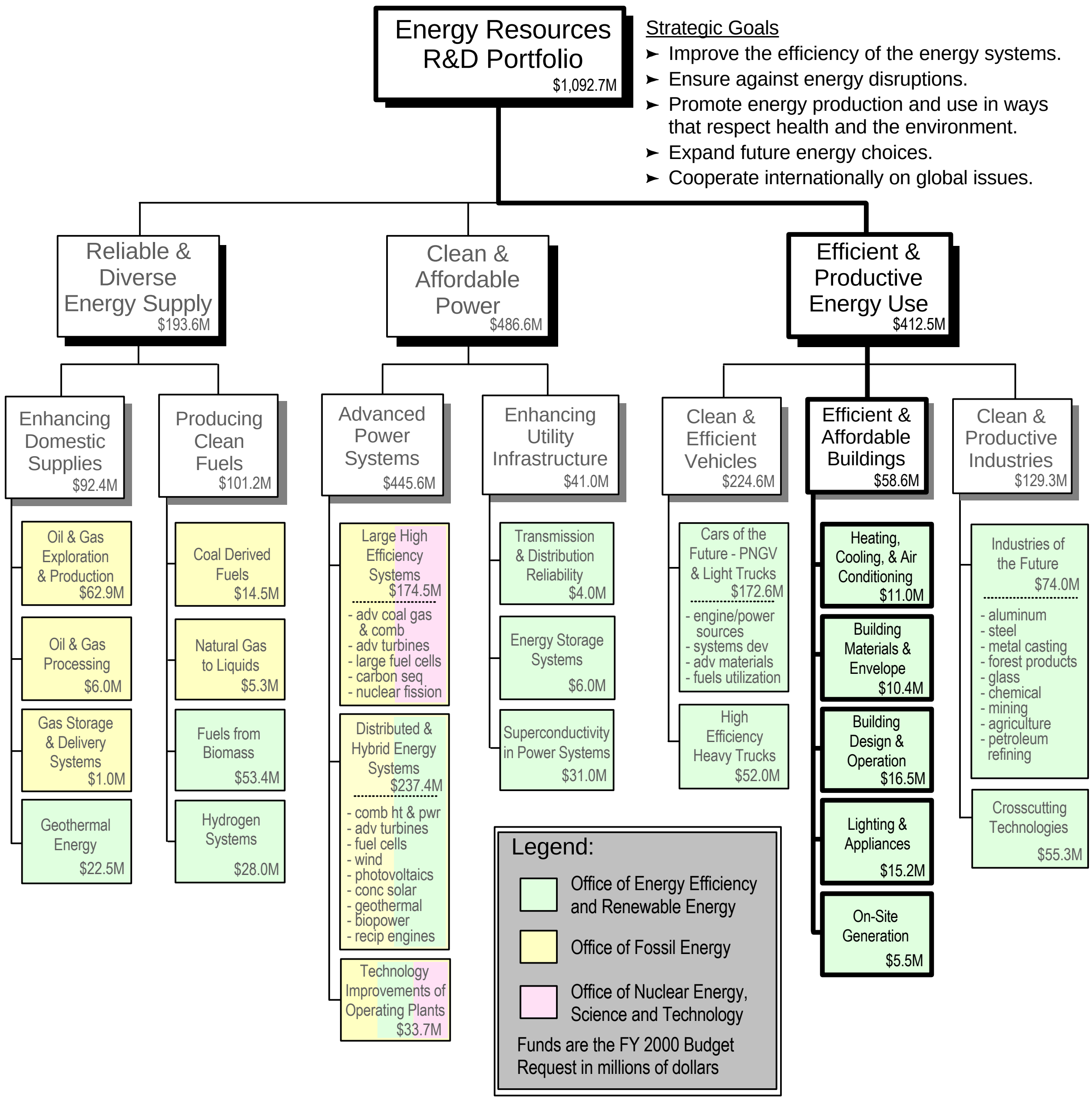
Chapter 8
Efficient and Affordable Buildings



Chapter 8

Efficient and Affordable Buildings

Table of Contents

Page

Page

Overview

Definition of Focus Area

The focus of the efficient and affordable buildings R&D portfolio is on buildings in both the residential and commercial sectors. Residential construction includes single-family, multi-family, and "industrial" (manufactured) housing. Commercial construction includes buildings used for commercial business such as offices, restaurants, hospitals, schools, warehouses, etc. Research and development (R&D) in the buildings sector ranges from improvements to the building shell (i.e., walls, windows, foundations) to improving the equipment used for heating and cooling the space or for providing building services like lighting and appliances, to methods of integrating all of these through "whole building" design techniques.

National Context and Drivers

The United States consumed roughly 94 quadrillion Btus (quads) of primary energy in 1996. The Nation's 100 million households and 4.6 million commercial buildings consume 37 percent or 34.5 quads of this total. Buildings also use two-thirds of all electricity generated nationally. More than $230 billion is spent each year in the United States to provide heating, cooling, lighting and related energy services for buildings. Even if the energy intensity of buildings remains constant, as more buildings are constructed, energy consumption and associated economic and environmental costs will continue to escalate. Energy consumption in buildings is a major cause of acid rain, smog, and greenhouse gas emissions in the United States, representing 35 percent of carbon dioxide emissions, 47 percent of sulfur dioxide emissions, and 22 percent of nitrogen oxide emissions.

One of the primary challenges to achieving efficiency in the building sector is its fragmentation. To start with, the building construction industry encompasses literally thousands of different businesses and millions of individual decision makers. Developers, designers, builders, utilities, engineers, and occupants pursue objectives which often are at cross-purposes. Also, unlike the transportation sector that is dominated by a few major firms responsible for final assembly and product delivery, the building sector has hundreds of thousands of builders who assemble individual components into complete structures. Furthermore, vast variability exists within the constructed structures themselves, so that even a single community might contain hundreds of building styles and sizes. One result of all this diversity is that product integration is less than optimal and buildings are typically designed and constructed as complex amalgamations of individual technologies, each of which carries out its intended function largely independent of (or even in spite of) others, rather than as a tightly integrated system of interrelated components. Inefficiencies and lost energy opportunities are frequent consequences of this situation.

Unfortunately, the number of decision makers that must be influenced and the effort required to pursue a change in the current predicament is high. The buildings sector is a risk-averse industry that has been slow to adopt new technologies that are more efficient than conventional ones. Although not a focus of this paper, Federal efforts in the buildings sector therefore also place a fair emphasis on activities that are designed to encourage the deployment of new energy efficiency technologies through education, training, and related efforts across the buildings community.

