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FORMAL REPORT

OFFICE OF BUILDING TECHNOLOGIES

EVALUATION AND PLANNING REPORT

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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 evaluation and planning activities undertaken on behalf of OBT during the past several years. It provides historical data on energy consumption patterns, prices, and building characteristics used in OBT's planning processes, and summaries of selected recent OBT analysis activities.

EXECUTIVE SUMMARY

The U.S. Department of Energy's (DOE's) Office of Building Technologies (OBT) leads a national effort to meet future increases in the need for energy services in the nation's buildings through improvement in energy efficiency and increases in the use of renewable energy. This report summarizes evaluation and planning activities conducted by OBT during 1991 and 1992. Evaluation and planning activities serve three vital functions within OBT: they ensure that OBT identifies and invests in those areas of research most likely to produce energy savings in the buildings sector; they assess the costs and benefits of policy options which affect the buildings sector; and they provide consistency with similar activities within the Office of Energy Efficiency and Renewable (EE) and other parts of DOE.

In 1990 Americans spent $188.5 billion for energy used in homes and commercial buildings. Most of these expenditures ($133 billion or 70 percent of the total) were for the purchase of electricity. This energy is used to heat and cool buildings, and to provide hot water, lighting, and other conveniences which significantly improve the comfort and quality of life at home as well as the efficiency of our workplaces.

Although we have improved the efficiency with which we use energy in our buildings, there is still tremendous potential for improving energy efficiency and increasing the use of renewable energy. Achieving that potential will not only reduce the costs associated with providing comfort and increasing productivity, but will also help to reduce environmental impacts due to energy production and use, and strengthen the U.S. economy by improving U.S. competitiveness in international markets.

OBT activities are shaped by Federal legislation and other Federal directives. Much of the analysis undertaken by OBT between 1989 and 1991 was in support of the development of the National Energy Strategy, which was completed in 1991.

Shortly thereafter, Congress began consideration of a comprehensive energy policy, culminating in the enactment of the Energy Policy Act of 1992 (EPAct) in October 1992. This Act includes many provisions affecting building energy use. OBT analysts continue to examine the impacts of EPAct on OBT's program.

TRENDS IN BUILDINGS ENERGY USE

Our society uses almost 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 primary energy use in the buildings sector has grown from 32.7 percent in 1979 to 36.2 percent in 1991, while industrial energy use has declined by 9.3 percent and transportation energy use has increased by 8 percent. In the commercial sector primary energy consumption increased by 22.6 percent while residential energy use increased by 7.8 percent in the same period.

In the residential and commercial sectors, growth in primary energy consumption has resulted primarily from increased use of electricity. The buildings sectors accounted for nearly two-thirds (64.9 percent) of electricity consumption in the U.S., and almost 38 percent of natural gas consumption.

In the residential sector, electricity use (including losses) has grown from 46 percent of all energy consumed in 1973 to about 63 percent in 1991. During this time direct coal use has declined to less than 0.1 quad, gas use has declined slightly from 5 quads to 4.7 quads, and petroleum use has decreased from nearly 3 quads to approximately 1.3 quads per year.

In the commercial sector, electricity use has grown from 54 percent in 1973 to over 71 percent in 1991 on a primary energy basis. 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 less than 1 quad per year.

In both sectors, space heating is the dominant end use, accounting for slightly more than 30 percent of primary energy consumption. In the residential sector, water heating and refrigerators/freezers account for an additional 30 percent of primary energy use. Appliances, not including air conditioners or refrigerators, account for more than one-third of electricity use. In the commercial sector, lighting and space cooling account for about half of the energy consumption on a primary basis; lighting is responsible for almost 40 percent of all electricity use in commercial buildings.

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 250 million in 1991.

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 slightly or remained constant since. 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.

Federal Buildings

The U.S. Government is the largest single energy consumer in the country. In Fiscal Year 1991, the Federal Government consumed 1.92 quads of primary energy at a cost of $11.3 billion. Most of the energy (1.14 quads) was used in general operations, which include vehicles and process energy. The remainder, 0.78 quads, was used in buildings and facilities. The government operates approximately 500,000 buildings and facilities, containing about 3.2 billion square feet of floorspace. The Department of Defense accounts for about two-thirds of the energy used in buildings.

The National Energy Conservation Policy Act (NECPA), as amended, requires Federal agencies to improve energy efficiency, measured as delivered energy per square foot, by 10 percent by 1995 relative to 1985. Delivered energy use per square foot has decreased by 9.6 percent since 1985. This is due to a 23 percent decrease in the use of non-electric fuels. However, electricity use has increased by about 5.7 percent during the same time, so efficiency improvements are less when measured in terms of primary energy.

Executive Order 12759, signed in 1991, extends and expands NECPA and sets a goal of 20 percent reduction by 2000. The National Energy Policy Act of 1992 repeats this goal and contains further provisions for the Federal Energy Management Program.

FACTORS AFFECTING ENERGY USE IN BUILDINGS

Many factors affect how much and what types of energy are used in buildings. These range from relatively simple factors such as total population to more complex issues such as the way consumers make decisions about energy. Understanding these factors, their relationships, and their impact on energy use continues to be an important area of inquiry for OBT.

Three causal factors have been identified and measured: changes in the aggregate level of energy-using activities in each sector; changes in the structure or composition of activities; and changes in energy intensities, or energy use per unit of activity or output. The effect of each factor on energy use is estimated, and compared to actual changes in energy use.

In the residential sector, population is the measure of activity. The structure of the sector is measured by household floor area and appliance ownership per capita. If energy intensity had remained at 1973 levels, residential primary energy use would have increased by about 45 percent between 1973 and 1987 due to changes in the level and structure of residential activity.

Energy intensities for space heating and major appliances fell significantly from 1973 to 1987. Useful energy per dwelling for space heating fell 34 percent. This was due to improved thermal characteristics of both new and existing buildings and to improved equipment efficiencies. Overall, reduced energy intensities would have cut residential primary energy use by 21 percent from 1973 to 1987 if structural and activity changes had not occurred. Actual delivered energy use in the residential sector decreased by 3 percent and primary energy use increased by 13 percent.

In the services sector, activity is measured by service sector value-added and structure by commercial floor area per unit of value-added, as well as heating fuel switching. The impact of structural change is small (6 percent increase in primary energy) compared to total energy use, but the activity effect (50 percent increase) is significant because service sector GNP grew 7 percent more than total GNP. Researchers estimate that a 40 percent decline in fuel heating intensity and an 18 percent decline in electric heating intensity took place. Overall, intensity improvements would have reduced delivered energy by 29 percent and primary energy use by 18 percent if other factors had remained constant. Actual delivered energy increased by 5 percent and primary energy by 26 percent.

Thus, improved energy efficiency had a significant impact on total energy use. Activity growth and structural changes would have caused significant increases in buildings energy use if improvements in energy intensities had not occurred. Most of these changes are technology based, and thus permanent. However, improvements in energy intensity seem to be slowing. The combination of slowed efficiency improvements with continued structural growth could lead to rapid increases in buildings energy use in the future.

The link between government policies and efficiency improvements is still not clear, however. Achieving further savings poses a significant challenge to policy makers, especially in light of concerns about the role of fossil fuel combustion in global climate change. It is more necessary than ever to fully disaggregate energy use patterns to understand the effectiveness of alternative policies.

FUTURE POSSIBILITIES

During development of the National Energy Strategy, from 1989 to 1991, considerable effort was devoted to defining possible energy futures. The potential for conservation and renewable energy use in buildings was evaluated, and various policy options for achieving improved efficiency and greater use of renewable energy were analyzed.

Determining the Potential for Conservation

Development of the National Energy Strategy (NES) included a three step process for assessing the potential for conservation 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.

A number of possible energy policy options affecting all aspects of energy production and consumption were independently analyzed. Options affecting buildings are described in Chapter 4 of this report. Selected options were then integrated to estimate their combined effects. Building efficiency standards and utility Integrated Resource Planning (IRP) were the only options with a direct affect on buildings energy use that were included in the integration.

Many policy actions affect more than one sector or fuel; changes in one sector often affect fuel prices, which in turn affect energy demand and supply in other sectors. For example, the effect of buildings efficiency standards decreases slightly in the integrated analysis because of lower overall energy prices. The impact of implementing the IRP option increases when combined with end-use conservation technology R&D options; the R&D actions make more efficient technologies available in the marketplace, while the IRP actions provide the financial vehicle necessary for their widespread application.

The Current Policy Base case shows an energy future in which no major changes in energy policy are assumed to occur. For the U.S. as a whole, primary energy consumption grows at about 1.3 percent per year. Renewable energy's contribution rises from about 8 percent of U.S. primary energy consumption today to 12 percent in 2030. Efficiency gains occur in all sectors, although highway fleet efficiency in the transportation sector rises slowly. Electricity consumption rises faster than any other end-use fuel, growing at 2.1 percent per year. Although buildings energy use grows at about the same rate as total energy use, this is slower than the projected growth in households or commercial floorspace. Renewable energy use in buildings increases from 1 quad in 1990 to 2.2 quads in 2030.

In the National Energy Strategy scenario, total U.S. primary energy consumption grows at just under 1.0 percent per year. Electricity consumption also grows much more slowly than in the Current Policy Base case, at 1.7 percent per year. Total renewable energy consumption is projected to increase more than 30 percent over the Current Policy Base case levels by 2030; renewable energy consumption in buildings is the same as in the Current Policy Base case. Energy consumption in the buildings sectors falls only slightly relative to the Current Policy Base case.

Energy Forecasts and the Energy Policy Act of 1992

The Energy Policy Act (EPAct) was passed by Congress in 1992. It contains provisions affecting all aspects of energy production and consumption. Section 1602, Least-Cost Energy Strategy, specifies that a strategy shall be designed to achieve "an increase in the efficiency of the Nation's total energy use by 30 percent over 1988 levels by the year 2010." Several forecasts are examined to determine the necessary energy savings required to meet the EPAct goals, assuming that efficiency improvements of 30 percent will be desired for each energy-using sector. Absolute savings required relative to base case projections vary depending on assumptions used for sectoral growth. Results suggest that meeting the goal of EPAct is technically feasible.

PROGRAM PLANNING

OBT's Research and Development program is designed to achieve the objective of holding buildings use of conventional energy constant, and accommodating sectoral growth with improved energy efficiency and increased use of renewable energy. Each year OBT undertakes an evaluation of its R&D program. The program is modified as needed to account for changes in public priorities and new information gained from the conduct of R&D. Analysis activities must also be redefined as national priorities change. A new Administration and the recent passage of the Energy Policy Act of 1992 have significant implications for OBT's evaluation and planning program area, as well as for the R&D program.

One of the key elements in prioritizing R&D programs is expected energy savings from improved technologies. The methodology that OBT uses to estimate potential savings has been significantly improved. For the longer term, OBT has started the development of a market penetration model for new technologies in the commercial sector.

Energy Savings Estimates

Savings estimates are developed on a program-by-program basis in which both technical performance and market penetration parameters are employed. The current slate of research activities within OBT is projected to reduce primary energy consumption in the buildings sector by 2.5 quads in 2010 and by a little over 9 quads in 2030. Relative to the projected building energy use from the National Energy Strategy analysis, the adoption of OBT-sponsored technologies would reduce the projected increase in annual building energy use between 1990 and 2030 (from 30 quads to over 50 quads) by roughly one-half.

The OBT savings in 2010 represent about 6 percent of projected total energy use in the buildings sector under the NES current policy baseline. In 2030, the savings relative to the NES current policy base case is nearly 18 percent.

The NES Strategy Scenario in the buildings sector was primarily concerned with more aggressive demand-side management (DSM) programs by utilities and more stringent building energy standards. Compared to the OBT research activities, the impacts from these programs have a greater near-term impact (i.e., through 2005). By 2030, however, the savings from research programs would outweigh the NES actions by a factor of three.

The long-term impacts of the OBT research portfolio are quite promising and could largely eliminate growth in building sector energy consumption after 2010. Before 2010, the picture is quite different. Even with the actions analyzed in the NES and the OBT research program, energy use in the building sector would still increase by over 20 percent. Clearly, accelerated adoption of existing and new near-term technologies will be required to move closer to a goal of constant energy use in buildings over the next two decades.

ANALYSIS PLANNING

OBT, along with other DOE offices addressing energy efficiency and renewables, faces a planning environment considerably different from that of the past few years--and one that will likely continue to evolve in ways that are difficult to predict. Among the recent and continuing changes that will affect evaluation and planning activities are:

- a new Administration committed to active public sector leadership in addressing environmental, resource, and economic productivity challenges, both domestically and outside the U.S.;
- a wide range of new (or expanded) data, planning, and analysis requirements mandated under the Energy Policy Act of 1992 (EPAct); and
- new or expanded DOE institutional (as well as statutory) requirements for technology characterization, program assessment, and wise allocation of resources.

Evaluation and Planning Program Objectives

OBT has adopted the following program objectives for sector-wide evaluation and planning:

(1) To provide a solid informational and analytic foundation for decision-making that contributes to national energy policy planning and implementation within the buildings sector, including:

- technology advancement (RD&D) and technology deployment activities by OBT;
- deployment programs by other DOE offices; and
- both RD&D and deployment activities by selected non-DOE public and private entities (states, utilities, industry and non-profit organizations).

(2) To establish an ongoing process for evaluating the methods and effectiveness of both OBT and non-OBT programs and policies that affect energy efficiency and renewables in the buildings sector, in order to provide timely and reliable feedback to decision-makers and program managers.

It is especially important for a planning and evaluation program to have clearly-defined criteria for its own success. By judging its own success through an open explicit process, the Evaluation and Planning program can help set an example for self-examination and feedback among other OBT programs.

OBT is currently developing a Multi-Year Plan that will guide its evaluation and planning activities over the next three to five years, allowing OBT to meet legislative and programmatic requirements. To a large extent, provisions of the Energy Policy Act will drive these activities, if they are funded.

Energy Policy Act of 1992

The Energy Policy Act of 1992 [Public Law 106-486 - October 24, 1992] mandates greatly expanded Federal responsibilities for improving the efficiency of energy use and encouraging the use of renewable energy in buildings. The Act specifies that DOE shall assist the States in upgrading building energy efficiency codes, establish energy efficiency standards for new Federal buildings, expand the coverage of appliance and equipment standards, establish a Federal Energy Efficiency Fund, provide new directions for research and development, and discharge numerous other specific responsibilities. Many of these actions require supporting analyses.

In general, the analytical requirements directly associated with the responsibilities of the Program Offices will best be met by the Offices themselves. There are, however, several areas where the Evaluation and Planning Program Element logically has lead responsibility for OBT. These include contributing to a report on global climate change and providing assistance in the development of a least-cost energy strategy.

DATA AND MODELLING

OBT has long recognized the need for accurate and consistent data to support its planning and evaluation activities. Further, other parts of EE and DOE either use or collect relevant data and conduct their own analyses. The past several years have seen unprecedented effort in developing standard data and coordinating data development activities with others.

OBT representatives participated in EIA's working groups to assess user data needs for its surveys of residential and commercial buildings. As a result of these efforts, both surveys have been modified. As the surveys are administered and evaluated, OBT researchers and others will benefit from the additional information collected and will be better able to address new issues and concerns as they arise.

OBT is developing a "Core Databook" containing data on all aspects of buildings energy consumption. The Databook contains current information on energy consumption, building and equipment characteristics, and environmental and economic data. This data set will allow OBT to quickly respond to questions from Congress, DOE management, industry groups and others, and will provide a consistent set of data to be used throughout OBT.

To support its commercial sector energy modeling activities, OBT sponsored development of new estimates of historical commercial floorspace and projections of floorspace to the year 2010. Historical estimates of commercial building floorspace are essential to any evaluation of broad changes in commercial sector energy efficiency. Projected floorspace is a key element in determining the relative importance the commercial sector will have in the nation's future energy picture. Changes in commercial floorspace are linked to changes in Gross National Product.

Researchers have also compiled, documented, and analyzed data used in forecasting models, and are storing these data in a computerized form that is easily accessible to researchers. For the residential sector, these data include unit energy consumptions for 12 end uses compiled from 65 studies, historical appliance shipments, historical appliance saturations, historical shipment-weighted efficiencies, cost versus efficiency relationships for appliances and building shells, and summaries of all current appliance efficiency standards for every end-use affected by the standards.

INTERNATIONAL ENERGY STUDIES

Information on technology development and the results of policies and programs outside the U.S. can expand the range of possible energy efficiency options for buildings in the U.S., and provide advance notice of export market opportunities for U.S. products and services. Tracking the progress of other industrial, developing, and transition economies toward improved efficiency and solar/renewable-based building energy systems can also provide needed perspective on global climate change mitigation strategies involving energy use. For these reasons, OBT assists in supporting analyses of energy use in other countries.

