ENERGY CONSERVATION

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Informal Report

ANALYSIS AND TECHNOLOGY TRANSFER REPORT

1989 AND 1990

BUILDING TECHNOLOGIES

August 1991

Prepared for the
OFFICE OF BUILDING TECHNOLOGIES
OFFICE OF CONSERVATION AND RENEWABLE ENERGY
U.S. DEPARTMENT OF ENERGY
Under Contract No. DE-AC02-76CH00016

BROOKHAVEN NATIONAL LABORATORY
Upton, New York 11973

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PREFACE

The U.S. Department of Energy (DOE) Office of Building Technologies (OBT) encourages increased efficiency of energy use in the buildings sector through the conduct of a comprehensive research program, the transfer of research results to industry, and the implementation of DOE's statutory responsibilities in the buildings area. The planning and direction of these activities require the development and maintenance of database and modeling capability, as well as the conduct of analyses.

This report summarizes the results of analytical and technology transfer activities undertaken on behalf of OBT during 1989 and 1990. It provides historical data on energy consumption patterns, prices, and building characteristics used in OBT's planning processes, and summaries of selected recent OBT analyses and technology transfer activities.

EXECUTIVE SUMMARY

The buildings sector used 29.6 quadrillion Btus (quads) of energy in 1989, or 36 percent of the total primary energy consumed in the United States. The major uses are for space heating and cooling, water heating, refrigeration, and lighting. Electricity is the dominant fuel, followed by natural gas, petroleum, and other fuels.

Although there were dramatic improvements in energy efficiency in this sector from 1975 to 1985, in recent years energy use has grown rapidly. The large growth expected in commercial building floor space and in residential units means that total building-sector energy consumption could increase dramatically by the year 2030.

The mission of the U.S. Department of Energy's (DOE's) Office of Building Technologies (OBT) is to lead a national program supporting private sector efforts to improve the energy efficiency of the nation's buildings and to increase their utilization of renewable energy sources. The Office is also responsible for energy efficiency planning and management for Federal buildings as well as buildings-related associated information, financial incentives, and regulatory functions that are determined to be appropriate for the Federal government.

To accomplish its goals, OBT plans and conducts research and development to make technologies available and provides information on their effectiveness. The selection and management of OBT research activities requires an understanding of where and how energy is used within the buildings sectors, how energy use is expected to change in the future, and the potential impact of new and emerging technologies on energy use. Analysis activities serve to collect energy use information, provide the analysis necessary to apply this information to research and development planning, and develop analysis tools which the program uses to set priorities for research projects.

Office-wide technology transfer activities provide general oversight and coordination for the transfer of OBT research results to the public and private sectors. These activities support individual program efforts.

This report summarizes analysis and technology transfer activities undertaken by OBT during 1989 and 1990.

PLANNING ENERGY CONSERVATION R&D FOR BUILDINGS

National Energy Strategy

In 1989 President Bush directed the Secretary of Energy to begin the development of a National Energy Strategy (NES). Analysis activities within OBT were dominated by NES development through most of FY 1989 and in FY 1990.

Concurrent with public hearings, background information was being prepared within DOE. OBT was responsible for preparing sectoral profile documents for both the residential and commercial sectors - two of fourteen such documents. These documents provided information on determinants, trends and potential for energy use in the buildings sectors. They were used as background for the residential and commercial chapters in the April 1990 *Interim Report*, which summarizes public concerns, publicly identified goals, publicly identified obstacles to achieving those goals, and publicly suggested options for action to remove or overcome the obstacles.

More recent NES activities within OBT have focussed on defining and analyzing buildings-related policy options for consideration by the President, and in preparing sections on residential and commercial energy use for the final NES document.

Program Planning

Systematic research planning is a key aspect of managing the Office of Building Technology's R&D. Program planning is designed to ensure that DOE identifies and invests in those areas of research most likely to produce energy savings in the buildings sector. Planning is also designed to ensure that Federal research dollars are utilized in a cost-effective manner.

An annual evaluation of OBT's R&D program helps to ensure that it is meeting the changing needs of the nation, the buildings industries, and consumers. The program is modified as needed to account for changes in public priorities and new information gained from the conduct of R&D. A quantitative evaluation methodology is used to help establish program priorities.

Long Range Planning - Phase 2

In FY 1988 the first phase of a strategic planning effort was completed. Phase I identified a set of key strategic planning issues and alternatives. In FY 1989 a methodology for program evaluation, consolidation, and redirection was developed.

The methodology proposes two primary activities: core program consolidation, and development of new areas of program focus. The purpose of the program consolidation effort is to identify areas in which progress has been sufficient (or where opportunities for future advances or their value are limited) to justify a shift from R&D to information dissemination.

The second part of the program evaluation activity is to identify new and exciting areas of program focus where the potential payoff of R&D is significant. Special emphasis will be given to areas identified in the development of the NES.

Although OBT has already successfully transferred some technology, OBT management decided that planning was needed to explore ways to increase the Office's effectiveness in this area. In FY 1989 and 1990, OBT conducted an interlaboratory technology transfer planning effort to develop a framework for improving its Office-wide technology transfer activities.

An *ad hoc* Technology Transfer Advisory Group recommended that OBT use the framework as a heuristic device in planning its technology transfer activities. This framework can be used (1) to discern the specific structural audiences that will reach functional audiences and (2) to exhibit a way that already-funded and proposed activities can be evaluated against target audiences and technology transfer functions to test the program's balance.

FOCUS ON THE ENVIRONMENT

Several environmental issues which are directly related to buildings energy use are currently capturing the nation's attention. As environmental concerns become more important, OBT examines its research program and priorities to ensure that these concerns are adequately addressed in the buildings sector.

Buildings Share of Fossil Fuel Emissions

By disaggregating the electricity component of energy use in buildings, a "generic" quad of buildings energy use can be defined. Results show that for each quad of energy used in buildings in 1987, 35 percent is supplied by coal, 30.8 percent by natural gas, 12 percent by oil, 7 percent by hydropower, 11.3 percent by nuclear, and 4 percent by renewables.

Significant emissions of carbon dioxide (CO_2), sulfur dioxide (SO_2), and nitrogen oxide (NO_x) from the burning of fossil fuels are associated with this energy use. These by-products are important because CO_2 has been identified as the major contributor to global climate change, and SO_2 and NO_x have been identified as the major precursors of acidic deposition. In addition, the buildings sector is responsible for its share of radioactive spent fuel generation.

Calculations of the quantities of these by-products associated with a quad of energy used in buildings show that each quad used accounts for 1.3 percent of total U.S. emissions of carbon (in the form of CO_2), 1.5 percent of SO_2 emissions, and 0.7 percent of NO_x emissions. The estimates for SO_2 and NO_x emissions account only for coal consumed at utilities and thus are low estimates of the total building sector contribution.

Total buildings sector energy consumption (27 quads in 1987) thus contributes slightly more than one-third of all U.S. CO_2 emissions, nearly 40 percent of SO_2 emissions, and about 20 percent of NO_x emissions. Most of these estimates are from coal; virtually all coal usage attributable to the buildings sector is due to its use in electricity generation. Improving the efficiency of electricity use in buildings thus becomes a critical component in reducing the levels of these emissions.

Several of OBT's research programs focus on electricity-using equipment. The objective for the advanced refrigeration systems program is to discover ways to improve the energy efficiency of electrically-driven residential appliances and commercial equipment used for space heating, cooling, hot water, and refrigeration applications. The objective of the lighting equipment research program is to provide the technology base necessary to achieve a 50 percent reduction in lighting energy use in buildings by the year 2000.

Chlorofluorocarbons (CFCs)

CFCs are another important pollutant released by buildings sector energy use. CFCs are used to provide wall, roof, and foundation insulation in buildings. Insulation produced using CFCs is also used to fill the wall cavities of home refrigerators and freezers and CFCs are used as the working fluids in air conditioners, heat pumps, and refrigeration equipment. A rough estimate of buildings sector CFC use in 1986 is about 88,000 short tons, which is 25 percent of total U.S. usage of CFCs that are regulated by the Montreal Protocol.

Some scientists and policymakers believe that emissions of certain gases have the potential to change the earth's climate dramatically by trapping heat in the atmosphere and producing a global greenhouse effect, and that measures are needed to reduce these emissions. The major greenhouse gases identified as responsible for this phenomenon are CO_2 (50-55 percent), CFCs (20-25 percent), and methane (20-30 percent). In addition to their heat trapping abilities, CFCs and halons may also pose a threat to the earth's natural shield of ozone which blocks a portion of the sun's ultraviolet radiation.

OBT's R&D program includes efforts to develop rigid foam insulations that are manufactured with alternative non-ozone-depleting agents. In addition, OBT has expanded its program to accelerate the development and testing of alternative refrigerants to replace the CFCs now being used.

DETERMINANTS OF ENERGY USE IN RESIDENTIAL AND COMMERCIAL BUILDINGS

Demographics

Most recent population growth has occurred in the Southern and Western regions of the country. This population shift contributes to decreasing energy use per household, because households in the South and West use less energy for space heating, and to the increasing use of electricity in both sectors due to greater demand for space cooling. Nationally, the number of persons per household has continuously declined, also contributing to a decrease in energy use per household.

In the commercial sector, primary energy consumption rose more rapidly than population from 1960 to 1989. While end-use energy has grown at a rate close to that of overall population growth, the faster growth of primary energy, which includes the inefficiencies associated with electricity production and transmission, is due to the accelerated use of electricity relative to other energy sources.

Economic Activity

In 1988 energy costs totaled $174.9 billion and accounted for approximately 3.6 percent of the GNP. In 1988 the value of construction in both the residential and commercial sectors (not including public utilities) accounted for 6.7 percent of the GNP. Buildings energy and construction costs together totaled 10.3 percent of the GNP.

Building Stock and Equipment

There are over 90 million households in the United States. About two-thirds of these households are single-family homes, just over one-quarter are multifamily homes, and the remaining are mobile homes. The number of households has grown at almost twice the rate of general population increase since 1960.

Most new homes use electricity or gas for space heating. The use of electricity has increased with the penetration of electric heat pumps. Central air conditioning was installed in 77 percent of single-family homes built in 1989, compared with 63 percent in 1980 and 34 percent in 1970. In 1987, nearly 20 percent of all U.S. households used electricity as a main heating fuel, compared to 16.8 percent in 1984. These statistics point to the increasing use of electricity in the residential sector when compared with the current housing stock.

In 1986 there were 4.2 million commercial buildings in the U.S. containing 58.2 billion square feet of floor space. Mercantile and service buildings are the largest segment of the population, with 31 percent of the number of buildings and 22 percent of the floorspace. Significantly more new buildings and floorspace are being located in the South.

Energy use varies considerably depending on building size and use, number of hours of operation, and number of workers. Healthcare buildings are the most energy intensive, followed by food sales and food service buildings. A cross-section of commercial buildings by age shows that average electricity intensity has increased from 12 kWh per square foot in buildings built before 1980 to 14 kWh per square foot in newer buildings. Both average and new building electricity intensities are higher in the South and West than in the Northeast and Midwest. Unless electricity intensity is reduced even further in new buildings or substantial conservation takes place in the existing stock, electricity use in commercial buildings is likely to continue to increase.

Codes and standards

Many types of regulation affect the cost and efficiency of buildings. These include building codes, energy codes, appliance or equipment standards, subdivision controls, zoning regulations, growth controls, environmental restrictions and financing regulations. Building and energy codes and appliance standards have the most direct effect on energy use, while financing regulations affect the tradeoff between higher first costs and lower operating costs.

Building codes can be cumbersome to maintain and enforce, and if they are too specific may have the effect of restricting the use of new technologies. Due to the plethora of codes and general lack of reciprocity agreements for inspections, the market for new technologies and construction techniques, in particular modular construction, is restricted.

Some form of energy code or standard for new construction exists in each of the fifty states. It is unclear what the actual effect of energy codes is on overall energy use. In some areas, new construction typically exceeds code requirements. In addition, effectiveness depends on how well a code is enforced and on the training and education of builders and local code officials. The major benefit of an energy code is that it establishes the minimum acceptable level of efficiency, that is, it eliminates the worst cases. Further improvements can then be accomplished by other means such as incentives.

Behavior

During times of increasing energy prices American consumers have substantially reduced energy use by making changes in behavior. These include turning thermostats down and using appliances more wisely. These changes are, however, easily reversible. Recent data suggest that this reversal is in fact occurring, both in the United States and in other countries; we seem to have reached a plateau of energy intensity or efficiency.

Construction Industry

No discussion of energy use in the buildings sectors is complete without including the role of the construction industry. Manufacturers of both materials and appliances control the availability of energy-efficient products. Builders and designers determine construction techniques and often decide what equipment will be used in a building.

The building sector has shown the slowest growth in productivity of any sector in the U.S. economy. The industry's highly fragmented nature has made it difficult to carry out efforts to improve productivity. Lack of investment in research and development may be partly responsible for this lack of growth in productivity. Diversity and fragmentation of the industry also affect the rate of adoption of new products and technologies.

While automation in the U.S. housing industry has increased (currently between 10 and 35 percent of single-family residences excluding mobile homes), it does not approach that of several other countries. Factory-built houses cost less and can be constructed faster than traditional site-built houses. They can be built with a higher degree of quality control and tighter construction tolerances. There is, however, little information or data on the net energy benefits of alternative construction methods such as panelization. A need exists for a systematic study of different construction methods, which would include foreign building practices that may be applicable to the U.S. industry.

HISTORICAL TRENDS: BUILDINGS RESPONSIBLE FOR A GROWING SHARE OF U.S. CONSUMPTION

Our society uses as much energy to provide comfort and services in buildings as it uses for industry, and more than it uses for transportation. The share of energy use in the buildings sector has grown from 32.7 percent in 1979 to 36.3 percent in 1989, while industrial use has declined by nearly 10 percent and transportation energy use has increased by 9 percent. In the commercial sector primary energy consumption increased by 21.2 percent while residential energy use increased by 9.4 percent in the same period. In 1989 the residential sector used 16.6 quads of primary energy and the commercial sector used 12.9 quads.

In the residential and commercial sectors, growth in primary energy consumption has resulted primarily from increased use of electricity. In the residential sector, electricity use (including losses) has grown from 46 percent of all energy consumed in 1973 to over 60 percent in 1989.

In the commercial sector, electricity use has grown from 54 percent in 1973 to over 69 percent in 1989. Peak electricity demand, in addition to total consumption, has become increasingly important as utilities try to delay investing in new generating capacity.

In the residential sector, space heating is the dominant end use, followed by water heating. Although space heating remains the dominant end use in the residential sector, its share is decreasing, while the amount of energy used for air conditioning and appliances is increasing. Current estimates for the commercial sector indicate that lighting is the dominant end use on a primary energy basis, followed by space heating and cooling.

PROJECTED BUILDINGS ENERGY USE

One important activity in developing the National Energy Strategy was detailed assessment of the conservation potential in the end-use sectors of the U.S. economy. First, an assessment was made of all available data on conservation potential. Second, the Energy Information Administration (EIA) used the conservation potential data to project two levels of technology penetration through 2030 and the resultant energy savings achieved by each. Third, these results were input to DOE's Fossil2 model in order to integrate them with other NES excursions.

Conclusions from the second activity, EIA's modeling efforts, include: (1) there is the technical potential for significant energy savings, particularly in the residential sector: (2) under the conservation assumptions, the mix of fuels remains similar to the reference case, except that natural gas used for space heating is saved in the residential sector; (3) space heating in both sectors is an important source of potential energy savings; and (4) lighting in the commercial sector is another source of potential energy savings.

DATA BASES AND ANALYSES

The Building Energy-Use Compilation and Analysis (BECA) data base compiles actual measured data on the economics and performance of implemented technologies, allowing us to evaluate their effectiveness. The single-family retrofit subset of BECA shows that shell measures typically result in savings on the order of ten to fifteen percent. Most HVAC measures that do not involve expensive equipment replacements result in savings of approximately five percent. Flame retention burners for oil furnaces are an exception; they result in larger savings, with a consistent five year payback. Ceiling insulation retrofits are the most cost-effective shell measure documented in the BECA data base; they also produce a consistent payback period of about five years.

In the commercial retrofit subset the typical building owner was willing to invest in energy conservation the equivalent of only about 8 months of energy costs. Changes to the HVAC system were the most popular retrofit strategy. Projects in which only maintenance practices were changed typically saved 12 percent of their pre-retrofit consumption. Very few predictions of savings came within 20 percent of measured results. Despite significant savings and short payback times for many projects, optimum savings are often not being achieved. This is due to limited owner willingness (or financial ability) to invest in all cost-effective measures, and to improper retrofit installation and/or maintenance.

INTERNATIONAL ENERGY STUDIES

Residential Energy Conservation Programs and Policies in OECD Countries

A study of national residential energy conservation policies and programs in five OECD (Organization for Economic Cooperation and Development) countries examined government programs designed to reduce energy (or oil) use in the residential sectors of each country, and analyzed which types of programs appeared to work well within the political context and structural changes taking place in each country.

Most of the problems associated with the use of each individual program tool can be avoided or alleviated by using a combination of tools aimed at achieving individual energy conservation goals. Response to information programs can be strengthened through the use of subsidies, just as participation in all programs can be maximized through effective information dissemination. Subsidy programs can be funded through revenue-generating programs, and subsidies can be used to influence consumer-investment decisions made in response to rising energy costs. Minimum efficiency standards for the energy-consuming end-use devices that consumers buy can be achieved through the use of regulation. And the acceptance of regulations can be enhanced through RD&D programs. Continued RD&D and the adoption of known efficiency measures can be encouraged through subsidies. And subsidized RD&D programs can be used to enhance relationships between public and private institutions. In short, the most effective residential energy conservation programs are designed using a variety of tools synergistically.

The last but far from least important aspect of successful residential energy conservation programs is program evaluation. Comprehensive evaluations require a considerable amount of data collection before, during, and after the program being analyzed is implemented. This requires considerable advance planning. It is essential, therefore, that consideration of the requirements for providing useful evaluations becomes part of the program design process.

Residential Energy Use in OECD Countries

One goal of International Energy Studies has been to quantify energy saved by households in major OECD countries, both to set the overall context in which energy conservation programs and policies operate and to understand implications of changes in household energy use for the future. While it is difficult to measure the amount of conservation caused by individual programs, it is possible to compare the total change in energy demand caused by changes in the components of demand (e.g., number and size of homes and households, characteristics of homes and equipment) with changes expected from major energy conservation programs.

In the United States, conservation in space heating and electricity used for appliances saved almost 26 percent of 1987 household consumption. In Japan, the savings amounted to approximately 10 percent of 1987 consumption. Finally, in the European countries, the savings reached 16 percent of 1987 consumption. This is true even though the actual energy use in 1987 was higher than in 1972. The disaggregated approach used in this study measured a significant amount of energy savings that are hidden with aggregate measures of energy savings. Only by disaggregating household energy demand into its structural and intensity components and analyzing the forces driving each component can we measure the impact of energy conservation on total household energy demand.

It is nonetheless difficult to measure the actual impact of energy conservation policies. The observed changes in consumption were far greater than what could have been expected from the limited number of policy measures implemented, and the observed changes often occurred before policies were even put in place. The best estimate is that, through 1987, policies were responsible for 25 to 33 percent of household energy savings in the study countries. This does not mean that policies were either ineffective or inefficient, only that other forces caused more change than did policies.

Residential Energy Use and Conservation in Venezuela

Work continued in 1989 and 1990 on a study of residential energy use in Venezuela. The extremely low energy prices in Venezuela (among the lowest in the world) are a major obstacle to implementing policy options for increasing the market penetration of natural gas and for improving the efficiency of appliances. A program of rebates might be necessary to encourage successful diffusion of efficient energy-consuming devices in an environment of low energy prices.

The results of a survey in Caracas were compared with similar studies performed in nine other Latin American countries. Inefficient use of electricity in households is common for most countries in the region. However, important structural and cultural differences between countries, regions, social groups - as well as between urban and rural areas - lead to the conclusion that no common set of efficiency measures can be applied to the whole region.

CONSUMER DECISION RESEARCH

The research conducted by OBT is directed toward the development of improved energy-efficient technologies and building practices. For these research products to have an impact on the efficiency of energy use, they must be successful in the marketplace. While it is impossible to know in advance if a new technology or practice will achieve significant market penetration, an understanding of the factors which are likely to affect the actual success of the improved technologies is valuable in selecting a portfolio of R&D activities.

Consumer decision research is sponsored by OBT to improve our understanding of the technology adoption process at all levels: marketing executive, plant manager, building owner and end user. This understanding aids in the design of the R&D portfolio by identifying projects that have high probabilities of market success. Consumer decision research can also assist in improving the market penetration of energy-efficient technologies.

Factors Influencing the Use of Commercial Daylighting

Numerous studies show that lighting is the largest energy use in commercial buildings. Reductions in energy consumption by lighting are achievable with daylighting; some estimates of load reduction run as high as 50 percent. Not only can daylighting reduce the total energy used, it can cause the greatest reduction to occur during peak mid-day periods when it is most needed.

During 1989 a national survey of over 300 commercial design architects was conducted to develop baseline information on their knowledge, perceptions, and use of daylighting in commercial building designs. In 1990 a seminar was held to determine the educational needs of architects that do not currently incorporate daylighting into their building designs.

Concerns expressed in the survey indicate that architects are not convinced of the cost-effectiveness of daylighting in commercial buildings. Architects listed several problems associated with daylighting designs. The most frequently mentioned problems were related to lighting controls and heat gains. Other, less frequently mentioned problems included glare or light intensity, availability of sufficient lighting during cloudy days, heat loss, and design difficulties.

APPLIANCE AND BUILDING ENERGY STANDARDS

Appliance Standards

The Energy Policy and Conservation Act, as amended by the National Energy Conservation Policy Act, by the National Appliance Energy conservation Act of 1987, and by the National Appliance Energy Conservation Amendments of 1988, provides energy conservation standards for 14 types of consumer products.

Cumulative primary energy savings from 1990 to 2015 due to standards enacted as of December 1990 are projected to be 21 quads. Large energy savings (2.5 quads) are projected for refrigerators, followed by water heaters and central air conditioners. Peak power requirements are expected to be significantly reduced due to refrigerator/freezer standards alone.

Cumulative net consumer savings over the period 1990 to 2015 are projected to be $44 billion (1987 dollars). Annual air pollutant emissions in 2015 are projected to be reduced by 1.5 to 2.0 percent because of the appliance standards. Cumulative reductions of 345 million tons of CO_2, 2.8 million tons of NO_2, and 4.3 million tons of SO_2 are projected from 1990 to 2015.

Federal Building Energy Standards

An interim standard for the design of Federal residential buildings was published in August 1988. Military housing, which represents most of the residential buildings procured by the federal government, will benefit most from this standard. A demonstration project has been undertaken to assess the impact of the standard. Economic analyses have estimated that use of the standard will save $27 million over a five-year period.

DOE published interim energy standards for the design of new commercial and multifamily buildings in January 1989. They became mandatory for all federal agencies in July 1989; they serve as voluntary guidelines for the private sector. Energy savings from using the standards are estimated to be 18 to 25 percent, depending on building type and climate.

TECHNOLOGY TRANSFER

The OBT technology transfer program seeks to enhance the technology adoption process by developing and implementing a system to transfer R&D results quickly, efficiently, and effectively to private- and public-sector users. The program supports technology transfer activities that will have a long-term, positive impact on the design, construction, and maintenance of energy-efficient buildings and community systems. The focus is on promoting familiarity and confidence in OBT products.

To supplement the technology transfer activities of OBT program managers, the program funds technology transfer projects that (1) are crosscutting in nature, (2) benefit from standardized formatting, or (3) have significant economies of scale. Projects generally fall into the following categories:

- needs assessments to determine future technology transfer directions,
- university education and practitioner training,
- preparation of research and progress reports on OBT R&D efforts,
- development and dissemination of design and decision tools,
- technical exchange, including conferences and workshops,
- support to program managers, and
- evaluation and tracking of technology transfer activities.

INTEGRATED RESOURCE PLANNING

Integrated resource planning (IRP) is a process that explicitly examines all possible means of meeting utility customer service demand. It allows for the comparison of traditional supply options with non-traditional supply as well as demand-side measures in order to satisfy projected demand at the lowest cost.

The Federal program in Integrated Resource Planning began in 1986 and has been developed in close cooperation with utilities, regulators, and other interested parties. The Federal role has been that of a catalyst, and the program has focused on information development and sharing. Responding to the needs of both utilities and regulators, DOE assists in methodology development, program evaluations and technology assessments, and sponsors conferences and publications.

Demand-Side Management and Buildings Energy Use

More than 500 utilities have implemented demand-side management (DSM) programs and current expenditures on electric utility DSM programs are more than $1 billion per year. Utility programs focus primarily on buildings: recent surveys by EPRI show more than 1000 residential programs and 400 commercial and industrial programs. Most industrial programs have focused on lighting, HVAC and motor improvements, with little attention to process improvements. It is likely that utility involvement in conservation programs will increase dramatically as the regulatory environment changes to provide incentives to utilities for achieving savings.

If utility programs are to capture a significant part of the potential for efficiency improvements, better performance and cost data on new technologies will be needed. Estimates of DSM potential generally include only technologies that are currently or nearly commercialized. For the future, a new set of technologies will be required. These needs, especially the need for reliable data, must be incorporated early in the OBT program planning process.

Energy use in the buildings sector will be significantly affected as demand-side management programs become more widespread. Technologies developed by DOE's Office of Building Technologies are particularly applicable for utility implementation, and interaction with utilities presents a significant opportunity for increased OBT technology transfer activities. Understanding the relationship between utility DSM programs and trends in electricity (and gas) use in buildings is critical to planning the research and development program for improving energy efficiency in buildings.

1. INTRODUCTION

The buildings sector used 29.6 quadrillion Btus (quads) of energy in 1989, or 36 percent of the total primary energy consumed in the United States. The major uses are for space heating and cooling, water heating, refrigeration, and lighting. Electricity is the dominant fuel, followed by natural gas, petroleum, and other fuels.

Although there were dramatic improvements in energy efficiency in this sector from 1975 to 1985, in recent years energy use has grown rapidly. The large growth expected in commercial building floor space and in residential units means that total building-sector energy consumption could increase dramatically by the year 2030.

The energy efficiency of a building begins with the design - the orientation, number and location of windows, choice of materials and amount of insulation, for example, all affect how much energy the building will use over its lifetime of 50 or 60 years. Further, the selection of equipment to provide heating, cooling and hot water are important. The quality of construction determines how well the building meets its design specifications. Finally, the operation of the building, that is, equipment maintenance, the thermostat setting, and other human decisions, also influence the energy use of a building.

New technologies, including advanced windows, highly efficient heating and cooling equipment, and improved lighting equipment could result in new buildings that use 80 percent less energy than the present buildings stock. Similarly, retrofit technologies could significantly reduce energy use in existing buildings. In many cases, currently available energy-efficient and cost-effective building equipment and practices have not been adopted because consumers, developers, architects, and other key members of the building community are either unaware of them or unwilling to make the required investments.

Energy productivity improvements in buildings offer the nation important benefits in terms of economic growth, increased national energy stability and security, a cleaner environment, and enhancement of the competitive position of U.S. industries in the world marketplace. Energy conservation gains contribute to economic growth by reducing consumer expenditures for energy (thus freeing these funds for other uses) and by affecting energy prices through demand reduction. Lower energy consumption frees capital from energy supply projects for other uses.

Lower consumption of electricity from fossil fuel-fired and nuclear power plants also leads to a reduction of associated pollutant emissions, such as carbon dioxide, sulfur dioxide, and radioactive wastes. National security is enhanced by decreased demand for imported petroleum products. The competitive position of U.S. industry in international markets can also be improved with more efficient energy use in the buildings sector and with domestically developed energy conservation technologies.

The mission of the U.S. Department of Energy's (DOE's) Office of Building Technologies (OBT) is to lead a national program supporting private sector efforts to improve the energy efficiency of the nation's buildings and to increase their utilization of renewable energy sources. The Office is also responsible for energy efficiency planning and management for Federal buildings as well as buildings-related associated information, financial incentives, and regulatory functions that are determined to be appropriate for the Federal government.

To accomplish its goals, OBT plans and conducts research and development to make technologies available and provides information on their effectiveness. OBT activities are structured to address building energy supply through increased use of solar technologies, building energy demand through efficiency improvement, and building sector infrastructure to implement and deploy building technologies into the private sector. The following section briefly describes the OBT program.

THE OBT PROGRAM

In the spring of 1990, the Office of Conservation and Renewable Energy within DOE was reorganized. The Office of Buildings and Community Systems (BCS) was replaced by OBT, accompanied by shifts in some program responsibilities. Within OBT, three offices now exist: the Office of Buildings Energy Research; the Office of Codes and Standards; and the Office of the Federal Energy Management Program.

Office of Buildings Energy Research

The Office of Buildings Energy Research manages the research activities which are expected to provide technologies to achieve OBT's goals for the building sector of an average reduction of 37 percent in energy consumption per square foot in residences and 30 percent per square foot in commercial buildings over the next 40 years. Because buildings have long lifetimes, the specific goals for new buildings are even higher.

Program emphasis is on those elements which are not only most energy intensive but also offer the best opportunity for improvement. For example, lighting is the largest end use of primary energy in commercial buildings, and it is also the most readily amenable to reduction in energy intensity, through the use of efficient technologies and daylighting. Space heating and cooling, major energy uses in residential as well as commercial buildings, are being made more efficient through improvements in the building envelope and in equipment.

The *Building Systems and Materials Division* addresses energy-efficient technologies related to the design and construction of new and existing buildings and the materials of which they are made. Research focuses on the building envelope and the indoor environment and how they interact in determining energy performance. It also promotes new methods for building design, construction, and evaluation.

Research activities in the *Building Equipment Division* focus on the equipment to provide heating, cooling, ventilation, lighting, hot water, and other services needed to operate a building efficiently and to offer its occupants a comfortable, safe environment. Both solar technologies and energy-efficient conventional technologies are under development. Current research includes efficient lighting systems, advanced refrigeration systems not dependent on ozone-depleting chlorofluorocarbons, solar-driven desiccant cooling systems, thermally activated heat pumps, improved combustion heating systems, and improved distribution of conditioned air through "smart building" technology.

Office of Codes and Standards

The Office of Codes and Standards formulates regulatory programs to implement the legislative requirements for appliances and buildings. The building energy performance and guidelines program recognizes that the building standards are voluntary for the private sector but mandatory for the Federal sector. Energy conservation standards are set on the basis of technical feasibility, economic justification, and their impact on energy savings.

The appliance standards program consists of test procedures and energy conservation standards. Under the appliance program DOE has established standard test procedures, which are used by the manufacturers of 13 types of energy-intensive residential appliances to provide energy efficiency and energy consumption information to consumers, including the appliance Energy Guide Labels required by the Federal Trade Commission for certain appliances.

Further detail about both the building and appliance standards programs is given in Chapter 4 of this report.

Office of Federal Energy Management

The Office of Federal Energy Management (FEMP) is responsible for energy conservation planning and management for the Federal government, which is itself a major consumer of energy. Specific program objectives are to reduce total energy use by the Federal government, increase energy efficiencies, and alter the fuel mix to increase use of renewable resources and reduce dependence on imported fuel. In implementing the program, the Office develops methods for life-cycle cost analysis, leads an interagency task force for energy management, and makes annual reports to the Congress on program activities.

FEMP was not part of OBT during 1989 and most of 1990, the years covered by this report; analysis and technology transfer activities related to FEMP are not included.

ROLE OF ANALYSIS AND TECHNOLOGY TRANSFER

The selection and management of OBT research activities requires an understanding of where and how energy is used within the buildings sectors, how energy use is expected to change in the future, and the potential impact of new and emerging technologies on energy use. Analysis activities serve to collect energy use information, provide the analysis necessary to apply this information to research and development planning, and develop analysis tools which the program uses to set priorities for research projects.

Office-wide technology transfer activities provide general oversight and coordination for the transfer of OBT research results to the public and private sectors. These activities support individual program efforts.

Prior to the reorganization, a staff section within BCS called Analysis and Technology Transfer (A&TT) coordinated these analysis and technology transfer efforts. This report describes the activities undertaken in 1989 and 1990 by A&TT, as well as summaries of other analytical work which is either used directly by A&TT or which complements A&TT efforts. It covers two years instead of one because emphasis given to National Energy Strategy development activities precluded preparation of the report last year.

Because this report focuses on 1989 and 1990, it includes areas which are no longer part of OBT, and does not include analysis activities related to new responsibilities of OBT. Thus, the Federal Energy Management Program (FEMP) is not included in this report. Likewise, the Integrated Resource Planning program (IRP), and its implications for energy use in buildings, is included in this report.

Planning the R&D program for buildings is a primary focus of analysis activities. The next chapter discusses annual program planning and longer-range strategic planning, the National Energy Strategy development process and it relationship to buildings' analysis activities, and other issues of importance to designing and managing the buildings R&D program.

Chapter 3 presents an overview of buildings energy use, a necessary foundation for planning R&D. A firm understanding of trends and determinants in energy use is essential in determining how to allocate scarce research dollars to achieve improved energy efficiency in buildings and to provide the technical foundation for the future. The chapter also includes forecasts of future energy use in buildings, developed during the NES process.

Chapter 4 presents summaries of other analysis activities relevant to understanding energy use and technology adoption in the buildings sectors. Included are OBT data base activities, studies of international energy use, and consumer decision research. Buildings and appliance standards programs, although not funded by A&TT, are also described.

Chapter 5 describes the office-level technology transfer activity, which supports individual program efforts. Technology transfer planning is included in Chapter 2.

Integrated Resource Planning (IRP) is a utility planning tool which fosters explicit comparisons between supply- and demand-side options for providing reliable service to customers at the least cost, including environmental and other social costs of alternatives. IRP is becoming increasingly important as the demand for electricity grows, existing plants age, and construction and siting of new facilities becomes more difficult. Chapter 6 briefly describes DOE's Integrated Resource Planning program, which began in 1986, and examines its implications for energy use in the buildings sectors.

In each section throughout the report a contact person is listed. Chapter 7 contains a list of references for each section. The Appendix contains the source data tables that were used throughout Chapter 3.

2. PLANNING ENERGY CONSERVATION R&D FOR BUILDINGS

NATIONAL ENERGY STRATEGY

On July 26, 1989 President Bush directed the Secretary of Energy to begin the development of a National Energy Strategy (NES). At the end of eighteen months a set of recommendations was submitted to the President.

The process began with 15 public hearings across the country, with testimony from more than 375 witnesses. In addition, more than 1,000 written submissions were received from State and local governments, consumer organizations, business, industry, and others. The goal of the public hearings was to open a dialogue with the public as a first step in building a national consensus. OBT participated in reviewing the public hearings and compiling summaries of the views expressed. Many concerns were expressed by the public, but overall "The loudest single message was to increase energy efficiency in every sector of energy use. Energy efficiency was seen as a way to reduce pollution, reduce dependence on imports, and reduce the cost of energy."