A third consequence of fragmentation is that the building industry spends relatively little on R&D. The industry is dominated by small firms that can ill afford research programs, and competition effectively prevents coordinated or integrated research. R&D expenditures for the buildings sector as a whole are an order of magnitude less than the national average. Given the importance of current energy consumption and projected growth in the buildings sector, maintaining and growing a vital research program for efficient buildings is critical to the success of the Department's overall strategic goal of increasing the efficiency and productivity of energy use.

Another significant element of the Department's R&D program is making homes more affordable for all Americans. Increased affordability is achieved by developing technologies and techniques which can either reduce the amount of energy used or improve the efficiency of its use in buildings at little or no net consumer cost. Such techniques are demonstrated, for example, by the Building America program which strives to increase a home's energy performance 50 percent over the Model Energy Code at little or no additional cost. The Building America program employs strategies such as improved design techniques that greatly reduce thermal leakage through the building envelope, or improved insulation and windows whose costs are offset by resulting reductions in the size of required space conditioning equipment. Other R&D efforts are focused on low-cost technology developments that offer sizable enough returns to justify their use within one or two years of implementation. One example is a thermal duct-sealing technology that can be used as part of the low-income Weatherization Program. This technology reduces leakage of thermal conditioning air by up to 30 percent and yet only costs a few hundred dollars to apply.

Linkage to CNES Goals and Objectives

The efficient and affordable buildings R&D portfolio directly supports CNES goal and objective:

- CNES Goal I, Objective 2 - Significantly increase energy efficiency in the transportation, industrial, and buildings sectors by 2010.

DOE's portfolio emphasizes areas where the opportunity for cost-effective energy reductions are greatest, such as heating and cooling, lighting, and systems integration. DOE estimates that successful realization of its R&D portfolio will reduce buildings energy use by 0.6 quads per year in the year 2010, and by 2 quads per year in 2020.

Uncertainties

The present R&D portfolio is a mixture of near and longer term research efforts. All R&D entails some measure of risk in that not all efforts are likely to come to fruition in terms of achieving the ultimate goal. Risk increases as endeavors become longer-term. Technical problems, both known and unknown, may arise that are insurmountable with current know-how and are hence candidates for longer-term, investigative research. Spreading risk across such a portfolio increases the likelihood of technical success in at least some subset of the endeavors.

In the current context of the building marketplace, the ultimate goal is reducing energy consumption. However, even if technical capability is achieved, market barriers such as declining real energy prices or conservatism on the part of building designers or builders may still impede market penetration, hence reducing success in achieving this goal.

Finally, there must be sustained commitment with budgets sufficient to continue R&D at a minimum threshold to achieve any measure of success within a reasonable time frame. The minimum funding threshold for any given effort varies as to the program's technical goals, necessary time frame, number of related efforts elsewhere, number of participants, and other factors. Below that level, an R&D program essentially becomes a maintenance program where researchers can keep up with innovations being achieved elsewhere but are unable to achieve much success in their own endeavors. Uncertain or widely varying budgets from one year to the next have similar impacts as researchers and their invested experience move on to more consistent and reliably funded activities.

Investment Trends and Rationale

The current portfolio of investments is driven by both the energy use and market characteristics of the buildings sector. The Energy Information Administration (EIA) projects that the United States will add 28 million households and about 16 million square feet of commercial floor space between now and 2020. Once built, these homes and buildings will last 50 years or longer—considerably longer than most power plants. That is, the impacts of buildings design, construction, and equipment decisions cast very long shadows into the future. Fully 30 percent of commercial floor space and 40 percent of all housing currently in use were built prior to 1960. Therefore, the portfolio must not only address new buildings, but existing buildings through retrofit and renovation.

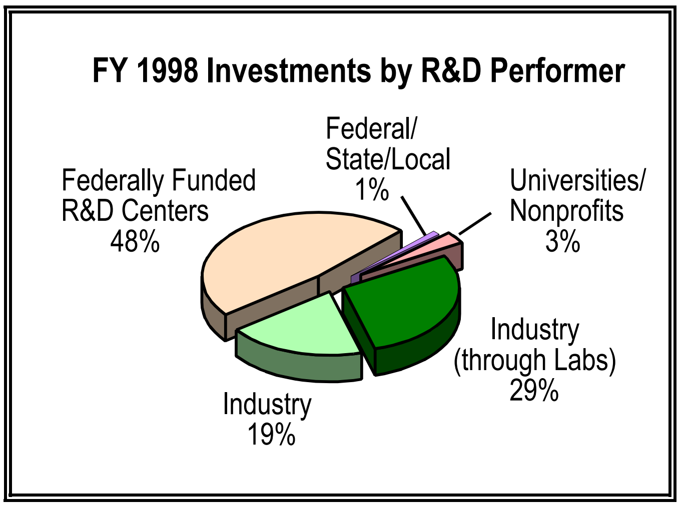
The potential savings impacts to the Nation's projected energy use in buildings are great—the Department projects that from 10 to 30 percent savings are cost-effective in existing buildings and from 30 to 70 percent in new construction. These savings will not only be realized in consumer's pocketbooks but also in reduced environmental impacts of energy production and use.

This paper presents an overview of the R&D portfolio for the buildings sector. R&D areas include (1) Heating, Ventilation, and Air Conditioning; (2) Building Materials and Envelope; (3) Building Design and Operation; (4) Lighting; (5) Appliances; and (6) On-Site Generation.

The first three areas target energy saving opportunities in heating, cooling, and ventilation, which account for 40 percent of building energy consumption on a primary basis. Areas 4 and 5 target the next largest areas of consumption. The final research area, On-site Generation, has the potential for addressing both electric and thermal needs of buildings.

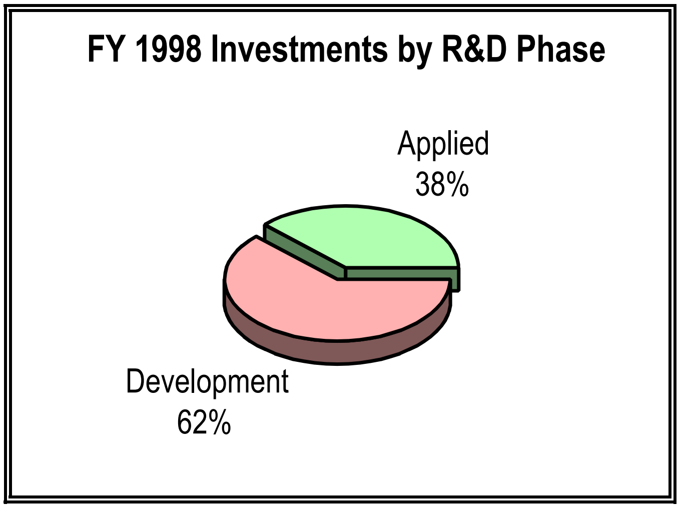
The buildings R&D portfolio is performed by two main entities, with monies spread roughly equally between them. About half (48 percent) of the research is performed by the private sector, either funded directly or through DOE laboratories. An equal amount of research is performed by the DOE laboratories themselves. Only a minor amount of the Department's research is performed by universities (3 percent) or other government agencies (about 1 percent).