FEDERAL APPLIANCE EFFICIENCY STANDARDS

Various legislative mandates enacted before 1992 require energy conservation standards for 12 of 13 types of consumer products (these are: (1) refrigerators, refrigerator-freezers, and freezers; (2) room air conditioners; (3) central air conditioners and heat pumps; (4) water heaters; (5) furnaces and boilers; (6) dishwashers; (7) clothes washers; (8) clothes dryers; (9) direct heating equipment; (10) kitchen ranges and ovens; (11) pool heaters; (12) television sets; and (13) fluorescent-lamp ballasts) and authorize the Secretary of Energy to prescribe amended or new energy standards. The Energy Policy Act of 1992 adds five products: (14) general service fluorescent lamps and incandescent reflector lamps; (15) showerheads; (16) faucets; (17) water closets; and (18) urinals, for which test procedures and labels will be developed. This Act sets standard levels for lamps, motors, commercial heating and cooling equipment, and commercial water heaters, and includes a schedule for possible amendments to the standards.

DOE is considering possible updated standards for eight products: room air conditioners, water heaters, mobile home furnaces, direct heating equipment, kitchen ranges and ovens, pool heaters, televisions, and fluorescent light ballasts. Data collection and analysis continue for possible updated standards for refrigerators and freezers, furnaces, central air conditioners, and heat pumps.

Researchers also completed data collection and modeling of alternative policies for improving energy efficiency of lighting equipment in buildings, including residential and commercial applications. Results show energy and economic savings for a wide range of policies, including component standards, building codes, incentive programs (rebates and tax credits), and education. The policies differ in magnitude, timing, and certainty of savings, as well as ease of enforcement and administrative burden.

BUILDING ENERGY STANDARDS

The Energy Policy Act of 1992 (EPAct) requires that the Department of Energy support the voluntary energy standards development process, advocate the use of model energy codes, and provide technical support to states and the federal government in adopting energy efficiency standards for new buildings. The program supports the building industry's development of new codes and standards. This includes supporting the development of the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) standards for new buildings, and working with Council of American Building Official's (CABO) Model Energy Code (MEC) for residential buildings. This support includes the analytical work required to develop cost-effective codes and needs assessments to determine the implementation needs at the state and local level.

The program is divided into three major areas of research and development: residential codes and standards, commercial codes and standards, and state and federal code support. The codes and standards research occurs within the residential and commercial portions of the program. Products include standards research, federal codes, and implementation materials. These products are transferred to the state and federal sectors through the support portion of the program. Activities include working with the DOE Regional Support offices, state energy offices, stakeholder organizations, and the Federal Energy Management Program.

The DOE provides an annual Report to Congress identifying the state-by-state actions taken and recommendations to improve the implementation of EPAct.

ANALYSIS HIGHLIGHTS

Lighting

Lighting accounts for about 19 percent of all U.S. electricity use and 7 percent of total U.S. primary energy use. In 1990, consumers spent $36 billion on lighting. OBT's Office of Codes and Standards sponsored an analysis of the benefits and costs of various Federal policies designed to promote energy-efficient lighting.

Results for both sectors show that new federal policies offer significant cost-effective opportunities for reducing lighting energy demand beyond what is currently projected to occur due to existing programs. Potential savings range from up to 15 percent for incentive/information policies to almost 65 percent for comprehensive mandatory standards. Voluntary standards achieve approximately two-thirds as much savings as do mandatory standards; economic benefits and emission reductions are also greater for mandatory standards.

Savings from the Energy Policy Act of 1992 (lamp standards) achieve one-quarter of the potential commercial energy savings from prospective comprehensive standards and one-seventh of the prospective savings for the residential sector. For the commercial and residential sectors combined, the difference in net present value for the two cases is approximately $50 billion.

New federal policies would reduce uncertainties for utilities in projecting future energy demand and for lighting equipment manufacturers in anticipating demand for their products. The policy options considered here are generally complementary; a mixture of strategies promises to be the most technically and institutionally sound approach. Continued research and development is essential for a continued supply of conservation resources.

Thermal Distribution

Thermal distribution systems are the ducts or pipes that transport the heat or cooling effect from equipment to the building spaces in which it is used. OBT's Building Equipment Division is sponsoring work to determine what is known about thermal distribution systems and to evaluate the potential for energy savings due to improvements in such systems.

Researchers have estimated that savings of 11 to 31 percent (0.87 to 2.38 quads) can be achieved in both existing and new (built by 2020) small buildings. Most of the savings are in forced-air systems. The smaller number represents savings that can be achieved using current technologies and practices, such as reducing leaks and increasing duct insulation. Achieving greater savings requires new technology development and research to better understand the processes involved in duct losses and interactions.

1. INTRODUCTION

In 1990 Americans spent $188.5 billion for energy used in homes and commercial buildings. Most of these expenditures ($133 billion or 70 percent of the total) were for the purchase of electricity. This energy is used to heat and cool buildings, and to provide hot water, lighting, and other conveniences which significantly improve the comfort and quality of life at home as well as the efficiency of our workplaces.

Energy used by the residential and commercial sectors accounted for 35.4 percent of all primary energy consumed in the United States in 1990. This is more than is used for transportation, and almost as much as for industry. The buildings sectors accounted for nearly two-thirds (64.9 percent) of electricity consumption in the U.S., and almost 38 percent of natural gas consumption.

Although we have improved the efficiency with which we use energy in our buildings, there is still tremendous potential for improving energy efficiency and increasing the use of renewable energy. Achieving that potential will not only reduce the costs associated with providing comfort and increasing productivity, but will also help to reduce environmental impacts due to energy production and use, and strengthen the U.S. economy by improving U.S. competitiveness in international markets.

PURPOSE AND SCOPE OF THIS REPORT

The U.S. Department of Energy's (DOE's) Office of Building Technologies (OBT) leads a national effort to meet the future needs for energy services in the nation's buildings through improvement in energy efficiency and increases in the use of renewable energy. This report summarizes evaluation and planning activities conducted by OBT during the past several years. It provides a continuing record of analysis accomplishments, and serves to make assumptions and results available to others both within and outside DOE.

OBT activities are shaped by Federal legislation and other Federal directives. Much of the analysis undertaken by OBT between 1989 and 1991 was in support of the development of the National Energy Strategy. In July 1989, President Bush directed the Secretary of Energy to begin developing a National Energy Strategy (NES). An *Interim Report* was published in April 1990, containing background information on energy use and policy options and goals for improving efficiency. OBT contributed information about the buildings sectors.

Beginning in the fall of 1989, OBT analysts began assessing the potential contribution that energy efficiency and renewable energy use in buildings could make toward meeting the nation's energy needs. This resulted in a subset of options to be evaluated for inclusion in the National Energy Strategy. The *National Energy Strategy - First Edition* was completed in February 1991.

Shortly thereafter, Congress began consideration of a comprehensive energy policy, culminating in the passage of the Energy Policy Act of 1992 (EPAct) in October 1992. This

Act includes many provisions affecting building energy use. During Congressional deliberations and after passage, OBT analysts extensively examined the impacts of EPAct on OBT's program.

The next section briefly describes OBT's mission and program, for which the evaluation and planning activities provide the foundation. The following section more specifically discusses the role of evaluation and planning within OBT and briefly describes the topics included in the remainder of this report.

MISSION OF THE OFFICE OF BUILDING TECHNOLOGIES

The mission of OBT is to increase energy efficiency and expand the use of renewable energy in buildings by developing new, cost-effective, environmentally-benign technologies and stimulating the best use of new and currently available technologies. OBT's objectives are to:

- limit energy consumption from conventional sources to not more than 30 quads by 2030, absorbing and supporting the predicted growth in population, GNP, and standard of living;
- increase the efficiency of energy use in buildings by 30 percent over 1988 levels by 2010; and
- increase the renewable energy used in buildings by 75 percent above 1988 levels by 2005.

OBT's strategy for achieving these sector goals consists of four components: research, development and demonstration of advanced energy-efficient technologies; appliance and building codes and standards; market outreach and conditioning; and the Federal Energy Management Program (FEMP).

The research, development and demonstration component emphasizes research on individual building materials, components and equipment, and research on the building as an overall system including its design, siting, construction, commissioning and operation. The codes and standards component of the strategy implements national legislation, including the Energy Policy Act of 1992, regarding cost-effective building codes, product testing procedures, labeling, and appliance and equipment standards. Outreach and market conditioning (Implementation and Deployment) creates market pull for advanced technologies through information and incentives programs. FEMP brings selected elements of the three strategies to bear on the Federal government's unique problems in promoting in-house energy efficiency.

Figure 1-1 shows the components of OBT's program. Advanced active and solar technologies could provide nearly all the heating energy needs of buildings and over one-half of the cooling and lighting needs. OBT's objective is to develop reliable solar technologies that can provide up to 80 percent of the heating and hot water requirements and 60 percent of the cooling requirements of buildings at costs competitive with conventional technologies by the year 2000. The program focuses on solar space and water heating tech-

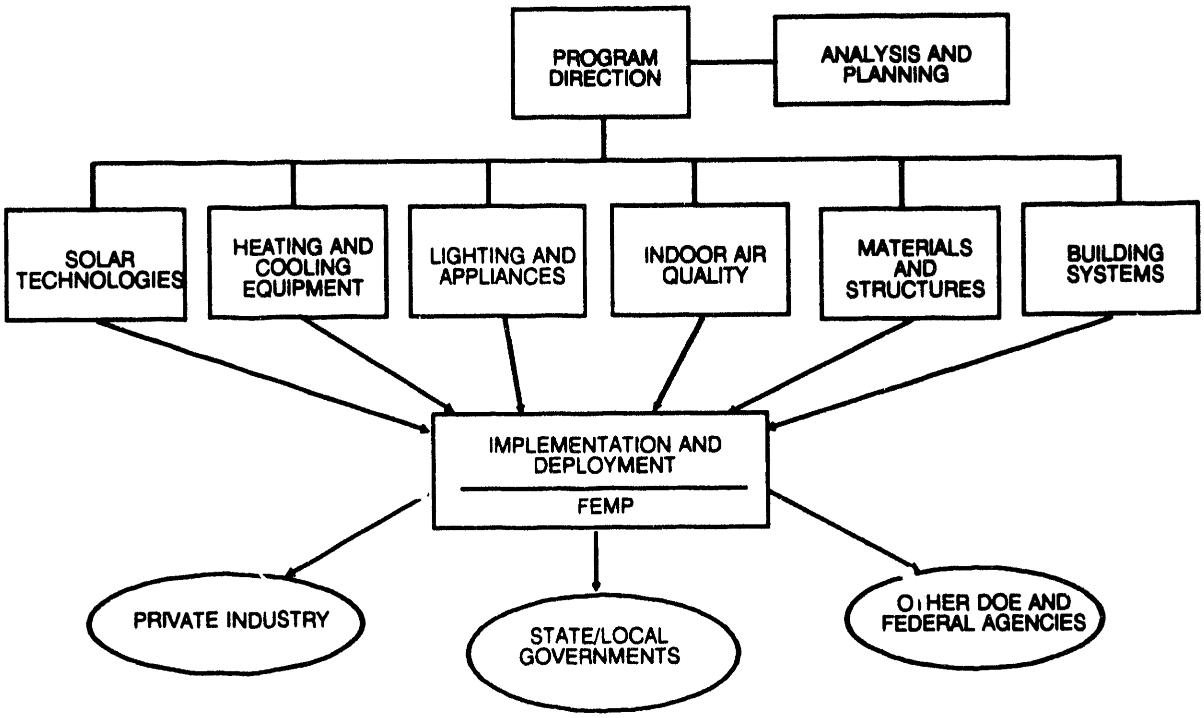

Figure 1-1. OBT Program Components

nologies, space cooling and dehumidification technologies, and daylighting and passive solar techniques.

Lighting equipment and appliances account for about 40 percent of energy consumption in buildings; a 50 percent improvement in efficiency is technically feasible. OBT conducts research on high-efficiency lighting, advanced refrigeration and appliance and lighting standards. Objectives are to develop and introduce to the market: commercial appliances and refrigeration technologies that are 50 percent more efficient than existing technologies and that do not use CFCs; fluorescent lamps that are 50 percent more efficient than existing technologies; and high-intensity discharge lamps that are five to six times more efficient than incandescent lamps. OBT is also responsible for implementing Federal requirements for appliance and equipment standards. OBT develops test procedures and reviews and establishes energy efficiency standards for the regulated appliances.

It is also technically possible to reduce energy consumption for space heating by 50 percent and for air conditioning and refrigeration by 30 to 40 percent. OBT conducts research on advanced-cycle absorption technology, free-piston Stirling engine-driven heat pumps, internal combustion engine-driven heat pumps, oil-fueled combustion equipment, distribution and controls, and advanced non-CFC refrigeration systems.

The focus of OBT's Indoor Air Quality program is on characterizing the relationship between indoor air quality and energy conservation and on developing measurement and mitigation technologies. This will make it possible to maintain or improve indoor air quality while improving the energy efficiency of existing and new buildings.

The Materials and Structures program conducts research and development on insulation materials and the energy efficiency of the building envelope, that is, walls, roofs, windows, and foundations. Advanced materials and improved design could save over 30 percent of the total energy required for heating, cooling and lighting in new buildings; OBT's objective is to save 1.5 quads of energy annually by 2020 through the use of improved building envelope technologies.

The Building Systems program addresses the whole building, including the design, construction, and operation of new and existing buildings. Research includes development of: advanced computer-based tools for commercial buildings; industrialized housing technologies; building standards; and building retrofit technologies. Objectives include improving materials and techniques for industrialized housing that will lead to homes that are 25 percent more efficient than the most stringent code requirements, saving 1 to 2 quads of energy in existing buildings by 2005, and developing building standards that will reduce energy consumption in new buildings by 25 percent.

OBT is also responsible for energy conservation planning and management for the Federal government, which uses about 1.4 quads of energy annually in its 500,000 buildings and facilities. OBT's objective is to reduce annual energy use by Federal facilities by 10 percent by 1995 and 20 percent by 2005; a 20 percent reduction in energy use would save over $700 million annually. The Energy Policy Act of 1992 calls for an accelerated and expanded Federal Energy Management Program; a discussion of the Act's implications for OBT's program is given in Chapter 4.

Responsibility for OBT's program is divided among three Program Offices:

- the Office of Building Energy Research, responsible for the development and demonstration of advanced building technologies, materials, and systems;
- the Office of Codes and Standards, responsible for the development and promulgation of energy efficiency standards for whole buildings, building equipment, and appliances; and
- the Office of Federal Energy Management, tasked with improving the efficiency of energy use in Federal facilities.

Each of the above Offices conducts analyses to assist in the discharge of their responsibilities; Planning and Evaluation within OBT conducts the analyses that cut across the areas of responsibility of the three Program Offices.

ROLE OF EVALUATION AND PLANNING

Evaluation and planning activities serve three vital functions within OBT: they ensure that OBT identifies and invests in those areas of research most likely to produce energy savings in the buildings sector; they assess the costs and benefits of policy options which affect the buildings sector; and they provide consistency with similar activities within the Office of Energy Efficiency and Renewable Energy (EE) and other parts of DOE.

The selection and management of OBT research activities requires an understanding of where and how energy is used within the buildings sector, how energy use is expected to change in the future, and the potential impact of new and emerging technologies on energy use. Evaluation and planning activities 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. Selected buildings energy use data are presented in Chapter 2 of this report.

Systematic research planning is a key aspect of managing OBT's R&D program. In 1991 and 1992 supporting analyses necessary for credible program prioritization were updated and extended to 2030. In addition, evaluation and planning continues to provide support and data to EE and other DOE analytical and planning exercises. Program and analysis planning are discussed in Chapter 3.

As part of the National Energy Strategy (NES) development process, OBT analyzed several policy options for capturing energy efficiency improvements in the buildings sector. These included: accelerated research, development, and demonstration; strengthened or expanded building and equipment efficiency standards; improved energy management in Federal facilities; increased use of home energy rating systems tied to energy-efficient mortgages; energy efficiency targets for public housing projects; and expanded low-income weatherization. Summaries of NES options and analyses are presented in Chapter 4.

In addition, the Energy Policy Act of 1992 contains many provisions which, if funded, will affect the direction and content of OBT's program. Areas of the Act relevant to buildings are summarized in Chapter 4. OBT's analysis activities will also be directed by provisions of the Act; these impacts are summarized in Chapter 3.

Highlights of specific analysis activities are given in Chapter 5. Over the past few years these have been driven by the development of the NES and the Energy Policy Act of 1992. A great deal of attention has been given to coordinating data and modelling development with other parts of DOE and to developing standard data sets to be used in all analyses. This report also contains highlights of relevant analytical efforts that were sponsored by individual Program Offices within OBT or by other organizations.

In each section of the report a contact person is listed. The Appendix contains the source data tables that are used in Chapter 2.

