agencies also contributed to housing-related R&D. These included the Departments of Defense, Interior, and Veterans Affairs. DOD's contribution was focused on automated control of electricity producing distributed generation systems, however, funding information was not available for these projects. In addition, on a combined basis, the Departments of Interior and Veterans Affairs supported roughly $72,000 of R&D addressing building codes and natural hazards and indoor air quality.

4.3 Federal PATH R&D by Category

4.3.1 Summary Data

Table 6 presents the results, aggregated by category, of the federal R&D funded specifically by the PATH program. Figures 7 and 8 present this data graphically for the number of projects as well as for average annual funding.

Category	Number of Awards	Average Annual Funding ($)
Building Design Improvements	2	168,182
Building Process Improvements & Automation	6	1,237,879
Building Product Improvement	9	3,701,515
Energy Efficiency	3	716,667
Energy Supply	1	266,667
Other	6	2,765,633
Structural Engineering & Natural Hazards	5	472,727
Wood Products & Quality	3	656,364
Total	35	9,985,634

Table 6. FY99 Federal PATH R&D by Category

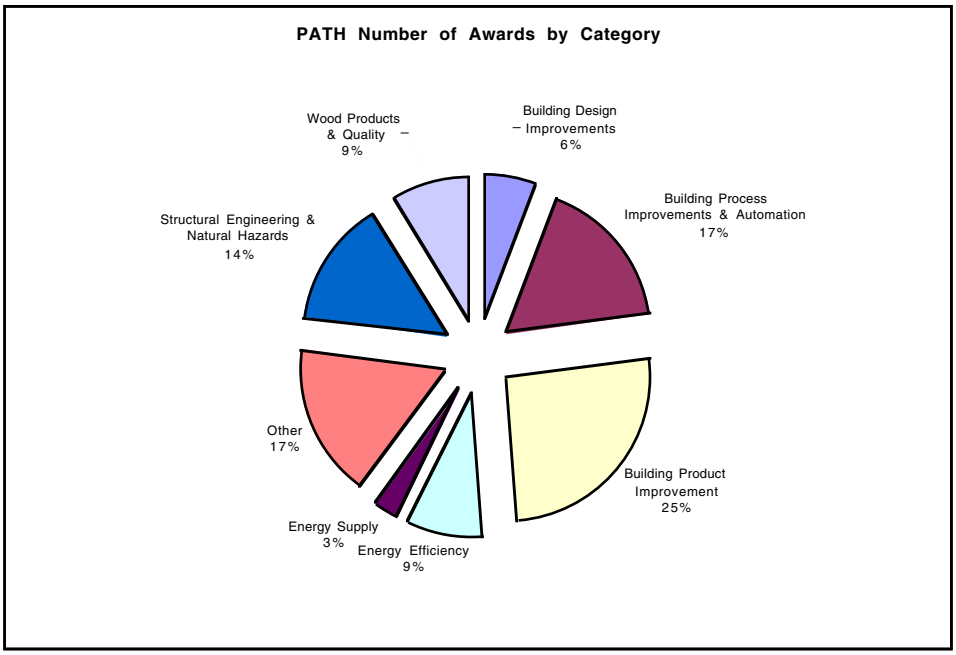

Figure 9. FY99 Federal PATH R&D Number of Project Awards by Category

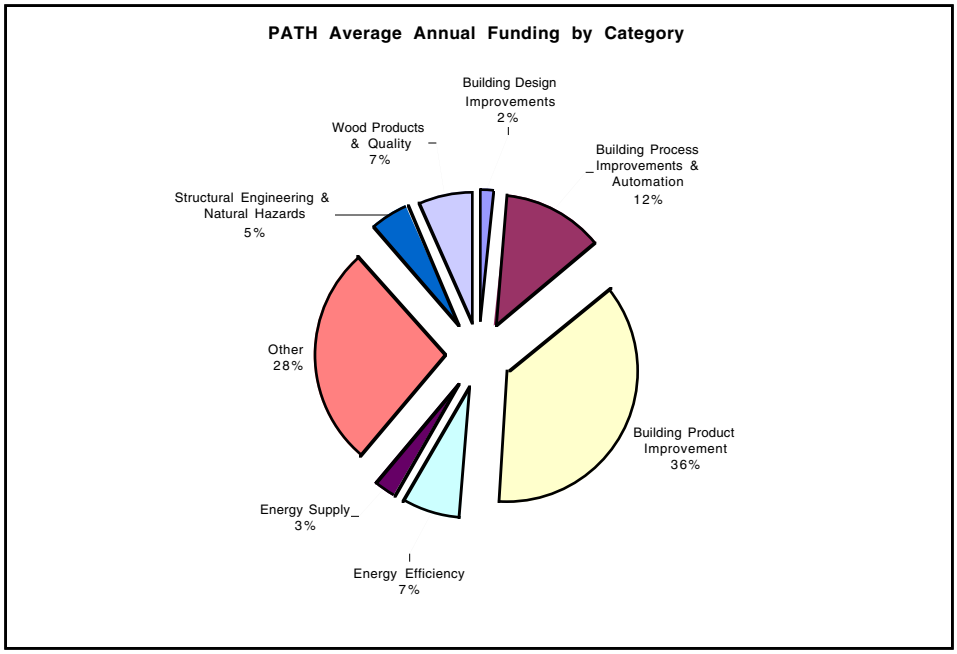

Figure 10. FY99 Federal PATH R&D Average Annual Funding by Category

4.3.2 Description by Category

Building Design Improvements

PATH invested roughly $170,000 to develop internet-based tools to help home owners evaluate energy efficiency improvements as well as develop adaptive shading technologies for future housing.

Building Process Improvements & Automation

Roughly $1.2 million was invested in alternative homebuilding techniques for both site-built and manufactured homes. These efforts included work on new fabrication technologies, labor-saving building systems, and new approaches to framing based on ISO 9000 practices.

Building Product Improvement

$3.7 million was invested in improving building products. Just over $800,000 of this was focused on developing alternatives to stick framing (e.g., clay masonry, composite structural insulated panels, insulated concrete panels, and steel framing). The roughly $2.8 million in remaining funds addressed a broad range of building product issues including technical analysis of new products, technical

support for the PATH demonstration projects, documentation of product evaluations and best practices, as well as support in developing the PATH operating plan. The evaluation of moisture control problems and techniques for avoiding them were also addressed.

Energy Efficiency

PATH invested roughly $700,000 in energy efficiency related R&D. Roughly one third of this funding was transferred to DOE to coordinate the PATH National Pilot sites. Another third focused on evaluating the effectiveness of advanced duct sealing technologies to increase energy efficiency as well as to assess the market potential and training requirements for wider use of these technologies. The final third of this funding focused on developing an energy saving residential thermostat that uses a variable deadband control.