Cost-sharing with the private sector varies greatly among research programs, but typically averages between 50 to 75 cents of private contribution for each dollar of public expenditure. Much of this cost-sharing takes place through Cooperative Research and Development Agreements (CRADA) and other types of cooperative research through the National Laboratories, as highlighted in the figure below.[1]



The next figure illustrates the funding divisions between stages of research—development versus applied R&D ("buildings" R&D is by definition does not include basic research). For these purposes, development is defined as enhancements to the performance or operation of a product or practice, with an emphasis on commercialization. An example might be the independent and objective testing or evaluation of a completed system under various operating regimes. Applied R&D examines broader research issues, such as materials compatibility or corrosion.

[1] The breakout of research, development, and demonstration (RD&D) by performer is based on the FY 1995 budget. However, the performer mix has not changed greatly since that time.



As the figure shows, the bulk of Departmental research dollars are devoted to development with the balance spent on applied research. This division is consistent with the primarily near- and mid-term focus of the current research portfolio.

Future Trends in Investment. The buildings R&D portfolio is undergoing a fundamental change. In the spring of 1997, it was recognized, with Congressional concurrence, that there was a need for broader industry input, increased competition and less fragmentation, and greater focus in the portfolio. The Office of Building Technology, State, and Community programs (BTS), which manages the bulk of the Efficient and Affordable Buildings research done by the Department, initiated a strategic planning process that is realigning the research in this sector.

In concert with the recently released Strategic Plan, BTS has initiated an effort to bring stronger focus and relevancy to the buildings R&D portfolio. The plan establishes a new way of doing business:

- Stronger and more effective partnerships with industry, including jointly developed government-industry technology roadmaps that incorporate consumer and end-user perspectives.
- A culture of competitively selected and peer reviewed projects.
- Establishment of BTS as the integrator of cost-effective, technology based, highly efficient energy consuming products and practices.
- An organization that is customer focused, highly productive and results driven.

In consultation with industry and other stakeholder organizations, BTS is developing technology roadmaps to define the future portfolio and to develop strategic alliances with industry. In 1998-1999, roadmaps are being developed for lighting; windows; heating, ventilation, and air conditioning (HVAC) equipment; and commercial and residential buildings (buildings systems integration). Additional roadmaps will begin in 1999 and carry through 2000. The roadmaps will have an impact on the FY 2000 budget as they evolve.

Federal Role

Research by the Department in the buildings area fills four needs. First, the Department can provide the critical mass necessary to accelerate progress in an area in which the private sector does limited research. Second, in many cases, important research would not occur at all in the absence of the Department's efforts due to the fragmented nature of the buildings marketplace. Third, it provides industry with objective analysis on new technologies and techniques to reduce barriers to new technology adoption. Finally, buildings research can reduce the huge energy costs incurred by the Federal Government—the single largest consumer of energy in the United States.

Key Accomplishments

The Department has a history of supporting RD&D in the area of buildings efficiency technology that has paid off handsomely for the Nation. The net result of just 5 Federal investments made back in the 1970s-80s[2] have resulted in present value savings in the U.S. economy totaling nearly $33 billion through 1997, while simultaneously eliminating more than 60 million metric tons of cumulative carbon emissions. These case study results were reviewed in detail by the General Accounting Office and reflect their conservative accounting methods.

Heating, Cooling, and Air Conditioning

Budget: FY98-$14.7M, FY99-$15.4M, FY00-$11.0M

Background

The demand for HVAC in homes and commercial buildings consumes nearly 14 quads of primary energy per year—40 percent of the primary energy in buildings and 15 percent of U.S. primary energy totals—amounting to $90 billion annually. Buildings consume 4.1 quads of primary fuel to make electricity and 1.85 quads of electricity directly, 5.4 quads of natural gas, 1.2 quads of fuel oil, and 1.2 quads of other fuels (e.g., wood) for thermal comfort services. Space heating and cooling dominate, accounting for over one-third (37 percent) of total energy usage in buildings.

Linkage to CNES Goals and Objectives

[2] The five technologies include the Flame Head Retention Oil Burner, Advanced (Low-E) Glass, Electronic Fluorescent Ballasts, the Efficient Refrigerator Compressor, and the DOE-2 Building Design Software.

This program directly supports CNES goal and objective:

- CNES Goal I, Objective 2 - Significantly increase energy efficiency in the transportation, industrial, and buildings sectors by 2010. *(increase efficiency of space conditioning, ventilation, and thermal distribution equipment; reduce peak-load electricity demand; and enhance indoor air quality)*

Program Description

A variety of equipment provide space conditioning services, including heat pumps, furnaces and boilers, chillers, and others. Thermal distribution systems include fans, ducting, piping, heat exchangers, and controls and can also be the means of primary ventilation. More highly advanced systems incorporate computers, sophisticated building sensors, and complex control strategies.

The equipment used in a given building is determined by building size, function, geographic region, availability of fuel types, consumer preferences, and other factors. Opportunities for the most cost-effective energy savings and improved performance in a given application vary by technology. Therefore DOE has a number of technology development activities underway.

In 1998 the Department joined with the Air Conditioning and Refrigeration Institute (ARI) in developing a roadmap for HVAC research for the future. The ARI initiative, HVAC&R Research for the 21st Century (known as "21-CR") is a comprehensive, industry-generated research agenda. Its major elements include improved equipment efficiency and new refrigeration cycles development, building systems integration, and new working fluids. This effort will help define the next generation of research with implementation beginning in FY 2000.

Geothermal Heat Pumps

Budget: FY98-$6.4M, FY99-$6.5M, FY00-$0.0M

Description, Objectives, and Performers. The geothermal heat pump (GHP), also known as a ground-source heat pump (GSHP) works on the same principle as a conventional (air source) heat pump of transferring heat from a cooler temperature to a warmer temperature. But whereas conventional heat pumps transfer heat to and from outside air, GHPs transfer heat to and from the earth. While this technology typically has a low life-cycle cost and is more efficient than conventional HVAC technology, first costs are high. DOE funds geothermal heat pump research and development and technical assistance programs at the International Ground Source Heat Pump Association (IGSHPA), consisting of 24 utilities, and Oak Ridge National Laboratory (ORNL).