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2. BUILDINGS AND ENERGY USE

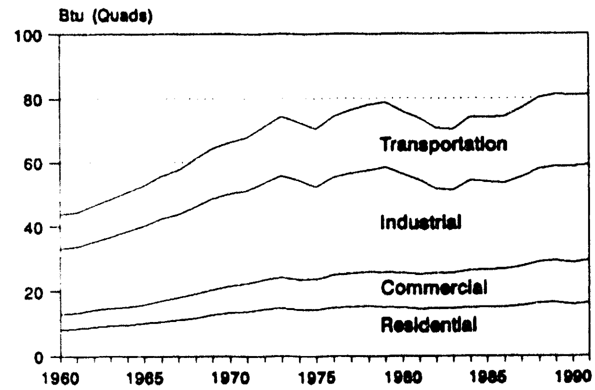
This chapter presents a brief overview of energy use in buildings over time. It also discusses some of the underlying determinants of energy use, such as population growth and buildings stock and equipment. It includes a discussion of types of government policies and how they can affect energy consumption. The last section presents various forecasts of energy use in buildings developed for the National Energy Strategy, and compares them to other forecasts.

TRENDS IN BUILDINGS ENERGY USE

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 36.2 percent in 1991, while industrial use has declined by 9.3 percent and transportation energy use has increased by 8 percent. In the commercial sector primary energy consumption increased by 22.6 percent while residential energy use increased by 7.8 percent in the same period.

Figure 2-1.

U.S. Consumption of Primary Energy by Sector, 1960-1991



Source: State Energy Data Report 1991

U.S. primary energy consumption by end-use sector over time is shown in the figure. In this report end-use energy is assumed to be 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 1991 the residential sector used 16.4 quads of primary energy and the commercial sector used 13 quads.

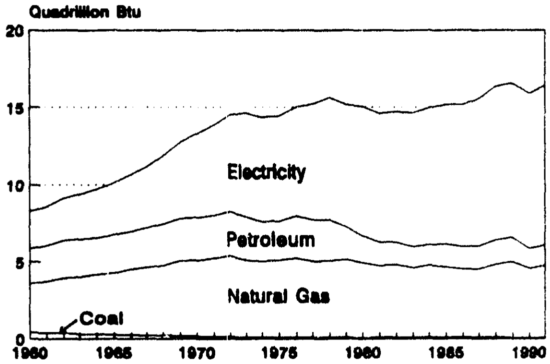
Fuel Use

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.

In the residential sector, electricity use (including losses) has grown from 46 percent of all energy consumed in 1973 to about 63 percent in 1991. During this time direct coal use has declined to less than 0.1 quad, gas use has declined slightly from 5 quads to 4.7 quads, and petroleum use has decreased from nearly 3 quads to approximately 1.3 quads per year.

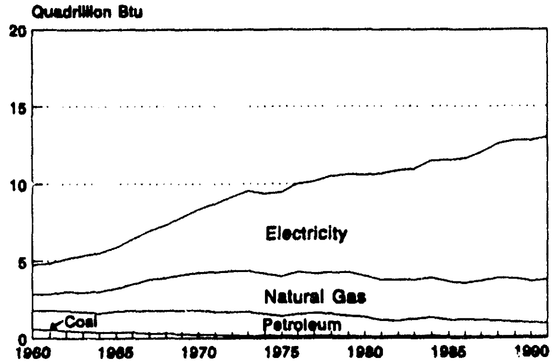
In the commercial sector, electricity use has grown from 54 percent in 1973 to over 71 percent in 1991. In the same time direct coal use has decreased, gas use has remained

Figure 2-2.
Residential Primary Consumption by Fuel Type



Source: State Energy Data Report 1991

Figure 2-3.
Commercial Primary Consumption by Fuel Type



Source: State Energy Data Report 1991

relatively constant at slightly more than 2.5 quads, and petroleum use has declined from 1.5 quads to less than 1 quad per year.

End Use Shares

The figures below show estimates of residential and commercial primary energy consumption by application for 1990. In both sectors, space heating is the dominant end use, accounting for about 30 percent of primary energy consumption in the commercial sector and over one-third in the residential sector.

In the residential sector, water heating and refrigerators/freezers account for an additional 30 percent of primary energy use. As the penetration of air conditioners and new appliances increases, it is likely that electricity use in the residential sector will continue to grow.

In the commercial sector, lighting and space cooling account for about half of the energy consumption on a primary basis; lighting is responsible for almost 40 percent of all

Figure 2-4.
End-Use Shares of Primary Energy Residential Sector, 1990

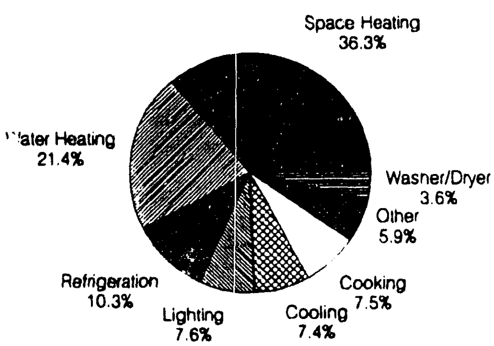


Figure 2-5.
End-Use Shares of Primary Energy Commercial Sector, 1990

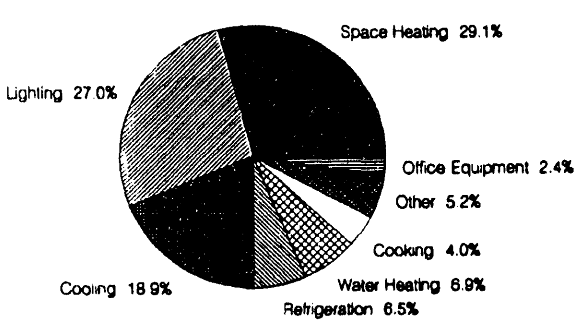
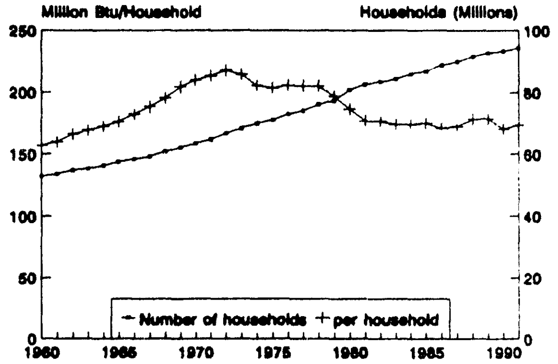
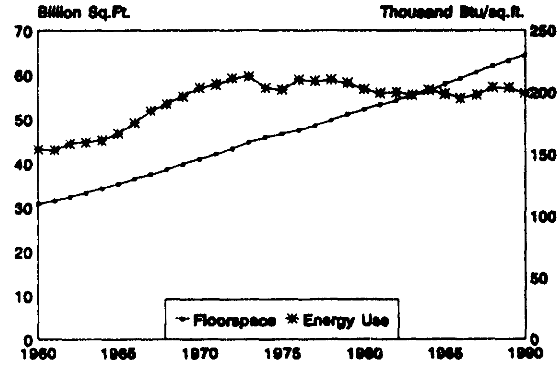


Figure 2-6.
Residential Primary Consumption by Household



Sources: State Energy Data Report, Statistical Abstract

Figure 2-7.
Commercial Sector Primary Energy Use per Square Foot of Floorspace



Source: See Chapter 6.

electricity use in commercial buildings. Tables showing the end-use splits by fuel type are given in the Appendix.

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 250 million in 1991. The two figures above show residential primary energy consumption per household and commercial primary energy consumption per square foot of floorspace.

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 slightly or remained constant since. 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.

Federal Buildings

The U.S. Government is the largest single energy consumer in the country. In Fiscal Year 1991, the Federal Government consumed 1.92 quads of primary energy at a cost of $11.3 billion. Most of the energy (1.14 quads) was used in general operations, which include vehicles and process energy. The remainder, 0.78 quads, was used in buildings and facilities. The government operates approximately 500,000 buildings and facilities, containing about 3.2 billion square feet of floorspace. The Department of Defense accounts for about two-thirds of the energy used in buildings.

Electricity accounts for about two-thirds of the total primary energy used in government buildings, and almost 70 percent of the total cost. Natural gas accounts for 17 percent of the primary energy used in Federal buildings.

Table 2-1
Energy Use in Federal Buildings

	1985	1991	% Change
Square Feet (millions)	3381.2	3207.3	-5.1
Primary Energy (10^{12} Btu)	823.6	778.2	-5.5
Delivered Energy (10^{12} Btu)	472.8	405.6	-14.2
Primary Energy (10^3 Btu/square foot)	243.6	242.6	-0.4
Delivered Energy (10^3 Btu/square foot)	139.8	126.4	-9.6

Source: U.S. Department of Energy. *Annual Report to Congress on Federal Government Energy Management and Conservation Programs, Fiscal Year 1991*, October 1992.

Table 2-1 shows primary and delivered energy per square foot for Federal buildings. The National Energy Conservation Policy Act (NECPA), as amended, requires Federal agencies to improve energy efficiency, measured as delivered energy per square foot, by 10 percent by 1995 relative to 1985. As the table shows, delivered energy use per square foot has decreased by 9.6 percent since 1985. This is due to a 23 percent decrease in the use of non-electric fuels. However, electricity use has increased by about 5.7 percent during the same time, so efficiency improvements are less when measured in terms of primary energy.

Executive Order 12759, signed in 1991, extends and expands NECPA and sets a goal of 20 percent reduction by 2000. The National Energy Policy Act of 1992 contains further provisions for the Federal Energy Management Program; these are discussed in Chapter 4 of this report.

FACTORS AFFECTING ENERGY USE IN BUILDINGS

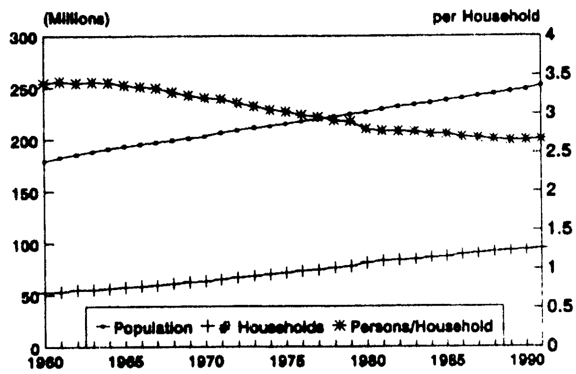
Many factors affect how much and what types of energy are used in buildings. These range from relatively simple factors such as total population to more complex issues such as the way consumers make decisions about energy. Understanding these factors, their relationships, and their impact on energy use continues to be an important area of inquiry for OBT.

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 2-8, contributing to a decrease in energy use per household.

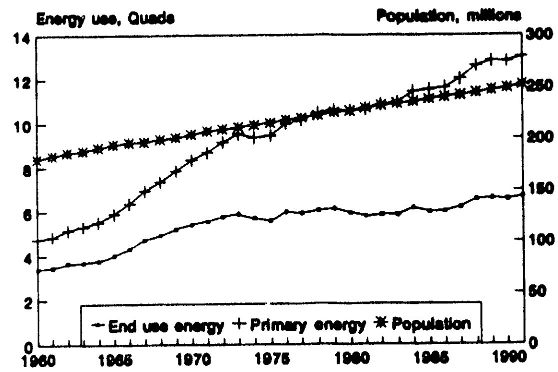
In the commercial sector, primary energy consumption rose more rapidly than population from 1960 to 1991 (Figure 2-9). While end-use energy has grown at a rate close to that of overall population growth, the faster growth of primary energy, which includes the inef-

Figure 2-8.
U.S. Population
and Persons/Household



Source: Statistical Abstract of the U.S.

Figure 2-9.
Commercial Energy Use
and Population Growth

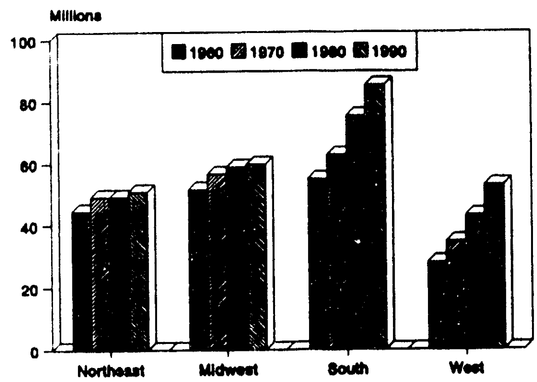


Sources: Statistical Abstract of the U.S., State Energy Data Report

ficiencies associated with electricity production and transmission, is due to the accelerated use of electricity relative to other energy sources.

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 2-10). 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.

Figure 2-10.
Regional Population, 1960-1990



Source: Statistical Abstract of the U.S.

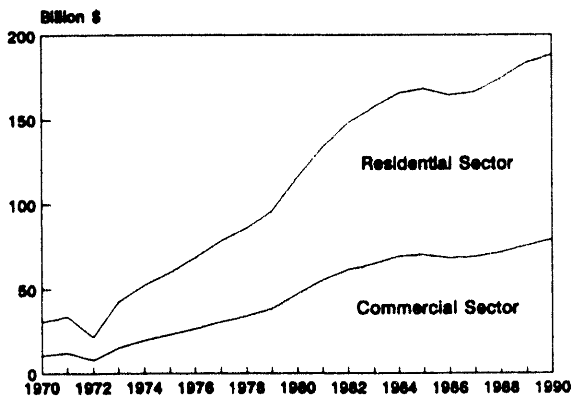
Economics

In 1990 U.S. energy expenditures totaled $472 billion. The largest portion was spent in the transportation sector ($182 billion), followed by the residential sector ($109 billion), the industrial sector ($102 billion) and the commercial sector ($79 billion). The commercial sector share of U.S. energy expenditures has grown from 13 percent in 1970 to 17 percent in 1990. Figure 2-11 shows buildings sector energy expenditures over time; these accounted for 3.4 percent of the U.S. gross domestic product in 1990.

Most of the expenditures in the residential and commercial sectors were for electricity. In the residential sector, $72 billion, or 66 percent of expenditures were for electricity. In the commercial sector, $60 billion (76 percent) was spent for electricity. Electricity is the most

Figure 2-11.

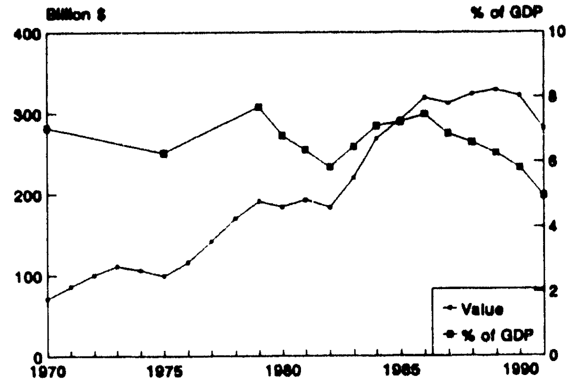
Cost of Energy



Sources: State Energy Price and Expenditure Reports

Figure 2-12.

Value of New Construction*



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

* Value of construction does not include public utilities.

expensive energy source in the U.S.; its average price is $19.33 per million Btu compared to $7.54 and $3.85 per million Btu for petroleum and natural gas, respectively.

The value of construction (Figure 2-12) dips during recession years but shows an overall steady increase. In 1990 the value of construction in both the residential and commercial sectors (not including public utilities) accounted for almost 6 percent of the GDP. Buildings energy and construction costs together totaled 9.2 percent of the GDP.

Building Stock and Equipment

Every three years the Energy Information Administration conducts surveys on energy consumption and characteristics of residential and commercial buildings, the Residential Energy Consumption Survey (RECS) and the Commercial Buildings Energy Consumption Survey (CBECS). These surveys provide a snapshot view of building stock, equipment, and energy use and expenditures. Data from these samples differ from data collected in other EIA surveys, such as the State Energy Data Report, which are based on information provided by suppliers rather than energy users. In addition, many of the supply surveys are conducted every year. Throughout this report, trend data are generally based on supply surveys. This section, which describes residential and commercial buildings and equipment, is taken from the RECS and CBECS reports.

Residential

In 1990, there were 94 million households in the U.S., up 15 percent from 1980. Most of these (about two-thirds) are single-family homes, one-quarter are multifamily units, and almost 6 percent are mobile homes. New housing is on average larger, more energy efficient, and most likely gas heated. While the number of housing units grew 15 percent, population increased by 10 percent, thus decreasing the number of persons per housing unit. Growth in the size of housing units also exceeded the growth in population; the per capita heated space increased from 575 square feet in 1980 to 602 square feet in 1990.