Concurrent with the public hearings, background information was being prepared within DOE. OBT was responsible for preparing sectoral profile documents for both the residential and commercial sectors - two of fourteen such documents. Preparation of the profiles involved considerable effort in responding to continually changing guidance and to comments from many reviewers both within and outside of DOE. These profile documents were developed from and expanded on the previous *Analysis and Technology Transfer Annual Report*; several sections of this report are based on the profiles.

The product of these activities was the publication in April 1990 of the *Interim Report*, which summarizes public concerns, publicly identified goals, publicly identified obstacles to achieving those goals, and publicly suggested options for action to remove or overcome the obstacles. OBT had initial responsibility for preparing the residential and commercial chapters of the *Interim Report*; the profile documents and the public hearing records provided the basis for the chapters. In addition, OBT has provided continual input and comments on the ongoing modeling efforts (and other document preparation) in support of the NES development process.

The third part of NES development within OBT has focussed on defining and analyzing buildings-related policy options for consideration by the President, and in preparing chapters on residential and commercial energy use for the final NES document. Options under consideration include:

- accelerated research, development, and demonstration of advanced technologies, including renewable energy technologies;
- expanded appliance and equipment labeling or standards, including labeling for commercial lighting system components;
- strengthened building energy efficiency standards;

- expanded use of mortgage financing incentives for residential energy efficiency, including the use of efficiency rating systems;
- improving low income home efficiency;
- establishment of a revolving fund for investments in Federal energy efficiency; and
- improving the energy efficiency of existing public housing, through the use of efficiency targets and incentives.

Analysis activities within OBT were dominated by National Energy Strategy development through most of FY 1989 and in FY 1990.

PROGRAM PLANNING

Contact: Jerome LaMontagne, BNL, (516) 282-2831

Systematic research planning is a key aspect of managing the Office of Building Techology's R&D. Program planning is designed to ensure that DOE identifies and invests in those areas of research most likely to produce energy savings in the buildings sector. Planning is also designed to ensure that Federal research dollars are utilized in a cost-effective manner. Program plans are keyed to three different planning horizons:

- near term - one year;
- medium term - five years; and
- long range - five to ten years.

At the beginning of each fiscal year, OBT develops an Annual Operating Plan (AOP) that covers research activities for that fiscal year. This document is a detailed plan for allocating approved funding to specific research and program management activities. The *Multi-Year Plan*, usually produced each year, is a medium-term plan that specifies program goals and identifies research activities five years into the future. A *Multi-Year Plan* was not prepared in FY 1989 or FY 1990 due to the priority given to National Energy Strategy development, although a draft plan was prepared in FY 1989.

OBT also periodically develops long-range or "strategic" program plans, which evaluate alternative courses of action for carrying out the program's mandate of leading a national effort to achieve energy productivity in the buildings sector. Such a plan was recently completed, and is referenced below and summarized in the previous version of this report, for FY 1988. Preliminary indications are that the new OBT strategy will involve:

- consolidating knowledge of buildings research developed over the past 15 years;
- communicating that knowledge to a variety of product manufacturers, intermediaries, and other users;

- assisting existing Federal programs to incorporate that knowledge into their efforts; and
- identifying new opportunities in technology where rapid and significant advances can occur.

A proposed methodology to implement the new strategy is described in a later section of this chapter.

Annual Evaluation

The annual evaluation of OBT's R&D program undertaken as part of the multi-year planning process helps to ensure that it is meeting the changing needs of the nation, the buildings industries, and consumers. The program is modified as needed to account for changes in public priorities and new information gained from the conduct of R&D.

Current and proposed research projects are evaluated in terms of their anticipated contribution to achieving the Office's objectives. These objectives and the evaluation criteria are listed in Table 2-1.

To evaluate progress made by each research project toward these objectives, quantitative estimates are made for evaluation criteria based on information provided by OBT program managers, principal investigators, and other experts. For example, to estimate energy savings for a new technology in 2010, it is necessary to estimate its economic and technological attributes, time of market entry, the attributes of competing technologies, the potential market size, and rate of market penetration. These estimates are then normalized and incorporated into a prioritization algorithm which weights the criteria and calculates a figure of merit for each project. The algorithm also considers program costs relative

Table 2 - 1

BCS PROJECT EVALUATION CRITERIA

OBJECTIVE	CRITERIA
Achieve the maximum possible cost-effective energy savings in buildings, with special attention to oil savings	Energy savings potential in 2000 Energy savings potential in 2010 Potential oil savings in 2010
Maintain healthy indoor and outdoor environments	Emissions reductions Improved indoor environments
Minimize the cost of energy services to consumers	Consumer cost savings
Improve the international competitiveness of U.S. building and equipment industries	Technical leadership Cost competitiveness

to benefits, and provides for sensitivity analysis of the prioritization results with changes in individual criteria values, criteria weights, and program costs. A flow chart for this project evaluation methodology is presented in Figure 2-1.

The quantitative evaluation process just described is the major input to establishing program priorities. The ranking of research projects is accomplished interactively between managers, investigators, and others, with OBT management selecting and reviewing sensitivity analyses to establish final rankings. Portfolio considerations (e.g., program balance, the maintenance of critical mass in key program areas) are also factored into the final set of priorities.

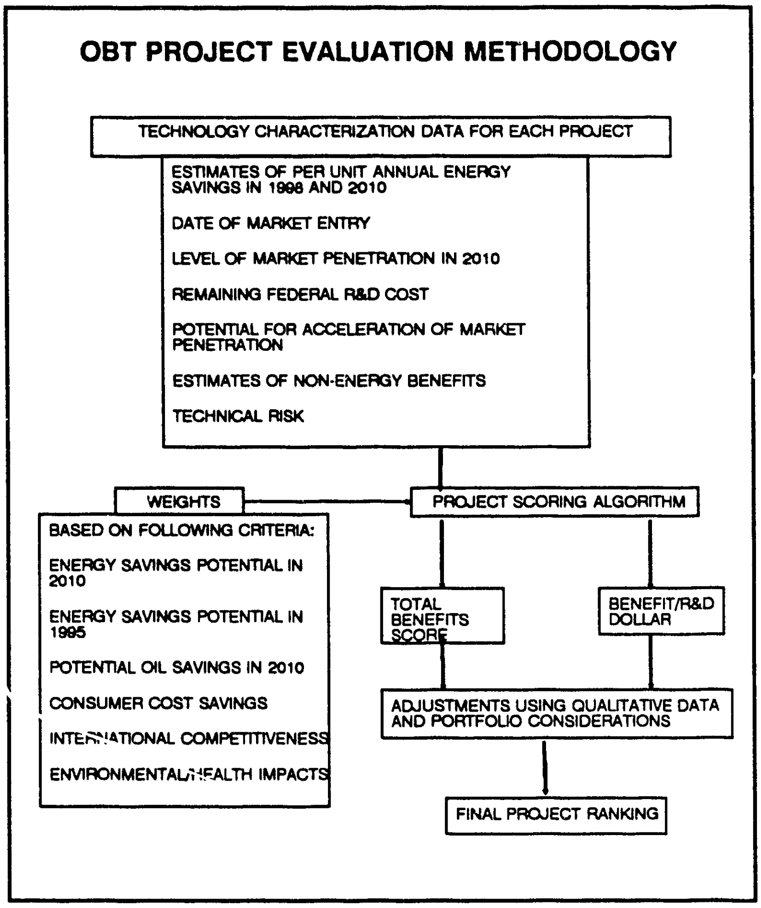


Figure 2 - 1

LONG RANGE PLANNING - PHASE 2

Program Evaluation Methodology

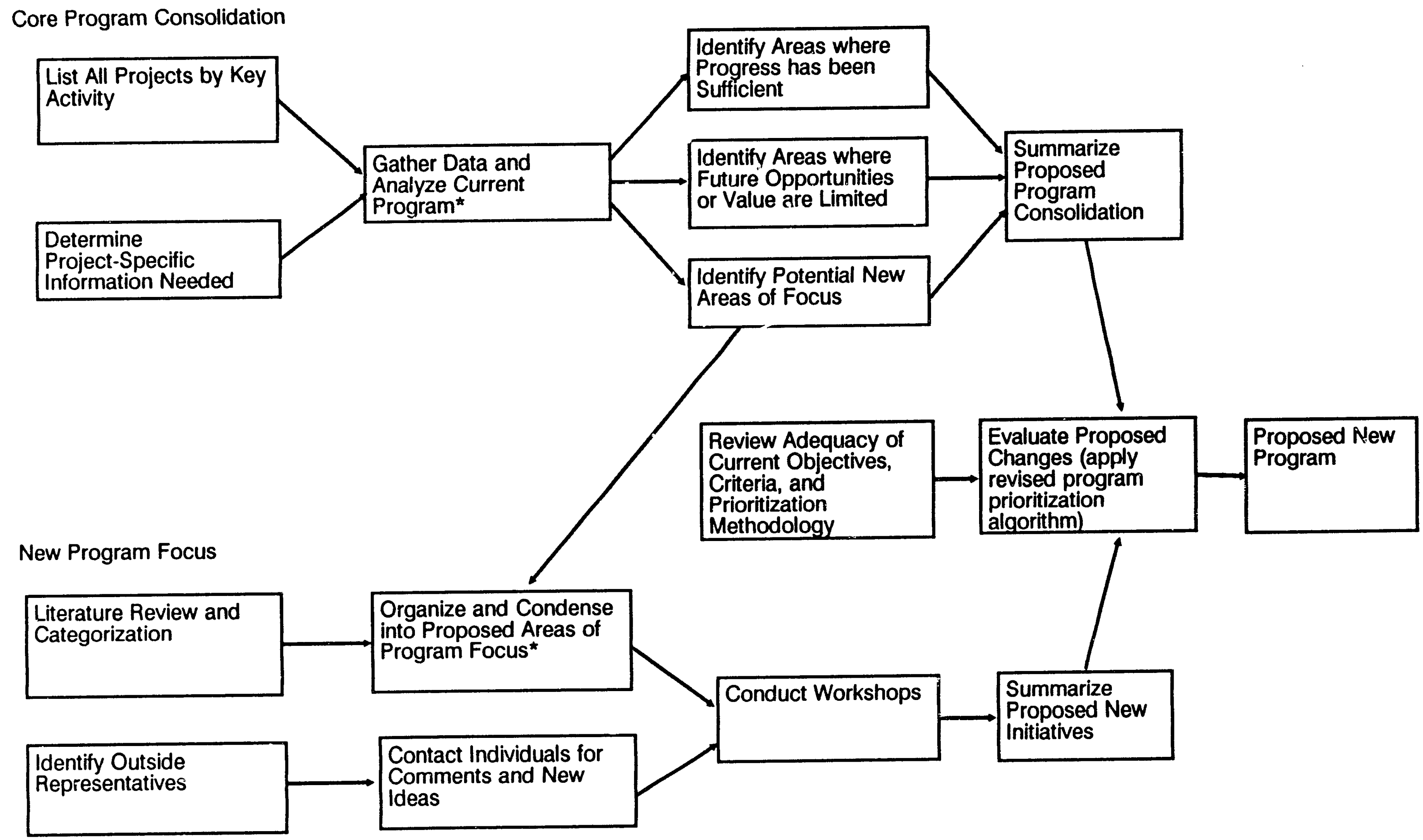
Contact: Jerome LaMontagne, BNL, (516) 282-2831

In FY 1988 the first phase of a strategic planning effort was completed. Phase I identified a set of key strategic planning issues and alternatives; results were described in the *Analysis and Technology Transfer Annual Report - 1988*. In FY 1989 a methodology for program evaluation, consolidation, and redirection was developed. However, the plan was not implemented due to the demands of the National Energy Strategy; it is likely that a program evaluation will be undertaken in the coming year, modified as necessary to account for the reorganization within CE.

Analysis Plan

The analysis plan, shown in Figure 2-2, consists of two primary activities, core program consolidation and development of new areas of program focus. The purpose of the program consolidation effort is to identify areas in which progress has been sufficient (or

Figure 2 - 2
Proposed Analysis Plan



* Use Current Program Evaluation Criteria

where opportunities for future advances or their value are limited) to justify a shift from R&D to information dissemination.

The methodology for identifying new program areas expands on the approach used previously for developing new initiatives in the multi-year planning process. It provides a more systematic and comprehensive way to provide new directions for OBT's R&D program.

Program Screening

A methodology for evaluating the current program is shown in Figure 2-3. The diagram is a starting point for development of detailed criteria for program evaluation. Results of the screening will be the grouping of subprojects into four categories:

- projects ready for commercialization or transfer which require no further OBT involvement;
- projects ready for commercialization or transfer which require further OBT support to succeed:
- projects not ready for commercialization which offer a low potential payoff; and
- projects not ready for commercialization which offer a high potential payoff and should be considered for continuation, expansion or redirection.

A possible model for establishing the commercialization status of research products is taken from Weijo. The program screening plan calls for review of these criteria, and testing the methodology through application by conducting pilot studies. These will involve active participation by program managers. The purpose of the pilot studies is to allow refinements in the project appraisal methodology before it is applied to the entire program.

New Program Focus

The second part of the program evaluation activity will be to identify new and exciting areas of program focus where the potential payoff of R&D is significant. Special emphasis will be given to areas identified in the development of the NES.

This activity will consist of two parts:

- a literature review to identify and review "on the shelf" reports (national laboratory program reviews, OTA studies, NES documents, etc.) that might either describe potential new initiatives or provide ideas that could be further defined as proposed new initiatives; and
- solicitation of ideas from outside DOE by identifying and contacting interest groups, industry associations, Congressional staffers and representatives of private sector companies who have an interest in energy conservation in buildings.

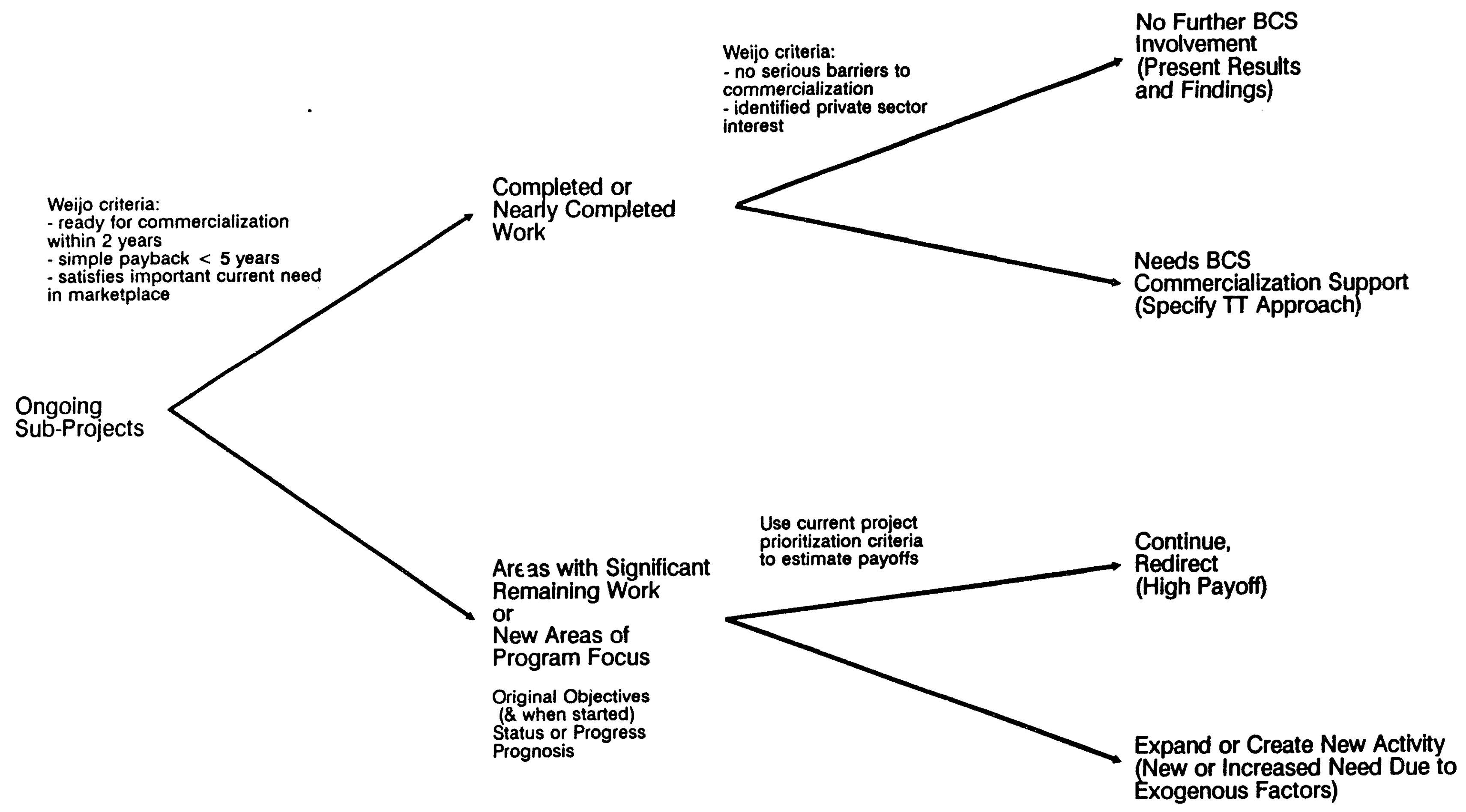


Figure 2 - 3
Screening Approach for Implementing Strategic Plan (Current Projects)

If time and funding permit, a series of in-house workshops will be held to consider and set priorities for ideas which emerge from the two activities above.

Technology Transfer Planning

Contact: Barbara Farhar, SERI, (202) 484-1090

Accelerating the adoption of new and existing cost-effective technologies has significant potential to reduce the energy consumed in U.S. buildings. A strategic issue for OBT is improving the transfer of energy tools, technologies, and practices to the array of users needing them.

Although OBT has already successfully transferred some technology, OBT management decided that planning was needed to explore ways to increase the Office's effectiveness in this area. In FY 1989 and 1990, OBT conducted an interlaboratory technology transfer planning effort to develop a framework for improving its Office-wide technology transfer activities. A guiding assumption for planning was that OBT's program, as an R&D program, should forge linkages with already existing programs whose goals involve actually enhancing energy efficiency in buildings.

An *ad hoc* Technology Transfer Advisory Group, which included representatives from OBT management and four national laboratories, reviewed the current program, brainstormed technology transfer approaches, identified applicable research results and references, and developed a framework that management could use in deciding on the best investments of technology transfer resources. Representatives of some 22 other programs and organizations were interviewed concerning their perceptions of the potential for transferring energy efficiency technologies through active linking with OBT.

Several key issues in transferring building energy technologies were identified:

- defining technology transfer clearly to include, for example, both scientific information exchange and activities that result in technologies actually being adopted and used;
- deciding whether OBT should transfer technologies developed only by its own program or technologies developed by others (including foreign countries) as well;
- identifying appropriate roles in technology transfer for the national laboratories;
- identifying the research and analysis support needed for an integrated OBT technology transfer program;
- identifying the management support needed for effective technology transfer; and
- identifying the most effective means to link the OBT R&D program with other programs and organizations within and beyond DOE to accomplish technology transfer.

OBT managers said they were particularly interested in obtaining evidence concerning the effectiveness of technology transfer strategies and mechanisms in achieving the actual use of energy efficiency technologies and practices in buildings.

The Framework

Eight kinds of audiences for OBT tools, technologies, and practices based on functional roles were defined:

- building researchers;
- product manufacturers;
- energy intermediaries;
- energy service deliverers;
- federal programs;
- information intermediaries;
- communities; and
- energy end users.

These functional audiences are distributed across a wide variety of organizational types or structural audiences. For example, energy program implementers may be found at utility companies, small consulting firms, community action agencies, state energy offices, and national laboratories. These functional audiences form networks across structural audiences, or organizations, based on common needs for information. To reach functional audiences effectively, OBT needs to be sophisticated in its approach to its audiences through a variety of organizational conduits, using segmentation techniques to provide credible information through trusted channels.

Four central technology transfer functions were defined for Office-level technology transfer:

- transferring research results;
- transferring new and existing OBT-developed technologies;
- transferring non-OBT energy technologies; and
- increasing awareness of the OBT program.

The Advisory Group developed a framework by creating a matrix using technology transfer functions as column heads and general functional target audiences as row heads (see figure). Two of these frameworks were produced by completing the cells of the matrix in two different ways: (1) identifying the organizational conduits (structural audiences) to reach each functional target audience, and (2) identifying activities to accomplish the function for the identified functional type of audience. For instance, using the framework on organizational conduits as a heuristic device, one cell of the matrix suggests that to promulgate OBT research results among federal buildings planners and managers, OBT could work with the National Institute of Standards and Technology (NIST), the Federal Energy Management Program (FEMP), the General Services Administration, the Department of Defense, and the Construction Engineering Research Laboratory.

Figure 2 - 4

Matrix of Technology Transfer Functions by Target Audiences

Target Audiences	Technology Transfer Functions* (1)	(2)	(3)	(4)
Building researchers				
Federal Buildings				
Conservation programs				
Legislative				
State and local Buildings				
Conservation programs				
Legislative concerns				
Private sector Product manufacturers and distributors				
Energy intermediaries				
Conservation programs				
Consumers/end users				
Internal DOE staff and national laboratories				

*(1) = Research results
(2) = New and existing OBT tools, technologies, and practices
(3) = New and existing non-OBT tools, technologies, and proactices
(4) = Program awareness

Recommendations

The Advisory Group recommended that OBT use the framework as a heuristic device in planning its technology transfer activities. This framework can be used (1) to discern the specific structural audiences that will reach functional audiences and (2) to exhibit a way that already-funded and proposed activities can be evaluated against target audiences and technology transfer functions to test the program's balance.

Based on a partial exploration of the opportunities for linkages with other programs and organizations, the Advisory Group concluded that OBT would find it particularly useful to pursue liaisons with FEMP, U.S. Department of Housing and Urban Development (HUD) programs, the National Association of Home Builders (NAHB), and NIST. Other significant opportunities for linkages exist with DOE's Office of Technical and Financial Assistance (OTFA), the National Appropriate Technology Assistance Service (NATAS), the National Association of Regulatory Utility Commissioners (NARUC), and the National Association of State Energy Officials (NASEO). OBT should continue to explore the potential for linking with other trade and professional organizations to develop a repertoire of working relationships that will affect technology transfer in a positive way.

The Advisory Group also concluded that the portion of OBT technology transfer dedicated to scientific information exchange appears to be working well in keeping buildings researchers informed about the program and its scientific progress. Standing and special-purpose review committees also appear to effectively involve the private sector with the program. These portions of the Office's technology transfer program should be preserved. Production of *Buildings Energy Technology*, *Research in Progress* and similar publications should be continued at about the same level of support. The national laboratories should continue to be supported in promoting scientific information exchange through the normal scientific processes of conferences, peer review, and publication.

It was also recommended that OBT should transfer new and existing tools, technologies, and practices developed by others, particularly through the Center for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET) and the Building Efficiency and Conservation Network (BEACON), if established. To fulfill its function of leading a national effort to increase the energy efficiency of the nation's buildings, OBT should include the transfer of any demonstrably workable technologies.

Finally, OBT management should undertake a systematic, ongoing review of the Office's technology transfer activities. This process could be initiated with an internal management review of technology transfer; convening technology transfer roundtables with extramural laboratory, government, and private-sector participation; and establishing a Technical Review Panel for Technology Transfer as a standing committee.

About 60 examples of technology transfer activities were developed, suggested by program managers, group members, existing projects, and outside sources. Using the criteria developed, the group evaluated and ranked these activities. Twenty of them emerged as the most important examples for OBT to consider in planning and funding its technology transfer program.

FOCUS ON THE ENVIRONMENT

Several environmental issues which are directly related to buildings energy use are currently capturing the nation's attention. Fossil fuel burning is recognized as the main source of CO_2, which, along with the devastation of the planet's natural vegetation, is causing global warming. Some fossil fuels are burned directly in our nation's buildings, however, their use in buildings is primarily through their use in producing electricity. Chlorofluorocarbon (CFC) compounds are believed to be the leading cause of ozone depletion in the atmosphere. CFCs are used extensively, both as working fluids in air conditioning and refrigeration systems, and as foaming agents in thermal insulation. Indoor air quality - particularly high concentrations of radon, but also other pollutants - is becoming an increasing concern in building design and operation.

OBT sponsors research which seeks to improve the efficiency of energy use in buildings. As environmental concerns become more important, OBT examines its research program and priorities to ensure that these concerns are adequately addressed in the buildings sector. OBT has also initiated an inventory of OBT studies related to environmental issues; this effort is described in the data base section of Chapter 4 of this report.

Buildings Share of Fossil Fuel Emissions

In the residential and commercial buildings sectors, natural gas accounts for approximately one-quarter of the primary energy consumed, oil for less than 10 percent, and electricity for over 60 percent. To examine the environmental effects of energy use in buildings, the electricity component must be disaggregated into the fuels used for generation. This is done by assuming that the fuel shares used to produce the electricity used in buildings are the same as the fuel shares for the economy as a whole, and adding these to direct fuel use in buildings. Results are in Table 2-2, taken from *The Composition of a Quad of Buildings Sector Energy: Physical, Economic, and Environmental Quantities*. The table shows the fuel use breakdown for a "generic" quad of energy used in buildings in 1987. This means that for each quad of energy used in buildings, 35 percent is supplied by coal, 30.8 percent by natural gas, and so on.

Table 2 - 2

Buildings Sector Primary Fuel Shares for a Generic Quad, 1987 (Percent)

Coal	35.0
Natural Gas	30.8
Oil	12.0
Hydro	7.0
Nuclear	11.3
Renewables	4.0

Source: Secrest and Nicholls, 1990.

Significant emissions of carbon dioxide (CO_2), sulfur dioxide (SO_2), and nitrogen oxide (NO_x) from the burning of fossil fuels are associated with this energy use. These by-products are important because CO_2 has been identified as the major contributor to global climate change, and SO_2 and NO_x have been identified as the major precursors of acidic deposition. In addition, the buildings sector is responsible for its share of radioactive spent fuel generation.

Calculations of the quantities of these by-products associated with a quad of energy used in buildings show that each quad used accounts for 1.3 percent of total U.S. emissions of carbon (in the form of CO_2), 1.5 percent of SO_2 emissions, and 0.7 percent of NO_x emissions. The estimates for SO_2 and NO_x emissions account only for coal consumed at utilities and thus are low estimates of the total building sector contribution. The quantities and percentages are shown in Table 2-3.

Total buildings sector energy consumption (27 quads) thus contributes slightly more than one-third of all U.S. CO_2 emissions, nearly 40 percent of SO_2 emissions, and about 20 percent of NO_x emissions. Most of these estimates are from coal; virtually all coal usage attributable to the buildings sector is due to its use in electricity generation. Improving the

Table 2 - 3

Emissions per Generic Quad of Buildings Sector Energy Consumption, 1987

	Carbon (10^{12} grams)	SO_2 (10^6 lb)	NO_x (10^6 lb)
Coal	8.79	654	310
Natural Gas	4.45		
Petroleum	2.43		
TOTAL	15.67	654	310
Percent of U.S. Total (1985)	1.3	1.5	0.7

Source: Secrest and Nicholls, 1990.

efficiency of electricity use in buildings thus becomes a critical component in reducing the levels of these emissions.

Using emissions associated with a generic quad provides a convenient way of estimating the environmental benefits of reducing energy use in buildings. In the *Energy Conservation Multi-Year Plan, 1990-1994* (Office of Conservation, 1988), OBT projects that it is possible to reduce buildings energy consumption by 11.2 quads (economically achievable) to 17.8 quads (technically achievable) by 2010 compared to projections without the development and adoption of energy-efficient technologies and practices. Using the generic quad fuel mix projected for 2010, these savings would reduce U.S. carbon emissions by 10 to 16 percent, SO_2 emissions by 9 to 14 percent, and NO_x emissions by 4 to 7 percent.

Acidic Deposition

Sulfur dioxide (SO_2) and nitrogen oxide (NO_x) have been identified as major precursors of acidic deposition, of which acid rain is one manifestation. Among other effects, acid rain has been linked to regional forest decline, and lake acidification in the northeastern United States.

SO_2 and NO_x are formed during the combustion of fossil fuels. Buildings sector energy use contributes to emissions of both these acidic deposition precursors, predominantly through its use of fossil-fired electricity, particularly coal. As discussed above, buildings were responsible, by virtue of their use of electricity, for two-fifths of our SO_2 and one-fifth of our NO_x emissions.

Several of OBT's research programs focus on electricity-using equipment. The objective for the advanced refrigeration systems program is to discover ways to improve the energy efficiency of electrically-driven residential appliances and commercial equipment used for space heating, cooling, hot water, and refrigeration applications. The objective of the lighting equipment research program is to provide the technology base necessary to achieve a 50 percent reduction in lighting energy use in buildings by the year 2000.

Chlorofluorocarbons (CFCs)

CFCs are another important pollutant released by buildings sector energy use. CFCs are used to provide wall, roof, and foundation insulation in buildings. Insulation produced using CFCs is also used to fill the wall cavities of home refrigerators and freezers and CFCs are used as the working fluids in air conditioners, heat pumps, and refrigeration equipment. A rough estimate of buildings sector CFC use in 1986 is about 88,000 short tons, which is 25 percent of total U.S. usage of CFCs that are regulated by the Montreal Protocol.

Because building energy-related uses account for such a high percent of total CFC production, the development of CFC substitutes will have a substantial impact on the buildings sector. Significant unresolved issues for the CFC substitutes currently under study include:

- uncertainty about their toxicity,
- uncertainty about when they would be available (some time after 1993),
- economic problems caused because replacements cost two to five times more than current products, which would be especially troublesome for insulation products,
- poorer performance than traditional CFCs, and
- their higher hardware costs.

Climate Change

Some scientists and policymakers believe that emissions of certain gases have the potential to change the earth's climate dramatically by trapping heat in the atmosphere and producing a global greenhouse effect, and that measures are needed to reduce these emissions. There is disagreement regarding the timing and extent of the potential resulting climate changes. Predicted effects of such climate change include sea-level rise and dramatic changes in regional weather patterns. The major greenhouse gases identified as responsible for this phenomenon are CO_2 (50-55 percent), CFCs (20-25 percent), and methane (20-30 percent).

The buildings sector contributes significantly to atmospheric loading of two of the above gases: CO_2 and CFCs. As discussed above, buildings are responsible for a third of the CO_2 released and for about a quarter of our CFC emissions.

Ozone Depletion

In addition to their heat trapping abilities, CFCs and halons may also pose a threat to the earth's natural shield of ozone--a gaseous allotrope of oxygen that in the upper atmosphere (the stratosphere) blocks a portion of the sun's ultraviolet radiation. Increased ultraviolet penetration has the potential to cause a higher incidence of cancer in human beings and possible damage to other forms of animal and plant life. The wide use of CFCs in the buildings sector contributes to this potential health problem.

An agreement signed in 1988 (the Montreal Protocol) pledges each signatory, including the U.S., to cut production of designated compounds between now and 1998--so that country-by-country output by that year (in terms of collective ozone-depleting potential (ODP)) will be no more than half what it was in 1986. A key feature of the protocol is the recognition that the compounds are not all equally threatening. For example, some CFCs such as CFC-11 and CFC-12 used in applications such as building refrigeration/cooling equipment have ODPs of 1.0. By contrast, HCFC-22 has an ODP of 0.05 or less, while that for Halon 1301 is 10.0. The Clean Air Act passed in 1990 will further hasten the phaseout of CFCs.

OBT's R&D program includes efforts to develop rigid foam insulations that are manufactured with alternative non-ozone-depleting agents. In addition, OBT has expanded its program to accelerate the development and testing of alternative refrigerants to replace the CFCs now being used.

Indoor Air Quality

Concern with outdoor air pollution has led to increasing awareness of the indoor air environment and concern about the problems of indoor air pollutants. Since most people spend most of their time inside, where exposure to toxic substances may be many times greater than what they experience outside, indoor air pollution may be the number one hidden health threat to Americans. In a typical house, indoor air quality may be affected by: aerosols from cigarette smoke; respirable particles and carbon oxides from heating and cooking appliances; carbon monoxides from automobile exhaust; complex organic chemicals in building materials, furniture cleaning fluids, and solvents; fibers of asbestos; airborne bacteria, fungi and house mites; as well as radon.

The discovery of inordinately high levels of radon in homes in eastern Pennsylvania during 1984 and 1985 brought national attention to this problem. Radon, a naturally occurring and almost chemically inert radioactive gas, is produced from the radioactive decay of radium which in turn is formed from the decay of uranium. The major source of indoor radon is radium in the soil and rocks under and surrounding homes. Radon can enter homes through cracks in concrete, wall-floor joints, and hollow block walls as well as through openings in sewer pipes and sump pumps. Indoor radon is confined to a small space unlike the outdoors where it can be readily dispersed. Radon levels vary from house to house depending upon differences in soil characteristics, building type, foundations, weather conditions, and occupancy lifestyles.

In the commercial sector, concerns about energy in the seventies and early eighties prompted architects to design tighter buildings with fixed glazing and energy-conserving ventilation systems. In many cases, the resulting buildings suffer from a build-up of pollutants including chemical vapors from office equipment and furniture, cleaning products, smoke, and even off-gases from the building materials used in construction. These problems are exacerbated in those commercial buildings where partitioning disrupts the originally planned ventilation scheme or where the ventilation system is not operated properly. Increased pollutant levels have led to growing concern about their impacts on human health, comfort and productivity. The World Health Organization has estimated that 30 percent of newly constructed and remodeled office buildings possess signs of "sick building syndrome" and that in these buildings 10 to 30 percent of the occupants will be affected.

Research indicates that air quality in buildings is dominated by sources such as construction materials, solvents, and soil gas rather than deficiencies in ventilation. After source control, ventilation is the best control strategy for indoor air quality. The trend to conserve energy in buildings has resulted in making new and existing buildings airtight so that less energy is required to heat or cool the indoor air. Initially it was felt that the tightening of buildings created poor indoor air quality. When this is done, airborne pollutants may become concentrated inside. However, when tightening is accompanied by more efficient ventilation, significantly lower levels of indoor air pollution may result.

Research areas include measurement techniques for indoor air pollutants, characterization of pollutant sources, the influence of building characteristics on indoor pollution, and analysis of energy-efficient mitigation techniques. Energy-efficient buildings must offer health and comfort advantages to the occupants. One of the necessary goals of advanced research in energy conservation technologies is to ensure that these technologies maintain a healthful and comfortable indoor air environment.