R&D Challenges. The objective of the DOE activity is to reduce the initial cost of the system. Research is needed to reduce the cost of installing the underground heat exchanger, the costliest portion of a GHP system. Reduction of costs in other system components also need attention. Goals include a 40 percent reduction in ground loop heat exchanger cost.

R&D Activities. Research is focused on developing methods to properly assess the thermal characteristics of the installation site to reduce the installation cost of the underground heat exchanger. There is also ongoing research on other system components and system integration, such as developing hybrid systems using small cooling towers, snow melt, and passive surface heat exchangers to reduce operating and capital costs.

Accomplishments. Among the DOE successes in this area were the use of improved simulation models to develop a "rule of thumb" for ground loop design that resulted in 40 to 50 percent shorter loops, and hence, lower first cost.

Absorption Technologies

Budget: FY98-$5.4M, FY99-$5.9M, FY00-$6.5M

Description, Objectives, and Performers. Absorption technologies are being pursued for both residential and commercial applications. The commercial research is focused on alternative working fluids and system enhancements to improve energy efficiency. The residential effort is centered around development of an absorption heat pump (AHP).

An AHP differs from an engine-driven heat pump in the way the refrigerant is compressed. An AHP absorbs the refrigerant vapor from the evaporator in a solution rather than using a mechanical compressor. The refrigerant is then separated from the solution by heating it with natural gas. A natural gas-fired absorption heat pump has the potential to have substantially lower (40 to 50 percent) operating costs compared to conventional heating and cooling systems and also offers an opportunity to serve cooling needs with natural gas. AHPs also have more uniform temperature distribution, can be operated at variable speeds, and provide significantly warmer air than that produced by electric heat pumps. An additional objective of the DOE effort is to help U.S. manufacturers recover a technical advantage in large commercial chiller applications by ultimately developing a gas absorption heat pump with a coefficient of performance of 1.8 in heating and 0.8 in cooling. The work is carried out through industry cost-shared programs with a major manufacturer and 3 small business establishments, 1 university and ORNL in close coordination with the Gas Research Institute (GRI) and major gas utilities. The program is 35 percent cost-shared.

R&D Challenges. The R&D challenge is the development of materials that will not corrode from the use of non-ozone depleting working fluids.

R&D Activities. Two different gas-fired absorption heat pump concepts are being researched. The Generator Absorber Heat Exchange ("GAX") is intended for markets where heating dominates energy use while the "Hi-Cool" unit is targeted towards cooling-dominated markets. In 1999, the first GAX prototype will be tested. This design uses a non-ozone depleting working fluid consisting of an ammonia/water mix. "Hi-Cool" research has advanced to initial stages of system development and is in the process of developing a prototype. Absorption chiller research continues with field testing of a lithium/bromide triple-effect chiller for cooling commercial buildings. Laboratory tests of this cycle have demonstrated significant (30-40 percent) improvements in energy efficiency of chiller applications.

Accomplishments. A complete residential GAX heat pump assembly was put into full operation and laboratory-tested in 1998. Measured heating efficiency was found to be 100 percent better than the best existing gas-fired condensing furnace.

Desiccants

Budget: FY98-$2.4M, FY99-$2.5M, FY00-$4.5M

Description, Objectives, and Performers. Desiccant systems take advantage of thermodynamic relationships between air temperature and humidity. Desiccant materials have a higher affinity for water than does air and can therefore be employed to absorb moisture and lower air humidity. Once the air is dried, cooling it requires less energy than if it were still humid. Energy and cost savings (as well as precise humidity control and alleviation of moisture-related indoor air problems) are thereby possible with proper desiccant system design. Desiccant systems are complex and not fully understood. The objective is to develop and disseminate credible information on desiccant systems operation and design in order to ensure their use where economically advantageous from an energy efficiency perspective or to address problems of indoor air quality. The National Renewable Energy Laboratory (NREL) and ORNL assist 2 industry teams consisting of a major HVAC manufacturer and desiccant wheel manufacturers. This activity focuses on the continued development and integration of desiccant wheel and complete system testing of new designs and materials as they emerge from manufacturers. The program is 40 percent cost-shared.

R&D Challenges. The R&D challenges are to better understand the properties of solid desiccant materials and system operation, thereby developing the information needed to achieve optimal system design. With liquid desiccants, the challenge is to reengineer the absorber to increase the stability of the liquid/air interface and reduce the potential for droplet formation and carryover into indoor air.

R&D Activities. R&D activities include objective testing, analysis and feedback to industry on the design, performance, and durability of prototype solid desiccant wheels and humidity control systems. There is also ongoing field testing to integrate prototype desiccants into conventional HVAC systems. Research continues with industry on a cost-shared project to develop high efficiency liquid dehumidifiers.

Accomplishments. A highly successful testing and evaluation program of solid desiccant wheels with industry was achieved.

Furnaces and Boilers

Budget: FY98-$0.5M, FY99-$0.5M, FY00-$0.0M

Description, Objectives, and Performers. Oil furnaces and boilers provide heat and hot water in over 10 million buildings. Oil-heating is provided by heating air or through hydronics (water radiating heat through a piped system). An oil burner system delivers and disperses the fuel, and ignites and monitors the flame used to heat the air or water. The objective of the DOE effort is to reduce oil consumption through improved burner design. The program works with three equipment manufacturers and the New York State Energy Research and Development Agency (NYSERDA), and is cost-shared with about 60 percent of funds coming from industry. Future plans are to have the program become 100 percent funded by industry.

R&D Challenges. The challenge is to develop low-cost, low NO_x emission burner technologies.

R&D Activities. DOE research focuses on improvements to burner design and operation. DOE is testing a prototype low NO_x version of the fan atomized burner. Research is also underway on a second generation burner that will be lower cost and include self-tuning features to maintain efficiency.

Accomplishments. DOE funded earlier development of the flame retention head oil burner which now dominates the marketplace resulting in $5.0 billion in cumulative consumer cost savings.