Energy Supply

Roughly $260,000 was invested by PATH in R&D on solar power roof tiles which would both generate electricity and help insulate attics and reduce cooling loads.

Other

PATH invested roughly $2.7 million in a number of contracts that addressed multiple R&D categories and provided numerous services including analysis, technical support, coordination, and dissemination. For example, NIST initiated the development of performance standards for housing, provided support to the National Evaluation Service's Building Innovation Center, and researched or supported several topics including housing durability, environmental performance of housing components, residential fire safety, and how to streamline the nation's building regulatory process. These funds also supported technology roadmapping efforts for both new and existing homes. In addition, several contracts provided PATH with suggested management and measurement approaches. Finally, funds were also used to develop and maintain communication channels for disseminating R&D results to the broader housing community. These efforts included the Toolbase outreach program's website and telephone hotline as well as more traditional catalogues and CD-ROMs.

Structural Engineering & Natural Hazards

PATH invested almost $500,000 in R&D addressing structural engineering and natural hazard reduction. Research addressing wind hazards, and specifically the development of in-house wind-hazard shelters, represented nearly 50 percent of the funding. The balance of the funding was spread over general structural

engineering research, the relationship between fire protection membranes and structural integrity of wood floors and ceilings, as well as the structural loads presented by eave icing during winter storms.

Wood Products & Quality

Wood products and wood quality received roughly $650,000 in investment to improve reliability of homes subject to wind and severe storm conditions, to investigate the durability and disaster-resistance of new types of structural oriented strandboard (OSB), develop technical guidance for recycled lumber to increase reuse in housing construction and rehabilitation, and reduce the susceptibility of wood and wood products to water-induced decay.

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Appendix A: RaDiUS Search Terms

This appendix lists the search terms used during numerous searches of the RaDiUS database to produce the broad search results that were then read to confirm relevance. For additional explanation of how these terms are formatted or how RaDiUS processes search requests, please refer to the RaDiUS webpages at www.rand.org/scitech/radius.