3. ENERGY USE AND BUILDINGS

This chapter discusses the determinants of energy use in buildings, presents historical and current energy use trends, and suggests a possible future for energy use in the buildings sectors. The material in the first two sections is adapted from background documents prepared by OBT for the NES development process, *Residential Energy Use: Determinants, Trends, and Potential A Residential Sector Profile* (May 1990) and *Commercial Energy Use: Determinants, Trends, and Potential A Commercial Sector Profile* (May 1990). Statistics have been updated where possible; further data may be found in the Appendix. The forecasts are also from the NES development process.

DETERMINANTS OF ENERGY USE IN RESIDENTIAL AND COMMERCIAL BUILDINGS

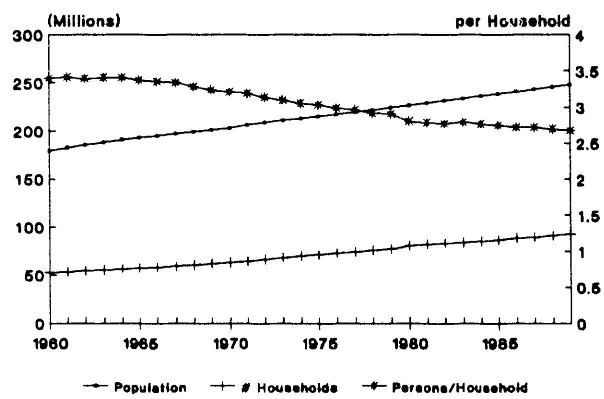
Demographics

While the resident U.S. population has grown at a rate of 1.1 percent per year since 1960, the number of households has grown faster, at nearly 2 percent per year. Thus the number of persons per household has continuously declined, as shown in Figure 3-1, contributing to a decrease in energy use per household.

In the commercial sector, primary energy consumption rose more rapidly than population from 1960 to 1989 (Figure 3-2). While end-use energy has grown at a rate close to that of overall population growth, the faster growth of primary energy, which includes the inefficiencies associated with electricity production and transmission, is due to the accelerated use of electricity relative to other energy sources.

Figure 3 - 1

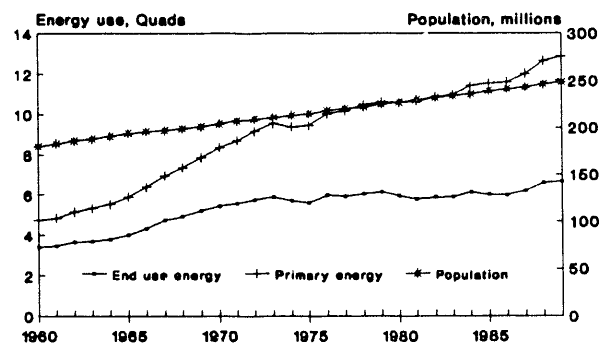
U.S. Population and Persons/Household



Source: Statistical Abstract of the U.S.

Figure 3 - 2

Commercial Energy Use and Population Growth

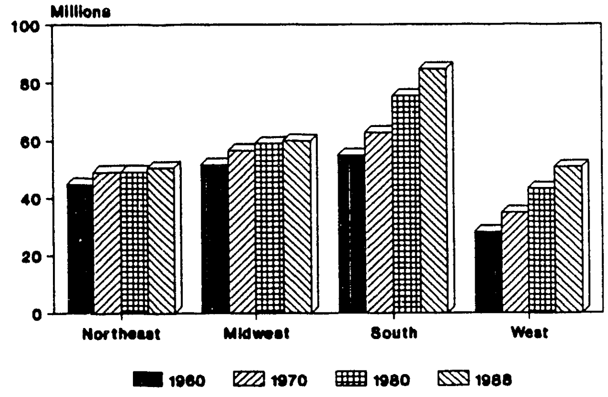


Sources:
Statistical Abstract of the U.S. 1990,
State Energy Data Report 1960 - 1989

Most of the population growth has occurred in the Southern and Western regions of the country, while the Northeast and Midwest have maintained fairly stable population levels (Figure 3-3). This population shift contributes to decreasing energy use per household, because households in the South and West use less energy for space heating, and to the increasing use of electricity in both sectors due to greater demand for space cooling. Also, electricity is often the fuel of choice for space heating in the South. If this trend in population growth continues, it is likely that electricity use will continue to grow rapidly.

Figure 3 - 3

Regional Population Growth



Source: Statistical Abstract of the U.S.

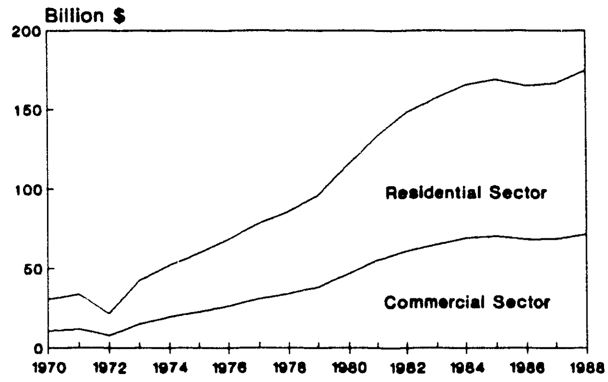
Economic Activity

As Figure 3-4 illustrates, buildings sector energy expenditures have risen steadily since the early seventies. In 1988 energy costs totaled $174.9 billion and accounted for approximately 3.6 percent of the GNP. The efficiency gains of new technologies introduced over that period have been outweighed by increases in population and in the number and square footage of new buildings added to the commercial inventory.

The value of construction (Figure 3-5) dips during recession years but shows an overall steady increase. In 1988 the value of construction in both the residential and commercial sectors (not including public utilities) accounted for 6.7 percent of the GNP. Buildings energy and construction costs together totaled 10.3 percent of the GNP.

Figure 3 - 4

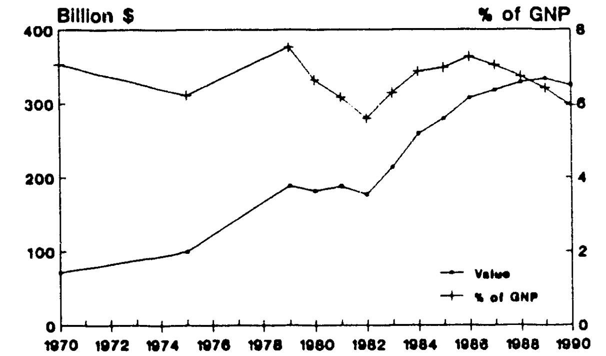
Cost of Energy



Sources: State Energy Price and Expenditure Reports 1989 and 1990

Figure 3 - 5

Value of New Construction*



Sources: Statistical Abstract of the U.S. 1990, Value of New Construction Put in Place April 1991

* Value of construction does not include public utilities.

Building Stock and Equipment

Residential

There are over 90 million households in the United States. About two-thirds of these households are single-family homes, just over one-quarter are multifamily homes, and the remaining are mobile homes. In the South there is a greater percentage of single-family homes than in the country as a whole; in the Northeast multifamily homes are more prevalent. The number of households has grown at almost twice the rate of general population increase since 1960.

Following population trends, new residential construction has taken place primarily in the South; almost 44 percent of single-family homes built since 1966 were built in that region, more than three times as many as were built in the Northeast. Single-family home construction continues to dominate privately-owned residential construction, accounting for more than 70 percent of all units built in 1989.

Most new homes use electricity or gas for space heating. In 1989 34 percent of new single-family homes and 45 percent of new multifamily buildings used electricity for space heating; 58 and 51 percent, respectively, used gas. The use of electricity has increased with the penetration of electric heat pumps, which captured 29 percent of the total market in 1986. Central air conditioning was installed in 77 percent of single-family homes built in 1989, compared with 63 percent in 1980 and 34 percent in 1970. In 1987, nearly 20 percent of all U.S. households used electricity as a main heating fuel, compared to 16.8 percent in 1984. These statistics point to the increasing use of electricity in the residential sector when compared with the current housing stock.

Partly because of the need for air conditioning, ducted systems using forced air are the most common means of distributing heat and cooling in new housing, capturing nearly 90% of the single-family market in recent years. Other types of distribution systems, such as hydronic (hot water), retain a significant representation in existing housing, especially in the Northeast.

Commercial

As of December 31, 1986 (the latest year for which data are available), there were 4.2 million commercial buildings in the U.S. containing 58.2 billion square feet of floor space. Mercantile and service buildings are the largest segment of the population, with 31 percent of the number of buildings and 22 percent of the floorspace. Office buildings show a significant increase in overall sector mix across age groups, representing 25 percent of the floorspace built after 1979. Significantly more new buildings and floorspace are being located in the South; almost one-half (46.5 percent) of the buildings and one-third (36.5 percent) of the floorspace constructed between 1980 and 1986 are located in that region.

Energy use varies considerably depending on building size and use, number of hours of operation, and number of workers. Healthcare buildings are the most energy intensive, followed by food sales and food service buildings. Food service buildings are the smallest on average; healthcare buildings are the largest. Both types, however, have long operating hours and low floorspace per worker. Healthcare buildings have the highest natural gas consumption per square foot and per operating hour; food buildings have the highest electricity consumption per square foot. Both types of food buildings, however, show relatively low consumption of gas and electricity per operating hour.

A cross-section of commercial buildings by age shows that average electricity intensity has increased from 12 kWh per square foot in buildings built before 1980 to 14 kWh per square foot in newer buildings. Intensity peaks at 15.9 kWh/sq.ft. in buildings constructed between 1961 and 1970, remains high in buildings built through 1979, and decreases somewhat in buildings built between 1980 and 1986. Both average and new building electricity intensities are higher in the South and West than in the Northeast and Midwest. Unless electricity intensity is reduced even further in new buildings or substantial conservation takes place in the existing stock, electricity use in commercial buildings is likely to continue to increase.

Most heated commercial buildings use furnaces or boilers. Furnaces dominate in all regions of the country except the Northeast, where boilers are as common. Nearly one-third of the heated buildings use individual space heaters or electric baseboards. Because the buildings using this type of equipment tend to be small, these buildings account for only about one-seventh of the total floorspace in heated buildings. Air-source heat pumps are used in 319,000 buildings, nearly twice the previous estimate for all heat pumps.

For buildings that did not use stand-alone units, forced air was the most common type of distribution system for both heating and cooling in the country as a whole. The Northeast uses a significantly larger share of radiators and baseboards.

Standard fluorescent bulbs are the predominant lighting equipment in about half the commercial buildings, followed by energy-efficient fluorescents and standard incandescent bulbs. In larger buildings energy-efficient fluorescent bulbs are more common.

Codes and standards

Many types of regulation affect the cost and efficiency of buildings. These include building codes, energy codes, appliance or equipment standards, subdivision controls, zoning regulations, growth controls, environmental restrictions and financing regulations. Building and energy codes and appliance standards have the most direct effect on energy use, while financing regulations affect the tradeoff between higher first costs and lower operating costs. The other types of regulations may indirectly affect building energy use but are beyond the scope of this discussion.

Building Codes

Twenty-six states currently have a mandatory statewide building code for commercial buildings; in an additional eight states, the code is mandatory for state buildings only.

Twenty-three states have a mandatory code for residential buildings. Other states may have a voluntary code, or localities may have a code in place. There are over 40,000 local jurisdictions in the United States.

Building codes adopted by a state or locality generally follow one of three model codes. The model codes tend to be regional, include plumbing, electrical, and other requirements, and are updated every year. Local governments then apply thousands of major and minor variations of these basic codes and have their own revision schedules. There are at least as many inspection systems, with differences in building code interpretations and varying degrees of enforcement.

Building codes can be cumbersome to maintain and enforce, and if they are too specific may have the effect of restricting the use of new technologies. Due to the plethora of codes and general lack of reciprocity agreements for inspections, the market for new technologies and construction techniques, in particular modular construction, is restricted.

State and Local Energy Codes

Some form of energy code or standard for new construction exists in each of the fifty states. These are generally based on standards developed by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE), or on one of the three model energy codes developed by building code organizations.

Considerable variation exists among the states in terms of the technical criteria and basis of each code, the types of buildings to which the code applies, procedures for determining compliance, and the governmental level at which the code is promulgated. The federal government or the state may have a code in place, but localities may adopt variations suited to their particular needs. In some states the code may apply to state-owned buildings only, or may be required only if adopted by units of local government. In some areas certification of compliance must be made to the electric utility prior to permanent service connection. In addition, the cycle for reviewing and updating codes varies from locality to locality.

Commercial building energy codes generally apply to both high-rise (>3 stories) residential buildings and to nonresidential buildings. In some states, residential building codes are used for low-rise hotels and motels. Energy codes generally include criteria for thermal envelopes, HVAC and water heating systems and equipment, and, for commercial buildings, lighting systems.

Codes are generally either performance-based or prescriptive. Performance standards allow greater flexibility in achieving efficiency goals, but they are more difficult to enforce. Some states permit a combination of the two approaches.

It is unclear what the actual effect of energy codes is on overall energy use. In some areas, new construction typically exceeds code requirements. In addition, effectiveness depends on how well a code is enforced and on the training and education of builders and local code officials. The major benefit of an energy code is that it establishes the minimum acceptable level of efficiency, that is, it eliminates the worst cases. Further improvements can then be accomplished by other means such as incentives.

Federal Building Energy Standards

Title III of Public Law 94-384, Energy Conservation and Performance Standards for New Buildings as amended, requires DOE to issue performance standards applicable to all new buildings. These standards are to be voluntary guidelines for the nonfederal sector and mandatory, by agency adoption, for the federal sector.

These performance standards are to be an energy consumption goal or goals. The standards will not specify how to achieve the goals but will specify the requirements criteria and evaluation methods to be used. The standards are to be designed to achieve the maximum practicable improvements in energy efficiency and increases in the use of nondepletable sources of energy. DOE is also charged with encouraging States and local governments to adopt and enforce the standards. Amendments to the law added the requirement for interim standards and demonstrations prior to final standards.

The standards effort is divided into two parts, one which addresses residential buildings and one which addresses commercial buildings. The commercial standards also address multifamily high-rise residential construction due to similarities in technical requirements and design.

An interim standard for the design of Federal residential buildings was published in August 1988. Military housing, which represents most of the residential buildings procured by the federal government, will benefit most from this standard. A demonstration project has been undertaken to assess the impact of the standard. Economic analyses have estimated that use of the standard will save $27 million over a five-year period.

Recommendations for the voluntary residential standard were developed by ASHRAE in 1987 and 1988, in an effort to represent many potentially affected groups in the development process. Development of the interim standard continued through 1989 and 1990; economic and environmental analyses were completed in August 1988. The draft interim standard is scheduled for issuance in late 1990.

DOE published interim energy standards for the design of new commercial and multifamily buildings in January 1989. They became mandatory for all federal agencies in July 1989; they serve as voluntary guidelines for the private sector. Energy savings from using the standards are estimated to be 18 to 25 percent, depending on building type and climate.

Further discussion of the Federal standards program can be found in Chapter 4 of this report.

Appliance Standards

In 1987, the federal National Appliance Energy Conservation Act (NAECA) establishing efficiency standards for 13 household appliances. These standards are estimated to save $28 billion worth of electricity and gas and to keep 342 million tons of carbon out of the atmosphere between now and the end of the century.

In 1988 the National Appliance Energy Conservation Act was extended to include fluorescent lamp ballasts, a significant energy end-use in commercial buildings. It has been estimated that the standards will reduce the power and electricity consumption of new ballasts by 9 to 10 percent during 1990 to 2010. Cumulative electricity savings reach 27,600 GWh by 2000 and 36,600 GWh by 2010, the equivalent of 4 to 5 percent of electricity consumption in commercial buildings in 1987. Cumulative net savings for consumers (reduced operating cost minus estimated extra first cost) are $10.7 billion by 2000 and $15.6 billion by 2010.

Several states are considering standards for lamps, luminaires and motors, either as separate equipment standards or as part of building or energy codes. If such standards were adopted nationwide, it is estimated that the electricity savings after 10 years would be approximately equal to savings due to the appliance and ballast standards.

Behavior

During times of increasing energy prices American consumers have substantially reduced energy use by making changes in behavior. These include turning thermostats down and using appliances more wisely. These changes are, however, easily reversible. Recent data suggest that this reversal is in fact occurring, both in the United States and in other countries; we seem to have reached a plateau of energy intensity or efficiency.

The contribution of behavioral changes to improvements in energy intensity has remained the same or slightly decreased since 1982. Space heating energy intensity began increasing in 1986. A similar situation exists with new appliances: efficiency gains in new models were greatest before 1985. Manufacturers and consumers do not see energy efficiency nearly as important as they did even two years ago. There are many options for reducing energy use in major appliances, but these seem uninteresting in today's energy price and policy climate.

Retrofit decisions also affect the overall energy intensity of the nation's housing stock. Structural retrofits include weatherstripping, attic insulation, caulking, and storm windows. The contribution of retrofits to improved energy intensity has decreased since the early 1980s, probably due to lower fuel prices, warmer winters, and the end of energy conservation tax credits.

Perhaps the single largest barrier inhibiting investment in energy efficiency and renewable energy options is the way in which consumers and businesses respond to market forces. Cost-effectiveness is a subjective concept, dependent on the perspective and judgment of the individual making the investment. Consumers and businesses typically require payback periods of less than three years when considering the purchase of most types of energy-efficient equipment. With energy prices at current levels, most investments in energy efficiency are not this attractive.

There are numerous reasons, in addition to response to market forces, why energy efficiency is not generally realized to the extent of its potential. These include limited access to capital, energy price uncertainties, government fiscal and regulatory policies, infrastructure limitations, and absence of credible information on the performance of energy-efficiency technologies. Other barriers include attitudes toward energy efficiency (lack of concern resulting in part from lower energy prices), and perceived risk of investments in energy efficiency.

Construction Industry

No discussion of energy use in the buildings sectors is complete without including the role of the construction industry. Manufacturers of both materials and appliances control the availability of energy-efficient products. Builders and designers determine construction techniques and often decide what equipment will be used in a building.

The industry consists of architects and engineers, builders and general contractors, trade contractors, material and component manufacturers, producers of manufactured and modular homes, and equipment appliance manufacturers. This diversity, and the fact that construction is often only part of the firm's activity, make it difficult to fully describe the industry.

A key characteristic of the construction industry is its fragmentation. Estimates indicate that over 38,000 components are used to construct a single-family house. A general contractor or builder and an average of nine subcontractors (carpenters, painters, plumbers, roofers, electricians, etc.) assemble these components into the finished structure. Thousands of manufacturers provide the material and components. Goods and services from more than 50 four-digit standard industrial classifications are necessary to build a home.

The construction industry spends very little on research. In 1984, total research expenditures were approximately 0.01 percent of sales. In the same year, the pharmaceutical industry spent about 7 percent of gross sales on research, the aerospace and automotive industries spent 4 percent, and the Japanese building industry about 3 percent. And although the U.S. agriculture industry contributes about the same as the building industry to the GNP, the building industry receives only a fraction of the amount of direct federal research appropriations that are spent on agriculture.

The building sector has shown the slowest growth in productivity of any sector in the U.S. economy. The industry's highly fragmented nature has made it difficult to carry out efforts to improve productivity. Lack of investment in research and development may be partly responsible for this lack of growth in productivity.

Diversity and fragmentation of the industry also affect the rate of adoption of new products and technologies. The number of industries and firms involved in construction, and the fact that they perform very little research on their own, slow the process of change within the building industry. It has been estimated that 15 years are required for new methods of construction to become widely used.

While automation in the U.S. housing industry has increased (currently between 10 and 35 percent of single-family residences excluding mobile homes), it does not approach that of several other countries. Sixty percent of single-family homes in Finland and 90 percent of new homes in Sweden are factory-built. Almost 80 percent of detached housing in Denmark that has been produced since the mid-1960s is constructed in factories.

The government of Japan and several large Japanese firms involved in home manufacturing are conducting research into factory-built housing. In Japan, the process is flexible enough to allow home buyers to participate in the design of their homes through the use of computers. Computerization helps integrate design through construction and erection of the home on the building site.

Factory-built houses cost less and can be constructed faster than traditional site-built houses. They can be built with a higher degree of quality control and tighter construction tolerances. There is, however, little information or data on the net energy benefits of alternative construction methods such as panelization. A need exists for a systematic study of different construction methods, which would include foreign building practices that may be applicable to the U.S. industry. Impediments due to the regulatory environment also need to be addressed.

Builders often decide what equipment is to be used in a new building. The builder's concern is generally the initial cost, not operating costs or energy efficiency. This must be largely due to the home-buyer's concern with initial cost; a builder must be competitive. There is a unique situation in the United States where a home, especially a first home, is not purchased for a lifetime but only until the buyer can afford a more expensive dwelling.

Architects and engineers are more important to the commercial sector than to residential construction. Surveys of architecture and engineering firms show that only 20 percent do work on residential design, and that fewer than 6 percent depend primarily on residential work. The greatest percentage of work is in commercial design; this is due to the larger size and greater complexity of commercial buildings compared to residential buildings. Architects and designers thus are key decision makers in determining energy use in commercial buildings, and can greatly affect the rate of penetration of new technologies.

Energy efficient design can save considerable energy over current practice. Improved design, with little or no increase in first cost, can potentially save 41 percent of typical building energy use on average over standard practice. Often, lack of knowledge among architects and engineers is the primary reason why more energy efficient designs are not used. For example, daylighting, which can significantly reduce the amount of energy used for lighting, is not widely used. Discussions among groups of architects and engineers revealed that the energy reduction benefits of daylighting are not understood. Participants said that daylighting would be used more frequently if practitioners had believable guidelines about when daylighting systems are most effective. In addition, participants had no experience with, and virtually no awareness of, computer simulation models that evaluate daylighting alternatives.

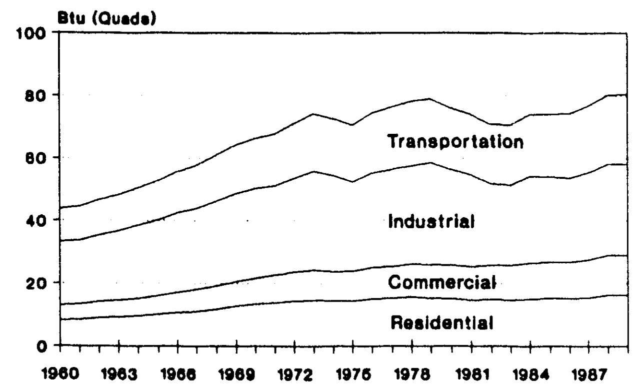
Due to the size and complexity of many newer commercial buildings, operation and maintenance also assume greater importance in their energy performance. As equipment and controls become more sophisticated, operation and maintenance engineers require more education and training to guarantee that buildings perform as designed. Operation and maintenance personnel are also often involved in decisions to replace existing equipment.

HISTORICAL TRENDS: BUILDINGS RESPONSIBLE FOR A GROWING SHARE OF U.S. CONSUMPTION

Our society uses as much energy to provide comfort and services in buildings as it uses for industry, and more than it uses for transportation. The share of energy use in the buildings sector has grown from 32.7 percent in 1979 to 36.3 percent in 1989, while industrial use has declined by nearly 10 percent and transportation energy use has increased by 9 percent. In the commercial sector primary energy consumption increased by 21.2 percent while residential energy use increased by 9.4 percent in the same period.

Figure 3 - 6

U.S. Consumption of Primary Energy by Sector, 1960-1989



Source:
State Energy Data Report 1960 - 1989

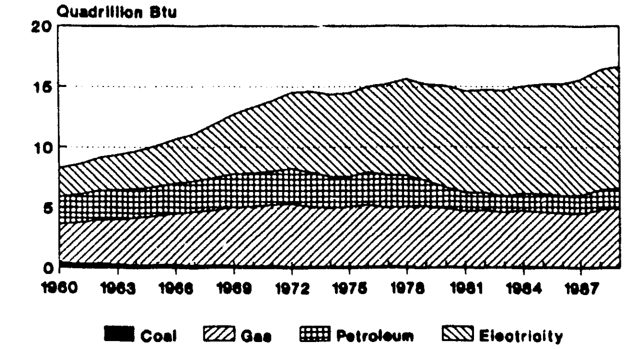
U.S. primary energy consumption by end-use sector over time is shown in the figure. In this report end-use energy is assumed the same as primary energy except for electricity. In the case of electricity, primary energy includes all of the energy used in its generation, transmission, and distribution. On average, 3.4 Btu of primary energy are required for each Btu of electricity delivered. In 1989 the residential sector used 16.6 quads of primary energy and the commercial sector used 12.9 quads.

Electricity is the Dominant Fuel in Buildings

In the residential and commercial sectors, growth in primary energy consumption has resulted primarily from increased use of electricity, as shown in the figures on the following page.

Figure 3 - 7

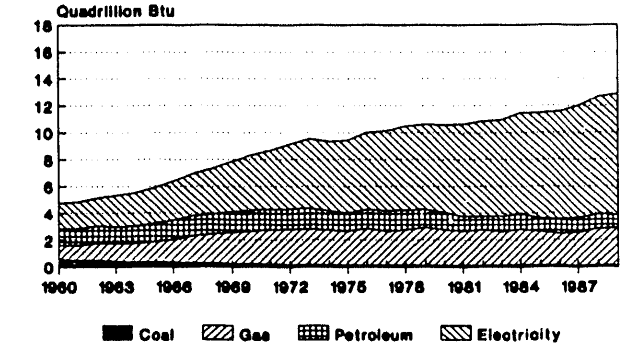
Residential Primary Consumption by Fuel Type



Source:
State Energy Data Report 1960-1989

Figure 3 - 8

Commercial Primary Consumption by Fuel Type



Source:
State Energy Data Report 1960 - 1989

In the residential sector, electricity use (including losses) has grown from 46 percent of all energy consumed in 1973 to over 60 percent in 1989. During this time direct coal use has declined to less than 0.1 quad, gas use has remained at about 5 quads, and petroleum use has decreased from nearly 3 quads to approximately 1.5 quads per year.

In the commercial sector, electricity use has grown from 54 percent in 1973 to over 69 percent in 1989. In the same time direct coal use has decreased, gas use has remained relatively constant at slightly more than 2.5 quads, and petroleum use has declined from 1.5 quads to approximately 1 quad per year.

Peak electricity demand, in addition to total consumption, has become increasingly important as utilities try to delay investing in new generating capacity. Forty-two percent of commercial buildings, representing over 70 percent of the electricity consumed in commercial buildings, now have peak-demand meters. For most (58 percent) of these buildings, the annual peak occurs in the summer. Winter peaks occur in about one-third of the buildings; the remaining have equal peaks in both summer and winter. Load management efforts in the commercial sector are complicated by the diversity in the sector. Some load shifting methods may result in greater overall energy use, and may affect the fuel mix used for electricity generation.

End Use Shares are Evolving

The table on the next page shows estimates of residential and commercial primary energy consumption by application and fuel for 1990. In the residential sector, space heating is the dominant use, followed by water heating. Current estimates for the commercial sector indicate that lighting is the dominant end use on a primary energy basis, followed by space heating and cooling.

Table 3 - 1

Buildings Primary Energy Consumption by Application, 1990 (Quads)

	Electricity	Gas	Liquids[a]	Other[b]	Total	Percent
Residential						
Heating	1.12	3.44	1.32	0.99	6.87	37.7%
Cooling	1.73	0.01	0.00		1.74	9.6%
Water Heating	1.33	1.13	0.23		2.69	14.7%
Other	6.56	0.34	0.04		6.94	38.1%
Total	10.74	4.92	1.59	0.99	18.24	100.0%
	Electricity	**Gas**	**Distillate**	**Other[c]**	**Total**	**Percent**
Commercial						
Heating	1.70	1.19	0.39		3.28	29.7%
Cooling	2.24	0.12	0.02		2.38	21.6%
Water Heating	0.10	0.08	0.01		0.19	1.7%
Lighting	3.50	0.00	0.00		3.50	31.7%
Other	1.33	0.37	0.00		1.70	15.3%
Total	8.87	1.76	0.42	0.00	11.05	100.0%

[a] Liquids include fuel oil, kerosene, and LPG.
[b] Other includes renewables and coal.
[c] Other includes include minor fuels and renewables.

Source: adapted from *Energy Consumption and Conservation Potential: Supporting Analysis for the National Energy Strategy*, Office of Energy Markets and End Use, Energy Information Administration, SR/NES/90-02, December, 1990. Non-building energy-uses are not included. Electricity is converted at the rate of 3.4 Btu of primary energy for each Btu of delivered electricity.

Although space heating remains the dominant end use in the residential sector, its share decreased between 1984 and 1987, while the amount of energy used for air conditioning and appliances increased. More people owned air conditioners and energy-intensive appliances in 1987 than in 1984. In the "other" category, approximately 12 percent is accounted for by refrigerators, and between 5 and 6 percent by lighting.

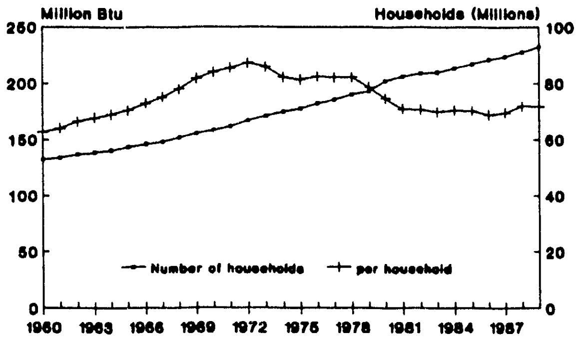
In the commercial sector, heating and cooling estimates include energy used for ventilation. Further, approximately one-half of the energy accounted for by "other" may be due to office and plug loads, a growing end use.

Energy Efficiency Improves

Energy use has increased over time in part due to higher levels of comfort and an increase in the number of energy using devices. It has also increased simply because the population has increased from 180 million people in 1960 to over 246 million in 1988. The two figures following show residential primary energy consumption per household and commercial primary energy consumption per square foot of floorspace.

Figure 3 - 9

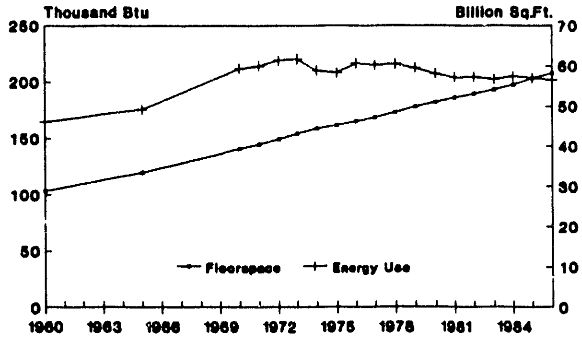
Residential Primary Consumption by Household



Sources:
State Energy Data Report 1960 - 1989,
Statistical Abstract of the U.S. 1990

Figure 3 - 10

Commercial Primary Energy per Square Foot



Sources: State Energy Data Report 1960 - 1989, Analysis and Technology Transfer Annual Report 1988

After steady growth to a high of 217 million Btu in 1972, energy use per household declined to 172 million Btu in 1986, but has grown to nearly 180 million Btu in 1989. Energy use per capita follows the same pattern. Similarly, while commercial floorspace has grown steadily, energy use per square foot has levelled off and slightly declined. These trends may be due somewhat to population shifts to warmer climates, but certainly reflect gains in energy efficiency of the various end uses.

PROJECTED BUILDINGS ENERGY USE

One important activity in developing the National Energy Strategy was a detailed assessment of the conservation potential in the end-use sectors of the U.S. economy. This was a three step process. First, an assessment was made of all available data on conservation potential. Second, the Energy Information Administration (EIA) used the conservation potential data to project two levels of technology penetration through 2030 and the resultant energy savings achieved by each. Third, these results were input to DOE's Fossil2 model in order to integrate them with other NES excursions.

This chapter presents results from the second activity, EIA's modeling efforts, for the buildings sector. These results are presented in detail in *Energy Consumption and Conservation Potential: Supporting Analysis for the National Energy Strategy.*

Methodology

EIA's forecasting models for residential and commercial buildings are basically accounting frameworks that carry initial snapshots of energy consumption, based on survey data from the mid 1980s, forward to 2030. Stock turnover and growth in the economy lead to the addition of new buildings, and the retirement of old buildings and equipment. The models account for these changes, correcting for the addition of more efficient buildings and equipment.

Three projections were developed. The reference case is an update and extension to the year 2030 of the base case in the EIA's *Annual Energy Outlook 1990* (AEO). The second and third projections present a High Conservation (HC) excursion and a Very High Conservation (VHC) excursion.

The original energy prices and macroeconomic drivers and all other forecast parameters are kept unchanged from the AEO 1990. The projections are made with stand-alone versions of EIA's residential and commercial models where fuel prices are exogenous. Therefore there are no macroeconomic feedbacks that would set new prices or activity levels.

The reference case is based on assumptions of a "business as usual" rate of technology change and consumer choice. It can be considered to include the level of conservation that would be achieved by improvements in the capital stock, if current government policies and programs remain in effect. It does not explicitly include efficiency improvements due to utility demand-side management programs; it does reflect Federal standards that become effective in 1990 and 1992.

The HC excursion assumes gradually increasing market penetration of cost-effective technologies and conservation. This excursion provides an estimate of conservation potential that is achievable with currently available technologies that are also cost-effective given the assumptions used for the projections. The VHC excursion estimates the technical potential for conservation, assuming that state-of-the-art technology and conservation measures penetrate the market even if they are not cost-effective.

Neither the reference case nor the excursions address the specific actions necessary to achieve improved energy efficiency.

Assumptions

Building energy consumption is a function of the insulating properties of the building shell and the characteristics of the appliances used in the building. Improved technologies for building construction, siting, and window design alter building shell characteristics (reducing the need for heating, cooling, and possibly lighting services), while more efficient equipment reduces the energy consumption necessary to meet a given level of delivered energy service. The conservation excursions assume increasing improvements in building shell integrity for both existing and new buildings, and improvements in appliance efficiencies.

Shell integrity indices relative to a base year were calculated for existing and new residential and commercial buildings, for both space heating and cooling. For example, for homes built in 1974 and earlier, a shell index for heating of 0.92 for the year 2000 was used in the HC excursion and an index of 0.84 was used in the VHC excursion. The 0.84 index for the VHC excursion, which corresponds to a 16 percent improvement over the base year,

Table 3-2
Shell Integrity Indices for Residential and Commercial Buildings

	2000			2030		
	Reference Case	High Excursion	Very High Excursion	Reference Case	High Excursion	Very High Excursion
Residential						
Space Heating						
1974 and earlier	0.96	0.92	0.84	0.90	0.84	0.40
1975 to 1987	0.98	0.96	0.92	0.96	0.92	0.40
1988 to 2030	0.91	0.60	0.25	0.89	0.35	0.15
Space Cooling						
1974 and earlier	0.98	0.98	0.96	0.97	0.96	0.78
1975 to 1987	0.99	0.99	0.98	0.99	0.98	0.78
1988 to 2030	0.92	0.75	0.60	0.90	0.60	0.40
Commercial						
Space Heating						
1986 and earlier	0.97	0.96	0.92	0.92	0.92	0.70
1987 to 2030	0.98	0.80	0.63	0.97	0.68	0.58
Space Cooling						
1986 and earlier	0.99	0.96	0.96	0.98	0.96	0.89
1987 to 2030	0.98	0.88	0.80	0.97	0.80	0.70

Source: *Energy Consumption and Conservation Potential: Supporting Analysis for the National Energy Strategy*

reflects technically feasible retrofits implemented in residences; the 0.92 index for the HC excursion assumes that one-half of the technically feasible retrofits will be cost-effective. Table 3-2 shows the shell indices used in the conservation excursions.