Building Materials and Envelope

Budget: FY98-$7.2M, FY99-$10.7M, FY00-$10.4M

Background

The building envelope is the barrier between the interior and exterior environment. It consists of the walls, windows, roof, foundation, and doors. Energy demand for heating, ventilation, and air conditioning is determined by the thermal integrity of the building envelope, “air-tightness,” and by occupant behavior. There is much interaction between building envelope, lighting, and HVAC components. DOE conducts a diversified portfolio of research into components and systems.

Linkage to CNES Goals and Objectives

This program directly supports CNES goal and objective:

- CNES Goal I, Objective 2 - Significantly increase energy efficiency in the transportation, industrial, and buildings sectors by 2010. *(increase the thermal performance of the* *building envelope, increase indoor air quality, reduce the environmental impact of building construction, and increase occupant comfort)*

Program Description

Component research includes advanced materials and insulations, high-performance windows, and innovative components such as self-drying roofs. DOE works with industry to develop systematic and objective evaluation methods for all envelope components. These range from thermal control windows ("superwindows") to dynamic wall systems, and from highly-reflective building surfaces designed to reduce cooling loads to energy efficient and durable commercial roofing systems. This research also provides the technical foundation for the industry consensus process for building standards and guidelines, such as those of American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) and the American Society for Testing of Materials (ASTM).

Windows and Glazings

Budget: FY98-$5.0M, FY99-$6.8M, FY00-$6.6M

Description, Objectives, and Performers. Windows are major determinants of heating needs, due to conductive losses, air infiltration, and solar gain; and to cooling needs, largely due to solar gain. As such, improving the thermal performance of window systems is an important element in reducing the energy required to provide consistent thermal comfort. The Department's goal is to conduct research and development on advanced window technologies and to develop design, rating, and information tools needed to optimize the use of these technologies. The program works with three manufacturers, two research institutes, an industry association, one university, and three National Laboratories in its research program. Roughly 80 percent of the funding goes to the National Laboratories.

R&D Challenges. Coating design, performance, and durability are technical barriers for electrochromic and other advanced window concepts. First costs for advanced window systems will also be barriers to market acceptance without substantial engineering improvements.

R&D Activities. Research on windows and glazing systems focuses on development of advanced materials, devices, and technologies as well as creating the analysis, simulation, and test procedures needed to accurately characterize performance. Electrochromic research continues on improving coating design and performance and durability of window that can be switched from clear to opaque to control cooling loads and manage daylight levels. This technology offers large energy savings potential, and the ability to shave peak electricity demand in the "Sunbelt," where much of the Nation's construction is occurring. DOE also provides testing of prototype high performance windows with superior thermal qualities using computer simulation, infrared, and thermal performance test facilities. Finally, DOE develops performance data, procedures, and tools that underlie the highly successful National Rating Fenestration Council windows rating system.

In 1998, the Department joined with industry partners in developing a vision and a roadmap for windows research for the future. This is the first portion of a broader building envelope roadmap. This effort will help define the next generation of research with implementation beginning in FY 2000.

Accomplishments. The low-emissivity (Low-E) window, which reduces the transfer of long-wave, infrared radiation was developed in the early 1980s. Currently, this technology accounts for 35 percent and 18 percent of residential and commercial window sales, with cumulative consumer savings of about $5 billion.

Walls, Roofs, and Foundations

Budget: FY98-$2.2M, FY99-$3.9M, FY00-$3.8M

Description, Objectives, and Performers. About 40 percent of the 34 quads of building energy use serves space conditioning and ventilation needs. The thermal performance of the building envelope is a major determinant of this energy use. The Department conducts research and development to significantly improve the thermal performance of walls, roofs, and foundations, and to investigate the effects of reflective surfaces and vegetation on building demand for cooling energy. In addition to the opportunity to lower energy use, other benefits include the increased durability of building envelope systems and materials and environmental improvements such as reduced construction waste, decreased use of ozone-depleting insulations, possible increased use of indigenous materials, and decreased summer temperatures (and air pollution) in urban areas through mitigation of the “urban heat island” effect. Major performers include ORNL, which hosts the Buildings Technology Center— a user facility that enables users (nearly 300 organizations) to share research costs with DOE. Lawrence Berkeley National Laboratory (LBNL) is the research organization for highly reflective surface research.

R&D Challenges. The lack of objective, widely available information on “whole-wall” and thermal reflective surface field performance, hinders market acceptance of novel, high performance technology. Uniform and comprehensive metrics are also needed to assess the environmental impacts of alternative insulation blowing agents. Durability of high performance roofing systems is another challenge.

R&D Activities. The Department’s “Buildings Technology Center” tests, models, and rates whole wall systems for thermal resistance, thermal mass benefit, and air leakage. Simplified tools are maintained on the Internet that allow building professionals to design energy efficient and durable wall and roofing systems. Research is targeted towards the development of advanced manufacturing processes for “next generation” insulation alternatives such as aerogels, evacuated panels, and non-HCFC foams. Commercial roofing systems typically have an installed R-value of 10 and a service life of 15 years or 30 percent of the remainder of the building envelope. DOE is performing laboratory and full-scale field testing of advanced roofing systems that are significantly more durable and energy efficient. To reduce cooling loads, buildings can incorporate highly reflective surfaces and roofing materials but a key issue is establishing field performance levels. DOE is therefore working to develop standardized protocols for measuring the energy performance of a variety of highly reflective roofing and pavement materials.

Accomplishments. Program accomplishments include the creation of a vacuum insulation panel that offers R-values an order of magnitude greater than that of standard insulation products.

Building Design and Operation[3]

Budget: FY98-$11.8M, FY99-$13.0M, FY00-$16.5M

Background

Buildings, although often "simple" in appearance, are in fact complex and dynamic systems made up of numerous components and subsystems. The interaction of these components and systems can have a profound impact on energy consumption, cost, and related pollution. Furthermore, because buildings differ greatly in size, shape, function, and intensity of use, these system interactions change from one building to the next.

The overall design and orientation of buildings have a substantial impact on energy consumption. The "pieces" of a building most relevant to an analysis of energy consumption are the building envelope (foundation, walls, windows, and roof); the heating, ventilating and air-conditioning subsystem; the lighting subsystem; the water heater and other appliances, including refrigerators, computers, and clothes washers and dryers; the energy controls associated with the HVAC and lighting subsystems; and the building occupants themselves. The energy requirements of a building or home depend not only on the *individual* performance of these components and subsystems but also on their *combined* performance when integrated into a unique building and how the building - as a system - is operated. There are large differences between building types in terms of systems design and operation considerations. For instance, in large office buildings, the interaction between lighting and other internal loads and HVAC is a very important design consideration, whereas this is not true in homes because lighting is a small energy user and is typically used in the evening hours when cooling loads are less.