Table 2-2
Energy-Related Characteristics of U.S. Households by Year of Construction, 1990

	Year of Construction							
	1939 or Before	1940 to 1949	1950 to 1959	1960 to 1969	1970 to 1979	1980 to 1984	1985 to 1987	1988 to 1990
Main Space-Heating Fuel (percent)								
Natural Gas	64	67	64	64	44	37	29	46
Electricity	5	9	10	18	38	48	59	27
Type of Structure (%)								
Single-family								
Detached	64	77	82	64	49	54	43	64
Attached	5	4	4	4	7	10	21	Q
Multifamily	30	19	14	28	33	26	24	12
Average Heated Floorspace (square feet)	1,637	1,468	1,616	1,545	1,478	1,480	1,581	2,143
Respondent Reports Home is "Well Insulated" (percent)	27	28	39	40	35	48	48	68
Percent of Homes with 100 Percent:								
Storm Windows	52	52	52	43	50	52	60	74
Storm Doors	44	50	48	38	35	29	33	42
Percent of Single-Family and Mobile Homes with:								
Roof/Ceiling Insulation	68	75	83	83	84	87	86	90
Wall Insulation	55	51	62	67	77	79	78	88

Q = data withheld
Source: Energy Information Administration. *Housing Characteristics 1990*, DOE/EIA-0314(90), May 1992.

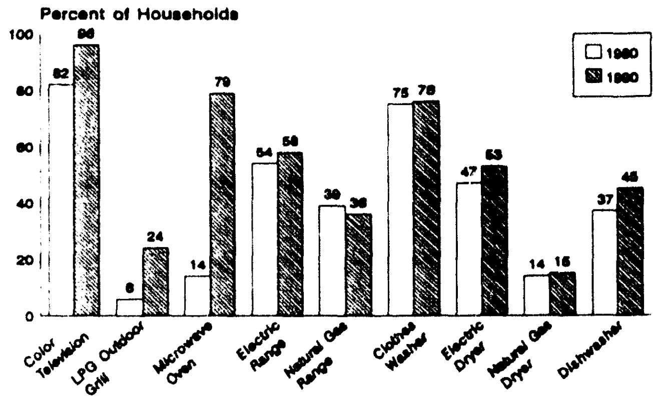
Natural gas remained the fuel of choice for space heating (55 percent) and water heating (53 percent) for all homes. Electric space heating increased from 18 percent in 1980 to 23 percent for all homes in 1990. Fuel oil is the main heating fuel in 11 percent of all homes. Air conditioning is found in 68 percent of all homes, compared to 57 percent in 1980, and in 91 percent of new homes built in the South and 51 to 74 percent of new homes in other regions.

New homes also have a higher incidence of conservation features, such as insulation and storm windows. This may indicate the effectiveness of conservation programs, or the enactment of more stringent building energy efficiency codes. Table 2-2 shows characteristics of the current U.S. housing stock, by year of construction.

Most appliances use electricity, and approximately 43 percent of all energy expenditures is for appliances. The 1990 RECS collected data on the average age of several types of appliances and energy-using equipment. Average age can be used to estimate equipment turnover and efficiency. The stock of heat pumps and air conditioners averaged between 8 and 9 years old, and conventional heating systems were 11 to 14 years old. Based on these average ages, heat pumps and air conditioners were 17 to 23 percent more efficient than new models in 1972, while average conventional gas furnaces were only 4 percent more efficient. The average water heater was 8 years old and estimated to be only about 3 percent more efficient than new models in 1972. Refrigerators are found in all households, and 15 percent have two or more. The average age of the first is 9 years and the second is 13 years. The average 9-year old refrigerator would be about 60 percent more efficient than a new model in 1972.

The 1990 RECS also found an increase in saturation of some appliances, particularly color television sets, gas grills, and microwave ovens. Between 1980 and 1990, the percentage of households with at least one color television increased from 82 to 96 percent. The penetration of gas grills rose from 6 percent in 1980 to 24 percent in 1990. Microwave ovens increased from 14 percent to 79 percent. Nationally, 23 percent of all households used microwave ovens to cook half or more of their food. Figure 2-13 shows changes in penetration for these and other appliances.

Figure 2-13.
Residential Appliance Saturations



Source: RECS

While buildings and equipment are becoming more efficient, people's behavior seems to show less concern with energy efficiency. Sixty-two percent of U.S. households maintained an average indoor temperature of 70 degrees or warmer in 1990, compared to 37 percent in 1981. At the same time, temperature setbacks were more common in 1990. Similarly, the percentage of households that kept air conditioners on all summer increased from 22 percent in 1981 to 35 percent in 1990. This may reflect the increasing penetration of central air conditioners, and the fact that the summer of 1990 was hotter than normal.

In 1990, approximately 0.8 million households used active solar energy systems for water and/or space heating. This is a small increase from 1980, from 0.2 percent to 1.0 percent. Most of these (67 percent) are in the West. Data on passive solar systems was not collected. Additionally, wood is used in about 25 percent of all U.S. households, unchanged from 1980. Total wood use declined dramatically from 1987 to 1990, however. Although more households use wood as a secondary fuel (primarily in fireplaces), the number of households using wood as a primary heating fuel declined, as did the intensity of use.

Commercial

In 1989 there were 4.5 million commercial buildings in the U.S. containing 63 billion square feet of floorspace. Floorspace has grown at about 3 percent per year for the past 10 years. Mercantile and service buildings account for the largest share of number of buildings and floorspace; office buildings account for nearly as much floorspace but fewer buildings. Thirty-two percent of the nation's entire office floorspace was built during the 1980's. Table 2-3 shows the breakdown of commercial buildings and floorspace by principal building activity.

Floorspace per worker and hours of operation per week vary considerably across building activity types. Floorspace per worker is high for parking garages, warehouses, and assembly buildings, and low for office buildings. This reflects differences in how labor-intensive the various activities are. Weekly operating hours vary from less than 40 for assembly buildings to continuous operation for lodging and public order and safety buildings. Both worker density and operating hours affect energy use.

Over the past ten years, the South and West regions showed the greatest percent increases in floorspace, but since 1986 the greatest percent increases were in the Northeast and South. Some of these increases reflect new construction, and some conversions of existing

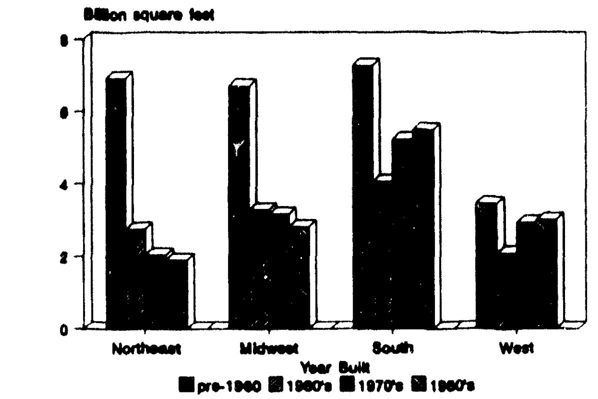
Table 2-3
Commercial Buildings Population, 1989
Principal Building Activity

	Number		Floorspace	
	(1000)	(%)	10^6 square feet	(%)
All Buildings	4,528	100	63,184	100
Assembly	615	13.6	6,838	10.8
Education	284	6.3	8,148	12.9
Food Sales	102	2.2	792	1.2
Food Service	241	5.3	1,167	1.8
Health Care	80	1.8	2,054	3.2
Lodging	140	3.1	3,476	5.5
Mercantile/Service	1,278	28.2	12,365	19.6
Office	679	15.0	11,802	18.7
Parking Garage	45	1.0	983	1.6
Public Order & Safety	50	1.1	616	1.0
Warehouse	618	13.6	9,253	14.6
Other	62	1.4	1,529	2.4
Vacant	333	7.4	4,161	6.6

Source: CBECS: Commercial Buildings Characteristics 1989, U.S. DOE/EIA, May 1991.

floorspace to commercial use. The South contains the largest percentage of buildings in the country including 50 percent of the buildings constructed in the 1980's and a majority of buildings smaller than 100,000 square feet. Figure 2-14 shows the age structure of commercial floorspace in 1989, by region.

Figure 2-14.
Commercial Floorspace by Region, 1989



Source: CBECS

The most common energy source in commercial buildings is electricity. Natural gas is used in 57 percent of energy-using buildings. The most common type of heating equipment is furnaces, followed by individual space heaters and packaged heating units. Furnaces are more popular in small to mid-sized buildings and in the Mid-West. Individual space heaters and boilers are more common in large structures and in the South and Northeast. The two most common pieces of cooling equipment, on a national scale, are packaged cooling units followed by individual room air conditioners. Packaged cooling units are almost twice as prevalent as room air conditioners, except in the Northeast, where they used almost equally.

The 1989 CBECS reports the amount of floorspace lit by different lamp types. Fluorescents provided lighting to almost 80 percent of all lit floorspace. Incandescent bulbs were used in only about 15 percent of lit floorspace, and show declining use in new buildings. High intensity discharge lamps and high efficiency ballasts are more common in newer buildings.

Eighty-five percent of commercial buildings possess at least one form of building shell conservation feature. The most common conservation features are roof or ceiling insulation and weather stripping or caulking. Over 40 percent of the floorspace built since 1986 is in a building with a computerized Energy Management and Control System (EMCS), compared with 27 percent for buildings built between 1980 and 1986 and lower fractions for older buildings.

Government Policies

Government policies, whether intended or not, can affect what kind and how much energy is used in our society. To be effective, such policies must be designed with an understanding of the objectives of the policy, the options available for meeting the objectives, and the effectiveness of the various options. Millhone et al. have developed a framework for developing an effective energy efficiency policy; this section summarizes their work.

The objective of government programs is to increase the availability, acceptance, and use of higher efficiency products in all sectors of the economy. The options for achieving this objective can be grouped into seven strategies:

- Performance measurement protocols;
- Product efficiency labels;
- Energy efficiency standards;
- Financial incentives;
- Information and education programs;
- Price, taxation and import policies; and
- Research, development and demonstrations.

Performance measurement protocols provide the "yardsticks" that make it possible to measure energy performance and compare measurements on a standardized basis. An example is the development of DOE's uniform test procedures for residential appliances. Measurement protocols are a prerequisite of labeling, incentive and performance standard strategies, and deserve first priority in developing energy programs.

Labels provide information to consumers about the relative efficiency and operating cost of products. Examples are the fuel economy stickers on cars and the yellow labels on home appliances. If consumers use the information, they will purchase more efficient products with lower operating costs.

Efficiency standards eliminate the least efficient products of a given type, and increase the number of more efficient products. The U.S. currently has three major energy efficiency standards programs in place - car and truck fuel economy standards, major home appliance efficiency standards, and energy efficiency standards for Federal buildings.

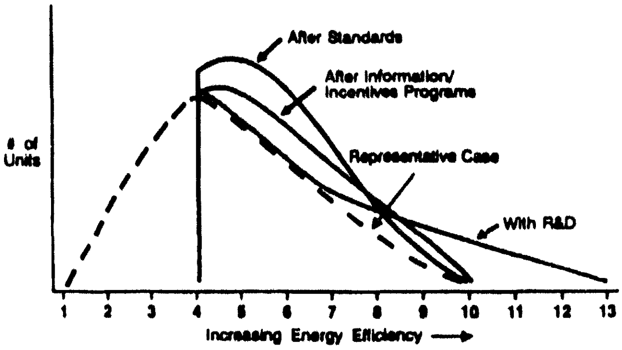
Financial incentives, if they are attractive enough, can cause consumers to change their purchasing behavior; many utilities utilize rebates in their demand-side management programs. Information and education programs can enhance the effectiveness of other strategies by disseminating clear and convincing information about the benefits of efficiency improvements. Price, taxation, and import policies affect the availability and price of energy supplies, and may encourage the use of a number of energy efficient products. This is different than incentive programs, which generally target specific products.

Research, development, and demonstrations lead to the introduction of new products. DOE's research program focuses on developing products and techniques that are more energy efficient than those currently on the market.

To illustrate the potential effects of these strategies, a typical product distribution curve relative to energy efficiency is shown in Figure 2-15. The dotted line represents the product distribution before the strategies are applied. A labeling program, by providing consumers with better information, might shift the curve slightly to the right. Research, development and demonstrations would extend the right-hand tail of the distribution curve by making more efficient products available. Standards cut off the left, less efficient side of the distribution curve and increase the use of more efficient products.

Figure 2-15.

Impact of Policies on Energy Efficiency



A successful program for improving energy efficiency must also consider how the various strategies would work in the marketplace. Some of the factors that affect the adoption of new ideas are the complexity of the new concept, the risk associated with the innovation, and the communication channels used by consumers and their leaders. Four of the strategies (performance measurement protocols, product energy efficiency labels, information and education programs, and research, development and demonstration programs) may be particularly effective at addressing many of these factors. The effects of other strategies on these factors are more difficult to predict.

The strategies discussed above are not meant to be used individually, but to be combined in an integrated program. Performance measurement protocols are basic to the other strategies, and require continuing efforts. Standards can be linked effectively with measurement protocols and information and education activities. Pricing policies will reduce the effectiveness of all the other strategies if they undervalue the cost of energy. Research, development and demonstrations are essential for continued, long-term progress and can produce new opportunities as part of a continuing dynamic, integrated process.

Understanding the Trends

Schipper, Howarth and Geller recently examined trends in energy use in the United States between 1973 and 1987 in order to understand the impact of improved efficiency on changes in energy use. Understanding the various determinants of energy use and how they interact is essential in forecasting future energy use and in designing policies that will be successful in improving energy efficiency. The authors looked at all sectors of the U.S. economy; this section summarizes their conclusions for the residential and commercial sectors.

Three causal factors are defined and measured in the study: changes in the aggregate level of energy-using activities in each sector; changes in the structure or composition of activities; and changes in energy intensities, or energy use per unit of activity or output. The effect of each factor on energy use is estimated, and compared to actual changes in energy use.

In the residential sector, population is the measure of activity. Population increased by 15 percent between 1973 and 1987, and if all other factors had remained constant, residential energy use would have increased by 15 percent. The structure of the sector is measured by household floor area and appliance ownership per capita. While penetration of central heating, cooking, and water heating equipment was already saturated in 1973, ownership of major appliances (refrigerators, freezers, washers, dryers, air conditioners, and dishwashers) increased by 28 percent, in number of units weighted by 1973 unit energy utilization of each unit.

Average household size declined, which decreased energy use per household, but increased the number of households per capita. Overall, the decline in household size led to an overall increase in energy use per capita of approximately 6.5 percent. The shift in regional distribution of homes decreased space heating requirements but increased cooling needs, leading to a decrease in delivered energy use of about 2 percent. If energy intensity had remained at 1973 levels, residential primary energy use would have increased by about 45 percent between 1973 and 1987 due to changes in the level and structure of residential activity.

Energy intensities for space heating and major appliances fell significantly from 1973 to 1987. Useful energy[1] per dwelling for space heating fell 34 percent. This was due to improved thermal characteristics of both new and existing buildings and to improved equipment efficiencies. Improvements in appliance efficiencies reduced expected electricity use by 12 percent, even with increased ownership. Overall, reduced energy intensities would have cut residential primary energy use by 21 percent from 1973 to 1987 if structural and activity changes had not occurred. Actual delivered energy use in the residential sector decreased by 3 percent and primary energy use increased by 13 percent.

In the services sector, activity is measured by service sector value-added and structure by commercial floor area per unit of value-added, as well as heating fuel switching. Service sector GNP grew by 50 percent from 1973 to 1987, in constant dollars. Floor space grew slightly faster and the ratio of floor area to total GNP increased because the share of service sector GNP in overall GNP increased from 61 percent to 65 percent. The mix of buildings and their geographical distribution changed slightly.

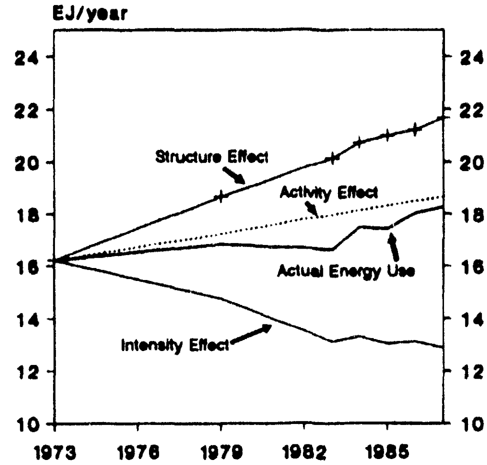
The impact of structural change is small (6 percent increase in primary energy) compared to total energy use, but the activity effect (50 percent increase) is significant because service sector GNP grew 7 percent more than total GNP. The authors estimate that a 40 percent decline in fuel heating intensity and an 18 percent decline in electric heating intensity took place. Increasing use of electric heating increased electricity use and decreased fossil fuel use. Overall, intensity improvements would have reduced delivered energy by 29 percent and primary energy use by 18 percent if other factors had remained

1 The authors measure useful energy as well as delivered and primary energy. By their measure, delivered quantities of oil and gas are counted at 66% efficiency, solids at 55%, and electricity at 100% to account for differences in the utilization efficiencies of the various fuels at the point of end use.

constant. Actual delivered energy increased by 5 percent and primary energy by 26 percent.