For appliances, the HC excursion begins with the adoption of existing standards for equipment in 1992, for both new and replacement equipment. After 1992, efficiencies are increased linearly over time, so that by 2030 they correspond to the best equipment efficiencies that currently exist. For example, the heating system performance factor for a heat pump (HSPF) is 7.3 in the reference case in 1990. In the HC excursion, this is increased to 9.8 by 2030, the latter value being for the best available heat pump in 1990.

The VHC excursion begins at the same point with the adoption of the best off-the-shelf technologies in all new applications and in the replacements for existing applications. After 1992, efficiencies are increased incrementally, so that by 2030 they correspond to the technically attainable limit. Table 3-3 gives the appliance efficiencies assumed in the forecasts.

Table 3-3
Assumed Appliance Efficiencies

	Energy Parameter[a]	Reference Case Range, 1990		High Conservation Excursion		Very High Conservation Excursion	
		Base[b]	Best	1992	2030	1992	2030
Residential							
Space Heating							
Heat Pump	HSPF	7.3	9.8	7.30	9.80	9.80	18.0
Gas Furnace	AFUE	0.72	0.90	0.78	0.97	0.97	1.80
Oil Furnace	AFUE	0.72	0.92	0.78	0.95	0.95	0.95
Electrical Resistance	Percent	0.95	0.95	0.95	0.99	0.99	0.99
Space Cooling							
Central Air	SEER	8.9	10.2	10.00	16.90	16.90	16.90
Heat Pump	SEER	8.9	10.0	10.00	16.40	16.40	21.00
Water Heating							
Electric	EF	0.88	0.93	0.88	3.50	3.50	3.50
Gas	EF	0.54	0.70	0.54	0.76	0.76	0.90
Refrigeration	kWh/yr.	954.00	515.00	976.00	515.00	515.00	400.00
Commercial							
Space Heating							
Heat Pump	HSPF	5.02	7.17	6.80	8.87	8.87	8.87
Gas Furnace	AFUE	0.72	0.92	0.80	0.92	0.92	0.92
Oil Furnace	AFUE	0.71	0.90	0.81	0.90	0.90	0.90
Space Cooling							
Central Air	SEER	10.58	12.62	10.58	17.00	17.00	17.00
Heat Pump	SEER	7.50	8.9	7.51	8.87	8.87	8.87
Water Heating							
Electric	EF	0.77	0.93	0.88	3.50	3.50	3.50
Gas	EF	0.66	0.89	0.66	0.89	0.89	0.89

[a] HSPF = Heating Seasonal Performance Factor; AFUE = Annual Fuel Utilization Efficiency; SEER = Seasonal Energy Efficiency Ratio; EF = Energy Factor

[b] Base efficiencies reflect Federal appliance standards and do not necessarily correspond to 1987 syock efficiencies.

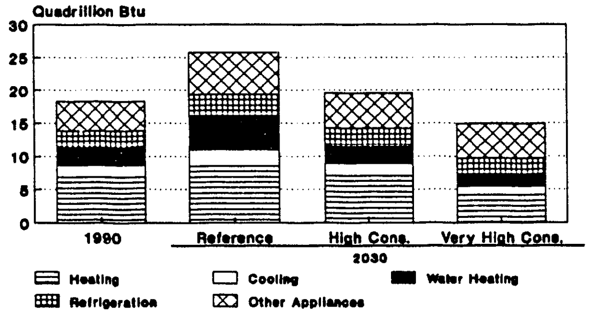
Source: *Energy Consumption and Conservation Potential: Supporting Analysis for the National Energy Strategy*

Conservation Potential

In the residential sector, primary energy consumption in the reference case increases at an average annual rate of 0.9 percent per year, reaching 25.7 Quads in 2030. In the same time, the population increases by 0.45 percent per year and the number of households is

Figure 3 - 11

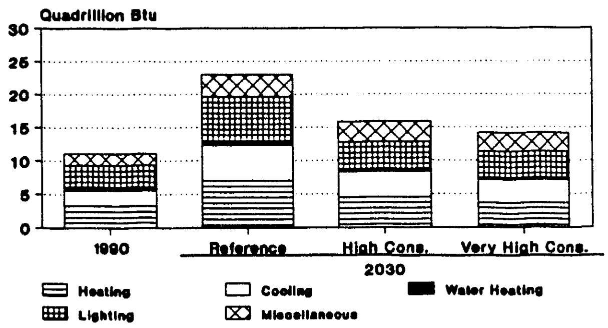
Projected Residential Primary Energy Consumption, by End-Use



Source: U.S. Department of Energy;
Energy Information Administration
SR\NES\90-02

Figure 3 - 12

Projected Commercial Primary Energy Consumption, by End-Use



Source: U.S. Department of Energy;
Energy Information Administration
SR\NES\90-02

Note: An additional 2 Quads of energy use is projected for the commercial sector, but is undistributed by end-use.

assumed to grow at a rate of 0.8 percent per year. In the high conservation excursion primary energy consumption grows at only 0.2 percent per year and in the very high conservation excursion primary consumption declines at an average rate of 0.5 percent per year to 2030. For these comparisons, electricity is converted at 3.4 Btu of primary energy for each Btu of delivered electricity.

Figure 3-11 shows residential energy consumption by end-use for each projection. Heating remains the dominant end-use except in the very high conservation excursion where other appliances, the only end use showing growth, account for approximately the same amount of energy as heating and cooling combined. In this case, the largest single source of conservation is natural gas used for space heating. This conservation is a result of more efficient heating equipment and more efficient building shells, as well as improvements in gas water heaters.

Figure 3-12 shows uncalibrated primary energy use projections for the commercial sector. Both conservation excursions result in significant reductions in energy use in 2030 relative to the reference case, although the difference between the two conservation excursions is not as pronounced as in the residential sector. Lighting improvements account for an important fraction of total savings.

In both sectors, the use of electricity increases in all cases from 1990 levels. This is due in part to the assumed lower price of electricity relative to oil and natural gas, which may lead to the selection of electric end-use devices over gas systems, and to new uses for electricity. Results from the HC excursion show, however, that it is possible to reduce electricity consumption in 2030 by 25 percent relative to the reference case in the residential sector. Savings of 30 percent are achievable in the commercial sector. Gas use shows reductions from 1990 in all cases in the residential sector; gas use increases only in the reference case in the commercial sector.

Conclusions from this analysis include: (1) there is the technical potential for significant energy savings, particularly in the residential sector; (2) under the conservation assumptions, the mix of fuels remains similar to the reference case, except that natural gas used for space heating is saved in the residential sector; (3) space heating in both sectors is an important source of potential energy savings; and (4) lighting in the commercial sector is another source of potential energy savings.

4. ANALYSIS ACTIVITIES

Analysis activities within OBT include the development and analyses of data bases, consumer decision research, international energy studies, and evaluation of current programs such as energy performance standards. The data bases contribute to our understanding of the current state of energy use and the buildings sector, and allow us to predict trends based on past experience. Consumer decision research identifies the players and factors which contribute to the success or failure of technological improvements in the marketplace, and identifies ways to speed implementation. Evaluation of energy performance standards contributes to our understanding of the real economic and technological limits and benefits from improvements in energy technologies.

DATA BASES AND ANALYSES

The data bases can be classified into two types. The first type comprises aggregated data bases that present a picture of the overall building stock of the United States, of regions within this country, or of foreign countries. The second type comprises collections of measured data on individual buildings. Examples of the first type are the Building Energy Accounting System (BEAS) data base maintained by PNL and the international data bases maintained by LBL. The Building Energy-Use Compilation and Analysis (BECA) data base maintained by LBL is the second type.

The BEAS data base provides historical and current energy use data for the residential and commercial sectors. Trends can be predicted from such data. For example, the population shift to the South can be quantified and used to redirect program goals to account for a growing demand for cooling systems in hot climates. The international data bases allow us to compare how the U.S. uses energy with energy use in other countries, and to evaluate conservation measures used elsewhere for possible adoption in the U.S. BECA compiles actual measured data on the economics and performance of implemented technologies, allowing us to evaluate their effectiveness.

Building Energy Accounting System (BEAS)

Contact: George Amols, PNL, (202) 646-5229

BEAS consists of a compilation of buildings, energy, and related data for quick access and analysis by OBT, national laboratory, and contractor staff. It includes the most current data on the existing stock of residential and commercial buildings and their energy consumption characteristics. The main purposes of BEAS are to provide data consistent with the needs of Headquarters in performing its planning and management functions, and to promote internal consistency in the use of data by DOE staff and national laboratory researchers.

BEAS is available in hard copy (Residential and Commercial Buildings Data Book); a subset of the most commonly used data is available on a floppy diskette for personal computer use. The most recent version (1988) of the Data Book includes regional data on new residential construction, appliance saturation levels and efficiencies, regional comparisons of commercial energy consumption, and energy prices for the residential and commercial sectors.

Although work on BEAS was minimal during 1989 and 1990 due to the demands of the NES development process, the data base has been updated. Most of the data presented in the historical trends section of Chapter 3 are taken from BEAS.

Buildings Energy-Use Compilation and Analysis (BECA)

Contact: Alan Meier, LBL, (415) 486-4740

DOE has supported a series of building energy-use compilations, the BECA database, for a number of years. The Buildings Energy Data Group (BED) at LBL compiles and analyzes measured energy performance data on buildings and equipment. The Group's goal is to identify building design strategies and end-use technologies that save energy, or modify electrical loads, and are cost-effective. An important research goal is to develop the wider use of "yardsticks" of building energy performance. Unfortunately, one cannot measure a building's energy use under controlled conditions. Instead, we must collect detailed information about the building, including its energy consumption, physical characteristics, and operating schedule. This information permits the conversion of "raw" measurements into standard energy performance indicators.

The major purpose of BECA is to provide feedback to researchers and building professionals. Researchers and DOE program managers are concerned with the effectiveness of energy-conserving technologies developed under DOE sponsorship. Building professionals and their clients are interested in the effectiveness of specific design approaches.

Because BECA data are compiled from other (primary or secondary) sources, they do not represent a statistically chosen sample. Nevertheless, because the most extensive compilations contain results from thousands of buildings throughout the United States, they can tell us a great deal about the nationwide energy-saving potential based on actual measurements rather than the engineering estimates and simulations which have been relied on until now.

The following sections document recent additions to the database and analysis activities. The final section is an updated summary of efforts to extrapolate BECA data to estimate potential energy savings on a national level.

Measured Results from Single-Family Home Retrofits: BECA-B Update

The "Buildings Energy Use Compilation and Analysis" (BECA) project at Lawrence Berkeley Laboratory addresses the need for retrofit performance data by compiling and analyzing data on the measured energy performance and economics of residential and commercial buildings designed or retrofitted with energy-saving features. Since the pre-

Table 4 - 1

Average Savings and Economics of Individual Retrofits, BECA-B

Measure	# of Buildings	State	% Savings	Cost ($1989)	SPT (yrs)	CCE ($1989 /MBtu)
Shell Measures						
Wall insulation	8	MN	11.9	1598	12.0	7.26
"	6	WI	20.1	1604	10.4	6.62
"	7	WI	16.9	806	5.6	3.56
Ceiling insulation	33	CA	12.7	694	5.7	4.40
"	16	CA	20.6	678	4.3	3.26
"	33,000	CO	12.5	504	6.2	2.43
"	71	MI	13.0	631	4.2	1.82
Interior foundation insulation	8	MN	15.0	2089	16.8	10.01
"	9	MN	5.6	2175	61	32.07
Exterior foundation insulation	5	MN	10.1	1343	20.7	11.53
"	6	MN	2.8	1712	127	67.30
Warm room zoning	5	MO	28.2	1583	10.6	4.69
Heating and Cooling System						
Cond. Furn. Repl. Unit	3	MN	16.1	4752	23.9	14.51
"	7	WI	23.8	2309	10.5	6.70
Forced Draft Furn. Repl. Unit	13	MN	13.3	3037	22.3	13.50
Forced Draft Boil. Repl. Unit	4	MN	13.1	3588	16.9	10.23
Furn. Repl. (Eff. Unknown)	33	WI	20.1	1864	9.6	6.08
Condensing heat extractors	43	KY	14.2	722	7.0	5.44
"	35	MN	3.8	722	22.7	15.82
Elec. vent damp. and elec. ign.	42	MN	6.6	444	14.4	10.04
Power gas burners	16	KY	5.9	556	10.7	6.42
"	14	MN	9.7	556	9.9	5.35
Flame retention burners	92	OR	22.8	556	4.8	2.81
"	19	NY	14.1	464	1.9	2.86
Central air conditioner repl.	12	TX	12.2	2757	12.9	14.2c/kWh
Hot Water System Measures						
Water heater wrap	74	OR	8.4	30	0.6	.3c/kWh
"	321	WA	4.1	47	3.8	1.9c/kWh

vious update of the single-family (BECA-B) database in 1984, there have been two major changes. Results for envelope weatherization measures have been expanded to include HVAC measures, and some high-quality submetered data are now available. We have added 63 data points, representing 16,401 houses. Data on costs and energy savings include furnace retrofits and replacements, central air conditioning replacement, envelope insulation, house-doctoring, warm-room zoning, and water heating measures. Additionally, there are some end-use monitored data on energy and peak power savings from electrical appliances.

Shell measures typically result in savings on the order of ten to fifteen percent[1]. Most HVAC measures that do not involve expensive equipment replacements result in savings of approximately five percent. Flame retention burners for oil furnaces are an exception; they result in larger savings, with a consistent five year payback. Ceiling insulation retrofits are the most cost-effective shell measure documented in the BECA data base; they also produce a consistent payback period of about five years. Water heating measures often have very short paybacks, about six months to three years.

The Wisconsin Audit Field Test found that condensing furnaces produced a 10.5 year payback at an average cost of $2100. The Minneapolis Energy Office study showed a 23 year payback for efficient but non-condensing furnace replacements. Given high installation costs, it pays to install replacement furnaces with the highest available efficiencies in cold-climate weatherization programs.

The Minneapolis Energy Office project on foundation insulation showed a 21 year payback for internal and external foundation insulation. However, where extra living space is created, this non-energy benefit may make the retrofit attractive despite a long payback period. The Urban Consortium's "warm rooms" project showed that zoning and weatherization of a limited area can produce large savings (on the order of thirty percent) at costs similar to those of conventional weatherization programs, which achieve ten to fifteen percent savings. However, zoning necessitates a change in lifestyle to achieve large savings. The Austin, Texas central air conditioning replacement study showed a 12.9 year simple payback period and a $1660 cost of avoided peak power (CAPP).

Results from the weatherization programs in our data base suggest that proper training, motivation, and final inspections were a key to consistent savings. Future work will elaborate on these initial findings, conduct additional comparative analyses, and relate BECA findings to trends in the U.S. residential stock.

Updated Results for Commercial Building Retrofits in the BECA-CR Data Base

In 1989, we updated earlier results in the BECA data base on measured savings and cost-effectiveness of commercial retrofit projects. The latest data cover 450 retrofit projects, representing over 1700 buildings. This update represents a 50 percent expansion of the initial data base (1984) on commercial retrofits and addresses new issues such as individual retrofit savings, weather and occupancy normalization, electric peak demand savings, the impact of office equipment load growth, predicted vs. actual savings, and savings persistence.

Key findings (see Figure 4-1) are:

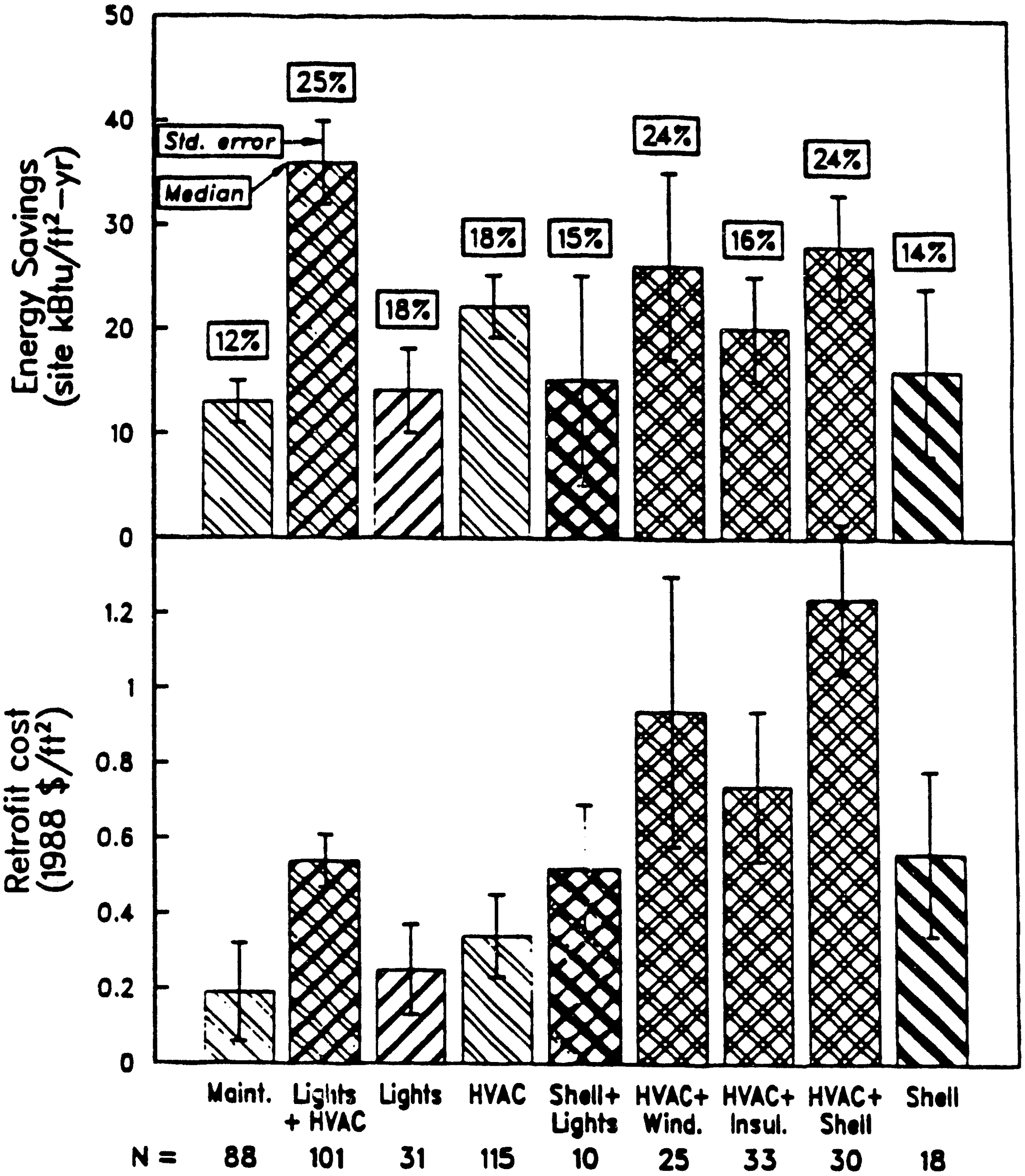
1 Unless otherwise indicated, energy savings refer to the main space heating fuel. Costs of measures are in nominal dollars. The simple payback period is based on local energy prices at the time of the retrofit.

- Median annual site energy savings amounted to 20 kBtu/ft^2, or 18 percent of whole-building usage; median retrofit cost was $0.56/$ft^2$ (1988 $), the median payback time was 3.1 years, and the median cost of conserved energy was $3.10/site MBtu. The typical building owner was willing to invest in energy conservation the equivalent of only about 8 months of energy costs.
- Changes to the HVAC system were the most popular retrofit strategy, installed in 85 percent to 95 percent of the projects in each building category (education, health, office, retail, and other). Lighting retrofits were done in over half of the offices and retail establishments, but only one-third of the health care projects and one-sixth of the schools.
- Projects with only HVAC and/or lighting retrofits had median payback times of 1-3 years, while those affecting the building shell, either alone or in combination with other measures, had payback times of 5 or more years.
- Projects in which only maintenance practices were changed typically saved 12 percent of their pre-retrofit consumption, often using in-house labor. Payback times were very short; the median was about 1 year.
- Retrofits installed after 1983 had lower savings, higher costs, and longer payback times than measures installed earlier, suggesting a decline in "cream-skimming" opportunities.
- Very few predictions of savings came within 20 percent of measured results.
- For over half of the projects there were multiple years of post-retrofit data; energy use continued to decrease for most of these buildings. However, projects reporting fuel and electricity use separately showed median electricity use increasing in each of the post-retrofit years, possibly due to growth in office equipment and other miscellaneous loads.

Before retrofit, median energy intensity for buildings in the data base was higher than that of the U.S. stock. Even after retrofit, the median for most building types was higher than the stock median, and well above that of new, energy-efficient buildings. Combined with evidence that many U.S. commercial buildings still lack even basic energy-efficiency measures, this suggests considerable remaining potential for saving energy in the commercial sector. Despite significant savings and short payback times for many projects, optimum savings are often not being achieved. This is due to limited owner willingness (or financial ability) to invest in all cost-effective measures, and to improper retrofit installation and/or maintenance. A comprehensive understanding of energy management as a process is needed, including both inspection and commissioning of installed retrofits and ongoing tracking of energy consumption as an indicator of operating problems.

Extrapolating Measured Performance of Individual Buildings to Estimate National Energy Conservation Potential

The first estimates of aggregate energy conservation potential appeared in the mid-1970s. The initial estimating procedures have not changed substantially, although assumptions are now much better researched and documented. The estimation is based on prototype units with specified physical characteristics. A prototype building might represent the "typical" single-family house, with average floor area, number of occupants, and appliance satura-



	Maint.	Lights + HVAC	Lights	HVAC	Shell+ Lights	HVAC+ Wind.	HVAC+ Insul.	HVAC+ Shell	Shell
Payback time (yrs)	1.1	1.4	2.0	2.9	4.7	5.7	6.2	6.7	8.6
CCE ($/site MBtu)	1.70	2.50	4.80	2.70	2.60	3.90	3.60	5.20	4.30
CCE ($/res. MBtu)	0.90	0.90	2.80	2.30	2.20	2.70	3.60	3.40	4.00

Figure 4 - 1
Savings and Costs of Retrofit Packages, BECA-CR

Energy savings, retrofit cost, median payback times (using national average energy prices), and costs of conserved energy of various commercial retrofit strategies, from the BECA-CR data base. Each project is assigned to the narrowest retrofit category which encompasses all retrofit measures. "Maint." retrofits are changes in maintenance priactices only. "Shell," as used here, refers to changes to both window measures, improved insulation, and infiltration reduction. Minor lighting retrofits also took place in some of the buildings assigned to the "HVAC + Wind," "HVAC + Insul.," and "HVAC + Shell" categories.

tions. Engineering calculations or computer simulations are used to estimate savings from one or more energy conservation measures. The savings for that prototype are then multiplied by a weighting factor to represent its fraction of the (national or regional) building stock.

A major drawback of the prototype-based procedure is its reliance on engineering calculations and simulation. There is no assurance that real houses, water heaters, or HVAC systems use as much energy as calculated. If the initial energy use is wrong, then subsequent calculations of energy savings from conservation measures will also be wrong. In addition, engineering calculations generally assume that conservation measures perform according to their specifications, for example, that R-38 insulation, as actually installed, will provide that level of thermal resistance, or that compact fluorescents will operate for their rated number of hours. The calculations can be adjusted to account for some of the discrepancies between nominal and actual performance, but only when these discrepancies are known and quantified.

The increased availability of monitored performance data now permits an alternative approach to estimating conservation potential, based on extrapolating measured savings from documented case studies to the whole stock. This method differs from the prototype-based procedure in its use of monitored savings rather than engineering estimates, and in using actual case studies rather than prototypes as the "building blocks." We tested this new extrapolation procedure by estimating the nationwide potential for energy-efficient space heating in existing multifamily buildings and new, electrically-heated homes.

Results from the BECA-B data base for multifamily buildings provided monitored space heating savings for over 200 projects, representing 20,000 apartment units. The BECA-B data base was not fully representative of the national stock; it over-represented larger multifamily buildings in cold climates, electrically-heated buildings, and those with high initial consumption. The Residential Energy Consumption Survey (RECS) and other sources were used to calibrate BECA results to reflect national stock and energy use characteristics. After a series of adjustments, we found that typical space heating retrofits of multifamily buildings could save abcut 0.2 Quads per year nationwide, while intensive retrofits could save 0.5 Quads. This estimate is based on monitored savings, but due to the scarcity of data for some types of multifamily buildings and retrofits, the estimates have considerable uncertainty attached to them.

We also estimated the potential space heating savings in new, electrically heated homes. While only one monitored case study was used (Bonneville Power Administration's Residential Standards Demonstration Program - RSDP), the sample was unusually large, diverse, and included a control group. Savings for 400 homes were weather- and occupancy-normalized using procedures developed for BECA. Average space heating savings were about 45 percent (2500 kWh). Four adjustments were made to this initial estimate, to account for differences from the U.S. electrically-heated stock, in terms of heating system type, floor area, climate, and initial energy consumption. The result was a substantial increase in estimated stockwide savings. We found that applying building standards equivalent to RSDP could save as much as 0.32 Quads/year, nationwide, after a decade.

This extrapolation method may give a more believable estimate of aggregate energy savings because it is based on monitored savings. Still, the method has limitations, related mainly to data availability. First, it can only include measures that have been implemented and well documented. Second, it may require information on both physical and demographic characteristics not normally compiled in either retrofit projects or stock surveys. Finally, since the case studies are often based on whole-building data, it can be difficult to estimate conservation potential associated with an individual conservation measure. As better data become available on both monitored case studies and stock characteristics, we will continue to test and refine the approach.

International Residential Energy Use Data Base

Contact: Lee Schipper, LBL, (415) 486-5057

A data base of residential energy use for eleven major OECD countries has been compiled by the International Energy Studies group at Lawrence Berkeley Laboratory. Different sources of information have been reconciled into a consistent time series from 1970 to 1987. The data base provides a consistent source of data that allows trends in European energy use to be analyzed and compared to trends in the United States. The data developed within this 12 year project have become a widely accepted reference source for international institutions, governments, utilities, and oil companies worldwide.

Countries included in the data base are: Canada, Denmark, France, Germany, Holland, Italy, Japan, Norway, Sweden, the United Kingdom, and the United States. Data variables include population, dwelling stock by type, several economic indicators, delivered energy consumption by fuel type, and climate data.

The data base is available in printed format or on diskette produced with SYMPHONY.

Environmental Projects Data Base

Contact: Barbara Farhar, SERI, (202) 484-1090

In 1989 OBT initiated the development of an inventory of OBT studies directly and indirectly related to environmental issues. The inventory is being stored in a data base developed using Oracle data base software.

Projects relating to indoor air quality, radon characterization and mitigation, infiltration and ventilation, and refrigerants are examples of the types of entries in the system. Project specific information includes the project title, type of environmental problem, pollutants, sponsoring organization, research organization, and funding levels.

INTERNATIONAL ENERGY STUDIES

Contact: Lee Schipper, LBL, (415) 486-5057

Knowledge of other countries' experiences are important for several reasons. First, progress in other countries is a frame of reference against which to judge our own progress. Second, information on other countries' energy use is needed to perform worldwide forecasts of energy availability. Third, significant drops in energy use can signal the adoption of new technologies that could be applied here. Fourth, experiences of other countries can help us evaluate the effectiveness of different kinds of energy policies.

During the past several years, the International Energy Studies group at Lawrence Berkeley Laboratory has been following residential energy use and its underlying structure in the major OECD countries, with support from OBT and others. The objectives of the work have been to 1) establish the data base of energy use in homes and buildings in OECD countries; 2) analyze the components of changes in energy use since 1973, particularly the permanence of these changes; 3) extend this analysis through the econometric work as well; 4) analyze the relationship between government conservation programs and actual savings in the residential sector; and 5) evaluate techniques or policies from overseas that may be relevant to the United States.

Work in 1989 and 1990 focused on residential energy conservation policies and programs in OECD countries, as well as examining the components of change in residential energy use. In addition, efforts continued to examine residential energy use in Venezuela.

Residential Energy Conservation Programs and Policies in OECD Countries

The International Energy Studies Group at Lawrence Berkeley Laboratory has completed a study of national residential energy conservation policies and programs in five OECD (Organization for Economic Cooperation and Development) countries. The study examined government programs designed to reduce energy (or oil) use in the residential sectors of each country, and analyzed which types of programs appeared to work well within the political context and structural changes taking place in each country. The countries are Denmark, France, Japan, Sweden, and West Germany; between 1972 and 1983 delivered household energy use declined in all of the countries except Japan.

The types of programs used by the governments are classified into three groups: those which fix the market, those which change the market, and those which alter the make-up of items on the market. This classification introduces the assumptions made by government decision-makers regarding why consumers are not behaving as desired (lack of knowledge, lack of motivation, lack of funds, etc.) and the rationales behind choosing between program types. The categories are not mutually exclusive, however. Because consumer behavior is usually determined by several interrelated factors, the most effective programs are often those which use a combination of tools from some or all of the categories, each in ways that mutually support the others.

Programs Which Fix the Market

Government decision-makers in the countries studied consistently implemented programs designed to fix the residential energy market. Such programs are based on the perception that consumers are not acting with economic rationality and are not doing so because market imperfections exist; decision-makers attempted to identify specific areas where market imperfections existed and to correct them. The two basic kinds of programs which attempt to fix the market are information and regulation.

Information campaigns aimed at changing consumers' energy consuming habits are the least predictable of program tools and tend to produce the least permanent results. In some cultural settings, advice from the government about "good" and "bad" behavior is widely accepted by the public and can be used to produce short-term behavioral changes. This can be particularly useful in times of crisis, when immediate and large-scale reductions in energy use are required. Information campaigns were used successfully toward these goals in Denmark, Japan, and Sweden following the oil price shocks in 1973 and 1979. In other settings, such campaigns can backfire and cause long-term negative impacts for the success of energy conservation. Even in countries where changes in energy-consuming habits have measurably reduced residential energy demand (for example, Denmark), the results are temporary; habit-based savings are often replaced by efficiency improvements, and tend to reverse as demands for energy services increase. Information programs aimed at encouraging investments in energy efficiency are equally unpredictable as campaigns aimed at consumer habits, but the measures adopted by participants produce more permanent savings.

The countries used various means to assemble and distribute information. Some used large, centralized agencies; other relied more on local governments. In contrast, West Germany utilized a diverse and decentralized group of institutions, and tended to rely on proven information channels, both public and private. Involving private institutions had an added advantage in that they provided information channels that consumers already trusted.

In a few cases, the governments of the study countries have used other methods of reaching the residential consumer. One of these methods is product labeling. Mandatory product labeling has been used for household appliances in the U.S., in France, and in Japan, and a voluntary program for labeling domestically-produced appliances is used in West Germany. In Denmark and France, labels are used in conjunction with the sale of residential buildings; in both countries, the home labeling programs are integrated with the national building code.

One of the most important roles of information programs is to support and encourage participation in other programs. Information programs are also important for informing the public about changes and adjustments to other programs over time; swift participant response to changes in the Swedish subsidy program clearly showed that the government had created an effective communication channel to the public.

Regulations have also been used to remove perceived imperfections in the residential energy market; requirements for individual heat-metering in multi-family dwellings and boiler inspections are two examples. These go beyond an information-providing role and are not based on the assumption that consumers are inherently market responsive. In these cases, policy-makers actually circumvent the consumer's decision-making process in the energy market.

Programs Which Change the Market

In some cases, consumers do respond to the market but the results are not seen as satisfactory by the government. When less energy consumption or more investments are desired, governments can intervene and change the market by introducing subsidies and/or manipulating the total price that consumers pay for the energy they buy. Subsidies are generally introduced when lack of capital and/or adequate financial incentive is seen as a barrier to consumer investments. Pricing and tariff schemes can dampen consumer expenditures in cases where consumers' demand for the energy they buy is price-elastic.

Subsidy programs can be seen as attempts to design investment-related information programs with less participation uncertainty: consumers are advised to make certain investments, and their acceptance of that advice is given motivation through carrot dangling. This method can be very effective in both ensuring broader participation than can be expected from information programs and in providing the subsidy-offering body control over the measures adopted by program participants. The latter factor can be used to influence the longevity of savings resulting from program participation. Subsidy programs are expensive to implement, however, and participation is constrained by the amount of money that the government is able/willing to spend: as each subsidy offered increases in value the number of interested participants grows, but the rate at which the program budget is exhausted increases as well. Thus it is difficult to reach large cross-sections of residential energy customers with subsidies without spending vast amounts of public funds. The countries in the study used tax benefits, grants and low-interest loans to subsidize energy conservation measures.

Pricing tools are among the most powerful instruments of government policies for promoting energy conservation in the residential sector. They are also the most controversial and therefore are subject to severe political/social constraints. The tools include: implementing, eliminating, or changing a tax; manipulating a tariff structure; or charging a base price not equal to marginal cost.

The motivation for and the use of pricing tools vary among the countries studied. In each country, pricing tools have been used to meet at least one of the following goals: promoting energy conservation, raising revenues (without an energy conservation objective), or encouraging fuel switching. In most of the study countries, energy pricing policy has been designed to generate revenue; promoting conservation and encouraging fuel switching have been secondary goals. Generating revenue and promoting conservation may or may not be compatible goals. A tax that is designed for the primary purpose of generating revenue may promote energy conservation and/or encourage fuel switching. A value added tax is an example of a pricing tool used for tax revenue maximization; a tax that is designed for the primary purpose of encouraging energy conservation may, however, generate progressively less revenue as consumers respond by reducing energy consumption. Therefore the goals of a government's energy pricing policy and their prioritization must be well defined before a pricing tool(s) is chosen. In practice this is often difficult because the government institutions that are responsible for pricing policies and those that are responsible for energy policies operate independently and may have conflicting goals.

Pricing tools have several advantages over other policy instruments for encouraging energy conservation. One advantage is that it is often easy to target a particular group of consumers with pricing tools. Pricing tools are attractive to policymakers because the tools' administrative costs are small compared to costs of other policy instruments. In fact, pricing tools are often used to generate revenue that far exceeds the cost of administering the tool. In addition, pricing tools are implemented through a direct channel to consumers: the consumer's energy bill.