($building) AND NOT (protein OR rna OR dna OR pathogen OR wetland OR biology OR mutant OR vaccine OR wolves OR wolf OR germplasm OR fertility OR bovine OR library OR gene OR genetic OR molecule OR molecular) AND NOT (mental OR etiologic OR gender OR cancer OR breast OR medical OR biomedical OR vision OR youth OR infant OR cognitive of medicare OR drugs OR drug OR heroin OR microscope) AND NOT (construction)

(construction) AND NOT (protein OR dna OR rna OR cotton OR pathogen OR wetland OR biology OR mutant OR vaccine OR wolves OR wolf OR germplasm OR fertility OR bovine OR cow OR library OR gene OR genetic OR molecule OR molecular) AND NOT (mental OR etiologic OR gender OR cancer OR breast OR medical OR health OR biomedical OR vision OR youth OR infant OR cognitive OR medicare OR drugs OR drug OR heroin OR microscope) AND NOT (vegetable OR fruit OR $textile OR vegetation OR bee OR grain OR crop OR hatchery OR $flavor) AND NOT (disorder OR disease OR injury OR psychiatric OR psychology OR $veteran OR emotion OR hiv OR aids OR pulmonary OR heart OR behavior OR renal OR pain OR alcohol OR alcoholism OR muscle OR bleed OR blood OR bleeding OR diagnosis OR prosthetic OR aorta) AND NOT (aortic OR retina OR arthritis OR injury OR injuries OR schizophrenia OR abuse OR nasal) AND NOT (reef OR $dolphin OR %biology OR bio% OR ecology OR eco% OR lion OR zoology OR fish OR %flies OR neurons OR animals OR %bacteria%)

low emissivity windows OR fenestration

computer aided design OR cad

hvac

wood

(earthquake OR flood OR hurricane OR earthquake engineering) AND NOT ($building OR construction)

(lighting OR composite) AND NOT ((construction OR $building OR wood))

fire protection OR fire modeling OR fire safety OR fire dynamics OR fire codes OR flame spread rates OR fire suppression OR smart fire detectors OR fire detectors

land development

(home OR house OR residential OR housing) AND NOT (construction OR $building)

(asbestos) AND NOT (construction OR building)

(masonry OR shear walls OR reinforce% concrete OR precast% concrete) AND NOT (construction OR building)

architectur% AND NOT (construction OR building)

plumb%

pipe OR pipes

air conditioner% OR air conditioning OR heater OR heat pump

acoustic OR acoustics

bridge%

(civil infrastructure OR civil engineering OR built environment) AND NOT (bridge OR bridges)

roof OR roofing

(solar heat) OR ((solar WITHIN 10 OF water))

fabricate OR fabricaton OR fabricated OR pre fab% OR prefab%

duct OR ducts OR vent OR vents OR ventilation

window OR windows

forest products OR forestry OR lumber OR timber OR forest OR plywood

light% OR lamp OR lamps

%construction%materials% OR %construction% %materials%

fram% AND structure%

steel%

paint OR painting OR (lead AND (contamination OR contaminated))

sewer OR septic OR sewage

natural gas

electrical power OR electric power OR heating oil

(path) OR (partnership for the advancing technology in housing) OR (coastal structure%) OR (hydraulic structure%) OR (airport%) OR (airfield%) OR (port%) OR (geotechnical) OR (geospatial) OR (energystar) OR (energy star) OR (sustainable development) OR (indoor air pollution) OR (indoor air quality) OR (green building) OR (environmental technology) OR (brownfield) OR (pavement)

(land development) OR (home automation) OR (electronic house) OR (manufactured housing) OR (expansive soil) OR (attic) OR (energy efficient residence) OR ((energy efficient) AND housing) OR (pressure treated) OR (industrialized housing)

Appendix B: Sponsors Exhaustively Searched

This appendix lists the sponsoring agencies, programs, etc. (e.g., the RaDiUS funding hierarchies) that were searched exhaustively for relevant R&D and potentially useful search terms. (Recall that RaDiUS organizes funding hierarchically based on Congressional appropriations and OMB budget categories). For additional explanation of how these hierarchies are organized and how to search them, please refer to the RaDiUS webpages at www.rand.org/scitech/radius.