The authors conclude that improved energy efficiency had a significant impact on total energy use. Activity growth and structural changes would have caused significant increases in buildings energy use if improvements in energy intensities had not occurred. Figure 2-16 shows this for the residential sector. Most of these changes are technology based, and thus permanent. They caution, however, that improvements in energy intensity seem to be slowing. Residential primary and useful energy use per household declined through 1983 but have increased in more recent years. Heating intensity, which fell by 4.5 percent per year through 1983, fell by less than 1 percent per year between 1983 and 1987. The combination of slowed efficiency improvements with continued structural growth could lead to rapid increases in buildings energy use in the future.

Figure 2-16. Residential Primary Energy Use Intensity, Activity, and Structure Effects



Source: Schipper, et al., p. 488.

The link between government policies and efficiency improvements is still not clear, however. Achieving further savings poses a significant challenge to policy makers, especially in light of concerns about the role of fossil fuel combustion in global climate change. It is more necessary than ever to fully disaggregate energy use patterns to understand the effectiveness of alternative policies (Ketoff and Schipper).

FUTURE POSSIBILITIES

During development of the National Energy Strategy, considerable effort was devoted to defining possible energy futures. The potential for conservation and renewable energy use in buildings was evaluated, and various policy options for achieving improved efficiency and greater use of renewable energy were analyzed. Possible policy options are described in Chapter 4. This section highlights results from the forecasting activities. The last part of this section examines two other forecasts, and briefly discusses the implications of the various forecasts for meeting the Energy Policy Act of 1992 goal of improving energy efficiency by 30 percent.

Determining the Potential for Conservation

Development of the National Energy Strategy (NES) included a three step process for assessing the potential for conservation 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.

Cost-Effective Energy Efficiency

This section is taken from: Roger S. Carlsmith et al., *Energy Efficiency: How Far Can We Go?*, Oak Ridge National Laboratory, ORNL/TM-11441, January 1990.

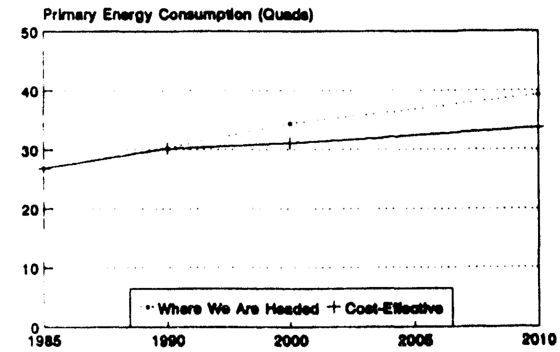
Although significant improvements in energy efficiency have occurred in the United States since 1973, overall energy efficiency has hardly changed since oil prices dropped precipitously in 1986. At the same time detailed studies of energy technologies point to large opportunities for more efficient energy use, even at current fuel prices. Questions now facing the U.S. are the extent to which the trends in energy efficiency are likely to continue, and what factors will influence these trends.

A multi-laboratory analysis conducted in support of the NES developed two scenarios that addressed these questions. The first, a reference case titled "Where We Are Headed," assumes a normal forecast of fuel prices, population, and economic activity. Furthermore, it assumes the continuation of present trends in construction, equipment manufacture, and personal lifestyle.

The second scenario, "Cost-Effective Efficiency," estimates the technical potential of cost-effective improvements in energy efficiency. The best available cost-effective technologies are installed as new and replacement equipment is needed, and as new technologies become commercially available. The analysis did not consider changes in government policy or other options that would be necessary to implement improvements in energy efficiency. It also did not include efficiency improvements in electricity production, transmission, and distribution.

By 2010 the reference case projects U.S. primary energy consumption of 102 quadrillion Btu (quads). The "Cost-Effective Efficiency" scenario shows only 88 quads in 2010. Thus there exists the potential to save 14 quads, or 13 percent, of projected energy requirements for 2010 in a cost-effective manner. Forty-one percent of these savings occur in the buildings sector, 33 percent in the industrial sector, and twenty-six percent in transportation. Building sector projections are shown in Figure 2-17.

Figure 2-17
Energy Efficiency: How Far Can We Go?
Buildings Sector



Source: ORNL/TM-11441

Over 50 quads of cumulative energy savings (from 1990 through 2010), worth more than $300 billion, are identified for the combined buildings (residential and commercial) sector, all at costs below the projected cost of supplying energy. In 2010 projected energy savings amount to 14 percent of the annual energy consumption projected for buildings in the reference case. Overall growth in primary energy consumption in buildings is reduced to 0.5 percent per year.

In the residential sector, 7 percent of the projected savings come from new shell measures, 23 percent from retrofits, and 70 percent from efficiency improvements in appliances and heating and cooling equipment. Of the 29 efficiency measures that were analyzed, the largest savings are projected for more efficient refrigerators. In the commercial sector, the biggest absolute reduction in energy consumption occurs for adjustable-speed fan motors. For the year 2010, the annual savings from retrofits account for 47 percent of the savings while new buildings account for 53 percent of the total. Equipment measures were included in both new building and retrofit savings. Improvements to lighting may also yield substantial savings, but these were not estimated for either the residential or commercial sectors.

Conservation Excursions

This section is taken from: *Energy Consumption and Conservation Potential: Supporting Analysis for the National Energy Strategy*, Energy Information Administration, SR/NES/90-02, December 1990.

The EIA modeling activity developed three projections. 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. These projections were made with EIA sector-specific models and data developed in the study described above.

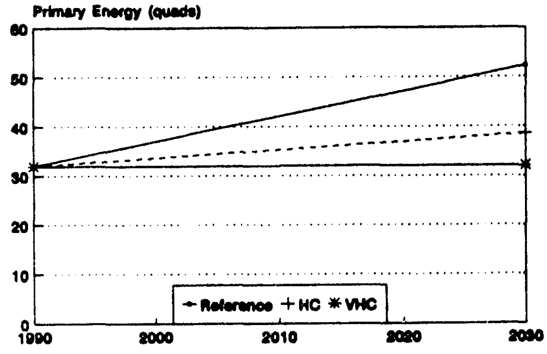
The reference case is based on assumptions of "business as usual." It is driven only by the underlying assumptions governing economic growth and energy prices. It is a trend projection.

The HC excursion assumes gradually increasing market penetration of cost-effective technologies and conservation. This excursion provides an estimate of conservation potential that is currently achievable. 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 either of the excursions address how improved energy efficiency may be achieved.

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.

In the reference case, buildings primary energy use increases by approximately 20 quads by 2030, at a rate of 1.2 percent per year. The high conservation excursion shows an increase of only 6.6 quads, with a growth rate of less than 0.5 percent per year. In the very high conservation excursion, energy use in buildings remains almost flat over the time horizon. Figure 2-18 shows these results. For these comparisons, electricity is converted at 3.4 Btu of primary energy for each Btu of delivered electricity.

Figure 2-18
Conservation Excursions
Buildings Sector



Source: EIA SR/NES/90-02

Heating remains the dominant end-use in the residential sector except in the very high conservation excursion where other appliances, which use predominately electricity, 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.

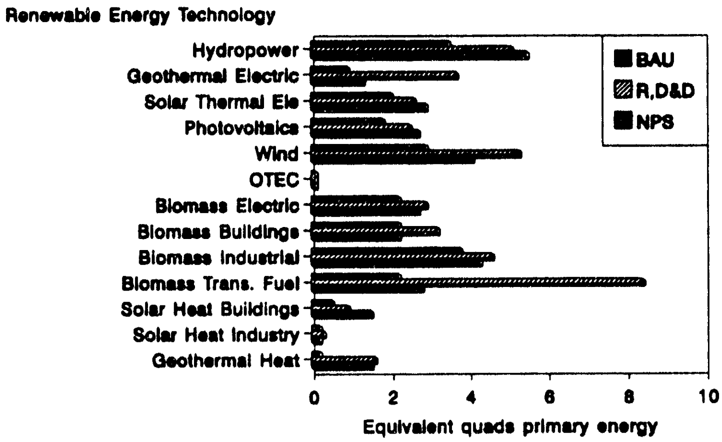
In the commercial sector, both conservation excursions result in significant reductions in energy use in 2030 relative to the reference case, although the difference between the two conservation excursions is not as pronounced as in the residential sector. Lighting improvements account for an important 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.

Determining The Potential For Renewable Energy

Currently, renewable energy supplies 8 percent of the U.S. demand for primary energy. Electricity generation from hydropower accounts for most of this (46 percent). Biomass in the industrial sector provides 26 percent of U.S. renewable energy in the form of process by-products from pulp and paper, and forest product industries. Biomass use in buildings accounts for 14 percent of current renewable energy use. The geothermal energy supply, 4 percent of total, includes energy from hot dry rock, geopressure, magma resources and hydrothermal sources that have direct use applications. Other renewable energy supplies

Figure 2-19
Renewables Contribution in 2030
(With Intermittent Constraints)



Source: SERI/TP-260-3674

include wind, alcohol fuels, solar thermal, and photovoltaics, which together account for 3 percent of U.S. renewable energy.

Renewable Technology Potential

This section is taken from: *The Potential of Renewable Energy: An Interlaboratory White Paper*, Solar Energy Research Institute, SERI/TP-260-3674, March 1990.

At the beginning of the NES development process an interlaboratory team was assembled to assess the potential for renewable energy technologies. Three scenarios were developed: Business as Usual (BAU), which assumes that Federal funding continues at current levels and energy/environmental policy is left unchanged; R,D&D (Research, Development, and Deployment), with an expanded federal R,D&D program, an additional $3 billion over the next twenty years; and a National Premiums Scenario (NPS), where substantial market incentives would be applied to induce consumers to select RET's at or near market competitiveness. These scenarios show that by 2030 the total renewables contribution could increase to 15 percent, 28 percent, and 22 percent respectively, of U.S. primary energy needs. Figure 2-19 shows results by technology.

The use of biomass for thermal purposes, including industrial cogeneration, is the principal use of biomass for energy production today. Industrial consumption of wood wastes for process heat and cogeneration uses totals about 1.8 quads and building heat uses, almost entirely residential wood consumption, totals about 1 quad. In the Business As Usual scenario, process heat (including cogeneration) use may increase to 3.8 quads by 2030, and building heat (again primarily residential use) to 2.2 quads.

With accelerated R,D&D, improvements in emission control catalysts and their costs, as well as other aspects of biomass combustion technology, will make wood burning more attractive than in the BAU scenario. However, the advances in biofuels technologies will result in competition for biomass supplies and, with high oil and gas prices, the economic incentives will be strong to use biomass wastes as feedstocks rather than as fuel. By 2030, only 1.9 additional quads of energy are projected to be used by residential and industrial consumers of biomass fuel, relative to the BAU scenario.

Solar building technologies include active and passive heating and cooling systems, as well as daylighting. It is estimated that currently in the United States more than a million active solar heating systems have been installed, and that 250,000 to 300,000 homes include some passive solar design features. Costs and energy savings due to passive systems are difficult to estimate. Utilization of both active and passive systems are projected to grow slowly in the BAU scenario, contributing 0.5 quads by 2030. With intensified R,D&D, improvements in the cost, manufacturability, and reliability of collectors and controls for solar buildings technologies result in almost a doubling of market penetration relative to the BAU scenario. With cost premiums, solar building technology market penetration essentially triples relative to the base case because the premium is expected to make these technologies significantly more attractive.

Heat from geothermal resources (the last category shown in Figure 2-19) can be used directly for space heating, greenhouses, food and industrial processing, enhanced oil recovery, aquaculture, refrigeration, and recreation. Cogeneration and the use of geothermal heat for feedwater heating in power plants are also possible. The BAU scenario shows a small growth in the use of stationary geothermal resources, primarily from expanded use of geothermal heat pumps and some development of hot dry rock technologies. Both the R,D&D and National Premiums scenarios project increases in those technologies over the BAU scenario as well as development of geopressured and magma resources. Use of stationary geothermal resources is region-specific, and depends on energy costs and demand center locations as well as the resource base itself.

Renewable Energy Excursion

This section is taken from: *Renewable Energy Excursion: Supporting Analysis for the National Energy Strategy*, Energy Information Administration, SR/NES/90-04, December 1990.

Following the detailed evaluation described above, a reference case and corresponding renewable energy excursion were developed for input to the NES. The Reference Case examines how much energy might be derived from renewable sources by 2030 under existing laws and regulations. The Renewable Energy Technology Excursion examines how much that contribution might be increased by accelerating cost and performance improvements of renewable technologies.

The Reference Case projects that renewable energy inputs for electrical generation will double by 2030. This includes no significant growth for hydroelectricity, which is projected to remain limited by regulatory constraints. Renewable energy use in dispersed applications is projected to more than triple, growing at an annual rate of 3.1 percent. Increased use of biomass, growth in the utilization of active and passive solar heating systems for residential and commercial buildings, and the use of geothermal heat pumps contribute to the increase.

The Renewable Excursion shows that the use of renewables for electrical generation and for dispersed applications can both double by 2030 over the Reference Case. For grid-connected systems, the largest increase occurs in geothermal development by 2010. The other emerging renewable electric sources begin their growth after the turn of the century, about ten years sooner than in the Reference Case. For dispersed applications, most of the increase over the Reference Case is due to the creation of an agri-crops-fed liquid fuels industry. There is also an increase in the use of geothermal heat pumps, because electric utilities are projected to provide incentives and cost reductions are expected in drilling techniques and installation of ground loops in large quantities. Rooftop-mounted photovoltaic systems do not achieve cost-effectiveness under the assumptions used in the analysis.

Putting It All Together

This section is taken from: *National Energy Strategy: First Edition 1991/1992*, February 1991, and *National Energy Strategy Technical Annex 2: Integrated Analysis Supporting The National Energy Strategy: Methodology, Assumptions and Results*, DOE/S-0086P, 1991/1992.

A number of possible energy policy options affecting all aspects of energy production and consumption were independently analyzed. Options affecting buildings are described in Chapter 4 of this report. Selected options were then integrated to estimate their combined effects. Building efficiency standards and utility Integrated Resource Planning (IRP) were the only options with a direct affect on buildings energy use that were included in the integration.

The integrating process was an iterative one. Detailed sector- and fuel-specific models maintained by the EIA and national laboratories were used to generate independent energy demand and supply projections. These independent energy projections were then integrated through the National Energy Strategy integrating energy model, Fossil2. Once the integrating energy model could replicate the results of the detailed models, the output of Fossil2 was introduced into an integrating macroeconomic model in order to provide non-energy price and quantity feedbacks in the overall economy. Once this was accomplished, the gross macroeconomic outputs (for example, Gross National Product, housing stocks, industrial production), were fed back into Fossil2 and final results were obtained.

Many policy actions affect more than one sector or fuel; changes in one sector often affect fuel prices, which in turn affect energy demand and supply in other sectors. For example, the effect of buildings efficiency standards decreases slightly in the integrated analysis because of lower overall energy prices. The impact of implementing the IRP option increases when combined with end-use conservation technology R&D options; the R&D actions make more efficient technologies available in the marketplace, while the IRP actions provide the financial vehicle necessary for their widespread application.

The Current Policy Base case shows an energy future in which no major changes in energy policy are assumed to occur. For the U.S. as a whole, primary energy consumption grows at about 1.3 percent per year. Renewable energy's contribution rises from about 8 percent of U.S. primary energy consumption today to 12 percent in 2030. Efficiency gains occur in all sectors, although highway fleet efficiency in the transportation sector rises slowly. Electricity consumption rises faster than any other end-use fuel, growing at 2.1 percent per year. Although buildings energy use grows at about the same rate as total energy use, this is slower than the projected growth in households or commercial floorspace. Renewable energy use in buildings increases from 1 quad in 1990 to 2.2 quads in 2030.

In the National Energy Strategy scenario, total U.S. primary energy consumption grows at just under 1.0 percent per year. Electricity consumption also grows much more slowly than in the Current Policy Base case, at 1.7 percent per year. Total renewable energy consumption is projected to increase more than 30 percent over the Current Policy Base case levels by 2030; renewable energy consumption in buildings is the same as in the Current Policy Base case. Energy consumption in the buildings sectors falls only slightly relative to the Current Policy Base case.

Energy Forecasts and the Energy Policy Act of 1992

The Energy Policy Act (EPAct) was passed by Congress in 1992. It contains provisions affecting all aspects of energy production and consumption. The parts of the Act that address buildings and OBT's program are discussed in Chapters 3 and 4 of this report.

Sec. 1602, Least-Cost Energy Strategy, of EPAct specifies that a strategy shall be designed to achieve "an increase in the efficiency of the Nation's total energy use by 30 percent over 1988 levels by the year 2010." The strategy is to be submitted to Congress as part of a report due not later than 2 years from the date of enactment; "efficiency" will probably be discussed in terms of Btu per dollar of GNP or some other broadly based metric. The strategy should allocate efficiency improvements among the sectors on the basis of cost; improvements will probably not be shared proportionally among the end-use sectors. However, before the development of a least-cost strategy, we assume for purposes of discussion that efficiency improvements of 30 percent will be desired for both the residential and commercial sectors.