The greatest difficulty in implementing pricing tools lies in determining, without knowing the targeted consumers' price elasticities of demand, the optimal total price that will achieve a policy goal. The problem of optimizing pricing tools is also complicated by the fact that they can cause feedback effects on the consumption of other goods and services in the economy: when total energy prices increase (or decrease) without corresponding increases (decreases) in household disposable income, consumers' ability to buy other goods and services in the economy is reduced (increased). Using pricing tools can also cause equity and efficiency problems; they tend to be regressive because low-income households spend a larger portion of their income on heating than richer ones. As energy prices increase, this relationship is exaggerated, and the economic burden on low-income households can become extreme.

Pricing tools have been used to varying extent in the study countries. The motivations behind the use of these tools has also varied greatly. The Danish government has implemented the most aggressive pricing policy, primarily using taxes. The Swedish government has done so to a lesser degree. The French government used both taxation and tariffs as pricing policy tools. West Germany and Japan have not used pricing or tariff measures. Most pricing tools were used after 1980, especially after residential oil prices fell in 1985-1986.

What was the impact of pricing policy on residential energy demand and conservation? Although one cannot separate the effects of different price increases in each country, energy consumption per dwelling for space heating fell the most in the three countries that taxed oil heavily (Denmark, France, and Sweden). In each of these countries, energy consumption per dwelling in 1986 was below the 1973 levels. In West Germany and Japan, by contrast, energy consumption per dwelling was higher in 1986. In addition, the share of dwellings using oil for space heating fell far more in the first three countries than in the latter two. The use of pricing policies in Denmark, France, and Sweden clearly accelerated energy conservation and fuel switching from oil to natural gas and electricity in existing dwellings and promoted the use of the latter two fuels in new dwellings.

Programs Which Alter the Make-up of Items on the Market

There are several tools that governments can use to intervene in the market and alter the make-up of products available to consumers. These tools can be used both in programs that remove the most inefficient products from the market and programs that add new, more efficient, products to the market. The funding of research, development, and demonstration projects is one important way that governments have attempted to get more efficient products onto the market. In Japan and West Germany Gentlemen's Agreements with appliance manufacturers have also served this purpose.

Although often difficult politically to implement, enforceable regulations that provide minimum efficiency standards for new homes, space-conditioning equipment, and appliances are the broadest reaching and most predictable tools for encouraging residential energy conservation. Because most of these products have long life-times, such regulations also produce savings that are not easily reversed. In addition, the costs associated with implementing and enforcing these regulations are usually small and marginal, since most countries already regulate such products for purposes of safety and hygiene.

The imposition of energy efficiency regulations has had a wider impact than is measured by reductions in energy use. Codes have led to reductions in the costs of many energy-saving technologies. This effect was important both in Germany and France, where thermal practices were very inefficient before 1973. As the demand for double or triple glazing increased, production costs fell. Faced with regulated construction practices, the industries that supply equipment and housing components aimed to lower costs of implementing the required energy-saving measures. In Germany, material supply companies and builders alike learned to produce new materials more cheaply and deploy them at less cost after standards were enacted; some suggest that strengthened building codes in Germany have stimulated this development. The codes led to improved construction practices, which in turn led to lower construction costs for energy-saving measures in new homes. In Sweden, where efficiency was (and remains) greater than in any other country, regulations have stimulated the market for ventilation and heat recovery, as well as for new I-beam studs. By 1984, seven competing kinds of I-beam constructions were available.

Ultimately, then, energy efficiency standards have an important impact on the marketplace. A guaranteed market for efficiency rewards innovative manufacturers, suppliers, and builders, by assuring that their markets will not be undercut by competitors whose products are less efficient and therefore can be sold for lower initial cost. These changes in the shape of the market for energy saving technologies may be one of the most important achievements of efficiency standards.

Two important issues emerge from the review of energy efficiency standards: cost-effectiveness, and the problem of acceptance of standards by those who produce the affected homes and equipment.

The cost-effectiveness of required energy efficiency measures is an important criterion in the design of energy-related aspects of the building codes (or other efficiency regulations) in each of the countries. Methods and assumptions (including important factors such as the acceptable payback period and assumed interest rate) for evaluating the cost-effectiveness of measures varied from country to country. There are few detailed cost-benefit studies documenting the economic payback associated with the quantity of thermal insulation required by individual standards. The consensus among experts in Germany, as well as studies of Denmark, and Sweden, was that requirements are "cost-effective" with the mortgage as the boundary condition for interest rate and payback. Despite the long-term cost-effectiveness of energy-efficiency measures required by standards, however, the economic drawback of increased construction or production costs is significant from both the builder's and consumer's points of view.

Building shell requirements can cause real changes in construction practice only if these changes are accepted by the construction industry. How rapidly builders respond depends in large part on the degree of cooperation between builders and housing authorities. The thermal requirements of all codes we studied were developed through government-industry negotiations. In many cases the new goals were first tested through competitions or trial houses, construction of which was supported by authorities. Such projects were widely publicized in France, Denmark, and Sweden, for example. Their success gave builders and suppliers, as well as future homeowners, confidence.

In the final analysis, efficiency standards alter the make-up of technologies on the market. But they also signal to consumers and producers the "right" level of energy efficiency, and give assurance that products that meet the standards achieve the "right" levels of efficiency. Most governments perceive that the social benefits of reducing energy use are greater than the benefits to individual building owners and occupants. Moreover, it could be argued that the individual benefits of increased energy efficiency are greater than the increased costs, but consumers are prevented from capturing these benefits because of market imperfections. Energy-efficiency standards address these issues by establishing a uniform method of accounting for energy concerns in new buildings and in new equipment. In this way, the efficiency requirements set a norm for construction practices or efficiency levels. The regulations also helped support the investment that many societies have made in know-how, i.e., professional boiler and system maintenance.

Program Design Considerations

Contextual factors, described both in terms of physical characteristics and trends toward structural change, define the appropriate energy conservation measures that can be promoted in any given case. Increased penetration of central heating and changes in household size, for example, will affect overall energy use. Examining context is the first step in conservation program design.

The second step in conservation program design is choosing the right tool or combination of tools for the task of promoting the measures identified in step one. Determining which is the "right" tool or set of tools for the task also depends on several interacting factors. The most important of these are legislative constraints (political, ideological, and budgetary), implementation constraints (the availability of infrastructure and the relationships between key institutions), and requirements for the predictability and sustainability of program results.

All of the political and ideological constraints to residential energy conservation policies and programs differ from government to government and over time. Some of these are easily identifiable by government decision makers, and thereby avoidable. These most obvious constraints provide "first-cut" criteria for eliminating inviable tools from those being considered. For example, laissez-faire policy in West Germany precluded aggressive intervention in the residential energy market. In Japan, policies aimed at producing continued improvements in the standard of living were seen as constraints to the range of tools that were viable for conservation programs.

The "second-cut" criteria for choosing tools are usually budgetary. Some programs, such as subsidies, are inherently fiscally-intensive. Others, such as regulations, can be implemented with very low costs to the government but may produce high costs to consumers affected by the policy. All programs involve income redistribution to some extent, in the sense that they create new expenses in one area and benefits from those expenditures in others. Where government budgets for conservation programs are limited, this concept can be used as the basis for forming synergistic policies for providing program funding: revenue generating programs (taxes and fees) can be used to fund revenue demanding programs, such as subsidies. With only a few exceptions, however, the revenue generating conservation programs in the countries we have studied have not ear-marked the funds to be recycled into other conservation programs. Programs that have large income-generating effects and do not provide guidelines for the redistribution of the funds they collect (i.e., where revenue is thrown indiscriminately into the national fiscal pot) can cause harmful distortions of national economies and can limit governments' ability to alter or reverse their revenue generating policies in the future. Such is the case in Denmark, where the national economy has become severely dependent on income generated through taxes on energy.

The relationships between actors, both public and private, that are responsible for designing, implementing, and responding to national programs are important determinants of the success or failure of programs. Regulatory programs aimed upstream (at manufacturers) require good cooperative relationships between the government and the industries they affect. Sweden provides a good example: the process used for developing and implementing building codes there is a success story largely because such relationships have been addressed and used to enhance the regulatory process. Strong relationships between government and the appliance industries in Japan and West Germany made gentlemen's agreements aimed at improving appliance efficiencies possible. The perceived lack of such relationships between the government and the housing construction industry in Japan limited the extent to which the Japanese government was able to influence the energy efficiency of new homes. The cooperation of industry can often be enhanced through research, development and demonstration (RD&D) programs, as was the case in France. The failure of the United States government in its attempt to implement mandatory national Building Energy Performance Standards in 1980 provides a good example of what can happen when governments attempt to design and implement such regulatory legislation without first gaining the support and cooperation of industry factions.

The availability of infrastructures for implementing programs is more important for the use of some tools than for others. Strong infrastructures are most important in the case of information programs. Such programs require an extensive network of effective institutional channels. A wide range of public and private institutions provided an effective infrastructure for disseminating information in West Germany.

Existing programs and regulations can also be seen as useful sources of infrastructure for energy conservation programs. The home loan system in Sweden and boiler inspection regulations in several countries are examples where existing programs were successfully piggy-backed by new energy conservation programs.

Using existing agencies and programs as opposed to creating new ones is advantageous for several reasons. Creating infrastructure institutions is costly and time consuming, and it is difficult to ensure their effectiveness. By accessing existing institutions, both public and private, time and expense can be held to a minimum and the risk of creating ineffective agencies is reduced. In addition, many such institutions are already trusted by the public as information sources. Efforts to create new agencies are particularly problematic when they involve stimulus at the national level for creating agencies meant to function at the local/regional level. There were several cases of programs in the study countries where new infrastructures were created for the purpose of implementing specific programs. Among these are the EPD program in Sweden and the Energy Consultant's Register in Denmark. Both of these programs were aimed at creating agencies for distributing information. In each case, the agencies proved unsustainable when funding at the national level was removed. The creation and subsequent collapse of such infrastructures can cause other important negative side-effects, such as the unemployment of displaced and isolated labor forces created under programs.

The "final cut" in choosing program tools should incorporate criteria based on requirements for the predictability and longevity of program results. Some tools produce "predictable" results and participation rates, whereas others have higher levels of uncertainty. In addition, some of them produce "permanent" savings while others produce short-term savings which are easily reversible in the long-run. Different tools are, therefore, appropriate to different conditions and goals.

Most of the problems associated with the use of each individual program tool can be avoided or alleviated by using a combination of tools aimed at achieving individual energy conservation goals. Response to information programs can be strengthened through the use of subsidies, just as participation in all programs can be maximized through effective information dissemination. Subsidy programs can be funded through revenue-generating programs, and subsidies can be used to influence consumer-investment decisions made in response to rising energy costs. Minimum efficiency standards for the energy-consuming end-use devices that consumers buy can be achieved through the use of regulation. And the acceptance of regulations can be enhanced through RD&D programs. Continued

RD&D and the adoption of known efficiency measures can be encouraged through subsidies. And subsidized RD&D programs can be used to enhance relationships between public and private institutions. In short, the most effective residential energy conservation programs are designed using a variety of tools synergistically.

Program Evaluation: Where Does It Fit In?

The last but far from least important aspect of successful residential energy conservation programs is program evaluation. Program evaluations are important both as part of the implementation process (i.e., de-bugging in a dynamic situation) and after programs are completed (i.e., enhancing the learning-curve effect). Evaluations played an important role in optimizing the Swedish home energy subsidy program, for example, and are currently a widely-sought-after commodity in countries considering the development of future residential energy conservation programs.

The current demand for well-designed and well-implemented evaluations of previous programs is difficult to meet. Although program evaluations have become more common in the United States, they are still relatively sparse in other countries (with the exception of Sweden). Even in cases where some initiative toward self-evaluation is taken, the results are often inadequate because planning and funding for evaluation efforts are seldom integrated into program design. Comprehensive evaluations require a considerable amount of data collection, before, during, and after the program being analyzed is implemented. This requires considerable advance planning. It is essential, therefore, that consideration of the requirements for providing useful evaluations becomes part of the program design process.

Residential Energy Use in OECD Countries

One goal of the International Energy Studies group at LBL has been to quantify energy saved by households in major OECD countries, both to set the overall context in which energy conservation programs and policies operate and to understand implications of changes in household energy use for the future. While it is difficult to measure the amount of conservation caused by individual programs, it is possible to compare the total change in energy demand caused by changes in the components of demand (e.g., number and size of homes and households, characteristics of homes and equipment) with changes expected from major energy conservation programs.

The present work has analyzed the components of changes in household energy use since 1973, drawing on the extensive database maintained by LBL (described above) covering the structure of energy use in homes in Japan, North America, and most countries of Western Europe. In the U.S., Japan, and the seven European countries included in this study (Denmark, France, West Germany, Italy, Norway, Sweden, and the United Kingdom), residential energy demand constitutes between 16 and 32 percent of overall primary energy consumption. In 1987, Americans consumed close to four times as much energy per capita as the average Japanese for home comfort, and almost twice what the average European uses. This difference has been closing in the last 15 years, but differences are still large.

Comparing changes in energy use is important to evaluate past performance and estimate future trends for each of the major countries. The evolution of aggregate energy consumption, whether measured in primary, delivered, or "useful" terms, hides the complex changes in components of household energy use that actually occurred. After growing steadily in the 1960s and early 1970s, household energy demand has been relatively flat in the 1972-1987 period, with the exception of Japan. Yet this stability hides enormous reductions in energy use per unit of activity for space heating and certain appliances, as well as significant increases in energy use for the same applications, caused by increases in living standards and acquisition of more heating and appliance equipment.

Space heating. Space heating is the largest component of household energy end-use in every country except Japan. Yet the relative importance of space heating has declined in all countries in the study between 1972 and 1987. This important change was caused both by the sustained growth of other end uses, particularly electricity use for appliances, as well as the decline in energy use per dwelling for space heating. Changes in the characteristics of homes, the fuels used for heating, and the intensity of space heating caused the overall changes. When these changes are examined separately, results show that the impact of reduced heating intensities in most countries was considerably greater than indicated by the heating per household figures.

Changes in the structure of space heating (population growth and household size, dwelling area, and central heating saturation) caused increases in household energy demand in almost all the study countries. Changes in the intensity of heating reduced demand in most, but not all, of the study countries. By 1987 heating use lay significantly above its 1972/3 levels in Japan and Norway, lay well below the 1972 level in the U.S. and Denmark, and hovered slightly under 1972 values in the other countries.

Heating patterns in the United States and Europe have converged. European households raised their heating comfort levels toward those of Americans; Americans lowered their heating intensity per household to that of the Europeans. A key difference remains: American homes are still 40 to 60 percent larger than those in Europe and Japan, and the gap is only closing very slowly. As a result, per capita energy use for space heating in the U.S. has remained considerably larger than that in Europe.

The implications of the historical record for future space heating demand are important. If structural growth obscured or offset conservation achievements in the past, but that growth is slowing because of saturation, then future conservation actions may have a more direct and penetrating effect on heating demand. If the present slack in prices and lack of initiative from authorities leads to a reversal of more of the savings in space heating, and if the pace of investments in improvements to existing and new homes also falls off, then household energy use for heating will grow at roughly the rate of increase in total heated area.

Homes in Sweden still have the most effective levels of insulation anywhere in the industrialized countries. Many homes in Norway and Denmark approach these levels. By contrast, the levels of insulation in the rest of Europe are much lower. The U.S. could learn from the construction and heating techniques practiced in Scandinavia. But the evolution of technology for building shells to date has been very much a local affair, so efforts to transfer technologies must pay close attention to the local conditions that influenced how these technologies were developed and implemented.

Appliances. Electricity use for appliances has been the most important component of growth in residential energy demand. Average growth rates for the 1972-1987 period varied between 2 and 4 percent per year in Denmark to 6.5 percent per year in Japan. Growth slowed between 1979 and 1984, but increased thereafter. Consumption for appliances showed little decline in absolute terms or in unit household intensity, although there were reductions in a few countries over limited periods.

If the ownership of the five major appliances (refrigerator, freezer, clothes washer, dishwasher, and clothes dryer) had increased while unit consumption had remained the same, then European households would have use 28 percent more electricity for these uses than they did in 1972. For the U.S., increased appliance ownership alone caused electricity use per household for major appliances to increase by 12 percent over 1972 consumption.

The electricity intensities (kWh/unit of service) of most electric appliances have fallen considerably since 1972, mainly as a consequence of improved technology. But unit consumption did not fall as rapidly as did intensity, because increased use of some appliances, increased size, and a wider range of features exerted an upward pressure on unit consumption.

The overall impact on household electricity use of changes in appliances varied along the same lines as did space heating. In high-income countries, such as Sweden, Denmark, or the U.S., appliance electricity use per household grew slowly. The impact of increased efficiency was sufficient to reduce or offset growth in electricity use per household generated by the increased ownership of appliances. In other countries, growth in ownership and size of appliances was more important than improvements in efficiency, so electricity use increased. Recently, however, efficiency improvements for appliances have slowed or even reversed.

Almost all energy saving from appliances came through replacement, a slow process. Savings, if any, are "permanent." Further, the supply of appliances is international; the technologies are the same everywhere. This means that local conservation programs might improve the mix of what is offered for sale and actually sold, causing energy saving even before technical improvements are put in place. But the international nature of manufacturers means that efforts to improve technologies should be international, and coordinated with efforts to improve marketing and sales of efficient appliances. Few manufacturers want to produce one product line for each country.

Savings in electric appliances, measured as percentage reductions in the intensity of new appliances over time, are roughly the same order of magnitude as the reduction in heating intensity of new housing over the pre-1973 stock. Unlike space heating, differences in efficiency of appliances between the U.S. and other countries persist. A major gap remains, particularly for freezers and refrigerators, where U.S. appliances are significantly larger than those in Europe or Japan. In general, European and Japanese appliances use 20 to 33 percent less electricity, per unit of service, than do American appliances.

Summary. In the United States, conservation in space heating and electricity used for appliances saved almost 26 percent of 1987 household consumption. In Japan, the savings amounted to approximately 10 percent of 1987 consumption. Finally, in the European countries, the savings reached 16 percent of 1987 consumption. This is true even though the actual energy use in 1987 was higher than in 1972. The disaggregated approach used in this study measured a significant amount of energy savings that are hidden with aggregate measures of energy savings. Only by disaggregating household energy demand into its structural and intensity components and analyzing the forces driving each component can we measure the impact of energy conservation on total household energy demand.

It is nonetheless difficult to measure the actual impact of energy conservation policies. The observed changes in consumption were far greater than what could have been expected from the limited number of policy measures implemented, and the observed changes often occurred before policies were even put in place. The best estimate is that, through 1987, policies were responsible for 25 to 33 percent of household energy savings in the study countries. This does not mean that policies were either ineffective or inefficient, only that other forces caused more change than did policies.

Three issues which require further attention have emerged from this work. First is the need for a careful and ongoing analysis of the patterns of household energy use. Few data are available on actual levels of insulation or other indicators of efficiency. For many European officials, "residential" was until recently a sector not even recognized in official energy balances. Without information on the structure of household energy use, analysts are unable to separate the effects of energy conservation from other changes in energy use, unable to pinpoint the savings caused by various technologies, and unable to relate the changes observed to those in the housing or equipment stock as a whole. Therefore savings caused by policies and program cannot be isolated.

Related to this problem is the quantification of energy savings from particular conservation strategies, such as retrofit insulation, and the comparison of these savings with costs. Careful observations of how energy use changes when different strategies are implemented are necessary. Very little has been done anywhere outside of the U.S. to measure the real savings before and after retrofit and estimate or tabulate the costs of these savings. Without such information it is impossible to prioritize conservation programs or allocate program funds to those areas that promise the greatest return.

The final issue in understanding the future patterns of household energy demand is that of the important but uncertain role of behavior and lifestyle. In every country examined, the impact of behavior on energy use has been studied, but the results have rarely been linked to observed changes in consumption. The behavior component of energy savings may be significant, and may reverse with lower energy prices. Understanding behavior is important for marketing energy efficiency strategies in the future. The gradual changes in peoples' lifestyles may significantly raise or lower energy demand. If these changes increase household demand, then either the expectations for energy savings may be disappointing, or the decline in household consumption caused by lifestyle changes might be mistaken for energy conservation.

Residential Energy Use and Conservation in Venezuela

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Work continued in 1989 and 1990 on a study of residential energy use in Venezuela. The first phase of the project consisted of a survey and analysis of household energy use for the city of Caracas. The second phase will extend the project to four more cities, which will account for almost 50 percent of Venezuela's urban population. The goal of the project is to provide recommendations for energy conservation and fuel-switching programs that will reduce household energy demand and increase the market share for residential gas in Venezuela.

Electricity use in Venezuela grew at an annual average rate of 10.2 percent from 1970 to 1986. Residential electricity use, which accounts for 19 percent of all electricity use, grew at 11.4 percent per year during the same period; residential electricity use per capita nearly tripled.

Residential electricity demand is driven by three major forces: electrification; ownership of electricity-using devices; and characteristics and energy intensity of these devices. Ninety-six percent of all households in Venezuela have access to electricity; electrification in urban areas is close to 100 percent and is 79 percent in rural areas. More than 80 percent of the population lives in urban areas.

The basic electricity end uses are refrigeration, lighting, and televisions. These are found in almost all households in Caracas. Ninety-five percent of all households own a refrigerator, and 3 percent have two, comparable to the penetration levels in the U.S. in the late 1970's and in Italy in the 1980's. Around 60 percent of electrified rural households in Venezuela own a refrigerator. Clothes washers are found in over 75 percent of the households in Caracas, and the use of electricity for water heating is rapidly increasing as a result of low electricity prices and the limited extension of the natural gas grid. Fewer than 2 percent of the households surveyed use gas water heaters.

Other results indicate that the intensity, or unit consumption, of energy use for refrigeration and water heating is high compared with other cities in Latin American countries and is higher than in several European countries. This appears to be a consequence of the quality and size of the appliances in the country; most available devices are oversized, old, and of obsolete design.

The extremely low energy prices in Venezuela (among the lowest in the world) are a major obstacle to implementing policy options for increasing the market penetration of natural gas and for improving the efficiency of appliances. A program of rebates might be necessary to encourage successful diffusion of efficient energy-consuming devices in an environment of low energy prices.

The results of the survey in Caracas were compared with similar studies performed in nine other Latin American countries. Inefficient use of electricity in households is common for most countries in the region. However, important structural and cultural differences between countries, regions, social groups - as well as between urban and rural areas - lead to the conclusion that no common set of efficiency measures can be applied to the whole region.

CONSUMER DECISION RESEARCH

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The research conducted by OBT is directed toward the development of improved energy-efficient technologies and building practices. For these research products to have an impact on the efficiency of energy use, they must be successful in the marketplace. While it is impossible to know in advance if a new technology or practice will achieve significant market penetration, an understanding of the factors which are likely to affect the actual success of the improved technologies is valuable in selecting a portfolio of R&D activities. It is important to choose those options which embody the attributes likely to lead to success in the marketplace; for example, the pursuit of energy efficiency without regard to cost will lead to the development of technologies which the marketplace will render irrelevant.

Consumer decision research is sponsored by OBT to improve our understanding of the technology adoption process at all levels: marketing executive, plant manager, building owner and end user. This understanding aids in the design of the R&D portfolio by identifying projects that have high probabilities of market success. Consumer decision research can also assist in improving the market penetration of energy-efficient technologies.

The purpose of current efforts is to conduct technology screening, market research, and commercialization planning to ensure the timely application of OBT-developed technology by U.S. industry. There are three main objectives: 1) screening and identifying promising equipment and practices which are ready to be commercialized; 2) assessing decision processes and other factors that significantly affect the likely market acceptance and penetration of these technologies; and 3) conducting commercialization planning and strategy development to overcome identified adoption barriers. Work in FY 1989 and FY 1990 focused on the second objective.

Factors Influencing the Use of Commercial Daylighting

Numerous studies show that lighting is the largest energy use in commercial buildings. Reductions in energy consumption by lighting are achievable with daylighting; some estimates of load reduction run as high as 50 percent. Not only can daylighting reduce the total energy used, it can cause the greatest reduction to occur during peak mid-day periods when it is most needed.

In 1988 a systematic examination of all technologies and practices under development by (then) BCS was conducted, to identify those that are near commercialization and would benefit from assistance. Daylighting was selected for immediate commercialization assistance, and two focus groups were conducted to begin to understand why daylighting practices are not widely used. Results of these efforts were summarized in the 1988 *Analysis and Technology Transfer Annual Report*, and are included in the references for this report.

During 1989 a national survey of over 300 commercial design architects was conducted to develop baseline information on their knowledge, perceptions, and use of daylighting in commercial building designs. Insight from the focus groups was used to identify issues for the survey. In 1990 a seminar was held to determine the educational needs of architects that do not currently incorporate daylighting into their building designs.

National Survey

In the survey, daylighting was defined as the intentional use of natural light as a partial substitute for artificially generated light. Except for recent graduates, architects of varying lengths of experience were well represented in the survey sample. Less than five percent of the sample had been in practice for five years or less. As a result, the use of new commercial daylighting practices, which may have been taught in schools of architecture during the last five years, may be under-represented in the results.

Analysis of survey results indicate that architects spend very little time designing daylighting systems. Only 20 percent of the architects reported being *very* familiar with commercial daylighting, while another 60 percent reported being *somewhat* familiar with daylighting practices. The survey results indicate that larger architectural firms more frequently use commercial daylighting in building designs. The survey did not explore the issue of whether the architects and/or the firms for which they work specialize in designing any particular types of buildings.

According to the architects who responded to the survey, the primary benefits of using daylighting in commercial buildings are energy conservation/savings and aesthetics. However, when asked their opinions about different positive and negative attributes of commercial daylighting, the architects were very positive about the aesthetic enhancements provided by daylighting and the increased satisfaction of building occupants and less positive about the potential energy savings. The architects were concerned about the initial cost of designing and installing a daylighting system as well as about increased maintenance costs. These concerns indicate that architects are not convinced of the cost-effectiveness of daylighting in commercial buildings.

Architects listed several problems associated with daylighting designs. The most frequently mentioned problems were related to lighting controls and heat gains. Other, less frequently mentioned problems included glare or light intensity, availability of sufficient lighting during cloudy days, heat loss, and design difficulties.

The length of a payback period for different aspects of a building's design is a very important consideration to architects. The architect's ultimate objective is to meet the needs of his or her clients, a goal which may mean not recommending a particular type of energy-efficient design. Architects most frequently felt that the longest payback period a client would accept was five years. However, when asked the payback period for commercial daylighting, the responses ranged from five to ten years. Obviously if architects feel their clients will only accept a five-year payback period and they estimate the minimum payback period for daylighting to be five years, they will be reluctant to recommend daylighting in their designs.

The architects were asked to rate other, situational factors that might influence the architect's decision to use daylighting. The intended function of the building was rated as the most important factor, closely followed by the local climate and the building's intended occupants. Overall, building codes were not considered to be a very important situational factor; however, 40 percent of the architects did consider it to be so. Previous research has shown that building codes in some locations across the country can have a negative impact on the use of daylighting.

Survey responses indicate that architects most frequently turn to trade magazines to acquire information about new building materials, products, and design features. Sweets catalog was the other important source of information for learning about new products and materials. Secondary types of information sources included technical trade journals or architecture journals and advertising provided by manufacturers and sales representatives.

Architects were generally aware of, though not very familiar with, computer-aided design (CAD) programs. Many of the architects expressed an interest in CAD software systems; however, they emphasized that the systems must be easy-to-use and must require very little time.

Commercial Daylighting Seminar

For daylighting to be effective in the overall design of a building, a number of factors must be taken into account. Some of these include: 1) the costs and benefits of daylighting as related to the total building energy performance are complex because fenestration and lighting systems interact with most other major building systems; and 2) occupant satisfaction with the lighting system is crucial in order to prevent overriding the control systems.

There is a general consensus that the major barriers to the use of daylighting for energy conservation purposes are lack of information, experience and design guidelines and tools, as well as high initial costs for materials and consulting fees. In order to increase the proper use of daylighting for conservation purposes there needs to be an educational outreach program geared at architects, and market research to assess the knowledge, priorities, and purchase decisions of building owners and engineers. After all, architectural firms are service organizations and they must develop designs they believe their clients want.

The objective of this task was to assess the daylighting educational needs of architects that do not currently incorporate daylighting for energy conservation purposes into their designs. Besides knowing their educational needs it was important to evaluate the best methods for reaching architects and lighting designers with information about daylighting. In order to keep costs down, this task focused on architects in the Pacific Northwest. This allowed PNL to take advantage of the recently opened Lighting Design Lab in Seattle.

Seattle City Light developed a four hour seminar reviewing the fundamentals of daylighting in commercial buildings with an emphasis on energy conservation. A sample of architects in the Seattle area that do not currently incorporate daylighting for energy conservation purposes into their designs were recruited for participation in the seminar.

Before the seminar the architects responded to a short questionnaire assessing their prior knowledge about daylighting, what design tools they currently use, and so on. After the seminar the architects and lighting designers were given a second questionnaire that evaluated what they learned from the seminar. In addition, the questionnaire inquired about their satisfaction with the seminar's content, other information they would like about commercial daylighting, and in what form they would like to receive additional information.

A follow-up questionnaire will be administered approximately six months to one year after the seminar to see whether the seminar participants have incorporated daylighting into any of their designs, and if so, what problems they may have encountered, their client's satisfaction with the results and future intentions toward the use of daylighting. If daylighting has not been incorporated into any of their designs it will be important to find out why.

Building Standards Adoption Process

Energy conservation standards provide design requirements which affect energy consumption of building systems. The intent of standards is to improve energy efficiency in buildings at reasonable costs. The ASHRAE Standards are the most widely recognized model document for criteria on energy conservation in new buildings. While not legally binding in the non-Federal building sector, the ASHRAE Standards form the basis for most state and local building conservation codes. These standards have been developed via a national voluntary consensus procedure, of which 90A-1980 is a revision to 90-75 and 90.1P is a revision to 90A-1980. The current status of building energy codes is discussed briefly in Chapter 3.

There are several federal actions that could be taken to accelerate adoption and compliance of new building standards. These actions might include: 1) support demonstration programs, 2) provide analysis of what conditions lead to greater compliance of existing standards, 3) support study of the state and local standard adoption process, 4) design a marketing effort to win over building organizations early on in the development of new standards, and 5) support the development of new, user-friendly design guidance computer software. Many of these activities are currently being supported by DOE to accelerate the adoption and compliance with the new ASHRAE 90.1P building standards and the DOE Interim standards. The Federal standards program is described later in this chapter.

The goal of this project was to review the state and local standard adoption process that was undertaken in response to the ASHRAE standards, 90-75 and 90A-1980 and 90.1P. The objective was to identify the factors that lead to greater compliance and/or more stringent standards and to discover what problems and barriers were encountered by states and local municipalities.

A literature review was conducted to review the adoption of standards by state and local governments during the last 20 years. This provided an opportunity to take a snapshot view of where the states currently are at with regards to their building energy standards. One goal of the review was to identify institutional--legal, organizational, and political--barriers that have been encountered by the adoption of building energy standards for new commercial buildings by state and local governments. Another goal of the review was to identify factors that lead to greater compliance and/or more stringent standards. It is important for the new building standards to be adopted; however, to achieve maximum practicable improvement in energy efficiency, the standards must be used. An effort was made to review how well the standards have been enforced, what factors were important in facilitating their enforcement and what problems were encountered by code officials at the local, state and federal levels.

Telephone interviews with state and local building/code officials were conducted to supplement the findings from the literature review. Due to a limited budget only two states, Arizona and New Mexico, were selected as case studies. These two states are close in proximity and most of the commercial building growth is occurring in only a few major cities. Arizona and New Mexico share many similarities, but they are quite dissimilar in their energy codes. Arizona's building energy codes are based on the 1977 Model Code for Energy Conservation while New Mexico's are based on the 1988 Model Energy Code.

By examining an "early adopter state" such as New Mexico, valuable insight was gained as to the obstacles and solutions that were encountered, factors that lead to greater compliance, and enforcement issues that surfaced. Whereas studying a "laggard state" such as Arizona, information was gathered on why the state has been reluctant and/or unable to adopt more stringent building energy codes.

Another goal of the telephone survey was to receive suggestions on ways to facilitate the adoption of new building standards. Information was sought on the best strategies to use, design and compliance aids/tools that are needed, as well as types of technical assistance. Questions were asked about problems or barriers the code officials foresee with the adoption and enforcement of new commercial building energy standards.

APPLIANCE AND BUILDING ENERGY STANDARDS

Federal legislation requires that energy efficiency standards, test procedures, and a labeling program be developed for a number of residential consumer products. The Federal Trade Commission is directed to prescribe the energy efficiency labels while DOE is responsible for the development of test procedures, consumer education, and for reviewing and establishing appliance energy efficiency standards.

Federal legislation also requires DOE to develop and issue energy performance standards for the design of new residential and commercial buildings. The following sections describe OBT activities in these two areas.

Appliance Standards

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The Energy Policy and Conservation Act, as amended by the National Energy Conservation Policy Act, by the National Appliance Energy Conservation Act of 1987, and by the National Appliance Energy Conservation Amendments of 1988, provides energy conserva-

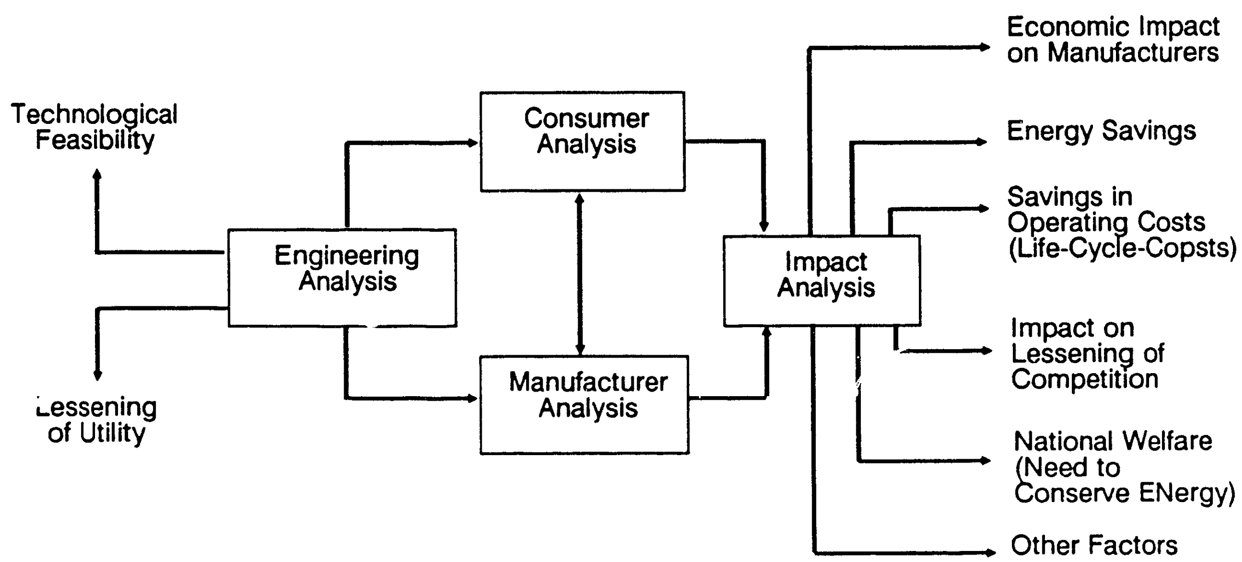

Figure 4 - 2
Appliance Standards Analysis

tion standards for 14 types of consumer products[2] and authorizes the Secretary of Energy to prescribe amended or new energy standards.