An example may be useful for illustrating the importance of systems design approaches. In homes, the thermal integrity of the windows, walls, and roofs determines the heating and cooling loads the HVAC system must meet to keep occupants comfortable. A well-built home designed and oriented to take advantage of "passive" solar heating in heating climates, or incorporating "superwindow" technology that admits light but not heat in cooling climates, can meet its lowered thermal load with smaller and less costly heating and cooling systems, and perhaps without such systems altogether.

[3] This area includes research activities from "Building Integration" and "Design Tools and Strategies" budget categories.

Due to industry fragmentation, the Department has a key role as an integrator in optimizing the design, installation, and operation of energy related building components using a systems approach. Because a systems approach may be nonintuitive and not lend itself well to simple design guides and checklists, much of the effort focuses on development of interactive, user-friendly design tools for use by the buildings community.

Linkage to CNES Goals and Objectives

This program directly supports CNES goal and objective:

- CNES Goal I, Objective 2 - Significantly increase energy efficiency in the transportation, industrial, and buildings sectors by 2010. *(reduce energy consumption through energy-efficient design techniques, reduce construction waste, increase use of passive solar in building designs, and reduce operation and maintenance costs)*

Program Description

The Department's research activities center on both building design and construction, as well as operation and maintenance (O&M). During building design and construction, subsystem, and component choices are made and actual construction begins. During the O&M phase, the building is occupied and in use. DOE develops tools and protocols for building design and operation as well as providing the technical basis for the industry consensus process for standards and guidelines, such as those of ASHRAE and ASTM.

Commercial Buildings

Budget: FY98-$5.0M, FY99-$5.2M, FY00-$8.0M

Description, Objectives, and Performers. DOE's commercial building research focuses on integrating technologies and practices to optimize whole building energy performance both during renovation and new construction. The objective of the research is to lower energy use by 25 percent or more, relative to conventional approaches, while increasing occupant comfort and productivity. DOE funds joint research with an industry consortium on integrated buildings designs and systems that are adaptable to changes in building use. Partners include National Laboratories and a consortia of universities, industry, and government organizations.

R&D Challenges. The R&D challenges are developing commercial whole building approaches for both new and existing buildings that are simple to integrate and that integrate simply with other building systems. They must be economically and ecologically sustainable, be acceptable to their community, and must easily adapt to a rapidly changing workplace. Addressing these challenges will in part require design tools and techniques which are robust, user-friendly, and accurately portray interactions between system components. These tools and techniques must be adaptable and transferable across design, construction, and operation stages of the building life-cycle.

R&D Activities. The Department's research on commercial building design and operation focuses on two areas: design strategies and energy performance tools that enable architects to optimize building performance at the point of design; and advanced building controls and diagnostics to optimize building operation once the building is occupied. Both approaches actively encourage the use of a "systems engineering" approach to the design and operation of commercial buildings, and thus the benefits are large, and cost-effective. Current Department research activities include development of software that incorporates consideration of passive solar options into small commercial buildings designs; new performance simulation software to replace DOE-2 ("EnergyPlus"); and the Whole Building Diagnostician, a hardware/software system to monitor real-time building performance. These tools and new technologies are field tested with the building industry in the context of real building projects via DOE's Commercial Exemplary Buildings Project. Measured energy cost savings of from 42 percent to 63 percent have been cost effectively achieved with no compromise of functionality or comfort.

In 1998, the Department joined with industry partners in developing a vision and a roadmap for commercial buildings design and operation research for the future. This effort will help define the next generation of research with implementation beginning in FY 2000.

Accomplishments. A success in this area is "DOE-2," a widely used performance simulation tool that calculates energy use and cost from weather, building attributes, and other data. Approximately 15 percent of new commercial floorspace is designed with DOE-2 for cumulative energy savings to date of approximately $21.4 billion.

Residential Buildings

Budget: FY98-$6.8M, FY99-$7.8M, FY00-$8.5M

Description, Objectives, and Performers. DOE's residential systems research program focuses on accelerating the development of innovative residential energy systems by conducting full scale experiments on new residential buildings and manufactured homes. This industry consists of over 100,000 builders, and tens of thousands of component manufacturers. There is little integration or coordination of energy components in systems, and the industry is quite risk-averse in that it is very slow to adopt new technologies and embrace change. Through the Building America program, DOE facilitates integration of research and application in residential new construction. Experiments are conducted using an iterative design, test, redesign, retest sequence to ensure that technical barriers are fully identified and resolved during the research process.

The Building America program has established a unique arrangement with four consortia of private-sector firms in the residential building industry to carry out its research agenda. Each consortia is made up of a team of architects, engineers, builders, equipment manufacturers, material suppliers, community planners, mortgage lenders, and contractors, including more than 80 companies total. These four industry teams have committed $30 million over the next 3 years to implement full-scale systems engineering housing technology innovations. All projects are cost-shared between DOE and the Building America teams.

R&D Challenges. The challenges involve reducing the energy consumption of new residential buildings by 25 to 50 percent with little or no increase in construction costs. Achieving this will require development of building techniques that are quick and easy to implement, reliable, widely deployable, and inexpensive. One of the greatest barriers to implementation is overcoming worker reluctance to abandoning traditional building practices, thus new innovations must bear all of these qualities to be successful.

R&D Activities. DOE will test and evaluate alternative design and construction strategies. This includes analysis of alternative wall insulation designs on productivity in factory-built housing, air sealing strategies for modular housing, and development and testing of sheathing-integrated moisture and air barrier systems. Other activities include development of new low thermal loss duct designs, super-insulated ceiling systems, and AC control strategies for hot humid climates to maximize moisture removal during low load conditions. DOE develops and tests passive solar designs and phase-change materials. DOE develops computer simulation software and hardware to effectively monitor residential building energy performance. As part of this program, DOE has many partners including major builders, materials and equipment manufacturers, universities, research institutes, and industrialized home manufacturers. These partners contribute to research both through cost-sharing, research in-kind, or by sharing facilities.

Accomplishments. DOE worked with a manufacturer to design the first manufactured house to meet ENERGY STAR performance criteria and developed strategies to achieve 30-50 percent reductions in heating, cooling, and hot water energy use, the results of which, have been incorporated into new products by Carrier Corporation, USG Corporation, General Electric Company, Owens Corning, Tamarack Technologies, Inc., Ryan Homes, Pulte Homes, Beazer Homes, and others. To date, a total of 972 houses have been completed in Building America projects. Additional community-scale projects have been initiated in Denver, CO, Los Angeles, CA, Pittsburgh, PA, and Tucson, AZ.