Two forecasts are examined to determine the necessary energy savings required to meet the EPAct goals, one associated with the National Energy Strategy (NES), the other from the most recent *Annual Energy Outlook* (AEO 1993) from the Energy Information Administration. *Energy intensity* (Btu/household/year for the residential sector and Btu/square foot/year for the commercial sector) is used as the measure for *energy efficiency*. The approach taken involves calculating energy intensity for each sector for a base year, reducing this intensity ("efficiency") by 30 percent, and multiplying this figure by the forecasts of sector size for 2010 to obtain the desired maximum levels of energy consumption.

For internal consistency, conversion of electricity consumption at end-use to primary energy was performed based on the conversion efficiencies specific to each forecast and

Table 2-4
Growth Rates in Forecast Driving Variables
(% increase/year)

	Historical (1970-1990)	NES (1990-2010)	AEO (1990-2010)
Occupied Housing Stock	1.95	1.09	0.78
Commercial Floorspace	2.45	2.13	1.78

forecast year. 1990 was used as the base year because 1988 figures were not available from the documentation from either forecast, and extrapolation would have introduced additional complexity with very little value added (energy intensity changes slowly in the buildings sectors).

The NES forecast has higher estimates for sectoral growth, leading to higher levels of energy consumption. These assumptions are shown in Table 2-4. Residential and commercial forecasts, and the reduction in the forecasts necessary to the meet the EPAct goal, are given in Table 2-5.

Perhaps the most interesting difference between the AEO and NES forecasts is in the choice of growth rates for the driving variables, which leads to significant differences in forecast energy use for 2010 (about 6 quads) and the necessary reduction to reach a 30 percent increase in efficiency (about 3.5 quads).

Other Views

In late 1991, the Alliance to Save Energy, the American Council for an Energy-Efficient Economy, the Natural Resources Defense Council, and the Union of Concerned Scientists published *America's Energy Choices: Investing in a Strong Economy and a Clean Environment*. The report was conceived as an alternative to the NES, and was intended to examine the role that energy efficient and renewable technologies could play in meeting the nation's economic and environmental challenges.

With the aid of a computer model developed by the Stockholm Environment Institute - Boston Center, four energy futures were analyzed:

> **Reference,** which reflects current policies and trends;
> **Market,** which selects energy technologies based on minimizing the cost of energy services purchased by consumers;
> **Environmental,** which assigns monetary values to the environmental impacts of energy use; and
> **Climate Stabilization,** which seeks to meet predetermined targets for the reduction of carbon dioxide emissions to the atmosphere.

Table 2-5
Implications of Increasing Buildings Sector Energy Efficiency by 30 Percent

	AEO Reference Case (1993)		NES Current Policy Base Case (1990)	
	1990	2010	1990	2010
Residential Sector				
Total Housing (Millions)	93.4	109.1	93.4	116.1
Energy Consumption (Quads)	9.83	11.55	10.2	12.0
Primary Energy (Quads)	16.88	20.05	17.47	22.29
Energy Intensity (Million Btu/household/year)	181		187	
Intensity less 30%	127		131	
Energy Consumption Goal		13.81		15.20
Commercial Sector				
Floorspace (Billion ft^2)	62.9	89.5	64.3	98.1
Energy Consumption (Quads)	6.72	8.27	6.7	9.0
Primary Energy (Quads)	13.12	16.39	13.29	20.17
Energy Intensity (Thousand Btu/ft^2/year)	209		207	
Intensity less 30%	146		145	
Energy Consumption Goal		13.07		14.19
Total Buildings Sector				
Forecast Energy Consumption (Quads Primary Energy)		36.44		42.46
Energy Consumption Goal		26.88		29.39
Reduction Needed to Meet Goal		9.56		13.07

GNP and other assumptions were taken from EIA's *1990 Annual Energy Outlook*. Information on the economic potential of efficiency improvements and renewable technologies in the form of conservation supply curves was combined with estimates of the rates at which savings could be implemented, including limitations imposed by such factors as capital stock turnover, the existing infrastructure, and market inertia. The achievable potential varied in successive scenarios, reflecting increasingly aggressive development and adoption of new technologies.

Energy use projections [primary energy, quads] for the buildings sector for 2010 for the four scenarios are shown below. While impressive, the energy reductions postulated in the scenarios are not without precedent; the report states that average U.S. energy intensity fell by 2.4 percent per year between 1973 and 1986, and that decreases in the three scenarios other than reference range from 2.1 to 2.8 percent per year.

Table 2-6
Alternative Forecast for 2010
Buildings Sector

	Residential	Commercial	Buildings Total
Reference	22.44	21.06	43.52
Market	15.61	16.06	31.67
Environmental	14.65	13.83	28.48
Climate Stability	13.40	11.49	24.89

Specific to buildings, the report states:

"Our analysis reveals a tremendous potential for cost-effective energy savings in the residential and commercial buildings sectors. These savings would result from the use of more than 60 types of conservation technologies and measures currently available, ranging from more efficient lighting, windows, and appliances in existing residences to more efficient heating, ventilating, and air conditioning systems in new commercial buildings. We did not include measures that our analysts judged to be too uncertain in terms of availability, performance, and/or cost." [p. 11]

Advanced measured excluded from the study included gas-fired residential heat pumps, vacuum-insulated windows, and electrodeless fluorescent lamps.

"Moreover, our analysis did not exhaust the pool of currently available energy-efficiency measures; examples of measures not considered include combined space- and water-heating systems and passive solar designs for new buildings." [p. 55]

The energy savings achieved in the Market and Environmental scenarios are in the range needed to meet the goal of a 30 percent improvement in buildings sector energy efficiency; the Climate Stabilization scenario exceeds the necessary savings by a wide margin. These results (and indeed, all of the forecasts summarized in this Chapter that address conservation in buildings) suggest that meeting the goal of EPAct is technically feasible.

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3. PLANNING FOR THE BUILDINGS SECTOR

OBT's R&D program is designed to achieve the objective of holding buildings use of conventional energy constant, and accommodating sectoral growth with improved energy efficiency and increased use of renewable energy. Each year OBT undertakes an evaluation of its R&D program. The program is modified as needed to account for changes in public priorities and new information gained from the conduct of R&D. Current developments in program planning are described in the next section. Portions of the Energy Policy Act which may affect the R&D program are summarized in Chapter 4.

Analysis activities must also be redefined as national priorities change. A new Administration and the recent passage of the Energy Policy Act of 1992 have significant implications for OBT's evaluation and planning program area; these are discussed in the last part of this Chapter.

PROGRAM PLANNING

One of the key elements in prioritizing R&D programs is expected energy savings from improved technologies. The methodology that OBT uses to estimate potential savings has been significantly improved and is described in the next section. For the longer term, OBT has started the development of a market penetration model for new technologies in the commercial sector. This effort is briefly described in the following section.

Energy Savings Estimates

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This section describes the development of energy savings estimates for buildings-related research programs currently being conducted by OBT. The estimates of savings are developed on a program-by-program basis in which both technical performance and market penetration parameters are employed. Potential energy savings is an important criterion in determining the portfolio of R&D projects.

A spreadsheet computational environment is used to estimate primary energy savings from each OBT R&D project. A number of additional projects were added to the existing spreadsheet framework for the 1992 effort. Separate sections in the spreadsheets were developed for incandescent and fluorescent projects. Lighting was added to the residential spreadsheets. Other projects added include solar water heating, refrigerators, building automation systems, and industrialized housing. Overall, fourteen program areas were included in this year's analysis.

Based on the most recent program-level engineering and market penetration estimates, the current slate of research activities within OBT is projected to reduce primary energy consumption in the building sector by 2.5 quads in 2010 and by a little over 9 quads in 2030. These potential savings are graphed in Figure 3-1 relative to the projected building energy use from the National Energy Strategy (NES) analysis conducted by DOE in 1990-

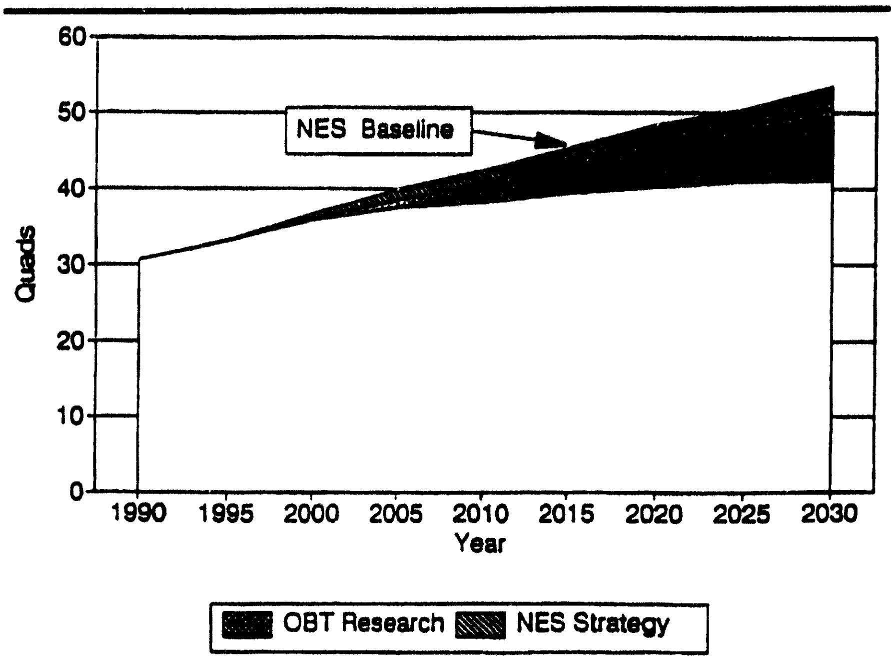

Figure 3-1.
Preliminary Estimate of Savings from OBT Research Programs Relative to NES Scenarios

1991. The adoption of OBT-sponsored technologies would reduce the projected increase in annual building energy use between 1990 and 2030 (from 30 quads to over 50 quads) by roughly one-half.

The top line in the figure shows the projected energy use under what the NES analysis terms "current policy base case." Thus, the OBT savings in 2010 represent about 6 percent of projected total energy use in the buildings sector under the NES current policy baseline. In 2030, the savings relative to the NES current policy base case is nearly 18 percent.

The middle line in the figure shows projected building sector energy consumption from the NES Strategy Scenario. The NES strategy in the buildings sector was primarily concerned with more aggressive demand-side management (DSM) programs by utilities and more stringent building energy standards. As compared to the OBT research activities, the impacts from these programs have a greater near-term impact (i.e., through 2005). By 2030, however, the savings from research programs would outweigh the NES actions by a factor of three.

Table 3-1 shows several broad disaggregations of the annual savings from the OBT research portfolio for the years 2010 and 2030. Programs classified as contributing to improved building equipment (HVAC and lighting) make up about two-thirds of the total savings.

Envelope-related projects account for about 0.9 quads in 2010, or a little less than 35 percent of the total projected savings. The fenestration and daylighting programs account

Table 3-1. Sources of Energy Savings from OBT Research Program, 2010 and 2030

	2010 (Quads)	2030 (Quads)
Type of Research		
Envelope	0.9	3.6
Equipment	1.6	5.5
Building Sector		
Residential	1.1	3.3
Commercial	1.4	5.8
Building Vintage		
Pre-1990	1.4	4.3
Post-1990	1.1	4.8
Total	2.5	9.1

for more than half of these projected savings. By 2030, the envelope programs account for 3.6 quads, or a little over one-third of the total projected savings.

The equipment-related projects involving HVAC equipment and lighting account for about 1.6 quads in 2010, but then grow rapidly in importance by 2030. In 2030, these projects account for about 5.5 quads, or over 60 percent of the total estimated savings. About half of the overall equipment savings in 2030 are attributable to more efficient fluorescent and incandescent lighting technologies.

About two-thirds of the total savings of the OBT research program is projected to be in commercial buildings. Large expected increases in lighting efficiency is a major contributing factor to this result.

Estimated savings in the commercial sector exceed that of the residential sector in all projection years, with the gap widening over time. By 2030, the savings potential in commercial buildings of the OBT programs considered in this analysis are almost twice that of the residential sector. Much larger savings from fenestration and daylighting and lighting equipment, as well as building automation systems, are primarily responsible for this result.

The programs with the largest savings impacts by 2030 in the residential sector are: 1) incandescent lighting (0.791 quads), 2) gas heat pumps (0.550 quads), and 3) duct improvement (0.347 quads). By 2030, the projects with the highest savings potential in the commercial sector are: 1) fluorescent lighting (1.359 quads), 2) fenestration and daylighting (0.977 quads), and 3) advanced electric heat pumps (0.842 quads). Note that none of the top three programs in either sector is common to both.

Finally, by 2030, a majority of savings will be from ("new") buildings built after 1990. The NES projects that of the 2030 building stock, 44 percent of the residential buildings and 60 percent of commercial buildings will be built after 1990. The anticipated high penetration of advanced fenestration technologies and adoption of industrialized housing are key factors in achieving equivalent savings in new buildings, as compared to existing, as early as 2000. Savings in retrofit buildings in 2010 is only about 20 percent greater than in new buildings. The large savings in new buildings is due in general to the much higher penetration rates that are assumed for this market. This is especially true in the envelope technologies, where the savings in new buildings is nearly double that of existing buildings in 2010.

A new element in the 1992 effort was the disaggregation of the building stock into "north" and "south" regions; this was done to allow better definition of the technical savings from the space conditioning technologies. The lighting and refrigerators estimates were only calculated on a national basis; the savings estimates were split equally (this is roughly the projected split in new construction between the two regions). The total estimated savings in 2030 in the north region are about 55 percent of the national savings. As expected, the envelope programs show considerably more potential in the north as compared to the south (2.13 quads vs. 1.48 quads). The savings from the equipment programs are more comparable, with total savings in the north about 15 percent higher than those in the south. The biggest potential savings in the north are from gas heat pumps; in the south the most savings stem from improved electric heat pumps.

A major conclusion from these results is that the long-term impacts of the OBT research portfolio are quite promising and could largely eliminate growth in building sector energy consumption after 2010. Before 2010, the picture is quite different. Even with the actions analyzed in the NES and the OBT research program, energy use in the building sector would still increase by over 20 percent. Clearly, accelerated adoption of existing and new near-term technologies will be required to move closer to a goal of constant energy use in buildings over the next two decades.

Market Penetration Rates

Energy savings achieved by a new technology depend on the characteristics of the technology as well as on how fast the technology is adopted in the marketplace. The methodology described above uses expert judgment to estimate market penetration rates for OBT technologies. Recognizing that these estimates can be improved, OBT has initiated development of a more sophisticated approach for forecasting market penetration rates for technologies in the commercial sector.

The objective of developing a market penetration model for use in OBT is to allow consistent, comparable, logical and explicable estimates of market penetration rates to be made across a broad range of products. The basic approach in the model is to establish user (i.e., decision maker) perceived economics in terms of return on investment, magnitude of investment relative to assets, payback period, and risk and to then use these results to enter a data set that establishes the likelihood of investment (i.e., purchase). This information, when combined with the number of potential users that have not already purchased the energy efficient products, subjective estimates of saturation level in terms of payback period, and awareness results in the determination of expected values of annual purchases, annual energy savings, cumulative purchases and energy savings as a function of time.

An underlying assumption in the model development is that decisions to utilize new products in commercial establishments are primarily based upon perceived product economics but decisions may take into account other factors. Thus, purchase decisions are described in probabilistic terms.

Finally, the market penetration model has been incorporated in a proposed methodology to apportion OBT's overall energy savings objective among the various program elements. This methodology would use a two-stage Monte Carlo approach to develop a probability distribution of total energy savings and the probability of achieving the overall goal.

ANALYSIS PLANNING

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OBT, along with DOE's other offices dealing with energy efficiency and renewables, faces a planning environment considerably different from that of the past few years--and one that will likely continue to evolve in ways that are difficult to predict. Among the recent and continuing changes that will affect evaluation and planning activities are:

- a new Administration committed to active public sector leadership in addressing environmental, resource, and economic productivity challenges, both domestically and outside the U.S.;
- a wide range of new (or expanded) data, planning, and analysis requirements mandated under the Energy Policy Act of 1992 (EPAct); and
- new or expanded DOE institutional (as well as statutory) requirements for technology characterization, program assessment, and wise allocation of resources.

The implication for OBT planning and evaluation is a need to be able to analyze existing and proposed programs not only in terms of energy impacts, but also:

- direct and indirect (life-cycle) environmental consequences - criteria air and water pollutants, greenhouse and ozone-depleting gases, toxics and other waste materials;
- economic consequences - jobs, productivity, competitiveness, and export potential; and
- a working familiarity with indirectly energy-related policies such as investments in human capital and institutional infrastructure ("delivery-systems").