LBL's assessment of the standards, since 1979, is designed to evaluate their economic impacts according to the legislated criteria (see Figure 4-2).

The economic impact analysis is performed in four major areas:

- An Engineering Analysis, which establishes the technical feasibility and product attributes including costs of design options to improve appliance efficiency.
- A Consumer Analysis, which forecasts appliance sales, efficiencies, energy use, and consumer expenditures to 2030.
- A Manufacturer Analysis, which provides an estimate of manufacturers' response to the proposed standards. Their response is quantified by changes in several measures of financial performance.
- An Impact Analysis, which provides an integrating framework for assessing the costs and benefits of appliance standards. The Impact Analysis includes a consumer Life-Cycle Cost Analysis, a Utility Analysis, an aggregate Cost-Benefit Analysis, and an Industry Impact Analysis.

The Engineering Analysis establishes appliance designs and related attributes such as efficiency and costs. Based on these costs, the Manufacturer Analysis predicts retail prices for use in the Consumer Analysis. Based on the relationship between the prices and efficiencies of design options, the Consumer Analysis forecasts sales and efficiencies of new and replacement appliances. The Manufacturer Analysis determines financial impacts on typical firms within the industry.

The Consumer Analysis also forecasts energy savings and consumer expenditures for the purchase and operation of the appliances. Consumer expenditures are used in the Life-Cycle Cost Analysis to determine consumer impacts. Based on the projected energy savings, the Utility Analysis calculates changes in sales, revenue, need for new generating capacity, and marginal costs of electric utilities.

In FY89 and FY90, we analyzed the impacts of proposed updates to standards for refrigerators, refrigerator-freezers, and freezers; small gas furnaces; dishwashers; clothes washers; and clothes dryers. Potential energy savings were demonstrated for these products, and standards levels were identified which are projected to save energy and to save money for consumers, without undermining the financial health of the appliance industry.

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2 The fourteen covered products are: (1) refrigerators, refrigerator-freezers, and freezers; (2) room air conditioners; (3) central air conditioners and heat pumps; (4) water heaters; (5) furnaces; (6) dishwashers; (7) clothes washers; (8) clothes dryers; (9) direct heating equipment; (10) kitchen ranges and ovens; (11) pool heaters; (12) television sets; (13) fluorescent lamp ballasts; and (14) any other product so classified by the Secretary of Energy.

A substantial effort was dedicated to projecting the impacts of an expected elimination of chlorofluorocarbons in new household refrigerators and freezers in the 1990s.

In FY91, we will analyze proposed energy efficiency standards for 9 products -all those in footnote, except refrigerators, refrigerator-freezers, and freezers; central air conditioners, and heat pumps; dishwashers; and clothes dryers. We are also performing an analysis of alternative policies for improving the energy efficiency of lighting, in residential and commercial buildings.

Engineering Analyses of Appliance Efficiency Improvements

The economic impacts of appliance efficiency standards depend largely on the relation between cost and energy consumption of a consumer product. Our engineering analysis seeks primarily to identify this cost consumption relation for selected appliances. In FY89 and FY90, we analyzed refrigerators, freezers, dishwashers, clothes washers, clothes dryers, and small gas furnaces. Two legislative requirements were addressed: estimating the maximum technologically feasible design options, and ensuring that new designs do not lessen consumer utility.

Our analysis selects appliance classes, baseline units, and design options, determines maximum technologically feasible designs and the efficiency improvement provided by each option, develops cost estimates, and generates cost-efficiency relationships. Data are obtained through contacts with trade organizations and manufacturers, from computer simulations, and from suppliers of purchased parts and materials. Public comments on a previous notice of proposed rulemaking (NOPR) for refrigerators, freezers, small gas furnaces, and televisions were reviewed and a reanalysis was performed for refrigerators and freezers. In the reanalysis it was assumed that the use of chlorofluorocarbons (CFCs) would be phased out by the mid 1990s. Therefore, substitutes for CFC-11, used in the insulation, and CFC-12, the refrigerant, were evaluated for the reanalysis. These analyses were used in the final notice of rulemaking published by DOE in November 1 of 1989.

For dishwashers, clothes washers, and clothes dryers, we completed an engineering analysis which was used by DOE for a NOPR for these three products. Public comments for these three products were incorporated in a reanalysis. The final notice of rulemaking is expected in early 1991.

In FY91, we plan to perform new analyses for nine products: water heaters, pool heaters, direct heating equipment, mobile home heaters, fluorescent ballasts, room air conditioners, ranges/ovens, televisions, and clothes washers. We will also analyze technologies for improving lighting efficiency.

Assessment of Impacts of Appliance Standards on Manufacturers

The Manufacturer Analysis assesses the impact of appliance standards on the profitability and competitiveness of the various appliance manufacturing industries to be affected by mandatory energy efficiency standards. The primary tool used for this evaluation is the

Manufacturer Impact Model (LBL-MIM). LBL-MIM uses engineering cost and efficiency estimates as well as economic and financial data for this analysis. Outputs include price, rate of profit, shipments, revenues, net incomes, and the standard errors for these estimates. LBL-MIM also provides estimates of retail prices used by the Residential Energy Model (LBL-REM) and by our life cycle cost analysis.

In FY89, we used LBL-MIM to prepare a final analysis of refrigerators, freezers, and small gas furnaces, and in the preparation of a Technical Support Document (TSD). In addition to the standards analysis, a regulatory impact analysis for the case of more costly chlorofluorocarbons (CFCs) was done. We also generated estimated retail prices for CFCs. An analysis and a TSD for dishwashers, clothes washers, and clothes dryers were completed in FY90.

Our results continue to indicate that federal energy efficiency standards are not likely to have a drastic impact on profitability because of the industry's ability to pass on variable costs with a markup.

We revised LBL-MIM to include the specification of a discount rate which allows LBL-MIM to better use data from LBL-REM. We had LBL-MIM reviewed by an external panel of representatives from industry, academia, and the Environmental Protection Agency. The review panel reviewed LBL-MIM's modeling approach and economic assumptions to identify strengths and areas for improvement. We also plan to more strongly integrate LBL-MIM's demand modeling with LBL-REM.

Residential Energy Demand Forecasting

The LBL Residential Energy Model (LBL-REM) provides estimates of the impacts on consumers of federal policies affecting energy consumption by home appliances, including furnaces and air conditioners. LBL-REM combines engineering estimates of possible appliance designs with a simulation of market behavior for the purchase of appliances, including fuel choice, efficiency choice, and usage behavior (see Figure 4-3).

LBL-REM has been improved this year by: explicitly modeling the elimination of chlorofluorocarbons (CFCs) from household refrigerators, refrigerator-freezers, and freezers in the 1990s; adding the capability to project household consumption of water and of hot water, and water and sewage costs, as a function of ownership and characteristics of clothes washers and dishwashers; preliminary analysis of uncertainty arising from key variables, including projected energy prices and purchase prices of efficient appliances.

The model was used to perform several analyses of impacts of federal policies on consumers and on national energy consumption, including: supporting DOE's promulgation of more stringent standards for refrigerators, refrigerator-freezers, freezers, and small gas furnaces; and of new standards for dishwashers, clothes washers, and clothes dryers.

In addition, LBL-REM results were used to analyze impacts on manufacturers, electric utilities, and the environment.

We plan to continue to model impacts of any proposed federal conservation standards, including incorporating into LBL-REM any new data from public comments on the advanced notice of proposed rulemaking for nine products. The future analysis of room air conditioners, water heaters, direct heating equipment, and pool heaters will be performed on a regional basis. We will develop new projections of energy consumption for televisions, mobile home furnaces, fluorescent lamp ballasts, and ranges and ovens. We will continue to improve the consumer analysis and forecasting capabilities of LBL-REM, and to enhance the capability to analyze uncertainty.

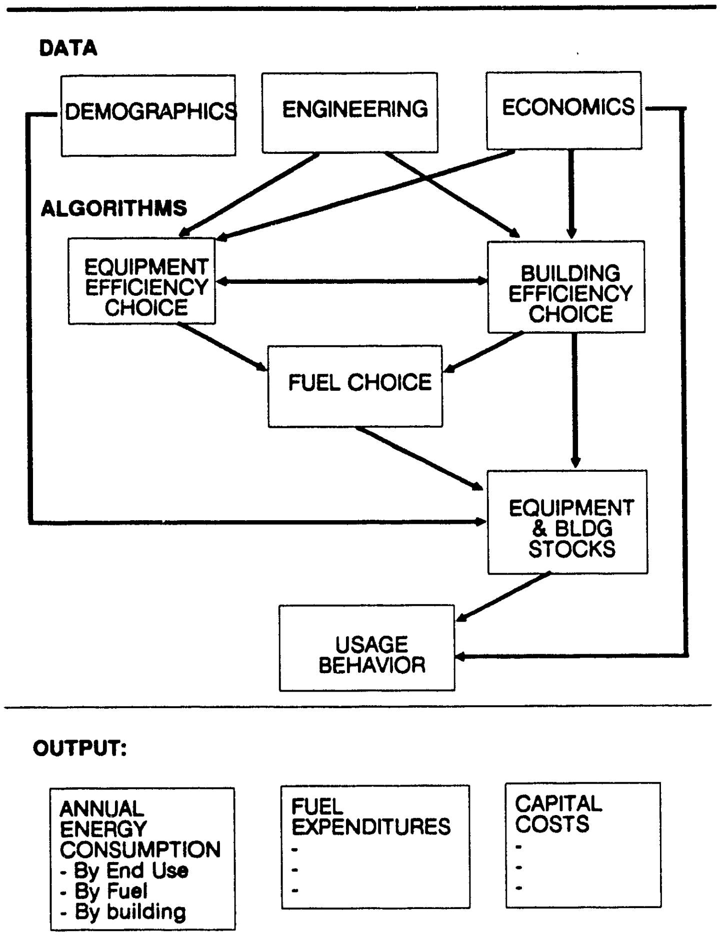

Figure 4 - 3
LBL Residential Energy Model

Energy, Economic, and Environmental Impacts

Cumulative primary energy savings from 1990 to 2015 due to standards enacted as of December 1990 are projected to be 21 quads. Large energy savings (2.5 quads) are projected for refrigerators, followed by water heaters and central air conditioners. Peak power requirements are expected to be significantly reduced due to refrigerator/freezer standards alone.

Cumulative net consumer savings over the period 1990 to 2015 are projected to be $44 billion (1987 dollars). Consumers will pay slightly more to purchase the more efficient products, but will recover that investment within a few years from a decrease in the amount owed on utility bills. Electric utilities are projected to lose some revenues as a consequence of reduced electricity sales, but they will also avoid some costs. In particular, several generation plants are projected to be deferred, as many as 9 GW (including peak-power requirements plus a 20 percent reserve margin) because of standards on refrigerators and freezers alone. For these products the cost of conservation is 1.4-1.9 cents/kWh.

Annual air pollutant emissions in 2015 are projected to be reduced by 1.5-2.0 percent because of the appliance standards. Cumulative reductions of 345 million tons of CO_2, 2.8 million tons of NO_2, and 4.3 million tons of SO_2 are projected from 1990 to 2015.

Household refrigerators and freezers use CFCs as refrigerants and as blowing agents in the foam insulation, totaling about 2 pounds of CFCs per appliance. Engineering designs for refrigerators and freezers have been identified which can eliminate CFCs in the 1990s, while achieving energy performance standards.

Building Energy Standards

In response to a growing awareness of the need for standardized conservation measures in the building industry, Congress passed the Energy Conservation Standards for New Buildings Act of 1976. This Act requires DOE to issue energy performance standards for the design of new buildings. These standards are to be voluntary guidelines for the nonfederal sector and mandatory, by agency adoption, for the federal sector.

These performance standards are an energy consumption goal or goals to be met without specifying how to achieve the goals but specifying the requirements criteria and evaluation methods to be used. The standards are to be designed to achieve the maximum practicable improvements in energy efficiency and increases in the use of nondepletable sources of energy. DOE is also charged with encouraging States and local governments to adopt and enforce the standards. Amendments to the law added the requirement for interim standards and demonstrations prior to final standards.

Design standards for building conservation fall into three categories: (1) federal residential buildings; (2) nonfederal residential buildings; and (3) commercial buildings. The federal residential standards, which are mandatory, address single-family and multi-family low-rise buildings (three stories or less, primarily military housing). The nonfederal residential standards, which are voluntary, generally address the same type of buildings as those in the first category. The commercial building standards also address multi-family, high-rise residential buildings.

Commercial Buildings

Contact: Ron Jarnigan, PNL, (509) 375-3813

DOE published interim energy conservation standards for the design of new commercial and multifamily buildings in January 1989. These interim standards became mandatory for all federal agencies in July 1989; they serve as voluntary guidelines for the private sector. Energy savings from using the standards are estimated to be 10 to 25 percent, depending on building type and climate.

Central to the development of the standards was DOE's close interaction with the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). ASHRAE develops the consensus industry standards that form the basis for state and local energy conservation standards. ASHRAE issued a standard similar to DOE's in late 1989, ASHRAE/IES Standard 90.1-1989.

DOE initiated a project to accelerate the adoption of these interim standards in the spring of 1990. The objective of the project is to develop guidelines, training materials, and programs for architects, engineers, and state officials on the new DOE and ASHRAE energy conservation standards. Part of the project is to conduct a highly publicized national "High Value, Energy-Efficiency Building" design competition and to monitor the successful designs built for the competition.

The standards are currently being studied to determine how they affect designers, builders, and other users. Also being examined are how the standards affect construction costs and the magnitude of energy savings. The results of this assessment will be reported to Congress and incorporated into the final standards.

The interim standards cover the following areas: lighting; exterior envelope (walls, windows, and roofs); electric power and distribution; heating, ventilation, and air conditioning (HVAC) systems and equipment; service water heating; energy management; auxiliary systems and equipment; and energy conservation in new building design by systems analysis. The range of elements covered is broader than in earlier standards, which did not address such important building envelope considerations as building orientation, configuration, glass placement and shading, or the relationship of the building envelope to the internal loads.

Each section of the standards that describes a major building component - for example, lighting or building envelope - includes a description of the principles of energy-conserving design for that component, followed by its minimum, prescriptive, and systems performance requirements.

Residential Buildings

Contact: Allen Lee, PNL, (503) 230-7584 (Federal Standard)
Todd Taylor, PNL, (509) 375-2676 (Voluntary, non-Federal Standard)

DOE published interim energy conservation standards for the design of Federal residential buildings in August 1988. The objective of the interim standards is to help ensure the design and construction of cost-effective, energy-efficient homes. The standards were designed to be mandatory guidelines for all Federal agencies that design and construct residential buildings.

What distinguishes the interim standards from other standards is the use of computer software and microcomputer technology. The Federal residential standards involve a unique computer software package that integrates economic and energy analyses of residential energy conservation options. The program, called COSTSAFR (Conservation Optimization STandard for SAvings in Federal Residences), was designed to simplify the process of selecting optimal energy conservation measures.

COSTSAFR determines the most cost-effective set of energy conservation measures for a specific type of residential building in a given location using local climate characteristics, local costs, various housing types, and alternative fuel types. This set of measures is expressed as a total point score, which, in turn, serves as the energy consumption goal for the design of the Federal residential building.

COSTSAFR is designed to provide detailed information on the interaction of up to 30 energy conservation measures in nearly any U.S. location for any of several building types, including single-family and multifamily residences and manufactured homes. COSTSAFR allows comparison of alternative designs with the performance compliance requirements of the standards.

The standard incorporates a comprehensive cost database for residential energy conservation options for various housing types throughout the country. The standard permits tradeoffs between equipment and envelope efficiency improvements based on cost-effectiveness criteria. Economic analyses have estimated that use of the standard will save $27 million over a five-year period.

A demonstration project has been undertaken to assess the impact of the standard on federal agencies, designers, the design process, builders, and the cost of construction. The project will also assess the savings of the standard by energy type; the analysis will be conducted in at least five climatic regions.

Recommendations for the voluntary residential standard were developed by ASHRAE in 1987 and 1988, in an effort to represent many potentially affected groups in the development process. Development of the interim standard continued through 1989 and 1990; economic and environmental analyses were completed in August 1988. The draft interim standard is scheduled for issuance in late 1990.

5. TECHNOLOGY TRANSFER

Contact: Martin Broders, ORNL, (615) 576-2731

The mission of the U.S. Department of Energy (DOE) Office of Building Technologies (OBT) is to lead a national effort to achieve maximum, cost-effective energy productivity in the buildings sectors. To achieve this mission, OBT is generating new technologies, research findings, methods, and databases in a wide range of building performance areas. The OBT technology transfer program attempts to promote adoption and use of these research and development results.

The OBT technology transfer program seeks to enhance the adoption process by developing and implementing a system to transfer R&D results quickly, efficiently, and effectively to private- and public-sector users. The program supports technology transfer activities that will have a long-term, positive impact on the design, construction, and maintenance of energy-efficient buildings and community systems. Our focus is on promoting familiarity and confidence in OBT products.

To supplement the technology transfer activities of OBT program managers, the program funds technology transfer projects that (1) are crosscutting in nature, (2) benefit from standardized formatting, or (3) have significant economies of scale. Projects generally fall into the following categories:

- needs assessments to determine future technology transfer directions,
- university education and practitioner training,
- preparation of research and progress reports on OBT R&D efforts,
- development and dissemination of design and decision tools,
- technical exchange, including conferences and workshops,
- support to program managers, and
- evaluation and tracking of technology transfer activities.

This chapter provides an overview of the specific projects undertaken over the past year with support from the program; it covers only FY 1989.

NEEDS ASSESSMENTS

Technology Transfer Planning

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A technology transfer plan is being developed to define steps that OBT should take to move its technology transfer effort forward in the most effective manner and in a way that fits overall OBT program goals. The plan will be coordinated with the technology transfer approaches developed as part of the National Energy Strategy.

The planning task is guided by the assumption that OBT should increase its effectiveness in transferring buildings energy technologies by linking with existing programs. An interlaboratory OBT Technology Transfer Advisory Group has been formed, with representatives from DOE/OBT, ORNL, Pacific Northwest Laboratory (PNL), Lawrence Berkeley Laboratory (LBL), and SERI to review the current program, brainstorm technology transfer approaches, identify applicable research results, and develop a framework that OBT management can use in deciding on the best investments of technology transfer resources. The Advisory Group is approaching the problem of technology transfer from the standpoint of national interest. When the group's mission has been accomplished, it will disband.

During 1989, several key activities have occurred. A detailed inventory was completed of recent and current technology transfer products, projects, and events. Technology transfer planning issues were defined within the context of OBT strategic planning. Some OBT program managers were interviewed about technology transfer. OBT technologies and products to transfer were identified, and technology ideas and initiatives were discussed and developed. Opportunities for linkages with existing programs such as the DOE Federal Energy Management Program, the Federal Laboratory Consortium, and federally assisted housing programs were discussed and developed. A framework to help in selecting technology transfer activities is being created.

OBT program managers expressed three common concerns during their interviews:

- they asked about the existence of empirical evidence of what works in technology transfer,
- they emphasized that networking is essential, and
- they asserted that OBT management should provide leadership emphasis and support to technology transfer activities.

Several examples of new ideas and initiatives include

- a Building Efficiency and Conservation Network (BEACON) to compile performance information, monitor technology advances, and transfer information to the buildings industry;
- a Technology Transfer Manual for OBT program managers and principal investigators;
- a Building Energy Technology Transfer Roundtable involving trade and professional organizations and other users; and
- a Technical Review Panel for technology transfer.

A technology transfer plan was developed in 1990 and is described in Chapter 2 of this report.

The Development of a Technology Adoption Strategy for the Existing Buildings Efficiency Research Program

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Applied Management Sciences, Inc., has developed a technology adoption strategy for the Existing Buildings Efficiency Research Program (EBER) with assistance from ORNL and support from both the EBER and the OBT technology transfer programs. The project report:

- characterizes the building energy retrofit service industry,
- describes the technology adoption process within the industry,
- identifies paths through which new retrofit technologies and practices are adopted, and
- develops a technology adoption strategy to support the DOE program.

The final report on the project was completed in May 1989.

Advanced Housing Technology

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The objective of this cooperative research program is to identify new and emerging technologies that could find application in the home building industry to improve product quality, energy efficiency, and cost effectiveness and to enhance the viability of the U.S. housing industry in an increasingly competitive international environment. A plan will be developed for advancing the adoption of selected innovative technologies that appear most promising in meeting the objective. The plan will emerge from an investigation of product and process innovation in the home building industry. In addition, NAHB/NRC proposes to develop an industry-wide program of quality improvement that can be implemented through the Home Builders Institute, the educational and training arm of NAHB.

The project team consists of NAHB/NRC; Arthur D. Little, Inc.; and the Massachusetts Institute of Technology. The project is scheduled to be completed in 1990.

UNIVERSITY EDUCATION AND PRACTITIONER TRAINING

Summer Institute on Energy and Design

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The Summer Institute on Energy and Design provides university faculty with resources to teach architecture students how to design energy-efficient buildings. It also informs design faculty of current OBT R&D activities and provides a forum for the exchange of information on the future research agendas of government, private industry, and the academic community. The Institute occurred annually between 1981 and 1987 and again during the summer of 1989.

The 4-day Institute involves a variety of half- and full-day workshops and field trips. The workshops are led by professors of architecture and are supported by resource notebooks that are subsequently used by participating faculty in their design courses.

In order to attract faculty from across the country, the Institute has been held at several different universities, including the Massachusetts Institute of Technology, the University of Miami, the University of Oregon, and the University of Washington. Approximately 380 faculty from more than 90% of the schools of architecture in the United States have participated. Evaluation forms completed by these participants and informal testimonials indicate that the Institute is a highly sought after educational development opportunity for architecture faculty.

The 1989 Summer Institute was held at the University of Washington in Seattle in July 1989, in cooperation with the University's School of Architecture. Nine faculty-led workshops were presented during the Institute, as selected in consultation with the Society of Building Science Educators. Approximately 60 architectural educators and guests participated in the workshops, lectures, field trips, and presentations.

Institute on Energy and Engineering Education

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The objective of the Institute on Energy and Engineering Education is to provide engineering educators with a variety of resources to help teach engineering students how to design energy-efficient buildings. The Institute provides a method of transferring the knowledge base of energy-efficient building design to future engineers. It creates a vital communications link between academic, government, and industry researchers and building design professionals. Professors meet and exchange ideas at a 4-day Institute meeting, which is the culmination of a year-long program of interaction.

In late October 1988, ACEC/RMF conducted the most recent Institute on Energy and Engineering Education at the University of Colorado, Boulder. Twenty-one professors of engineering and architecture attended as active participants, and the following organizations provided speakers:

OBT	Electrical Power Research Institute
ORNL	Gas Research Institute

Consolidation Coal Corporation
Hertzberg Consulting Engineers, Inc.
W. S. Fleming & Assoc.
Architectural Energy Corp.
Clanton Engineering
The American Society of Heating, Refrigerating, and Air Conditioning Engineers
Environmental Protection Agency
University of Boulder

Working in three-person teams, the participants analyzed the heat flow patterns and energy budgets of four campus buildings. They also reviewed building plans and equipment data provided by University of Colorado, Boulder, graduate students. Using information from the reference texts in the Technical Resource Library provided by ACEC/RMF, participants identified and researched alternative energy conservation options (ECOs). Each team then modeled its base building and evaluated a set of ECOs, using the ASEAM-2.1 software. Several teams were able to use the advanced parametric processor function within ASEAM-2.1 to investigate the energy impacts of different variables. The results of these investigations were presented on the last day of the Institute. It is hoped that the case study methods will be used by the educators in their engineering curricula.

The Institute was highly rated by participants who completed evaluation forms:

- 75% indicated that the Institute symposium was good to excellent in providing useful subject materials for curriculum refinement and improvement;
- 80% indicated that the Institute symposium was good to excellent in providing an overview of current building technology, trends, and approaches for energy efficiency and conservation;
- 83% indicated that the Institute symposium identified important research problems in the energy and buildings areas; and
- 95% rated the Institute as a whole as either good or excellent.

ACEC/RMF also distributed copies of the manufactured housing slide rule to all the past participants of the Institute symposium, as well as to members of ACSA.

Energy and Engineering Bibliography

Dale Stanton-Hoyle
American Consulting Engineers Council, Research Management Foundation (ACEC/RMF)
1015 15th Street, NW, Suite 202
Washington, D.C. 20005

ACEC/RMF completed an update of an annotated bibliography to be used as a resource document by participants at the Energy and Engineering Education Institute and by others. A review of the 1985 bibliography was conducted to identify those publications that are up-to-date reference documents and to delete from the listing those documents that have been outdated by changes in building systems, technology, and software. New citations were added to make the bibliography more current. The bibliography contains 340 entries divided into 22 subject categories.

Copies of the bibliography may be obtained from ACEC/RMF.

Building Energy Case Studies for Architectural Education

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With sponsorship from the DOE technology transfer program and various private sector organizations, ACSA offered a national energy conservation student design competition annually for 7 years, from 1980 to 1987. In late 1987, believing that the DESIGN + ENERGY competition program had fulfilled the objectives set for it, ACSA and its sponsors set out to find ways to continue to build on educational opportunities and resources for students of architecture.

Following consultations with educators in professional schools of architecture and with a variety of past and prospective program sponsors, ACSA joined ORNL and DOE in efforts to redirect the competition program, in order to provide a series of enduring, technically detailed educational case studies. These case studies, when completed, will become available as teaching resources to architectural educators throughout the United States. Three case studies will be produced in the first cycle of the program, extending through mid-1989. Each case will be evaluated in an educational setting prior to publication, with results of the evaluations leading to improvements in the final documents. The 5-year program is co-sponsored by the National Institute for Architectural Education.

A Request for Proposals was issued to U.S. schools of architecture in early 1988. In mid-1988, out of a field of more than 25 proposers, three were selected by the program advisory group: the University of Pennsylvania, Yale University, and the University of New Mexico. Teams from each of these schools worked through the summer and fall of 1988, gathering data and drafting the case study materials. The draft case study syllabi were then used by two other schools of architecture to test their effectiveness.

During March 1989, ACSA held a day-long technical workshop during its annual meeting in Chicago. There, all schools participating in the program met to compare results and to discuss progress. Faculty representatives from the evaluating schools attended the session, as did a number of observers from other schools that plan to participate in future rounds of the program. A DOE representative also attended and participated in the program.

The first phase of the case study development program was completed with the final meeting of the case study authors, evaluators, interested observers, and sponsor representatives in mid-September at the New York offices of the National Institute for Architectural Education.

After the case study authors presented their work, the evaluators made presentations, and general discussions were held among all participants. Suggestions and recommendations from the session resulted in an agreement by ACSA to circulate the case studies for additional peer reviews by established educators. The case study authors made additional revisions to their work based on comments received through this process, and the case studies were published by ACSA in November 1989.

Society of Building Science Educators (SBSE) 1988 Energy Curriculum Project

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Mail Stop JO-20
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Seattle, Washington 98195

ORNL received a final report by SBSE summarizing the results of its *1988 Energy Curriculum Project for Schools of Architecture*. The report is a curriculum document and catalogue of design patterns that can be used to integrate energy concerns into the design studies in schools of architecture. It is hoped that the document will increase the rate at which energy-related technical knowledge is transferred to architecture students.

The first section of the report describes the purpose, definition, and use of the design patterns as a method of communicating building science principles. The second section presents case studies of thermal, lighting, and acoustical design patterns. The document concludes with a survey of energy-related environmental systems course work and curricula in architecture schools across the United States.

Copies of this report may be obtained from Joel Loveland or Marilyn Brown.

RESEARCH AND PROGRESS REPORTS

Report on OBT Research in Progress

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A report on FY 1988 Research in Progress by OBT was published in December 1988. The report provides an inexpensive and timely means of communicating current OBT research activities to members of the buildings community. The publication was widely disseminated in early 1989. A report is being planned on FY 1990 Research in Progress.

Program Overviews/Technology Briefs

Noni Strawn
Solar Energy Research Institute (SERI)
1617 Cole Boulevard
Golden, Colorado 80401

Overviews of selected OBT R&D programs have been developed over the past two years by SERI and ORNL. The overviews are two-page descriptions with graphics that appear in the front of OSTI's monthly publication, *Buildings Energy Technology*. Topics covered to date include:

- OBT overview,
- roofing research,
- foundations research,
- lighting research,
- indoor air quality,
- appliance standards,
- energy analysis software,
- advanced refrigeration systems,
- existing buildings research,
- least-cost utility planning,
- community energy systems,
- heat pump technology - absorption and engine driven,
- alternatives to chlorofluorocarbons (CFCs) in refrigeration,
- advanced window technologies,
- radon mitigation studies,
- combustion equipment technology,
- daylighting research,
- energy-efficient industrialized housing,
- ground-coupled heat pumps,
- monitoring protocols and audit procedures,
- building materials, and
- International Energy Agency's (IEA's) Center for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET).

Approximately 1000 reprints of each overview are made available to OBT program managers for distribution and use.

ORNL reviewed the mailing list for OSTI's *Buildings Energy Technology*. Of the nearly 600 recipients, more than 100 were tagged for removal from the complimentary subscription list because of their tangential relationship to buildings energy issues. The list will be augmented by adding members of the U.S. CADDET National Team. It is hoped that OSTI will implement these mailing list changes in early 1990.

Subscriptions to *Buildings Energy Technology* (publication #PB89-900700) can be obtained for an annual price of $90 by writing to:

National Technical Information Service (NTIS)
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

Database of Building Trade Publications

Marilyn Brown
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Oak Ridge, TN 37831-6206

In 1987, Karen Haas Smith developed a database of trade and professional publications serving the buildings industry that will accept material related to the research programs conducted by OBT. The lists are categorized by trade audience.

Categories include:

- the appliance industry,

- builders and construction engineers,
- building owners and managers,
- electrical engineers and contractors,
- remodelers,
- architects and lighting designers,
- business and investment periodicals,
- the electric utility industry,
- the insulation industry,
- applied science and technology publications,
- computer-aided-design publications, and
- government and public works officials.

Each list includes the name of the editor, address, telephone number, and a brief description of the publication's readership and editorial scope. The circulation and publication frequency of each publication are also included to aid in placement planning efforts.

The lists, are used by ORNL and others to disseminate information about OBT activities and products. Copies are available from Marilyn Brown.

Energy Conservation Technical Guide, Volume 2: Utilities

Pat Taylor
Technical Communications Consultant
306 Timberhill Court
Knoxville, Tennessee 37922

This guide, published in late 1988, describes selected results from recent residential, commercial, and industrial energy demonstrations and pilot programs. It is designed to be of help to utility management personnel who have only a general technical background. Topics that are featured show performance and economic results, and technical reports addressing topics in the text are referenced for complete detail. Research in progress that shows important near-term promise is mentioned, and reports are referenced. The guide is organized into five chapters with two indices:

Chapter 1. Introduction
Chapter 2. Utility Supply-Side Energy Efficiency
Chapter 3. Utilities and Demand-Side Energy Management
Chapter 4. The Challenge of Integrated Resource Planning
Chapter 5. Associations of Integrated Resource Planning
Organization Index
Subject Index

Energy Conservation Technical Information Guide, Volume 3: Residential Buildings

Rebecca Vories
Infinite Energy
P.O. Box 17945
Denver, Colorado 90217

This report, published in late 1989, describes the current state of the art of energy conservation in residential buildings as practiced in the field, with emphasis on cost effective approaches. Primary audiences for this technical reference guide include utilities and state energy offices. The discussion focuses initially on conservation in new buildings, and a description of how these approaches differ in retrofit situations follows.

Bibliography of Recent OBT-Supported Publications

Marilyn Brown
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Oak Ridge, Tennessee 37831-6206

A bibliography, *Recent Publications of DOE's Office of Buildings and Community Systems*, was completed by Marilyn Brown and Jeff Hayes in January 1989. It is available as an ORNL report (CON-276) from Marilyn Brown or NTIS.

The bibliography lists recent publications describing the results of the OBT R&D program. It includes reports, articles, book chapters, monographs, and other documents published between 1985 and the present. More than 900 citations are listed. Major categories include new buildings, existing buildings, building energy analysis and monitoring, space conditioning equipment, lighting, appliances, building structures, integration of buildings, community energy supplies and services, and technology transfer. Both an author and a subject index are provided.

OBT: Buildings Energy Technology Document Database

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The ORNL Evaluation and Technology Transfer Group conducted an investigation and evaluation of the various OBT bibliographic databases. The individual databases maintained by the OBT Building Systems, Building Services and Building Equipment Divisions, and the Analysis and Technology Transfer activity were included in this investigation.

Each OBT Division maintains its own bibliographic database. These databases were obtained on computer disk in ASCII text format. In each case, a FORTRAN program was written that enabled these databases to be imported into a dBASEIII+ database without any retyping of bibliographic data including abstracts. A database management system, similar to the one that was designed and developed by ORNL for IEA-CADDET, was then modified to accommodate the basic annotated bibliographic data common to most of these individual OBT bibliographic databases. This OBT Energy Database "shell" was then adapted to each OBT Division bibliographic database, providing each division with a fully operable database management system.

The interface with the DOE ENERGY Database was also investigated. Selected document records were downloaded from the OSTI:DOE ENERGY Database and were successfully imported into a dBASEIII+ database. This exercise demonstrated the feasibility of retrieving selected document records from the DOE ENERGY Database and importing them into an OBT ENERGY Database without any retyping of bibliographic data including abstracts.

Trade Magazine Articles

Peter Rush and Richard Braun
Sumner Rider and Associates, Inc. (SR&A)
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New York, New York 10017

SR&A has worked for 3 years with OBT to place articles about research activities in the trade press. This activity was initiated to reach the various building industry practitioners (builders, developers, architects, retailers, remodelers, and others) who are critical to the implementation of energy-efficient building practices and products.

Each year, several areas of OBT research are targeted for trade press coverage. A news release is prepared for each topic, and magazine articles are generated from the interest that results. Some of the recent press coverage resulting from this project is highlighted in the material that follows.