Lighting and Appliances

Budget: FY98-$8.1M, FY99-$9.6M, FY00-$15.2M

Background

In 1996, lighting in U.S. residential and commercial buildings used about 4.8 quadrillion Btu of primary energy, or about 14 percent of all energy used in buildings, at a consumer cost of $34 billion. In commercial buildings, lighting service demand represents one-fourth of total energy demand. Conventional lighting technologies still predominate throughout the economy—incandescent and standard fluorescent lamps account for almost two-thirds of the energy used to light buildings in the United States. Significant room for efficiency improvement exists. As artificial lighting is exclusively an electric technology, any savings achieved at the point of end use is tripled at the utility generation plant, bringing with it concomitant carbon reductions and other associated benefits.

Appliance technology comprises major building energy-consuming equipment other than that for space-conditioning and lighting. Appliances provide a variety of energy services, including water heating, food preparation and storage, clothes washing and drying, dish washing, and other services ranging from entertainment to security. Many smaller appliances present a difficult target for improved energy efficiency because of their low individual energy use and low frequency of use. The best candidates for efficiency improvements are those that involve transport, compression, heating or cooling of fluids (e.g., refrigeration, water heating), or involve significant use of transformers or electric motors. In some cases, process substitution (e.g., microwave drying in place of thermal drying) may offer additional alternatives for energy savings.

Water heating is the third largest end use for buildings in terms of magnitude, consuming about 3.9 quadrillion Btu in 1996 (11.3 percent of total buildings energy use), at a consumer cost of $25.9 billion. Refrigeration/freezers are also large energy users, about 2.2 quadrillion Btu in 1996 (6.4 percent of total buildings energy use) at a cost of $16.3 billion.

Linkage to CNES Goals and Objectives

This program directly supports CNES goal and objective:

- CNES Goal I, Objective 2 - Significantly increase energy efficiency in the transportation, industrial, and buildings sectors by 2010. *(reduce the first-cost of energy efficient light sources, develop new and innovative light sources and delivery systems, integrate natural light into lighting systems, and measure and assess the impact of alternative lighting regimes on worker health, safety, and productivity; increase energy efficiency of major energy consuming appliances, integrate appliances to capture and reuse waste heat, and develop appliances which use renewable energy sources rather than fossil fuels)*

Program Description

Electric lighting improvements underway include new and more efficient light sources, fixtures, light distribution systems, and improved ways of utilizing lighting based on the effects of lighting on vision and workplace productivity. Improved daylighting systems allow daylight to be used in buildings to offset electric lighting needs while achieving improved heating, cooling, comfort, and health performance. In 1998, the Department joined with industry partners in developing a roadmap for lighting research for the future. This effort will help define the next generation of research with implementation beginning in FY 2000.

Improved technologies underway include heat pump water heaters, improved insulations for refrigerators, and "integrated" appliances where, for example, waste heat from one serves as a heat source for another.

Lighting

Budget: FY98-$2.4M, FY99-$3.1M, FY00-$4.5M

Description, Objectives, and Performers. Lighting is responsible for 15 percent of energy use in buildings. Lighting systems include sources, fixtures and distribution systems, and controls. Artificial light sources include incandescent, fluorescent and High Intensity Discharge lamps (the “bulb”), while fixtures, by use of reflectors and diffusers, distribute the light. Lighting distribution systems can also include more advanced concepts, such as fiber optics, for distributing light from natural or artificial sources. Controls include occupancy detectors for automatically turning off light fixtures, discrete digital timer controls, and centralized computer controls. Lighting quality is also an area of intense interest, affecting worker productivity, comfort, and even health and safety. DOE’s program is intended to help cut the energy used by lighting in half over the next 15 years. The Lighting program partners with numerous manufacturers, utilities, universities, and users in carrying out its research agenda. The program is 75 percent funded by industry.

R&D Challenges. The R&D challenges include optimizing component performance, size, and manufacturing processes to achieve cost-effective substitutes for conventional technology.

R&D Activities. Research includes a cost-shared effort with industry to develop a low-cost compact fluorescent lamp (CFL). This involves optimizing the power supply circuit, electrodes, phosphors, and ballast for performance and low-cost manufacture. DOE is also researching a new light source, the low-power sulfur lamp, which involves scaling down current technology to develop a smaller bulb as well as a solid-state source for microwave production. Fixture research is focused on efficient light distribution from non-linear sources (such as fluorescent), by redesigning fixtures traditionally used for (incandescent) point sources. DOE is developing expert controls systems to manage and control lighting subsystems. In addition, DOE is researching distribution systems for natural and artificial high-intensity, light sources. Finally, DOE conducts experiments and field tests that include testing high intensity outdoor lamps of different spectrums to produce a better quality light that improves vision while allowing lamps to be operated with less energy.

Accomplishments. Research on energy-efficient electronic ballasts in the late 1970s resulted in a product that captured 31 percent of sales, with up to 30 percent reduced energy use and cumulative energy savings worth $3.7 billion over the life of the technology.

Refrigeration

Budget: FY98-$3.1M, FY99-$2.9M, FY00-$3.1M

Description, Objectives, and Performers. Refrigeration includes both residential refrigerators/freezers, and commercial refrigeration uses such as in supermarkets. It encompasses not only component efficiencies, but also replacements for ozone-depleting substances used as working fluids. The objectives of the DOE activity are to eliminate all use of ozone-depleting chemicals while simultaneously increasing the operating efficiency of refrigeration equipment. BTS also works with four manufacturers and the National Institutes for Science and Technology in this research program. Cost-sharing in this area is essentially 1:1 in matching funds.

R&D Challenges. The R&D challenges are to reduce the costs and ensure compatibility of alternative working fluids and equipment designs so that they are economically competitive with conventional technology for widespread application.

R&D Activities. For new refrigerants, DOE is completing the successful seven-year, industry-led, jointly-funded program of materials compatibility and lubricants research. This program has paved the way for a new generation of chlorine-free refrigerants to replace refrigerants which deplete the ozone layer. DOE is completing laboratory development through a CRADA for a pre-production refrigerator/freezer using 50 percent less energy than current designs, and will be demonstrating supermarket refrigeration/HVAC energy savings in field tests of new systems with industry partners.

Accomplishments. A “fridge of the future” that uses half as much energy as today’s refrigerator-freezers and a fifth as much as 1972 models was designed and demonstrated at a DOE National Laboratory during 1997. This reduction in energy use (from 2 to 1 kWh per day) exceeds the decrease called for in a 1997 rule, which requires refrigerators sold in 2001 to use 30 percent less electricity than those on the market today.