Other important external influences, however, will remain unchanged, including the continued pressure to hold down growth in Federal spending. Thus, competition for funding among new program initiatives will require that:

- new OBT proposals be well-justified with credible data and analyses;
- the proposed continuation or expansion of existing programs be supported with thorough and competent evaluations; and that
- analysis, planning, and evaluation activities themselves be carried out in the most cost-effective manner possible, avoiding duplication and emphasizing cooperative, cost-shared activities wherever possible.

More generally, this new planning environment may require a fundamental reassessment of many established OBT program strategies, procedures, and operating assumptions.

Evaluation and Planning Program Objectives

OBT has adopted the following program objectives for sector-wide evaluation and planning:

(1) To provide a solid informational and analytic foundation for decision-making that contributes to national energy policy planning and implementation within the buildings sector, including:

- technology advancement (RD&D) and technology deployment activities by OBT;
- deployment programs by other DOE offices; and
- both RD&D and deployment activities by selected non-DOE public and private entities (states, utilities, industry and non-profit organizations).

(2) To establish an ongoing process for evaluating the methods and effectiveness of both OBT and non-OBT programs and policies that affect energy efficiency and renewables in the buildings sector, in order to provide timely and reliable feedback to decision-makers and program managers.

Criteria for Success

It is especially important for a planning and evaluation program to have clearly-defined criteria for its own success. By judging its own success through an open explicit process, the Evaluation and Planning program can help set an example for self-examination and feedback among other OBT programs.

Indicators of effectiveness for OBT's planning and evaluation program include:

- consistency of the baseline data on energy use and stock characteristics within the buildings sector, used as a common basis for quantitative analyses throughout the Office and elsewhere within DOE (e.g., by EIA and DOE/Policy);

- a thorough, well-documented understanding of the major factors (and uncertainties) affecting energy use and efficiency trends in U.S. buildings--including the quantitative and qualitative impacts of current DOE and non-DOE programs/policies;
- an ability to create promising new program and policy options that are able to gain support within the Department, from Congress and the Administration in general, and among other stakeholders in private industry and the public;
- tools and capabilities to reliably quantify energy, environmental, and economic/productivity impacts of specific programs and policy options at various levels of detail, and to document the methods and assumptions used for future reference (or refinement); and
- timely analytical and data products to meet specific legislative and DOE organizational requirements.

OBT is currently developing a Multi-Year Plan that will guide its evaluation and planning activities over the next three to five years, allowing OBT to meet legislative and programmatic requirements. To a large extent, provisions of the Energy Policy Act will drive these activities, if they are funded. The implications of the Energy Policy Act of 1992 are discussed in the next section.

Energy Policy Act of 1992

The Energy Policy Act of 1992 [Public Law 106-486 - October 24, 1992] mandates greatly expanded Federal responsibilities for improving the efficiency of energy use and encouraging the use of renewable energy in buildings. The Act specifies that DOE shall assist the States in upgrading building energy efficiency codes, establish energy efficiency standards for new Federal buildings, expand the coverage of appliance and equipment standards, establish a Federal Energy Efficiency Fund, provide new directions for research and development, and discharge numerous other specific responsibilities. Many of these actions require supporting analyses.

In general, the analytical requirements directly associated with the responsibilities of the Program Offices will best be met by the Offices themselves. There are, however, several areas where the Evaluation and Planning Program Element logically has lead responsibility for OBT. These include contributing to a report on global climate change and providing assistance in the development of a least-cost energy strategy. Specific sections of the Act where it appears that Evaluation and Planning has lead or significant responsibility on behalf of OBT are summarized below.

TITLE I - Energy Efficiency, Sec. 127, Report on the Potential of Cooperative Advanced Appliance Development requires that not later than 18 months from enactment the Secretary, in consultation with the Administrator of EPA, prepare a report on the potential for the development and commercialization of appliances which are substantially more efficient than required by Federal or State law. The report shall describe actions to coordinate and assist utilities and manufacturers in development and commercialization of highly efficient appliances, describe proposals for Federal promotion, identify Federal purchase methods, and identify funding levels. Evaluation and Planning will provide support to the Office of Building Energy Research in preparing this report.

Sec. 128, Evaluation of Utility Early Replacement Programs for Appliances requires that the Secretary, in consultation with EPA, utilities, and appliance manufacturers, shall evaluate and report to Congress within 18 months of enactment on the energy savings and environmental benefits of programs directed toward the early replacement of older, less efficient appliances. Evaluation and Planning will provide support to the Office of Building Energy Research in preparing this report.

Title XII - Renewable Energy, Sec. 1202, Demonstration and Commercial Application Projects for Renewable Energy and Energy Efficiency Projects specifies the development of a National Renewable Energy and Energy Efficiency Management Plan to be submitted to Congress within one year after the date of enactment; Evaluation and Planning will be responsible for OBT's contribution to this plan.

Sec. 1211, Innovative Renewable Energy Technology Transfer Program requires that the Secretary and the Administrator of the Agency for International Development report annually to the Committee on Energy and Natural Resources of the Senate and to the appropriate committees of the House of Representatives on the progress being made to introduce renewable energy technologies into foreign countries; Evaluation and Planning will contribute to these reports on behalf of OBT.

Title XVI - Global Climate Change, Sec. 1601, Report requires that "Not later than 2 years after the date of the enactment of this Act, the Secretary shall submit a report to the Congress that includes an assessment of -

(1) the feasibility and economic, energy, social, environmental, and competitive implications, including the implications for jobs, of stabilizing the generation of greenhouse gasses in the United States by the year 2005;

(2) the recommendations made in Chapter 9 of the 1991 National Academy of Sciences report entitled "Policy Implications of Greenhouse Warming", including an analysis of the benefits and costs of each recommendation;

(3) the extent to which the United States is responding, compared with other countries, to the recommendations made in Chapter 9 of the 1991 National Academy of Sciences report;

(4) the feasibility of reducing the generation of greenhouse gases;

(5) the feasibility and economic, energy, social, environmental, and competitive implications, including the implications for jobs, of achieving a 20% reduction from 1988 levels in the generation of carbon dioxide by the year 2005 as recommended by the 1998 Toronto Scientific World Conference on the Changing Atmosphere;

(6) the potential economic, energy, social, environmental and competitive implications, including implications for jobs, of implementing the policies necessary to enable the United States to comply with any obligations under the United Nations Framework Convention on Climate Change or subsequent international agreements."

This will be a major study, perhaps on the scale of the NES. DOE/Policy will likely lead the effort, with heavy involvement from EE at the sector level - especially in the buildings area, where there remain significant, cost-effective opportunities. The emphasis on employment, competitiveness, and social impacts presents a challenge - there has been little thoughtful work undertaken in these areas over the past decade. Evaluation and Planning will be responsible for OBT's contributions under this section.

Sec. 1602. Least-Cost Energy Strategy specifies that "the first National Energy Policy Plan (in this title referred to as the "Plan") under section 801 of the Department of Energy Organization Act (42 U.S.C. 7321) prepared and required to be submitted by the President to Congress after February 1, 1993, and each subsequent Plan, shall include a least-cost energy strategy prepared by the Secretary. In developing the least-cost energy strategy, the Secretary shall take into consideration the economic, energy, social, environmental, and competitive costs and benefits, including costs and benefits for jobs, of his choices."

"Such strategy shall be designed to achieve to the maximum extent practicable and at the least-cost to the Nation--

(1) the energy production, utilization, and conservation objectives of subsection (d);

(2) the stabilization and eventual reduction in the generation greenhouse gasses;

(3) an increase in the efficiency of the Nation's total energy use by 30% over 1988 levels by the year 2010;

(4) an increase in the percentage of energy derived from renewable resources by 75 percent over 1988 levels by the year 2005; and

(5) a reduction in the Nation's oil consumption from the 1990 level of approximately 40 percent of total energy use to 35 percent by the year 2005."

The least-cost strategy shall also include --

"(1) a comprehensive inventory of available energy and energy efficiency resources and their projected costs, taking into account all costs of production, transportation, distribution, and utilization of such resources;

(2) a proposed two-year program for assuring adequate supplies of energy and energy efficiency resources and technologies described in paragraph (1), and an identification of administrative actions that can be undertaken within existing Federal authority to ensure their adequate supply;

(3) estimates of life-cycle costs for existing energy production facilities;

(4) baseline forecasts of short-term and long-term energy needs under low and high case assumptions of economic growth; and

(5) an identification of all applicable Federal authorities needed to achieve the purposes of this section, and of any inadequacies in those authorities."

In the development of the least-cost strategy, full consideration is to be given to the relative costs of energy and energy efficiency resources, and the economic, energy, social, and environmental consequences resulting from the establishment of any particular order of Federal priority. Policies for consideration are identified, and a period for public review and comment is provided for. As with the report on global climate change, focus on employment, competitiveness, and social impacts poses challenges; DOE/Policy will probably lead in the development of the National Energy Policy Plan, with major support from EE and the sectors. Development of the least-cost strategy will also require that OBT develop estimates of the criteria to be used to prioritize policy actions. Evaluation and planning will prepare OBT's contributions to the development of the least-cost strategy.

Sec. 1604, Assessment of Alternative Policy Mechanisms for Addressing Greenhouse Gas Emissions states: "Not later than 18 months after the date of enactment of this Act, the Secretary shall transmit a report to Congress containing a comparative assessment of alternative policy mechanisms for reducing the generation of greenhouse gases." [Policies include emissions trading, incentives, and source efficiency standards; the section calls for short and long-run analysis of the social, economic, energy, environmental, competitive, and agricultural costs and benefits, including costs and benefits for jobs and competition.] As with Sec. 1602, OBT will probably be tasked with estimating the criteria values needed for comparative policy assessment.

Sec. 1608, Innovative Environmental Technology Transfer Program, (h) Eligible Technologies mandates that "not later than 6 months after the date of enactment of this Act, the Secretary shall prepare a list of eligible technologies and services under this section." Building technologies will certainly be included, and OBT is likely to be charged with preparing the list for these technologies. The intent of the section is to reduce the U.S. trade deficit through the export of energy technologies and expertise.; OBT is also likely to be asked to provide information to be used in the evaluation of candidate technologies for financial support. Evaluation and Planning will probably take the lead in meeting OBT's responsibilities under this section.

Title XX - General Provisions; Reduction of Oil Vulnerability, Sec. 2028, Telecommuting Study requires that DOE, in consultation with the Department of Transportation, conduct a study of the potential costs and benefits to the energy and transportation sectors of telecommuting. The study is to be completed within 180 days of enactment; OBT's role in preparing the study is unclear. If there is input from OBT, it will probably be developed by Evaluation and Planning.

Title XXI - Energy and Environment, Subtitle A - Improved Energy Efficiency, Sec. 2101, General Improved Energy Efficiency, subsection (b), states: "The goals of the program established under subsection (a) [see sections 2102-2108] shall include-

(1) in the buildings sector --

(a) to accelerate the development of technologies that will increase energy efficiency;

(b) to increase the use of renewable energy; and

(c) to reduce environmental impacts."

Subsection (c) calls for a 5-year program plan to guide the research, development, and demonstration activities under this subtitle to be prepared and submitted to Congress within 180 days of enactment of this Act. Within OBT, responsibility for preparing the plan is likely to fall to the Office of Building Energy Research rather than Evaluation and Planning; Evaluation and Planning may be called upon to contribute.

In preparing the plan, the Secretary is required to consult with appropriate representatives of industry, utilities, institutions of higher education, Federal agencies, including national laboratories, and professional and technical societies. $178 million for fiscal year 1993 and $275 million for fiscal year 1994 are authorized to be appropriated for carrying out this subtitle, including all building, industry, and utility sectors energy conservation research and development, and inventions and innovations under energy conservation technical and financial assistance.

Sec. 2102, Natural Gas and Electric Heating and Cooling Technologies specifies that the natural gas heating and cooling program shall include activities on thermally activated heat pumps and other advanced natural gas technologies, including fuel cells for residential and commercial applications. The electric heating and cooling program is to focus on advanced heat pumps, thermal storage, and systems that utilize replacements for CFCs. Plans for these activities will be included under Sec. 2101.

Sec. 2104, Advanced Buildings for 2005 states that the Secretary shall initiate a 5-year program to increase building energy efficiency including activities on:

(1) building design, design methods, and construction techniques;
(2) building materials, including recycled materials, and components;
(3) on-site energy supply conversion systems such as photovoltaics;
(4) automated energy management systems;
(5) methods of evaluating performance; and
(6) insulating products manufactured with nonozone depleting materials.

Sections 2102 and 2104 specify that within one year of the enactment of this Act, the Secretary shall solicit proposals for conducting activities under this section. Plans for these actions will be developed under Sec. 2101.

Title XXII - Energy and Economic Growth, Sec. 2203 Supporting Research and Technical Analysis, (c) Technology Transfer requires that within one year following enactment, the Secretary shall submit a report to Congress on the adequacy of technology transfer activities conducted by the National Laboratories, along with a proposal recommending ways to reduce the length of time required to consummate cooperative research and development agreements. Implementation and Deployment [I&D] will have lead responsibility on this activity for OBT; Evaluation and Planning will assist in preparing OBT's contribution to this report.

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4. BUILDINGS AND FEDERAL ENERGY POLICY

Chapter 2 discussed the potential for improving energy efficiency and increasing the use of renewable energy in buildings. Much of the analysis that contributed to those estimates was undertaken during the development of the National Energy Strategy. This chapter describes the process of developing the National Energy Strategy and presents the policy options that were evaluated for improving efficiency in buildings.

After completion of the National Energy Strategy, Congress passed a comprehensive energy policy act. The last section of this chapter describes the portions of that act that address energy use in 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). 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.

Concurrent with the public hearings, background information was prepared within DOE. The product of these activities was the publication in April 1990 of the *Interim Report,* which summarizes publicly identified concerns, goals, obstacles to achieving those goals, and suggested options for action to remove or overcome the obstacles. 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."

During the fall of 1989, the Office of Conservation and Renewable Energy (now the Office of Energy Efficiency and Renewable Energy (EE)) and several national laboratories assessed the potential contribution that energy efficiency and renewable energy could make toward meeting the nation's energy needs. The Energy Information Administration (EIA), with support from EE, then used the potential data to project various levels of technology penetration through 2030. This information was further examined in the context of the NES analytical framework, using DOE's integrating model Fossil2. Results from these activities are summarized in Chapter 2.

At the same time, using results from the public hearings, policy options for all areas of energy use and production were defined and analyzed. The Office of Energy Efficiency and Renewable Energy produced seven documents examining a number of options for improving efficiency and increasing the use of renewable energy. As a result of these activities and input from many others, including the Economic Policy Council and the Office of Management and Budget, a subset of options was selected for inclusion in the NES. The *National Energy Strategy - First Edition* was delivered to the President in February 1991.

The seven areas evaluated by EE were: renewable energy; the Public Utility Regulatory Policies Act; Integrated Resource Planning; improving energy efficiency in buildings; liquid fuels from biomass; conversion of municipal solid waste to energy; and waste minimization in industry.

Policy Options for Improving Energy Efficiency in Buildings

As previous sections of this report have shown, energy use in buildings represents a major target of opportunity for improved energy efficiency by encouraging the timely adoption of cost-effective technologies now available, and the development and commercialization of advanced technologies. A number of policy options for improving buildings energy efficiency were analyzed; results of the analyses are briefly summarized below.

Accelerated Research, Development, and Demonstration

The current ($35 million per year) Federal R&D program - leveraged through cost-sharing with industry - has led to major advances in building technologies and practices, producing significant savings in energy and consumer expenditures, with benefit/cost ratios estimated to be as high as 400:1. Technologies such as the solid-state ballast for fluorescent lights, low-emissivity glazing for windows, and the high-efficiency refrigerator compressor have all resulted from successful DOE-sponsored buildings energy R&D projects. Thirteen such projects are expected to produce annual energy savings of as much as 2 quads by 2010, worth over $10 billion per year. The DOE investment was $25 million.

Considerable potential remains for further improvements in technical performance through research and development, as well as cost reduction and demonstration of energy-efficient and renewable technologies to further their acceptance. For example, gas-fired absorption heat pumps could approximately double the efficiency of space heating with gas; advanced light sources could deliver from 120 to 200 lumens per watt, compared to 17 for today's incandescent and 80 for today's fluorescent lamps.

Publicly identified options from the NES hearing process included a number of suggestions for increased Government support for research and development of new technologies, as well as suggestions for demonstration projects. This option would approximately double Federal support, from $50 million (including expenditures for Congressionally mandated programs) to $100 million per year for each of the next 5 years. Within the context of increased support, this option would also provide an increased emphasis on the demonstration of new options to accelerate their market acceptance.

It is difficult to generalize the costs and benefits of R&D; there is considerable variation in terms of costs, fuel-specific savings, and timing of benefits associated with a given piece of research or a new technology. The benefits of research are difficult to quantify because of the long lead times from inception to completion, uncertainty regarding success, and unforeseen benefits not associated with original objectives. The rate of adoption of innovations is also highly uncertain.