Low-Emissivity (Low-E) Windows

LBL's low-E glazing research, which was the subject of a 1988 SR&A national release, was featured in five publications:

- *Remodeling,*
- *Energy Conservation Digest,*
- *Professional Building,*
- *Shelter,*
- *Air Conditioning, Heating and Refrigeration News.*

Insulation Fact Sheet

A national release on DOE's Insulation Fact Sheet was sent to 60 magazines and daily newspapers. The DOE Insulation Fact Sheet was also featured in the SR&A *News Feature Service* Home Improvement Special made available in October 1988 to 4000 newspapers nationally. The news release appeared in *The New York Daily News*, the largest general circulation newspaper in the United States; and a *Woman's Day Remodeling* special issue also featured the fact sheet, together with art work from the booklet. In addition, the national release was featured in a 1988 issue of *Decorating Remodeling* magazine as part of an article on insulation. DOE's map, with insulation recommendations for existing homes, was included.

According to the Conservation and Renewable Energy Information Referral Service (CAREIRS), which distributes the fact sheet, approximately 9000 individual requests for the booklet were received in 1988.

Software Tools

SR&A distributed a summary information paper on ASEAM-2.1 to 34 building design and construction and energy-related publications. The release has appeared in *Energy Conservation Digest; High Technology Business*; and *Air Conditioning, Heating, and Refrigeration News*.

The September/October issue of *Home Energy* featured an article entitled "Comparing Building Energy Analysis Software," written by Peter Weiss and Marilyn Brown with inserts by Sarah Kirchen (DOE) and Susan Reilly (LBL). *Architectural Record* has agreed to publish a feature article spotlighting OBT software tools. The article was written by Marilyn Brown and Richard Braun.

Current Activities

SR&A is preparing an information paper on the publication of "Affordable Housing Through Energy Conservation: A Guide to Designing and Constructing Energy-Efficient Homes," a four-part set of voluntary performance guidelines for new residential construction. The paper is being prepared as a national release for consumer and trade publications.

SR&A is also developing a summary information paper on the national and regional impact of the National Appliance Energy Conservation Act of 1987 (NAECA). The paper incorporates analyses by scientists of the Energy Analysis Program, LBL, and the American Council for an Energy-Efficient Economy. The paper will be offered to a key publication.

Home Energy Outreach

Karina Lutz, Editor
Home Energy
2124 Kittredge, Suite 95
Berkeley, California 94705

A contract with *Home Energy* was completed in August 1989 to support the preparation and publication of articles on DOE R&D activities. The project is cost shared by three DOE programs: the Residential and Commercial Conservation Program (RCCP), the Existing Buildings Energy Research Program, and the OBT Technology Transfer Program.

Coordination with CAREIRS on the Production of Fact Sheets for Consumers

Grace Gilden/John Lippert
The Conservation and Renewable Energy
Inquiry and Referral Service (CAREIRS)
P.O. Box 8900

Silver Spring, Maryland 20907
800-523-2929

CAREIRS continues to develop and update fact sheets and information briefs for use in responding to consumer requests for information. Through its toll-free telephone number and post office box, CAREIRS handles consumer requests for information on energy conservation techniques and technologies and on the renewable energies. The following fact sheets are representative of those available through CAREIRS:

- Heat Pumps
- Improving the Efficiency of Oil and Gas Heating Systems
- Insulation Fact Sheet
- Passive Cooling Techniques
- Sources of Solar and Energy-Efficient House Plans
- Learning about Energy Conservation
- Tips for Energy Savers
- Earth Sheltered houses
- Movable Insulation
- Improving the Energy Efficiency ofWindows
- Air-to-Air Heat Exchangers
- Automatic and Programmable Thermostats
- Hot Water Energy Conservation

Recently revised fact sheets include:

- Caulking and Weatherstripping
- Residential Indoor Air Pollution
- Efficient Air Conditioning
- Alternatives to Air as Heat Sources for Heat Pumps
- Appliance Labeling

Several new fact sheets are available, including:

- Recycling Waste to Save Energy
- Landscaping for Energy-Efficient Homes
- Home Energy Audits
- Fans and Ventilation
- Energy-Efficient Factory-Built Houses
- Options for Saving Energy and Reducing Costs with Electric Heating

DESIGN AND DECISION TOOLS

Completion and Dissemination of ASEAM-2

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Washington, D.C. 20005

ASEAM-2 is a state-of-the-art, simplified whole-building energy analysis program that incorporates the latest technical and user interface features for personal computers. It is the only public domain microcomputer program that can treat the energy analysis of new building designs and retrofit applications for both residential and commercial buildings. It was completed with funding from OBT, the Residential and Commercial Conservation Program, and the Federal Energy Management Program.

In late 1988, ASEAM-2.1 received a National Award for Energy Innovation. The submittal to the 1988 awards program was based upon the multiple ways in which ACEC/RMF has provided ASEAM-2.1 to different audiences - university faculty, state and local energy offices, nonprofit scientific and educational organizations, and building design professionals. ACEC/RMF accepted the award in conjunction with the firm that developed the software programming, W. S. Fleming & Associates.

Approximately 350 ASEAM-2.1 software packages have been distributed by ACEC/RMF. The National Energy Software Center (NESC) also distributes ASEAM-2.

TECHNICAL EXCHANGE

Weatherization: Gateway to the Future

Marilyn Brown joined Ernie Freeman (DOE/OBT), Bill Raup (DOE/Office of State and Local Assistance Programs), and Jack Stacey (DOE/Kansas City Support Office) as panelists in a workshop entitled "Putting DOE Research to Work." The panel was convened twice at the 1988 Weatherization Conference in St. Louis and attracted about 50 participants each time. The following suggestions were offered as ways to put DOE research to work more effectively:

- Technical information should be presented at weatherization meetings because technical constituents attend.
- A survey of research and information needs by region should be conducted.
- A list of weatherization contacts is needed so that information going to state energy offices reaches the right people.
- A central clearinghouse is needed to disseminate information on the performance of specific applications of technologies.
- Regional meetings of weatherization staff should take place at national laboratories from time to time to facilitate communication.

Center for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET)

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Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge, Tennessee 37831-6206

DOE, on behalf of the United States, became a member of CADDET beginning March 18, 1988. The goal of CADDET is to accelerate the exchange of information on demonstrated energy-efficient technologies among private sector end-users and government agencies within member countries, thus leading to better informed decision making and increased adoption of successful, energy-efficient technologies. Thirteen countries now belong to CADDET: Australia, Canada, Denmark, Finland, Italy, Japan, the Netherlands, New Zealand, Norway, Sweden, Switzerland, the United Kingdom, and the United States.

CADDET conducts four principal activities to achieve this objective:

- publication of a quarterly newsletter,
- development of a register of international information on demonstrated energy-efficient technologies,
- production of brochures containing detailed information on a subset of the more notable technologies, and
- analysis of selected technological areas, drawing upon the results of demonstrations from around the world.

After 18 months of operation, the United States has developed a CADDET National Team of nearly 75 individuals representing key public- and private-sector energy R&D organizations and associations of manufacturers, distributors, and end-users. A National Team Workshop was held in Washington, D.C., on December 6, 1989. Approximately 60 people attended, reviewed CADDET's progress to date, and offered suggestions for future activities.

SUPPORT TO PROGRAM MANAGERS

Replacement of the OSTI Standard Distribution Mailing List (UC-350)

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Oak Ridge National Laboratory
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Oak Ridge, Tennessee 37831-6206

The standard distribution list maintained by OSTI for the dissemination of OBT-supported reports was updated in September 1989. It now contains approximately 340 entries representing key trade and professional associations, information dissemination centers, federal agency offices, research laboratories, private corporations, university research centers, and state energy offices. The composition of the list remains largely the same, but the names and addresses are now more current.

EVALUATION AND TRACKING OF TECHNOLOGY TRANSFER

Innovation Case Studies

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In January 1989, ORNL completed a report entitled *Commercializing Government-Sponsored Innovations: Twelve Successful Buildings Case Studies* (ORNL/CON-275). Three goals guided the research:

- to better understand the factors that hinder or facilitate the transfer of OBT R&D results,
- to determine which technology transfer strategies are most effective and under what circumstances each is appropriate, and
- to document the market penetration and energy savings achieved by successfully commercialized innovations that have received OBT support.

Five fully commercialized innovations (i.e., those with at least 5% market penetration) were examined:

- solid-state ballasts for fluorescent lighting;
- low-E coatings for windows;
- unequal parallel compressor systems for supermarkets;
- flame retention head oil burners; and
- DOE-2, a building energy analysis software package.

Seven semi-commercialized innovations were also examined:

- dielectric coatings,
- heat pump water heaters,
- radiant barriers,
- the Wisconsin audit,
- Computerized, Instrumented, Residential Audit (CIRA),
- the hotbox method for testing heat transfer through walls, and
- tracer gas testing.

Each of the case studies provides background information on the technology, a summary of the steps in its development and deployment, and an assessment of the importance of the DOE role. Estimates of the market penetration and energy savings achieved by an innovation are reported when possible. For several of the innovations, recommendations are made for future technology transfer activities that would accelerate market penetration and use.

6. INTEGRATED RESOURCE PLANNING

Contact: Jacob Kaminsky, DOE, (202) 586-9204
Barbara Pierce, BNL, (516) 282-3123

Integrated resource planning (IRP) is a process that explicitly examines all possible means of meeting utility customer service demand. It allows for the comparison of traditional supply options with non-traditional supply as well as demand-side measures in order to satisfy projected demand at the lowest cost. It differs from traditional utility planning in at least three ways (Berry and Hirst):

- it explicitly includes conservation and load-management programs as energy and capacity resources;
- it considers environmental and social factors as well as direct economic costs; and,
- it carefully analyzes the uncertainties and risks posed by different resource portfolios and by external factors.

Integrated resource planning to date has focused primarily on including demand-side options in utility planning processes. While only 10 states have implemented a full-scale integrated resource regulatory framework (Mitchell), many utilities are designing and implementing conservation and load management (C&LM) programs. These programs are designed to reduce demand and/or to shift load; the overall result may or may not be reduced energy use, depending on the objectives and needs of the individual utility.

Utilities have entered demand-side management (DSM) for a variety of reasons. In areas where capacity shortfalls are forecast, utilities are trying to avoid or delay construction of new generating capacity because of its cost and the increasing difficulties in obtaining site licensing and construction permits. In some instances, utilities are required to implement conservation and load-management programs by regulators as part of rate hearings. Collaborative processes, either voluntary or required, are increasingly being used to design such programs.

The Federal program in Integrated Resource Planning began in 1986 and has been developed in close cooperation with utilities, regulators, and other interested parties. The Federal role has been that of a catalyst, and the program has focused on information development and sharing. Responding to the needs of both utilities and regulators, DOE assists in methodology development, program evaluations and technology assessments, and sponsors conferences and publications. DOE is helping to ensure that utility planners and regulatory officials have the information they need to design and implement effective programs, and can benefit from the experiences (both successes and failures) of others.

The federal partnership with many of the ongoing activities also helps ensure that broader issues of national importance, such as energy security, economic competitiveness, and environmental considerations, are addressed. In addition, Federal involvement helps keep advances in utility planning in the public domain. Finally, Federal involvement provides a major opportunity for transfer of DOE R&D results.

THE FEDERAL PROGRAM

Federal involvement in the area of least-cost planning began in 1986 when Congress appropriated $1 million to "allow the Department to initiate a "least-cost" planning program with utilities to assist them in choosing services, options and conservation programs which will provide efficient and low-cost service to customers" (U.S. House). In that first year, DOE sponsored a survey to collect input from utilities, regulators, public interest groups, and others to gain an understanding of what these different groups meant by least-cost planning and what they thought the federal role should be.

With this information, DOE developed a research program consisting of projects in four major areas: technology assessment, market penetration, integrated utility planning, and technology transfer. A competitive solicitation was issued; fourteen grants were awarded out of more than 50 proposals. The most popular subject was integrated utility planning, which was addressed by most of the projects directly or indirectly.

Congress has since appropriated approximately $1 million each year, increasing to about $3 million for FY 1991. Efforts have continued to define those areas which needed special attention to make least-cost planning a reality. During FY 1988, 35 research and technology transfer projects were conducted jointly with utilities, utility regulators and national laboratories.

DOE released its second major competitive solicitation in FY 1989. The solicitation was targeted toward the particular least-cost planning problems faced by rural utilities in the northeastern United States. Eighteen proposals were received and nine grants were awarded.

Cost-sharing remains an important aspect of DOE's program. In the first solicitation, approximately $700,000 in DOE funding elicited more than $2 million in shared support from the grantees. In the second solicitation, more than $1 million matched $600,000 in DOE funds. Other projects also include cost-sharing.

In FY 1990, more than 40 projects were underway. Descriptions of ongoing and completed projects can be found in U.S. Department of Energy (1989) and (1990) and Berry and Hirst (1989).

In the future, DOE will assist in transferring the experience gained by electric utilities to gas utilities. Special attention will be given to the role of renewable resources. Models and data will be developed to allow full fuel cycle analyses, including quantifying and incorporating environmental externalities in resource planning. DOE will continue to assist regulators and utilities in developing incentive mechanisms to encourage increased utility implementation of IRP and DSM, and continue to promote the sharing of experiences and data by cosponsoring conferences and workshops around the country.

Demand-side management will continue to be a major focus of the Federal program. Activities include technology assessments and program evaluations to validate performance and cost-effectiveness. Innovative load management technologies will be identified and demonstrated. DSM data needs will be identified, and data comparable to that available on supply-side options will be developed. The Federal government also has an opportunity to apply DSM techniques to its own facilities.

The Federal program was developed and implemented by OBT until the reorganization within the Office of Conservation and Renewables in March 1990; at that time the program was moved to the Office of Utility Technologies. It is included in this report not only because it was under the auspices of OBT during most of the period covered by this report, but also because the impacts of demand-side management programs are felt primarily in the buildings sectors.

DEMAND-SIDE MANAGEMENT AND BUILDINGS ENERGY USE

More than 500 utilities have implemented DSM programs and current expenditures on electric utility DSM programs are more than $1 billion per year (Tempchin et al.). Utility programs focus primarily on buildings: recent surveys by EPRI show more than 1000 residential programs and 400 commercial and industrial programs (Blevins and Miller). Most industrial programs have focused on lighting, HVAC and motor improvements, with little attention to process improvements. Currently DSM activity tends to be concentrated among a handful of utilities, although the group of leading utilities may change with changing regional conditions (Geller and Nadel). It is likely that utility involvement in conservation programs will increase dramatically as the regulatory environment changes to provide incentives to utilities for achieving savings.

The types of programs offered by utilities range from mass mailings of information to comprehensive efficiency packages that are aggressively marketed and paid for by the utility. Programs are generally targeted to one sector or customer class, such as small commercial. These programs will accelerate the market penetration of some commonly employed technologies, and will change the energy intensity of buildings and of some end-uses. Impacts may be particularly important in regions with extensive electric space heating. In the future, the fuel mix in the buildings sector may be affected as gas utilities become more active in DSM and as fuel-switching is explored as a conservation measure.

Potential Savings from Utility Programs

Several types of savings estimates are possible. One is the maximum technical potential, that is, how much electricity could be saved if policies (including R&D to lower costs, rebates and incentives, information programs, etc.) were in place to immediately implement all currently available efficient technologies. EPRI has recently performed such a study (Faruqui et al, March 1990), which estimates that savings of 24-44 percent of base case electricity consumption are possible in the year 2000.

In the residential sector, between 27 and 46 percent of the projected electricity use could be saved; the greatest opportunities are for residential appliances (including lighting), space heating and water heating. In the commercial sector, between 23 and 49 percent could be saved, with the greatest potential in efficient technologies for lighting, space cooling and miscellaneous plug loads. Savings potential in the industrial sector ranges from 24 to 38 percent of projected base case electricity use; most of the savings are due to improved motor drives. Each of the three sectors accounts for approximately one-third of the total maximum technical potential. These estimates do not consider cost-effectiveness or the likelihood of adoption.

EPRI has also estimated the likely impact of utility DSM programs on electricity demand (Faruqui et al, 1990). These estimates considered six program categories, as well as program penetration and participation rates. Results show annual electricity savings of 1.1 percent in 1990, 3 percent in 2000 and 6 percent in 2010 due to utility programs, including increases in electricity consumption due to electrification programs as well as reductions from other program categories. Thus utility programs are likely to capture between 6.8 and 12.5 percent of the maximum technical potential for electricity savings for the nation as a whole.

The Reference Case used to develop the National Energy Strategy, by contrast, shows 1.6 percent savings in electricity use due to utility DSM programs in 2000, and a 3.2 percent reduction in 2010 (U.S. Department of Energy September 1990).

Individual utility programs can achieve significantly greater savings than national estimates indicate. A recent study (Nadel) of over 200 C&LM programs for commercial and industrial customers found that typical programs reach less than 5 percent of eligible customers, reduce energy use among participants by less than 10 percent, and reduce utility peak demand by less than 1 percent. The best commercial and industrial programs, however, reach 70 percent or more of targeted customers, reduce customer electricity use by 10 to 30 percent, and reduce peak demand by up to 5 percent. Most of these programs cost utilities less than $0.04 per kWh saved. Data on customer costs are rarely available. Summary data are shown in the table on the following page.

A comparison by end-use of estimated potential savings and the savings achieved in the best utility programs for the commercial sector is shown in Table 6-2. The potential savings estimates include a technology cost component, and thus are not maximum technical potential, as used in the EPRI study. However, they do not include program delivery costs or barriers to measure adoption, so they do not estimate achievable potential. The estimates of potential savings thus represent a cost-effective potential, and are used to illustrate what has been achieved by well designed and implemented utility programs. The best programs achieve a 25 percent reduction in electricity used for lighting, approximately 20 percent reduction in electricity use in multiple end-use retrofit programs, and 30 percent reduction from new construction programs. These programs, if widely implemented, may slow the increasing use of electricity in the buildings sectors relative to other fuels.

Table 6 - 1
Summary of Commercial and Industrial Program Results

Program Type	Number of Programs	Cumulative Participation Rates[2] Average	Best	Percent Savings[3] Average	Best	Utility Cost Median $/kW	$/kWh
Audits	29	1-4%	60-90%	4-5%	6-8%	$200	$.009
Lighting							
Information	4	1%	3%[1]	NA	NA	NA	<$.01
Rebate	36	<1-3%	10-25%	2.6%	NA	$246	$.01
Installation	8	2-5%	30-55%	NA	10%, up to 50% of ltg use[1]	$316	$.028
HVAC rebate	19	<1%	10%	11% of AC use		$318	$.029
Motor rebate	15	<1%	15%[4]	5% of motor use		$356	$.0055
Industrial	17	0-3%	5-9%	NA	NA	$246	$.008
Storage cooling	20	NA	38%	>90% of A/C kW		$296	
Thermal a/c	8	NA	NA	>90% of A/C kW		$144	
New Construction							
Technical assist.	6	NA	NA	NA	NA	NA	~$.03
Rebate	8	NA	NA	NA	NA	$221	~$.01
Comprehensive	3	NA	NA	NA	30%[1]	NA	~$.03[1]
Miscellaneous							
Water heater wrap	2	NA	11%	NA	NA	$620	$.019
Heat pump WH	2	NA	NA	50% of wtr htr use		NA	NA
Refrigeration	5	0.1%	NA	NA	NA	$100-200	NA
ETS	2	NA	NA	>90% of elec ht kW		$100-200	
Multiple End-use							
Rebate	23	0-4%	10-16%	NA	7%	$277	$.009
Loan	6	0-3%	7%	NA	NA	NA	$.008
Perform contract'g	11	0-2%	15%[1]	NA	15-18%[1]	$1090	$.028
RFP & bidding	3	<2%	NA	NA	NA	NA	NA
Comprehensive	10	1-2%	70%[1]	10%	18-23%[1]	NA	$.033[1]

Notes:
1. Based on experience from pilot and/or limited scale programs.
2. Percent of eligible customers.
3. Percent of pre-program kWh use by participating customers unless otherwise noted. Most of these figures are based on engineering estimates.
4. Percent of motor horsepower sold in a year.

Source: Nadel

Implications for OBT

Forecasting buildings energy use and the impacts of OBT-developed technologies is an integral part of OBT's analytical effort. Analysis of the effects of utility DSM programs on buildings energy use needs to performed in order to incorporate them into future forecasts. Special attention needs to be paid to potential changes in the energy intensity of specific end-uses. If DSM activity increases, as is likely, changes in the fuel mix in the buildings sectors will also need to be analyzed. Utility programs may significantly reduce the growing use of electricity in buildings. Regional differences may also become increasingly important.

If utility programs are to capture a significant part of the potential for efficiency improvements, better performance and cost data on new technologies will be needed. Estimates of DSM potential generally include only technologies that are currently or nearly commercialized. For the future, a new set of technologies will be required. These needs, especially the need for reliable data, must be incorporated early in the OBT program planning process.

Further, the increase in utility DSM programs dramatically expands the market for OBT-developed technologies and presents new opportunities for technology transfer activities. Within DOE, close ties between the IRP program and OBT program managers can improve communication between researchers and end-users. Utilities will be better informed

Table 6 - 2
Commercial and Industrial Programs
Potential vs. Achievements
by End-Use

End-Use	Potential[1]	Savings from Best Programs[2]
Lighting	60% of lighting use	~25% of lighting use
HVAC	51% of commercial HVAC use	11% of A/C and heat pump use
Motors	17% of motor use	~5% of motor use
New construction	50% or more[3]	30%
Multiple end-use retrofits	45% in the commercial sector	18-23% in commercial buildings

Notes:
1. For measures with a cost-of-conserved energy less than $.05 per kWh assuming a 6% real discount rate. Costs of program delivery and barriers to measure adoption are ignored.
2. Some of these performance levels were achieved in pilot or other limited-scale programs. Most of these performance levels are based on engineering estimates.
3. Based on computer simulations of over 100 new commercial buildings.

Source: Nadel.

about new technologies, and researchers will be able to incorporate needs of utilities into R&D planning decisions.

In developing the National Energy Strategy and in planning OBT's research program, several types of policy options are evaluated to determine the relative cost-effectiveness of different ways to achieve energy efficiency improvements in buildings. Options include information programs, incentive programs, codes and standards, as well as various tax and other options. How these options interact and the most effective combinations need to be determined.

Estimates of the achieved or potential electricity savings from utility programs relative to standards and traditional market forces are also important to utilities and their regulators to determine realistic estimates of the potential of utility DSM programs. In California, utility programs are estimated to have been responsible for 25 percent of electricity efficiency savings in 1985, more than that attributed to building and equipment standards and less than due to market forces (California Energy Commission). Results from the EPRI study discussed above (Faruqui et al, 1990) include savings of nearly 9 percent due to standards and market efficiency improvements built into the base case for 2000. Standards will be responsible for capturing approximately 15 percent of the estimated technology-cost saving potential in New York (Miller et al). The interaction between appliance standards and utility programs are particularly important. Estimates of relative effectiveness and costs need to be refined.

Also important to OBT analysis efforts are the insights that evaluations of utility programs can provide on the relative effectiveness of different kinds of programs. While it is difficult to generalize across programs for many reasons, some useful conclusions can be drawn. In particular, results show that comprehensive programs which include both information and rebates or incentives are the most successful. This is consistent with the examination of government residential conservation programs in OECD countries, discussed in Chapter 4 of this report. These important results need to be incorporated into OBT's policy analysis activities, and evaluation data needs must be defined. Stronger interaction with OBT's consumer decision efforts will benefit implementation of both government-sponsored and utility programs.

Finally, without entering the debate on whether utilities are an appropriate delivery mechanism for efficiency improvements or on the potential effects of the changing regulatory environment on the utility industry, it is important to understand the limitations of utility programs. Utility programs currently focus on electricity use and to some extent gas. Other end-uses and consumers need to be addressed to achieve balanced, efficient energy use in the buildings sectors. Oil heat customers are an obvious example. Utility programs are designed at the service area level to meet the needs of individual utility companies, and concerns such as customer class cross-subsidies and free riders may not be important to the nation as a whole when the goal is to improve overall energy efficiency in buildings.

Conclusions

Energy use in the buildings sector will be significantly affected as demand-side management programs become more widespread; many of these programs focus on improving the efficiency of buildings and their equipment or on fuel switching. Technologies developed by DOE's Office of Building Technologies are particularly applicable for utility implementation. Understanding the relationship between utility DSM programs and trends in electricity (and gas) use in buildings is critical to planning the research and development program for improving energy efficiency in buildings.

In the short term, it is important to ensure that programs are evaluated properly and that the results are shared across the country, and that reliable data on the technologies as well as the technologies are available. The long term challenge is to maintain a research, development and demonstration program that will continue to provide a wide range of technology and design options for the future.

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APPENDIX. DATA TABLES

U.S. Consumption of Primary Energy By Sector, 1960-1989
(Trillion Btu)

Year	Residential	Commercial	Industry	Transportation	Total
1960	8,284	4,749	20,163	10,598	43,795
1961	8,582	4,846	20,253	10,775	44,455
1962	9,102	5,154	21,050	11,225	46,531
1963	9,367	5,333	21,989	11,659	48,342
1964	9,684	5,531	23,293	11,999	50,507
1965	10,119	5,900	24,244	12,434	52,697
1966	10,654	6,386	25,528	13,102	55,670
1967	11,142	6,946	25,755	13,749	57,591
1968	11,865	7,361	26,915	14,859	61,000
1969	12,717	7,859	28,101	15,497	64,174
1970	13,310	8,344	28,593	16,087	66,334
1971	13,842	8,694	28,535	16,718	67,789
1972	14,529	9,166	29,871	17,709	71,275
1973	14,642	9,532	31,570	18,607	74,352
1974	14,361	9,357	30,694	18,116	72,528
1975	14,454	9,443	28,429	18,244	70,569
1976	15,008	10,019	30,264	19,100	74,392
1977	15,214	10,171	31,111	19,820	76,317
1978	15,626	10,477	31,423	20,614	78,158
1979	15,197	10,615	32,636	20,473	78,920
1980	15,069	10,586	30,635	19,695	75,985
1981	14,606	10,644	29,264	19,508	74,022
1982	14,737	10,857	26,141	19,071	70,806
1983	14,645	10,951	25,746	19,135	70,486
1984	15,037	11,413	27,720	19,871	74,042
1985	15,235	11,517	27,168	20,098	74,019
1986	15,217	11,592	26,663	20,760	74,232
1987	15,558	12,009	27,865	21,360	76,792
1988	16,371	12,642	29,046	22,188	80,247
1989	16,630	12,867	29,463	22,382	81,342

Source: *State Energy Data Report 1960 -1989*, U.S. DOE/EIA, May 1991.

Resident Population and Number of Households, by Region

	Total U.S.		Northeast		Midwest		South		West	
	Population (Thousands)	Households (Thousands)	Population (Thousands)	Households (Thousands)	Population (Thousands)	Households (Thousands)	Population (Thousands)	Households (Thousands)	Population (Thousands)	Households (Thousands)
1980	226,546	80,390	49,135	17,471	58,866	20,859	75,372	26,486	43,172	15,574
1981	229,637	82,620	49,262	17,788	59,006	21,211	77,057	27,482	44,313	16,138
1982	231,996	83,540	49,324	17,847	58,957	21,227	78,483	28,048	45,232	16,417
1983	234,284	84,336	49,526	17,937	58,930	21,234	79,732	28,517	46,095	16,648
1984	236,477	86,019	49,713	18,218	59,091	21,530	80,786	29,221	46,887	17,050
1985	238,736	87,489	49,858	18,424	59,193	21,758	81,891	29,859	47,794	17,448
1986	241,095	88,797	50,056	18,600	59,292	21,935	83,003	30,429	48,745	17,833
1987	243,400	90,031	50,278	18,768	59,538	22,153	83,884	30,899	49,700	18,211
1988	245,807	91,538	50,545	19,016	59,878	22,479	84,655	31,400	50,679	18,643

Source: U.S Bureau of the Census, Current Construction Reports, Series P-25, No. 1024, *State Population and Household Estimates, With Age, Sex, and Components of Change: 1981 - 1987.*
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Consumption of Energy by the Residential Sector, by Fuel Type, 1960-1989
(Trillion Btu)

Year	Fuel Type: Coal	Fuel Type: Gas	Fuel Type: Petroleum	Fuel Type: Electricity	Total End-Use Energy Consumed	Electrical Energy Losses	Primary Energy Consumed
1960	408.3	3,211.8	2,265.3	687.4	6,572.7	1,711.3	8,284.0
1961	372.0	3,362.3	2,331.9	731.7	6,797.8	1,784.2	8,581.0
1962	356.7	3,600.3	2,440.9	794.3	7,192.2	1,910.1	9,102.3
1963	309.6	3,695.3	2,459.4	855.6	7,319.9	2,046.7	9,366.6
1964	272.0	3,899.6	2,375.0	927.5	7,474.1	2,210.3	9,684.4
1965	254.0	4,019.3	2,480.6	992.9	7,746.8	2,372.0	10,118.8
1966	245.8	4,260.5	2,470.7	1,081.2	8,058.2	2,595.8	10,654.0
1967	211.1	4,439.8	2,556.8	1,160.5	8,368.2	2,774.2	11,142.4
1968	191.1	4,578.4	2,685.2	1,301.9	8,756.6	3,108.1	11,864.7
1969	177.7	4,864.4	2,738.7	1,456.0	9,236.8	3,479.9	12,716.7
1970	153.4	4,952.6	2,755.2	1,591.0	9,452.1	3,857.9	13,310.0
1971	144.5	5,092.4	2,777.1	1,704.4	9,718.4	4,123.4	13,841.8
1972	111.0	5,256.9	2,895.4	1,837.7	10,101.0	4,427.5	14,528.6
1973	105.2	5,000.5	2,825.2	1,976.3	9,907.3	4,734.9	14,642.2
1974	103.8	4,898.0	2,573.5	1,972.8	9,548.1	4,813.4	14,361.5
1975	84.7	5,024.1	2,494.9	2,006.7	9,610.5	4,843.0	14,453.6
1976	82.4	5,148.7	2,720.4	2,069.2	10,020.7	4,987.7	15,008.4
1977	83.5	4,914.4	2,695.0	2,201.6	9,894.4	5,319.6	15,214.1
1978	84.6	4,986.9	2,619.9	2,301.3	9,992.7	5,633.0	15,625.7
1979	73.6	5,052.4	2,113.7	2,329.8	9,569.5	5,627.1	15,196.6
1980	60.4	4,855.4	1,747.9	2,448.1	9,111.7	5,957.6	15,069.3
1981	70.3	4,652.1	1,543.4	2,464.4	8,730.1	5,876.1	14,606.2
1982	75.7	4,750.7	1,441.0	2,489.1	8,756.5	5,980.3	14,736.8
1983	75.8	4,514.5	1,362.2	2,562.2	8,514.8	6,139.8	14,654.6
1984	82.3	4,685.0	1,426.5	2,661.7	8,855.4	6,183.3	15,038.8
1985	69.3	4,566.1	1,536.9	2,708.9	8,881.2	6,353.8	15,235.0
1986	69.2	4,432.3	1,511.7	2,794.7	8,807.9	6,409.0	15,216.9
1987	65.6	4,435.7	1,542.2	2,901.6	8,945.1	6,612.9	15,558.1
1988	65.9	4,757.4	1,621.3	3,046.5	9,491.1	6,880.3	16,371.4
1989	58.3	4,921.5	1,628.7	3,089.7	9,698.1	6,931.7	16,629.8

Source: *State Energy Data Report 1960-1989*, U.S. DOE/EIA, May 1991.

Consumption of Energy by the Commercial Sector
By Fuel Type, 1960 - 1989
(Trillion Btu)

Year	Coal	Gas	Petroleum	Electricity	Total End-Use Energy Consumed	Electrical Energy Losses	Primary Energy Consumed
1960	572.1	1,055.9	1,227.5	542.7	3,398.3	1,350.9	4,749.2
1961	521.0	1,114.5	1,247.5	570.8	3,453.8	1,391.8	4,845.5
1962	515.6	1,248.9	1,279.7	619.6	3,663.8	1,490.0	5,153.8
1963	438.8	1,301.6	1,262.2	686.8	3,689.5	1,643.1	5,332.5
1964	374.9	1,412.0	1,246.9	738.0	3,771.8	1,758.8	5,530.6
1965	356.5	1,483.3	1,386.5	789.0	4,015.3	1,885.1	5,900.4
1966	359.4	1,668.7	1,435.7	851.1	4,322.9	2,062.8	6,385.7
1967	307.6	2,014.7	1,483.0	926.0	4,731.4	2,214.1	6,945.5
1968	275.8	2,134.3	1,510.1	1,015.5	4,935.7	2,424.9	7,360.6
1969	260.3	2,315.8	1,519.8	1,109.8	5,205.7	2,652.8	7,858.5
1970	217.1	2,454.6	1,551.1	1,203.2	5,426.1	2,911.0	8,344.2
1971	203.6	2,568.9	1,509.8	1,290.1	5,572.4	3,121.4	8,693.8
1972	156.6	2,674.1	1,530.0	1,409.4	5,770.2	3,396.3	9,166.4
1973	148.1	2,660.0	1,565.5	1,518.8	5,892.3	3,639.7	9,532.0
1974	151.7	2,614.2	1,422.7	1,502.1	5,690.6	3,666.1	9,356.7
1975	123.4	2,556.2	1,309.7	1,597.7	5,587.0	3,855.9	9,442.9
1976	120.4	2,716.8	1,460.9	1,677.6	5,975.7	4,043.7	10,019.4
1977	121.8	2,546.8	1,510.9	1,753.9	5,933.5	4,238.0	10,171.4
1978	129.2	2,642.1	1,449.8	1,814.3	6,035.5	4,441.0	10,476.5
1979	114.9	2,834.0	1,334.1	1,853.8	6,136.8	4,478.2	10,615.0
1980	87.3	2,665.7	1,287.5	1,906.5	5,947.0	4,639.0	10,586.1
1981	96.9	2,577.5	1,090.2	2,033.1	5,797.6	4,846.5	10,644.2
1982	111.7	2,670.8	1,008.4	2,077.1	5,871.0	4,986.4	10,857.4
1983	117.0	2,504.6	1,135.7	2,118.2	5,875.5	5,075.1	10,950.6
1984	126.5	2,593.9	1,158.7	2,266.7	6,145.9	5,266.7	11,412.6
1985	107.2	2,503.3	1,035.6	2,352.4	5,998.5	5,518.6	11,517.1
1986	107.0	2,382.6	1,064.6	2,440.4	5,994.6	5,597.4	11,592.0
1987	99.4	2,499.1	1,076.2	2,541.5	6,216.3	5,792.7	12,009.0
1988	102.3	2,743.7	1,071.4	2,677.4	6,594.8	6,047.3	12,642.1
1989	87.7	2,800.5	996.0	2,769.3	6,653.5	6,213.7	12,867.2

Source: *State Energy Data Report 1960 - 1989*, U.S. DOE/EIA, May, 1991.