Heat Pump Water Heater and Appliances

Budget: FY98-$0.0M, FY99-$0.0M, FY00-$2.1M

Description, Objectives, and Performers. Appliances and hot water account for nearly one-fourth of energy use in buildings. Of this, hot water accounts for about half. Current research is focused on the heat pump water heater (HPWH) which offers performance improvements 2-3 times that of conventional electric resistance water heating.

R&D Challenges. The challenge is to reduce the cost of equipment and installation through design improvements.

R&D Activities. Residential HPWH have the potential to cut electric water heating bills in half. Research is underway to develop and begin field testing of innovative heat pump water heater concepts that have much lower cost and are easier to install than conventional technology. DOE will be developing and testing “drop-in” HPWH designs in conjunction with major manufacturers. In FY 2000, the appliance research effort will focus on development of prototypes of high efficiency laundry equipment.

Accomplishments. Accomplishments include performance testing and evaluation of energy and water savings of H-Axis washing machines.

Solar Water Heating

Budget: FY98-$2.6M, FY99-$3.6M, FY00-$5.5M

Description, Objectives, and Performers. Solar heaters consist of a collection system that captures the sun's thermal energy, a distribution system, and a control system to regulate these functions. Some types of systems also include an energy storage system.

R&D Challenges. The challenges are to increase the durability and effectiveness of components while decreasing the component costs.

R&D Activities. Research efforts are focused on exploring the use of new materials (polymers) and components (heat pipes) to create the next generation system. The goal, by 2004, is to reduce system costs for solar water heating from $0.08/kWh to $0.04/kWh and for pre-heating of building ventilation air from $0.02/kWh to $0.005/kWh .

Accomplishments. Solar hot water systems research has resulted in a total reduction in cost from $0.20/kWh in 1980 to the current $0.08/kWh. A recent accomplishment is the development of a selective absorbing coating for solar collectors, *Black Crystal*, that has the potential to replace the industry standard material, black chrome. The transpired solar collector for pre-heating ventilation air won an R&D 100 Award and reduced costs to $0.02/kWh.

On-Site Generation

Budget: FY98-$1.0M, FY99-$1.8M, FY00-$5.5M

Background

Generating electric power at individual building sites versus at remotely-located central power plants offers a number of potential benefits to the Nation. First, on-site generation avoids many of the disadvantages associated with transmission and distribution—costly infrastructure and permitting, health and aesthetic externalities, and energy loss. Second, because distributed generation often takes place in close proximity to other thermal loads, such as space conditioning and water heating, the “waste” heat that is rejected from the generation process can be used by these other applications, i.e., cogeneration. This leads to very high system efficiencies, on the order of 80-90 percent (i.e., the electric and thermal output divided by the fuel input). These high efficiencies translate, in turn, into reduced emissions relative to conventional central station fossil generation.

Linkage to CNES Goals and Objectives

This program directly supports CNES goal and objective:

- CNES Goal I, Objective 2 - Significantly increase energy efficiency in the transportation, industrial, and buildings sectors by 2010. *(reduce overall energy consumption by eliminating line loss caused by electricity transmission, increase the use of natural gas as* *generation source for electricity, and increase opportunities for cogeneration of electricity and heat for building space conditioning)*

Program Description

On-site power plants can range in size from a few watts to several hundred kilowatts. Potential "distributed" generation technologies include fuel cells, photovoltaics, micro turbines, and reciprocating, and rotary engines. The Department's buildings research in this area is currently focused on fuel cells.

Fuel Cells

Budget: FY98-$1.0M, FY99-$1.8M, FY00-$5.5M

Description, Objectives, and Performers. Fuel cells are similar to batteries in that they produce electricity through electrochemical reactions. A battery depletes itself or must be recharged, but a fuel cell produces power continuously when supplied with an appropriate fuel and oxidant. A fuel cell consists of positive and negative electrodes immersed in an electrolyte. A hydrogen-bearing fuel is supplied to the anode along with oxygen, usually derived from air, to the cathode. During operation, the fuel is oxidized and the resulting chemical reaction produces direct current electricity. Waste heat from the reaction is available for recovery for thermal applications, from water heating to space conditioning, and in applications where all available heat is recovered, fuel cell system efficiencies—cogeneration—can exceed 85 percent. The objective is to develop the components and systems necessary to bring fuel cells to building applications. The BTS program works with five manufacturers and Argonne National Laboratory in carrying out its research agenda, with a cost-share of 40 percent.

R&D Challenges. The research challenges are fuel cell cost, longevity of components, and compatibility with various sources of hydrogen.

R&D Activities. The Department's research in buildings-applicable fuel cells, initiated in FY 1995, draws to the extent feasible on research in transportation and military applications, but focuses on the unique needs of buildings, that include lower noise levels, increased power densities, and durability in the 40,000 hour range (versus 3,000 for an automotive fuel cell). The Department's research is focusing on fabrication and testing of the prototype methane reformer and its incorporation into a Proton Exchange Membrane fuel cell. The Department's near-term R&D goal is to develop a first-generation prototype Proton Exchange Membrane fuel cell by FY 2002, and to demonstrate its performance in a commercial building.

Accomplishments. This is a new program so there are no accomplishment to date.

Summary Budget Table (000$)

Efficient and Affordable Buildings Research Areas	FY 1998 Appropriated	FY 1999 Appropriated	FY 2000 Request
Heating, Cooling, and Air Conditioning	**14,650**	**15,390**	**11,000**
Geothermal Heat Pumps	6,400	6,500	0
Absorption Technologies	5,400	5,910	6,500
Desiccants	2,350	2,480	4,500
Furnaces and Boilers	500	500	0
Building Materials and Envelope	**7,187**	**10,723**	**10,400**
Windows and Glazings	4,959	6,829	6,610
Walls, Roofs, and Foundations	2,228	3,894	3,790
Building Design and Operation	**11,811**	**12,970**	**16,500**
Commercial Buildings	5,000	5,200	8,000
Residential Buildings	6,811	7,770	8,500
Lighting and Appliances	**8,115**	**9,560**	**15,230**
Lighting	2,350	3,100	4,500
Refrigeration	3,140	2,860	3,130
Heat Pump Water Heater and Appliances	0	0	2,100
Solar Water Heating	2,625	3,600	5,500
On-site Generation	**1,000**	**1,750**	**5,500**
Fuel Cells	1,000	1,750	5,500
Total	**42,763**	**50,393**	**58,630**