Department of Energy / Energy Conservation / Building Technology

Department of Energy / Energy Supply / Solar Energy / Biopower/Biofuels energy systems - Power systems

Department of Energy / Energy Supply / Solar Energy / Electric energy systems/Energy storage R&D

Department of Energy / Energy Supply / Solar Energy / Electric energy systems/High temperature superconductivity R&D

Department of Energy / Energy Supply / Solar Energy / Electric energy systems/Transmission reliability

Department of Energy / Energy Supply / Solar Energy / Extramural awards

Department of Energy / Energy Supply / Solar Energy / Geothermal energy

Department of Energy / Energy Supply / Solar Energy / Hydropower development

Department of Energy / Energy Supply / Solar Energy / Solar energy/Concentrating solar power

Department of Energy / Energy Supply / Solar Energy / Solar energy/International solar energy program

Department of Energy / Energy Supply / Solar Energy / Solar energy/Solar building technology research

Department of Energy / Energy Supply / Solar Energy / Solar energy/Wind energy

Department of Commerce / National Institute of Standards and Technology / Building Fire Research Laboratory

Housing and Urban Development / Policy Development and Research

Department of Agriculture / Forest Service / Forest & rangeland research / Forest Products Laboratory/Madison,WI

Department of Defense / Army Corps of Engineers

National Science Foundation / Engineering / Civil and Mechanical Systems / Construction/Geotechnology/Structures

National Science Foundation / Engineering / Civil and Mechanical Systems

National Science Foundation / Engineering / Electrical and Communications Systems

Health and Human Services / Center for Disease Control / National Institute for Occupational Safety & Health

Environmental Protection Agency

Department of Transportation / National Highway Transportation Safety Administration

Department of Transportation / Federal Aviation Administration

Department of Transportation / Federal Highway Administration

Department of Transportation / Research and Special Projects Administration

Dept of Education

Dept of Labor

Appendix C: Agency Data Limitations

During this search, several agencies were realized to have incomplete FY99 data in the RaDiUS database. This appendix describes these occurrences, how they were addressed, and what their impact may have been on the overall results of the search.

Department of Agriculture

Eight projects at the Department of Agriculture had neither project funding information nor budget authority meaning these projects had no estimate of funding.

Department of Commerce

Seven projects at the Department of Commerce had neither project funding information nor budget authority meaning these projects had no estimate of funding.

Department of Defense

Due to the desire to exercise discretion and sensitivity, DOD does not provide RaDiUS with complete and unrestricted information for all of its unclassified R&D projects. While some of this information is included in RaDiUS, it may only be viewable to employees of DOD, the federal government at large, or government contractors. Given that the results of this search were to be publicly available, no restricted records were included in this search. This means that some R&D may have been missed by the search effort.

In addition, some DOD projects have incomplete funding information meaning that funds were estimated from budget authority where possible. However 23 DOD projects had neither project-level budgets or budget authority information available. For this reason, no funding estimate could be included for these 23 projects.

A final limitation was that the Army Corps of Engineers, which does provide funding information, does not provide the project descriptions needed to assess

the relevance of 107 projects representing $15.5 million in Corps R&D. During discussions with Corps personnel it became apparent that RaDiUS does not include all aspects of the Corps' R&D portfolio—perhaps due to the OMB coding problem discussed in Chapter 2. For this reason, even though project descriptions were not available, all 107 projects were included in the resulting database, though these records were categorized as "Unknown".

Department of Health & Human Services

The FY99 RaDiUS data for the Department of Health and Human Services lacked project descriptions for the National Institute for Occupational Safety & Health (NIOSH). During discussions with a representative from NIOSH, actual FY99 budget --not average annual funding levels-- and project totals were provided to RAND and substituted into the project database.

Department of Housing & Urban Development

The RaDiUS database also had incomplete FY99 information for the Department of Housing and Urban Development (HUD). Fortunately, HUD was able to provide detailed project information from other sources. This information was substituted into the project database.

Department of State

While RaDiUS does not include any FY99 R&D for the State Department, contact with agency representatives determined that in the past applied R&D has been conducted jointly by Diplomatic Security and Foreign Buildings Operations. These efforts have addressed blast mitigation, perimeter wall testing, and field test verification of software simulations.

Department of Transportation

Within the Department of Transportation, the Federal Highway Administration (FHA) had roughly 170 projects worth $135 million that lacked project descriptions. Discussions with FHA confirmed that if project descriptions were available, these projects would be properly categorized as either "Structural Engineering & Natural Hazards" or "Concrete, Cement, Pavement, & Asphalt" R&D categories. However, since it was not possible to differentiate which category was appropriate for a given project, these projects were placed along with others into the more general "Transportation Infrastructure" category.

Finally, one DOT project lacked both project-level funding and budget authority information meaning it had no associated funding.