Residential Sector Primary Energy Consumption per Household, 1960 - 1989

Year	Number of Households (Millions)	Fossil Fuel Consumption (Tril. Btu)	Fossil Fuel Consumption per Household (Mil. Btu)	Total Electricity Consumption (Mil Btu)	Electricity Consumption per Household (Mil. Btu)	Total Primary Energy Consumption (Tril. Btu)	Primary Energy Consumption per Household (Mil. Btu)
1960	52.8	5,885.3	111.5	2,399.0	45.4	8,284.0	156.9
1961	53.6	6,066.1	113.2	2,515.9	47.0	8,582.1	160.1
1962	54.8	6,397.9	116.8	2,704.4	49.4	9,102.3	166.1
1963	55.3	6,464.3	116.9	2,902.3	52.5	9,366.6	169.4
1964	56.2	6,546.6	116.5	3,137.8	55.9	9,684.4	172.5
1965	57.4	6,753.9	117.7	3,364.9	58.6	10,118.8	176.3
1966	58.4	6,977.0	119.5	3,677.0	63.0	10,654.0	182.4
1967	59.2	7,207.7	121.8	3,934.7	66.4	11,142.4	188.1
1968	60.8	7,454.7	122.6	4,410.0	72.5	11,864.7	195.1
1969	62.2	7,780.8	125.1	4,935.9	79.4	12,716.7	204.4
1970	63.4	7,861.1	124.0	5,448.9	85.9	13,310.0	209.9
1971	64.8	8,014.0	123.7	5,827.7	90.0	13,841.8	213.6
1972	66.7	8,263.3	123.9	6,265.2	93.9	14,528.6	217.8
1973	68.3	7,931.0	116.1	6,711.2	98.3	14,642.2	214.4
1974	69.9	7,575.3	108.4	6,786.2	97.1	14,361.5	205.6
1975	71.1	7,603.8	106.9	6,849.9	96.3	14,453.6	203.3
1976	72.9	7,951.5	109.1	7,056.9	96.8	15,008.4	205.9
1977	74.1	7,692.8	103.8	7,521.2	101.5	15,214.1	205.3
1978	76.1	7,691.4	101.1	7,934.3	104.3	15,625.7	205.3
1979	77.3	7,239.7	93.6	7,956.9	102.9	15,196.6	196.6
1980	80.8	6,663.6	82.5	8,405.7	104.0	15,069.3	186.5
1981	82.4	6,265.7	76.0	8,340.5	101.2	14,606.2	177.3
1982	83.5	6,267.4	75.1	8,469.4	101.4	14,736.8	176.5
1983	83.9	5,952.6	70.9	8,702.0	103.7	14,654.6	174.7
1984	85.4	6,193.7	72.6	8,845.0	103.6	15,038.8	176.1
1985	86.8	6,172.3	71.1	9,062.7	104.4	15,235.0	175.5
1986	88.5	6,013.2	68.0	9,203.7	104.0	15,216.9	171.9
1987	89.5	6,043.5	67.5	9,514.5	106.3	15,558.1	173.8
1988	91.1	6,444.6	70.7	9,926.8	109.0	16,371.4	179.7
1989	92.8	6,608.4	71.2	10,021.4	108.0	16,629.8	179.2

Sources: *State Energy Data Report 1960 - 1989*, U.S. DOE/EIA, May 1991.
U.S Bureau of the Census, *Statistical Abstract of the United States: 1990* (110th edition.) Washington, DC, 1990.

Residential Sector Energy Prices, 1970 - 1988
(Current Dollars Per Million Btu)

Year	Coal	Natural Gas	Distillate Fuel	Kerosene	LPG and Ethane	Electricity *	Average
1970	1.13	1.06	1.39	1.54	2.11	6.51	2.12
1971	0.97	1.12	1.41	1.59	2.05	6.82	2.24
1972	1.05	1.19	1.41	1.59	2.16	7.11	2.38
1973	1.17	1.26	1.64	1.87	3.62	7.45	2.73
1974	2.16	1.42	2.61	2.93	3.73	9.08	3.40
1975	2.47	1.67	2.74	3.14	4.03	10.29	3.83
1976	2.31	1.94	2.94	3.32	4.39	10.97	4.17
1977	2.49	2.31	3.32	3.78	4.91	11.90	4.82
1978	2.56	2.50	3.56	4.04	4.76	12.65	5.19
1979	2.47	2.91	4.83	5.61	6.55	13.63	6.01
1980	2.90	3.60	7.02	8.32	7.92	15.71	7.55
1981	3.55	4.19	8.63	10.53	8.35	18.17	8.93
1982	3.64	5.05	8.38	10.47	9.24	20.11	9.92
1983	3.15	5.88	8.11	9.32	9.47	21.04	10.85
1984	3.40	5.95	8.24	9.05	9.29	20.96	10.86
1985	3.25	5.94	7.92	8.68	8.93	21.66	11.12
1986	3.11	5.67	6.35	6.88	8.39	21.75	10.97
1987	2.76	5.39	6.05	6.48	8.46	21.82	10.93
1988	2.64	5.32	6.11	6.50	8.22	21.92	10.87

* Electricity converted at 3,412 Btu per kWh.

Sources: *State Energy Price and Expenditure Report: 1970-1982*, U.S. DOE/EIA, April 1985.
State Energy Price and Expenditure Report: 1988, U.S. DOE/EIA, September 1990.

Commercial Sector Energy Prices, 1970 - 1988
(Current Dollars Per Million Btu)

Year	Coal	Natural Gas	Distillate Fuel	Kerosene	LPG and Ethane	Motor Gasoline	Residual Fuel	Electricity*	Commercial Average
1970	0.45	0.75	1.10	0.77	1.24	2.86	0.45	6.10	1.97
1971	0.41	0.80	1.16	0.82	1.36	2.91	0.67	6.52	2.17
1972	0.45	0.86	1.17	0.81	1.36	2.90	0.71	6.76	2.35
1973	0.45	0.92	1.37	0.97	1.47	3.11	0.86	7.14	2.60
1974	0.86	1.05	2.28	2.17	2.60	4.33	1.92	9.02	3.45
1975	1.31	1.32	2.42	2.32	2.60	4.66	1.91	10.11	4.09
1976	1.08	1.62	2.65	2.67	2.93	4.81	1.98	10.98	4.46
1977	1.16	2.00	3.02	2.97	3.44	5.12	2.27	12.17	5.21
1978	1.27	2.20	3.18	3.15	3.53	5.28	2.20	13.12	5.65
1979	1.26	2.69	4.51	4.81	3.99	7.09	3.10	13.49	6.24
1980	1.54	3.32	6.45	6.46	5.15	9.77	4.12	16.06	7.88
1981	1.81	3.91	7.96	7.48	5.95	10.96	5.12	18.43	9.55
1982	1.88	4.70	7.68	7.30	6.32	10.44	4.67	20.11	10.44
1983	1.75	5.43	6.90	6.88	6.83	9.13	4.51	20.57	11.05
1984	1.79	5.40	6.83	7.56	6.78	8.94	4.78	20.90	11.29
1985	1.80	5.34	6.35	6.82	8.47	9.01	4.28	21.31	11.72
1986	1.66	4.94	4.59	4.49	8.19	6.77	2.54	21.10	11.40
1987	1.54	4.64	4.52	4.86	7.61	7.22	2.85	20.45	11.05
1988	1.54	4.51	4.33	4.34	7.69	7.33	2.28	20.35	10.87

* Electricity converted at 3412 Btu/kWh.

Sources: *State Energy Price and Expenditure Report, 1970 - 1982*, US DOE/EIA, April 1985.
State Energy Price and Expenditure Report, 1988, US DOE/EIA, September 1990.

Value of New Construction, 1970 - 1988

	Value of New Construction (million current $)	Gross National Product (billion current $)	Percent of GNP
1970	71,698	1,015.5	7
1971	117,904	1,102.7	11
1972	133,887	1,212.8	11
1973	147,368	1,359.3	11
1974	147,763	1,472.8	10
1975	99,489	1,598.4	6
1976	162,953	1,782.8	9
1977	188,048	1,990.5	9
1978	225,934	2,249.7	10
1979	188,742	2,508.2	8
1980	181,483	2,732.0	7
1981	188,304	3,052.6	6
1982	176,925	3,166.0	6
1983	214,271	3,405.7	6
1984	258,879	3,772.2	7
1985	279,337	4,014.9	7
1986	313,613	4,231.6	7
1987	319,639	4,524.3	7
1988	327,102	4,880.6	7
1989	333,515	5,201.0	6
1990	324,435	5,457.0	6

Note: Value of construction does not include expenditures for public utilities, highways and streets, or water supply facilities.

Sources:

U.S Bureau of the Census, *Statistical Abstract of the United States: 1988(108th edition.)* Washington, D.C., 1988.

U.S Bureau of the Census, *Statistical Abstract of the United States: 1990 (110th edition.)* Washington, D.C., 1990.

Bureau of the Census, Current Construction Reports, Value of New Construction Put in Place: April 1991, C30-9104.

New Privately Owned Residential Construction in the U.S., 1966 - 1989
(Thousands)

Year	Number of Single Family Units	Percent of all Units	Number of Multi-Family Units	Percent of all Units	Number of Multi-Family Buildings
1966	779	66.87	386	33.13	N/A
1967	844	65.33	448	34.67	N/A
1968	899	59.65	608	40.35	N/A
1969	811	55.28	656	44.72	N/A
1970	813	56.69	621	43.31	N/A
1971	1,014	59.44	692	40.56	74
1972	1,143	57.99	828	42.01	86
1973	1,174	58.29	840	41.71	90
1974	932	55.08	760	44.92	75
1975	866	66.82	430	33.18	45
1976	1,034	75.09	343	24.91	48
1977	1,258	75.92	399	24.08	59
1978	1,369	73.33	498	26.67	73
1979	1,301	69.54	570	30.46	78
1980	957	63.72	545	36.28	74
1981	819	64.69	447	35.31	64
1982	632	62.82	374	37.18	47
1983	924	66.43	467	33.57	60
1984	1,025	62.05	627	37.95	75
1985	1,072	62.95	631	37.05	73
1986	1,120	63.78	636	36.22	72
1987	1,123	67.29	546	32.71	59
1988	1,085	70.92	445	29.08	48
1989	1,026	72.10	397	27.90	44

Source: U.S. Bureau of the Census, Current Construction Reports-Series C25, *Characteristics of New Housing: 1989.* U.S Department of Commerce, Washington DC, 1990. and earlier issues.

New Privately-Owned Single Family Housing for 1966 - 1989, by Region
(Number of Units, in Thousands)

Year	Total No. of Units	Northeast		MidWest		South		West	
		No. of Units	Percent of Total Units	No. of Units	Percent of Total Units	No. of Units	Percent of Total Units	No. of Units	Percent of Total Units
1966	792	129	16.3	191	24.1	334	42.2	137	17.3
1967	817	123	15.1	195	23.9	344	42.1	155	19.0
1968	840	128	15.2	210	25.0	342	40.7	160	19.0
1969	767	116	15.1	171	22.3	331	43.2	149	19.4
1970	793	111	14.0	170	21.4	356	44.9	156	19.7
1971	1,014	134	13.2	208	20.5	467	46.1	204	20.1
1972	1,143	149	13.0	231	20.2	524	45.8	239	20.9
1973	1,174	155	13.2	255	21.7	514	43.8	251	21.4
1974	932	131	14.1	217	23.3	394	42.3	190	20.4
1975	866	113	13.0	215	24.8	358	41.3	181	20.9
1976	1,034	121	11.7	271	26.2	410	39.7	232	22.4
1977	1,258	135	10.7	300	23.8	512	40.7	311	24.7
1978	1,369	141	10.3	300	21.9	571	41.7	357	26.1
1979	1,301	135	10.4	294	22.6	535	41.1	337	25.9
1980	957	100	10.4	170	17.8	455	47.5	233	24.3
1981	819	87	10.6	140	17.1	408	49.8	183	22.3
1982	632	79	12.5	92	14.6	340	53.8	121	19.1
1983	924	106	11.5	142	15.4	476	51.5	200	21.6
1984	1,025	129	12.6	156	15.2	508	49.6	233	22.7
1985	1,072	168	15.7	151	14.1	514	47.9	239	22.3
1986	1,120	193	17.2	170	15.2	505	45.1	253	22.6
1987	1,123	196	17.5	201	17.9	467	41.6	259	23.1
1988	1,085	188	17.3	191	17.6	457	42.1	248	22.9
1989	1,026	159	15.5	191	18.6	420	40.9	257	25.0

Source: U.S. Bureau of Census, Current Construction Reports-Series C25, *Characteristics of New Housing: 1989.*

Number of New Privately-Owned Multi-Family Buildings for 1971 - 1989, by Census Region,,
(Thousands of Buildings)

Year	United States	Northeast Region	Percent of US	Midwest Region	Percent of US	Southern Region	Percent of US	Western Region	Percent of US
1971	74	9	13	14	20	28	38	22	29
1972	86	13	15	17	20	32	37	24	28
1973	90	13	15	17	19	35	39	24	27
1974	75	9	12	15	20	31	42	19	26
1975	45	6	13	11	24	15	34	13	29
1976	48	6	13	12	26	13	27	16	34
1977	59	6	10	13	23	16	28	23	39
1978	73	6	8	17	23	24	32	26	37
1979	78	6	8	16	21	29	37	27	34
1980	74	5	7	14	20	31	43	22	30
1981	64	5	8	11	18	32	49	16	25
1982	47	4	8	7	15	25	53	11	23
1983	60	4	7	8	13	34	57	14	22
1984	75	5	7	9	11	43	56	19	25
1985	73	8	11	9	12	34	46	22	30
1986	72	9	13	11	16	29	40	23	30
1987	59	9	15	10	17	20	34	19	32
1988	48	9	19	9	19	15	31	15	31
1989	44	8	18	8	18	14	32	14	32

Source: U.S. Bureau of the Census, Current Construction Reports-Series C25, *Characteristics of New Housing: 1989*, and earlier issues.

Number of New Privately-Owned Multi-Family Units for 1971 - 1989, by Region
(Thousands of Units)

Year	United States	Northeast Region	Percent of US	Midwest Region	Percent of US	Southern Region	Percent of US	Western Region	Percent of US
1971	692	91	13	148	21	260	36	201	29
1972	828	132	6	174	21	304	37	218	26
1973	840	131	6	175	21	333	40	202	24
1974	760	95	13	152	20	344	45	170	22
1975	430	69	6	93	22	164	38	103	24
1976	343	50	15	84	24	103	30	106	31
1977	399	41	10	99	25	125	31	133	339
1978	498	41	8	117	23	181	36	160	32
1979	570	53	9	121	21	227	40	169	30
1980	545	46	8	104	19	242	44	153	28
1981	447	40	9	78	17	218	49	111	25
1982	374	41	11	51	14	199	53	82	22
1983	467	33	7	59	13	270	58	104	22
1984	627	40	6	65	10	358	57	164	26
1985	631	46	7	79	13	298	47	207	33
1986	636	61	10	100	16	259	41	216	34
1987	546	62	11	101	18	193	35	190	35
1988	445	62	14	89	20	138	31	156	35
1989	397	60	15	76	19	129	32	131	33

Source: U.S. Bureau of the Census, Current Construction Reports-Series C25, *Characteristics of New Housing: 1989.* U.S Department of Commerce, Washington DC, 1990 and earlier issues.

Space Heating Fuels Used in New Privately-Owned Single Family Homes, 1966 - 1989
(Number of Units, in Thousands)

Year	Total Number of Buildings	Electricity		Gas		Oil		Other or None	
		#	%	#	%	#	%	#	%
1966*	319	63	20	205	64	42	13	10	3
1967	764	153	20	506	66	86	11	19	3
1968	797	173	22	516	65	92	11	16	2
1969	714	180	25	457	64	66	9	9	1
1970	745	210	28	466	62	59	8	11	1
1971	1,014	313	31	605	60	83	8	15	1
1972	1,143	416	36	621	54	93	8	13	1
1973	1,174	488	42	549	47	123	10	16	1
1974	932	454	49	382	41	84	9	11	1
1975	866	425	49	343	40	81	9	18	2
1976	1,034	499	48	407	39	110	11	19	2
1977	1,258	635	50	476	38	120	9	28	2
1978	1,369	710	52	511	37	109	8	40	3
1979	1,301	662	51	512	39	86	7	41	3
1980	957	482	50	394	41	29	3	52	5
1981	819	407	50	339	41	16	2	57	7
1982	632	315	50	252	40	17	3	48	8
1983	924	448	49	400	43	22	2	53	6
1984	1,025	492	48	460	45	24	2	49	5
1985	1,072	528	49	466	44	36	3	42	4
1986	1,120	497	44	527	47	52	5	45	4
1987	1,123	445	40	583	52	58	5	38	3
1988	1,085	402	37	587	54	60	6	36	3
1989	1,026	352	34	596	58	50	5	28	3

* = Data reflect only houses begun in the last half of this year.

Source: U.S. Bureau of the Census, Current Construction Reports-Series C25, *Characteristics of New Housing: 1989.* U.S Department of Commerce, Washington DC, 1990, and earlier issues.

Space Heating Fuels Used in New Privately-Owned Multi-Family Buildings, 1974 - 1989
(Thousand Buildings)

Year	Total Number of Units	Electricity		Gas		Oil		Other or None	
		#	%	#	%	#	%	#	%
1974	75	46	60	29	39	1	1	Z	Z
1975	45	26	58	18	40	1	3	Z	Z
1976	48	28	59	17	35	2	5	Z	S
1977	59	38	64	18	32	3	4	Z	S
1978	73	47	65	23	31	2	3	Z	S
1979	78	51	65	25	32	1	2	1	1
1980	74	46	63	27	36	Z	S	1	1
1981	64	40	63	23	36	Z	S	Z	S
1982	47	30	64	16	34	S	S	1	1
1983	60	41	68	19	31	S	S	Z	S
1984	76	53	70	22	30	S	S	Z	S
1985	73	45	61	27	37	1	1	Z	S
1986	72	42	57	30	41	1	1	1	1
1987	59	30	51	28	47	Z	S	1	1
1988	48	24	49	23	49	1	1	Z	S
1989	44	20	45	22	51	1	2	S	S

Notes: S = insufficient validity, Z = less than 0.5%.

Source: U.S. Bureau of the Census, Current Construction Reports-Series C25, *Characteristics of New Housing: 1989,* U.S Department of Commerce, Washington DC, 1990.

Residential Air Conditioning Equipment

Year	New Single Family Homes With Central Air Conditioning					New Multi-Family Homes with Air Conditioning				
	Total Number of Units	Installed		Not Installed		Total # of Buildings	Installed		Not Installed	
		#	%	#	%		#	%	#	%
1973	1,174	571	49	604	51	90	S	S	S	S
1974	932	448	48	484	52	75	57	76	18	24
1975	866	399	46	467	54	45	33	74	11	26
1976	1,034	511	49	523	51	48	32	67	16	33
1977	1,258	679	54	579	46	59	40	69	18	31
1978	1,369	797	58	572	42	73	51	70	22	30
1979	1,301	784	60	517	40	78	59	76	19	24
1980	957	598	63	358	37	74	58	79	16	21
1981	819	530	65	289	35	64	50	78	14	22
1982	632	416	66	216	34	47	39	83	8	17
1983	924	642	70	282	30	60	51	85	9	15
1984	1,025	723	71	302	29	76	65	86	11	14
1985	1,072	746	69	326	31	73	59	81	14	19
1986	1,120	775	70	346	30	72	60	83	12	17
1987	1,123	801	71	322	29	59	46	78	13	22
1988	1,085	810	75	275	25	48	38	79	10	21
1989	1,026	785	77	241	23	44	34	76	10	24

Notes: S = insufficient validity.

Source: U.S. Bureau of the Census, Current Construction Reports-Series C25, *Characteristics of New Housing: 1989.* U.S Department of Commerce, Washington DC, 1990, and earlier issues.

Commercial Buildings 1986, by Census Region
Number of Buildings, Thousands

	U.S.	Northeast	Midwest	South	West
All Buildings	4154	663	1096	1570	825
Activity					
Assembly	575	71	156	241	108
Education	241	29	42	80	90
Food Sales	102	Q	23	47	Q
Food Services	201	40	63	58	40
Health Care	52	10	9	17	17
Lodging	137	22	30	53	31
Mercantile/Service	1287	227	349	481	231
Office	614	91	153	238	131
Public Order & Safety	55	13	Q	18	Q
Warehouse	549	99	154	219	77
Other	103	17	30	31	24
Vacant	238	27	73	87	52
Year constructed					
1900 or before	188	62	89	18	18
1901 to 1920	255	73	82	66	34
1921 to 1945	629	118	178	201	131
1946 to 1960	878	127	203	361	187
1961 to 1970	730	103	191	284	152
1971 to 1973	243	29	86	89	40
1974 to 1979	572	68	133	244	128
1980 to 1983	350	42	64	170	75
1984 to 1986	309	42	70	137	60
Energy Sources					
Electricity	4013	645	1042	1524	802
Natural Gas	2278	297	736	745	501
Fuel Oil	542	264	109	136	33
District Steam or Water	78	17	22	25	13
District Chilled Water	15	Q	7	3	Q
Propane	351	55	99	146	Q
Minor Fuels	163	32	50	57	25
No Energy Sources	136	18	53	43	22

Q Data withheld.
Source: *NBECS: Characteristics of Commercial Buildings 1986*. DOE/EIA-0246(86).

Commercial Buildings 1986, by Census Region
Floorspace, Million Square Feet

	U.S.	Northeast	Midwest	South	West
All Buildings	58,229	11,830	16,034	19,427	10,937
Activity					
Assembly	7,339	1,229	2,004	2,724	1,382
Education	7,321	1,603	2,212	2,174	1,332
Food Sales	712	Q	219	192	Q
Food Services	1,281	219	445	391	226
Health Care	2,107	328	559	806	415
Lodging	2,785	602	636	949	597
Mercantile/Service	12,805	2,785	3,525	4,487	2,008
Office	9,546	1,782	2,535	2,838	2,390
Public Order & Safety	680	289	Q	147	Q
Warehouse	8,996	1,905	2,246	3,548	1,387
Other	1,726	354	622	357	392
Vacant	2,931	555	853	904	620
Year constructed					
1900 or before	2,368	886	1,121	211	150
1901 to 1920	3,665	1,359	978	878	450
1921 to 1945	8,594	2,349	2,513	2,019	1,713
1946 to 1960	9,712	1,768	2,207	3,963	1,774
1961 to 1970	11,469	2,018	3,059	4,200	2,192
1971 to 1973	4,307	696	1,224	1,527	859
1974 to 1979	8,230	1,318	2,268	3,019	1,625
1980 to 1983	5,205	834	1,258	1,904	1,209
1984 to 1986	4,678	603	1,404	1,705	966
Energy Sources					
Electricity	57,036	11,561	15,756	18,968	10,751
Natural Gas	38,140	7,107	12,579	10,793	7,661
Fuel Oil	11,163	5,158	2,101	2,583	1,321
District Steam or Water	4,645	1,379	1,799	729	738
District Chilled Water	1,191	200	437	362	Q
Propane	3,362	818	679	1,381	485
Minor Fuels	1,557	358	423	517	260
No Energy Sources	1,171	Q	273	447	Q

Q Data withheld.
Source: *NBECS: Characteristics of Commercial Buildings 1986*. DOE/EIA-0246(86).

Commercial Buildings 1986, by Year Constructed
Number of Buildings (1000)

	U.S.	pre-1920	1921-1960	1961-1979	1980-1986
All Buildings	4154	443	1507	1545	660
Region					
Northeast	663	135	245	199	84
Midwest	1096	172	381	409	133
South	1570	84	562	617	307
West	825	52	318	320	135
Activity					
Assembly	575	77	225	210	63
Mercantile/service	1287	141	475	459	211
Office	614	63	199	237	115
Warehouse	549	42	201	208	98
Other	1128	119	407	430	173
Energy Sources					
Electricity	4013	421	1446	1516	630
Natural Gas	2278	281	912	810	275
Fuel Oil	542	96	222	182	42
District Systems	85	14	31	29	10
Propane	351	34	116	136	66
End Uses					
Space Heating	3681	399	1330	1387	566
Cooling	2882	260	1015	1137	469
Water Heating	2896	291	1034	1118	452
Cooking	563	60	188	222	92
Manufacturing	132	14	47	48	23

Source: *NBECS: Characteristics of Commercial Buildings 1986*, DOE/EIA-0246(86).

Commercial Buildings 1986, by Year Constructed
Floorspace (million sq ft)

	U.S.	pre-1920	1921-1960	1961-1979	1980-1986
All Buildings	58229	6034	18306	24006	9883
Region					
Northeast	11830	2245	4117	4032	1437
Midwest	16034	2100	4720	6552	2662
South	19427	1089	5982	8747	3609
West	10937	600	3487	4676	2175
Activity					
Assembly	7339	1328	2613	2668	730
Mercantile/Service	12805	1342	3571	5371	2521
Office	9546	1031	2282	3723	2510
Warehouse	8996	620	3283	3750	1343
Other	19544	1714	6557	8495	2778
Energy Sources					
Electricity	57036	5844	17572	23904	9716
Natural Gas	38140	3941	12443	15945	5811
Fuel Oil	11163	1771	3754	4117	1520
District Systems	4815	688	1701	2123	303
Propane	3362	351	983	1453	575
End Uses					
Space Heating	54510	5632	16750	22842	9287
Cooling	46601	4205	13281	20459	8655
Water Heating	48836	4997	14606	20732	8501
Cooking	17227	1437	4441	8039	3310
Manufacturing	3081	359	871	1290	561

Source: *NBECS: Characteristics of Commercial Buildings 1986*, DOE/EIA-0246(86).

Commercial Buildings 1986
Heat Production Equipment
Number of Buildings
(1000)

			Heat Production Equipment Used					
	All Buildings	All Heated Buildings	Warm-Air Furnaces	Boilers	Individual Space Heaters or Electric Baseboards	Packaged Heating Units	Air-Source Heat Pumps	Receives District Heat
All Buildings	4154	3684	1793	627	1062	540	319	76
Census Region								
Northeast	663	603	251	253	152	59	37	17
Midwest	1096	971	629	184	264	97	36	22
South	1570	1414	577	115	439	214	194	25
West	825	696	335	75	208	170	53	11
Year Constructed								
Before 1921	443	397	187	133	118	Q	Q	Q
1921 - 1960	1507	1342	657	382	420	136	66	28
1961 - 1979	1545	1383	701	178	377	248	150	28
1980- 1986	659	562	248	48	148	138	88	Q
Principal Activity								
Assembly	575	542	300	118	167	50	38	8
Education	241	238	86	87	50	38	13	9
Food Sales	102	101	40	Q	28	22	Q	Q
Food Service	201	189	101	19	32	66	Q	Q
Health Care	52	52	21	12	8	10	Q	3
Lodging	137	130	35	33	59	10	12	8
Mercantile/Service	1287	1213	653	170	377	171	80	11
Office	614	612	291	98	117	108	99	17
Public Order/Safety	55	53	28	14	18	Q	Q	Q
Warehouse	549	335	150	33	141	42	28	4
Other	103	73	32	13	29	5	Q	4
Vacant	238	146	56	18	37	16	Q	Q

Q = data withheld.
Source: *NBECS: Characteristics of Commercial Buildings 1986*, DOE/EIA-0246(86).

Electricity Consumption in Commercial Buildings, 1986

	All Buildings Using Electricity					Peak Demand-Metered Buildings			
	Number of Buildings (thousand)	Total Floorspace (million square feet)	Total Electricity Consumed (billion kWh)	Electricity Consumed per Building (Thousands kWh)	Electricity Consumed per Square Foot (kWh)	Number of Buildings (thousand)	Total Floorspace (million square feet)	Electricity Consumed (billion kWh)	Electricity Consumed per Square Foot (kWh)
All Buildings	3,965	56,508	700.6	176.7	12.4	1,673	33,978	513.3	15.1
Region									
Northeast	635	11,429	125.9	198.3	11.0	266	6,068	86.1	14.2
Midwest	1,028	15,680	171.1	166.4	10.9	344	8,562	118.8	13.9
South	1,506	18,753	254.1	168.7	13.6	718	12,328	192.3	15.6
West	796	10,647	149.5	187.8	14.0	345	7,020	166.0	23.6
Building Floorspace									
1,001 - 5,000	2,098	5,899	110.2	52.5	18.7	741	2,144	67.8	31.6
5,001 - 10,000	893	6,588	81.4	91.2	12.4	388	2,892	46.0	15.9
10,001 - 25,000	540	8,843	91.6	169.6	10.4	278	4,532	59.9	13.2
25,001 - 50,000	238	8,499	91.5	384.4	10.8	131	4,835	67.2	13.9
50,001 - 100,000	118	8,178	88.7	751.7	10.8	76	5,291	69.4	13.1
100,001 - 200,00	51	7,042	73.0	1431.4	10.4	36	5,010	60.5	12.1
200,001 - 500,00	23	6,730	90.1	3917.4	13.4	18	5,228	74.5	14.3
Over 500,00	6	4,728	74.1	12,350.0	15.7	5	4,047	67.9	16.8
Principal Activity									
Assembly	571	7,287	48.0	84.1	6.6	186	3,473	31.6	9.1
Education	240	7,200	52.4	218.3	7.3	141	4,743	36.4	7.7
Food Sales	102	712	28.9	283.3	40.6	61	463	21.7	46.9
Food Service	201	1,277	35.4	176.1	27.7	112	803	20.6	25.7
Health Care	51	2,104	38.7	758.8	18.4	30	1,621	27.7	17.1
Lodging	137	2,785	35.2	256.9	12.6	68	1,783	25.4	14.2
Mercantile/Service	1,273	12,710	157.1	123.4	12.4	505	7,359	113.9	15.5
Office	607	9,499	187.8	309.4	19.8	258	6,358	150.3	23.6
Public Order/Safety	50	665	8.8	176.0	13.2	26	387	7.3	18.9
Warehouse	487	8,540	73.8	151.5	8.6	206	5,005	54.8	10.9
Other	94	1,700	24.3	258.5	14.3	39	1,038	17.0	16.4
Vacant	152	2,030	10.1	66.4	5.0	41	945	6.6	7.0

Q = data withheld.
Source: *NBECS: Commercial Buildings Consumption and Expenditures 1986*, DOE/EIA-0318(86).

Commercial Buildings End-Use Energy Consumption for 1986, by Major Fuel

	Number of Buildings (thousand)	Total Floorspace (million square feet)	Total Energy Consumption (trillion Btu)					
			All Major Fuels	Electricity*	Natural Gas	Fuel Oil	District Heat	Propane
All Buildings	3,992	56,825	5,040	2,390	1,723	442	422	63
Region								
Northeast	639	11,506	1,046	430	244	270	94	9
Midwest	1,036	15,728	1,603	584	742	63	196	19
South	1,517	18,882	1,485	867	426	86	81	26
West	800	10,708	906	510	311	Q	51	Q
Year Constructed								
1900 or before	179	2,294	129	42	54	23	Q	Q
1901 - 1920	237	3,520	274	96	109	31	37	Q
1921 - 1945	596	8,077	666	201	254	108	97	7
1946 - 1960	843	9,410	754	302	308	87	44	12
1961 - 1970	715	11,352	1,252	615	435	91	98	13
1971 - 1973	238	4,290	474	226	158	22	Q	Q
1974 - 1979	557	8,186	739	438	196	56	Q	9
1980 - 1983	342	5,179	3989	254	102	16	Q	10
1984 - 1986	286	4,517	354	216	106	8	Q	8
Principal Activity								
Assembly	572	7,305	401	164	157	42	31	7
Education	241	7,292	635	179	254	103	97	3
Food Sales	102	712	151	99	45	Q	Q	Q
Food Service	201	1,281	260	121	114	Q	Q	12
Health Care	52	2,107	457	132	205	Q	80	Q
Lodging	137	2,785	311	120	105	20	Q	12
Mercantile/Service	1,280	12,781	1,002	536	332	105	Q	17
Office	610	9,532	1,010	641	258	39	71	Q
Public Order/Safety	53	678	86	30	25	Q	Q	Q
Warehouse	491	8,558	466	252	143	48	Q	Q
Other	94	1,704	169	83	46	Q	Q	Q
Vacant	160	2,090	92	35	38	Q	Q	Q

Q = data withheld.
* End-use electricity converted at 3,412 Btu per kWh.

Source: *NBECS: Commercial Buildings Consumption and Expenditures 1986*, DOE/EIA-0318(86).

Commercial Buildings End-Use Energy Expenditures for 1986, by Major Fuel

	Number of Buildings (thousand)	Total Floorspace (million square feet)	Total Energy Expenditures (million dollars)					
			All Major Fuels	Electricity	Natural Gas	Fuel Oil	District Heat	Propane
All Buildings	3,992	56,825	60,762	47,186	8,355	2,059	2,620	543
Region								
Northeast	639	11,506	14,362	10,886	1,472	1,272	639	93
Midwest	1,036	15,728	15,848	10,869	3,400	278	1,170	131
South	1,517	18,882	17,945	14,856	1,958	394	516	221
West	800	10,708	12,607	10,575	1,524	Q	294	Q
Year Constructed								
1900 or Before	179	2,294	1,376	891	278	126	Q	Q
1901 - 1920	237	3,520	3,559	2,597	521	163	268	Q
1921 - 1945	596	8,077	6,698	4,233	1,324	491	596	54
1946 - 1960	843	9,410	8,717	6,428	1,495	405	279	109
1961 - 1970	715	11,352	14,741	11,574	2,038	413	613	103
1971 - 1973	238	4,290	[illegible],418	4,175	755	99	369	Q
1974 - 1979	557	8,186	9,337	8,326	912	247	Q	73
1980 - 1983	342	5,179	5,632	4,862	520	74	Q	89
1984 - 1986	286	4,517	4,783	4,100	510	43	Q	63
Principal Activity								
Assembly	572	7,305	5,009	3,707	811	221	214	56
Education	241	7,292	5,782	3,606	1,189	448	519	20
Food Sales	102	712	2,176	1,923	201	Q	Q	Q
Food Service	201	1,281	3,241	2,451	604	Q	Q	112
Health Care	52	2,107	3,824	2,287	884	Q	486	Q
Lodging	137	2,785	3,330	2,251	523	92	Q	104
Mercantile/Service	1,280	12,781	13,231	10,781	1,706	516	Q	140
Office	610	9,532	14,777	12,884	1,178	194	507	Q
Public Order/Safety	53	678	720	475	133	Q	Q	Q
Warehouse	491	8,558	5,620	4,537	722	204	Q	Q
Other	94	1,704	2,013	1,568	204	Q	Q	Q
Vacant	160	2,090	1,040	715	200	Q	Q	Q

Q = data withheld.
Source: *NBECS: Commercial Buildings Consumption and Expenditures 1986*, DOE/EIA-0318(86).

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