It is also difficult to separate the benefits associated with research from the other elements involved in the implementation of the resulting technologies. Research is a necessary, but not sufficient, factor in improving the efficiency of energy use in the future; the availability of improvements created by R&D will affect the degree to which the efficiency of energy use in building can be improved.

While the NES time frame did not allow the detailed analysis necessary to address these concerns, several of the excursions described earlier permit an estimate of the energy savings benefits due to R&D. This analysis concludes that doubling Federal R,D&D activities will advance the commercial availability of new energy-efficient and renewable technologies for buildings on the order of 5 to 10 years. This results in annual energy savings over the NES Reference Case of at least 7 quads by 2030, as well as an increased contribution of building-scale renewable energy sources.

Building and Equipment Standards

This analysis focuses on two closely related options for improving energy efficiency and increasing renewable energy applications in new buildings, appliances, and equipment: (1) strengthening building energy efficiency standards, and (2) updating of appliance and equipment standards, plus extending them to new categories of equipment.

DOE would strengthen building energy efficiency standards by three related actions: 1) technical assistance and encouragement to States and local governments to adopt Federal residential and commercial building energy efficiency standards, 2) legislation shifting regulatory responsibility for the energy efficiency of manufactured housing from HUD to DOE, and 3) legislation requiring all new buildings subsidized by Federal funds or Federally-insured mortgages to meet the Federal energy efficiency standards.

DOE has established efficiency standards for 13 categories of residential appliances. This option would expand coverage of efficiency standards to commercial lighting systems and consideration of additional categories of residential and commercial equipment, including commercial space conditioning equipment and controls, office equipment, and small (up to 25 HP) electric motors. Mandatory standards would be extended to these new categories only to the extent that performance testing and labeling by private industry would not accomplish the same cost-effective energy savings.

The two options were evaluated using spreadsheet models developed for the residential and commercial sectors. For a given year, the spreadsheets calculate total energy requirements for each end-use and fuel type by multiplying the estimated stocks by (fuel-specific) saturations and unit energy consumption (UEC) values. These models were initially calibrated to the EIA Reference Case which was prepared for the NES and also used as a basis for the NES Reference Case forecasts of the Fossil-2 model.

To estimate savings for a "Buildings and Appliance Standards" scenario, the spreadsheets were run with an alternative set of inputs that reflect the expected changes in shell and equipment efficiency that would result from setting standards for additional types of equipment, as well as from updating the existing Federal standards. New buildings and equipment entered the stock at the same growth and replacement rates used in the Reference Case; appliance saturations and fuel mix are also the same.

As of 2030, the spreadsheet models show net annual savings from new building and appliance standards (compared with the Reference Case) of 0.7 quads site energy (electricity converted at 3413 Btu/kWh) in the residential sector and 2.2 quads in the commercial sector. These savings do not include the continuing impact of existing Federal standards or of state building codes already in place. The models also show annual electricity savings of 9 percent in the residential sector and 27 percent in the commercial sector in 2030.

Associated with these annual energy savings are annual net savings in the cost of energy services to consumers, amounting to over $10 billion per year for building standards and over $20 billion per year for equipment standards by 2030 (in 1989 dollars, prior to discounting). The discounted net present value of these savings (using 10 percent real interest rate) is about $25 billion for building standards and about $40 billion for equipment standards. An additional benefit due to the standards is a net reduction in CO2 emissions of about 100 million tons per year by 2010, and over 180 million tons per year by 2030.

DOE direct expenditures associated with this option would increase by about $8 million per year over the next five years, to support analysis and technical assistance. Other DOE programs would support complementary activities, such as demonstrations, design tool development, training, and technical support for utility conservation incentive programs. By 1995, it is estimated that annual support from non-Federal sources would be at least twice as large as the direct Federal budget costs. These non-Federal expenditures would consist mainly of utility-sponsored incentive and technical assistance programs, plus code adoption and compliance activities by state and local agencies and professional societies.

Federal Energy Management

The Federal government is the largest single energy consumer in the United States, using 1.9 quads of energy annually at 8000 facilities worldwide. The public hearings held during the development of the National Energy Strategy revealed broad support for increasing the efficiency of energy use by the Federal government.

On April 17, 1991 the President signed the Executive Order on Federal Energy Management, which directs all Federal agencies to reduce overall energy consumption in Federal buildings and facilities by 20 percent by the year 2000 and fuel consumption in Federal vehicles by 10 percent by the year 1995. By the year 2000, these actions will save American taxpayers up to $800 million dollars in annual energy costs and cut Federal energy consumption by up to the equivalent of 100,000 barrels of oil per day.

The NES option discussed here would help implement the goals outlined in the Executive Order by establishing a Federal fund for energy efficiency. This option would provide capital for energy efficiency investments from a revolving fund of $300 million whose sole mission would be to reduce Federal energy costs. Cost savings resulting from the investments would be used to replenish the fund, pay back the Treasury, and provide incentives for agency participation.

The revolving fund addresses the largest barrier to Federal investment in energy efficiency, which is the Federal budgeting process. Federal agencies are often not able to fund cost-effective energy efficiency and renewable energy projects in their facilities because requests for capital must compete against agency mission priorities. In practice, requests for capital are seldom approved even if they have attractive life-cycle costs.

The first $300 - $500 million allocated by the fund would probably have payback periods of two to four years, allowing the fund to support about $100-$150 million per year of investments, while being continually replenished after the third year. In less than 10 years, the revolving fund would be able to return the original $300 million, plus a return, to the Treasury. Thereafter, the continuing savings from the investments should be sufficient to maintain the revolving fund for the indefinite future.

Initial capitalization would require appropriations of approximately $50 million in the first year, $75 million in the second, $100 million in the third and $75 million in the fourth year. The program could reduce Federal energy use in buildings by more than 5 percent and result in net cumulative savings to the Treasury of $1.5 billion by 2000.

Energy-Efficient Mortgages

This option considers an expanded, nationwide system of home energy rating systems tied to mortgage financing. Technical assistance and training programs will support state and local adoption of home energy rating systems. Lenders will be encouraged to offer "energy-efficient mortgages" which incorporate the cost of energy-saving measures and reflect the resultant savings in the loan formula used to qualify home buyers. After five years of development and demonstration, energy efficiency information would be required prior to sale.

Currently, several Federal lending institutions offer ways to encourage energy efficiency in new and existing homes. There are also several private or state home rating systems in various parts of the U.S. These approaches differ significantly, however.

This option would provide Federal financial and technical support to develop a home energy rating system and procedures for qualifying homes for energy-efficient mortgages, including developing standard forms and guidance as well as training for real estate agents, lenders and others in the shelter industry. In addition, local demonstrations of energy-efficient mortgage programs would be conducted.

This option would substantially increase the information on energy efficiency available to home buyers and expand the utilization of available mortgage financing options. Thus this program would address important barriers to energy efficiency in the residential sector. Presumably significant energy savings would accrue as efficiency improvements are undertaken in response to the information and improved financing options. This approach may be less costly than other mechanisms for encouraging housing retrofit such as direct incentives, time-of-transfer standards or direct weatherization. At the same time, requiring additional information will add cost and administrative burdens to the process of selling and financing homes.

Energy Efficiency in Low-Income Housing

This option addresses energy efficiency in two areas of low-income housing--public housing and residences served by State weatherization programs. Energy use in public housing is about 50 to 65 percent greater (per square foot) than in private multi-family housing. This option would establish energy use/efficiency targets for public housing projects and would improve incentives for project managers and tenants by allowing them to retain a larger share of savings from efficiency improvements. The option also includes increased monitoring and evaluation of public housing energy use, especially following major energy-related capital improvements.

Establishing energy performance targets for public housing would be a complex undertaking. Costs of this option would be about $5 million per year, to provide additional technical support to HUD and individual Public Housing Authorities. Currently, Federal costs for energy used in public housing are $0.6 to $1.0 billion per year. It is estimated that about 25 to 30 percent of annual energy use could be saved and, because managers and tenants would share the cost savings, about 10 percent ($100 million per year) of Federal outlays could be saved.

The second part of this option would encourage States to increase the percentage of funds used for low-income weatherization, as a fraction of total allocations under the Low-Income Home Energy Assistance Program (LIHEAP). Under LIHEAP, States can provide direct payments to eligible households to help them meet their energy bills, or provide weatherization assistance; States can use up to 25 percent of LIHEAP funds for low-income weatherization.

With a shift of $250 million per year from direct assistance to weatherization, an additional 185,000 homes could be weatherized providing lasting benefits. Assuming 10 to 20 percent savings, annual savings would be 1.7 to 3.4 TBtu and between $17 and $34 million.

ENERGY POLICY ACT OF 1992

The Energy Policy Act of 1992 [Public Law 102-486, enacted October 24, 1992] mandates major increases in Federal responsibilities for improving energy efficiency in buildings. The Act calls for expanded activities in all areas of OBT's program, including:

Building Standards and Guidelines

Building Energy Efficiency Standards [Sec. 101]: States shall certify within two years of enactment to the Secretary that residential building codes meet or exceed the CABO Model Energy Code of 1992, and that commercial building codes meet or exceed ASHRAE Standard 90.1-1989. Standards for new Federal buildings that meet or exceed the above standards will be established; compliance shall be assured by allowing expenditure of Federal funds only if a building meets or exceeds standards. Support for code development and review are provided for, and progress shall be reported to Congress.

Residential Energy Efficiency Ratings [Sec. 102]: Not later than 18 months after enactment, the Secretary shall promulgate guidelines for voluntary home energy rating systems, and provide technical assistance to State and local organizations to encourage their use.

Appliance and Equipment Standards, Testing, and Labeling

Energy Efficiency Labeling for Windows and Window Systems [Sec. 121]: Provide technical and financial assistance to support a voluntary national window rating program that will develop energy ratings and labels for windows and window systems.

Energy Conservation Requirements for Certain Commercial and Industrial Equipment [Sec. 122]: Develop mandatory minimum efficiency standards, testing procedures, and labels for commercial air conditioning, space heating, water heating equipment, and electric motors.

Energy Conservation Requirements for Certain Lamps and Plumbing Products [Sec. 123]: Adopt a mandatory energy conservation program for incandescent lamps, fluorescent lamps, and plumbing products, including test procedures and standards, and develop recommendations for establishing State and local incentive programs for the voluntary replacement of plumbing products.

High-Intensity Discharge Lamps, Distribution Transformers, and Small Electric Motors [Sec. 124]: Study and report to Congress on the technical feasibility and economic justification of efficiency standards for these classes of equipment; develop testing procedures and labels if justified.

Energy Efficiency Information for Commercial Office Equipment [Sec. 125]: Assist industry in developing voluntary efficiency rating and labeling programs for commercial office equipment.

Energy Efficiency Information for Luminaires [Sec. 126]: Assist industry in the conduct of a voluntary rating and labeling program for luminaires.

Federal Energy Management

Federal Energy Management Amendments [Sec. 152]: Requires that each Federal agency install in Federal buildings all energy and water conservation measures with payback periods of less than 10 years by 2005. A Federal Energy Efficiency Fund is to be established by the Secretary for this purpose ($10 million FY94, $50 million FY95, as necessary thereafter). Provision is made for the demonstration of new technology in federally-owned facilities, and a study of the potential use of the purchasing power of the Federal government to promote the development and commercialization of energy-efficient products is required. A survey of the energy savings potential in Federal buildings is to be conducted; a plan is to be prepared within 180 days of enactment.

Energy Savings Performance Contracts [Sec. 155]: Authority to enter into energy service contracts is provided.

Intergovernmental Energy Management Planning and Coordination [Sec. 156]: Conduct of regular, biennial conference workshops in each of the 10 Federal regions on energy management, conservation, efficiency, and planning strategy. [GSA lead Responsibility, DOE "in consultation"]

Federal Energy Management Training [Sec. 157]: Each executive department, the EPA, NASA, GSA, and USPS shall establish and maintain a training program to ensure that facility energy managers are trained energy managers.

Energy Audit Teams [Sec. 158]: The Secretary shall assemble from existing personnel with appropriate expertise energy audit teams to perform energy audits of Federal facilities.

Federal Energy Cost Accounting and Management [Sec. 159]: Not later than 120 days from enactment, the Director of OMB shall establish guidelines to be employed by each Federal agency to assess energy consumption for all buildings and facilities owned, operated, managed, or leased where the government pays utilities separate from the lease.

Inspector General Review and Agency Accountability [Sec. 160]: Guidance and cooperation with Inspector Generals with respect to audits and compliance; detailed reporting requirements.

Procurement and Identification of Energy Efficient Products [Sec. 161]: The Administrator of General Services, the Secretary of Defense, and the Director of the Defense Logistics Agency, in consultation with the Secretary of Energy, shall implement a program to identify and designate those energy efficient products that offer significant potential savings, and issue guidelines to encourage the acquisition and use of such products by all Federal agencies. The Secretary of Energy shall report to Congress annually on the progress, status, activities, and results of these programs.

Federal Energy Efficiency Funding Study [Sec. 162]: The Secretary of Energy, in consultation with other agencies, shall conduct a detailed study of options for the financing of energy and water conservation measures; report due to Congress 180 days after enactment.

Government Contract Incentives [Sec. 167]: Each agency shall establish criteria for the improvement of energy efficiency in Federal facilities operated by Federal Government contractors and subcontractors to encourage contractors to adopt and utilize conservation measures.

Building Energy Research

Study and Report on Vibration Reduction Technologies [Sec. 173]: Report to Congress 12 months after enactment on the cost-effectiveness, energy efficiency, and environmental impacts of active noise and vibration cancellation technologies.

Demonstration and Commercial Application Projects [Sec. 1201]: The Secretary shall solicit proposals for demonstration and commercial application projects for renewable and energy efficient technologies. Projects may include the following technologies: (E) Photovoltaics, including utility scale and remote applications, (F) Solar thermal, including solar water heating, (I) Fuel cells, including transportation and stationary applications, and (L) Factory-made housing.

Implementation and Deployment

Energy Efficient Lighting and Building Centers [Sec. 103]: Establish or enhance centers in each of the ten regions served by a DOE support office.

Evaluation and Planning

Report on the Potential of Cooperative Advanced Appliance Development [Sec. 127]: Prepare a research plan for the development and commercialization of appliances substantially more efficient than current law.

Evaluation of Utility Early Replacement Programs for Appliances [Sec. 128]: Evaluate and report to Congress on the energy savings and environmental benefits of programs directed toward the early replacement of older, less-efficient appliances.

Report on Global Climate Change [Sec. 1601]: Not later than 2 years after the date of enactment, the Secretary shall submit a report to Congress that includes an assessment of the feasibility and economic, energy, social, and competitive implications, including implications for jobs, of stabilizing the generation of greenhouse gases in the United States by the year 2005, achieving a 20 percent reduction in the generation of carbon dioxide from 1988 levels by 2005, and other related analyses. [EP/OPA lead, OBT Support; OBT designated lead in assessment of feasibility and economic implications of reducing the generation of greenhouse gases]

Least-Cost Energy Strategy [Sec. 1602]: Development of a least-cost strategy that increases the Nation's energy efficiency and the percentage of energy derived from renewable resources. A comprehensive inventory of available energy and energy efficiency resources and their projected costs will be included. [EP/OPA lead, OBT support]

Assessment of Alternative Policy Mechanisms for Addressing Greenhouse Gas Emissions [Sec. 1604]: Includes analysis of Federal standards for energy efficiency for major sources of greenhouse gases, including efficiency standards for appliances and buildings, incentives programs. [EP/OPA lead, OBT support]

REFERENCES

NES Technical Annex # 18: Energy Efficiency in New and Existing Buildings, Appliances, and Equipment, June 21, 1991, draft.

National Energy Strategy Interim Report, DOE/S-0066P, April 1990.

U.S. Congress. *Energy Policy Act of 1992*, Public Law 102-486, October 24, 1992.

5. ANALYSIS ACTIVITIES

This chapter presents summaries of some of the analysis activities supported by OBT during 1991 and 1992. Not all were sponsored by the Planning and Evaluation activity, but all have relevance to program planning and evaluation.

DATA AND MODELLING

OBT has long recognized the need for accurate and consistent data to support its planning and evaluation activities. Further, other parts of EE and DOE either use or collect relevant data and conduct their own analyses. The past several years have seen unprecedented effort in developing standard data and coordinating data development activities with others. This section describes some of OBT's efforts in this area.

In addition to the results presented here, OBT representatives participated in EIA's working groups to assess user data needs for its surveys of residential and commercial buildings. As a result of these efforts, both surveys have been modified. As the surveys are administered and evaluated, OBT researchers and others will benefit from the additional information collected and will be better able to address new issues and concerns as they arise.

Buildings Databook

OBT is developing a "Core Databook" containing data on all aspects of buildings energy consumption. This data set will allow OBT to quickly respond to questions from Congress, DOE management, industry groups and others, and will provide a consistent set of data to be used throughout OBT.

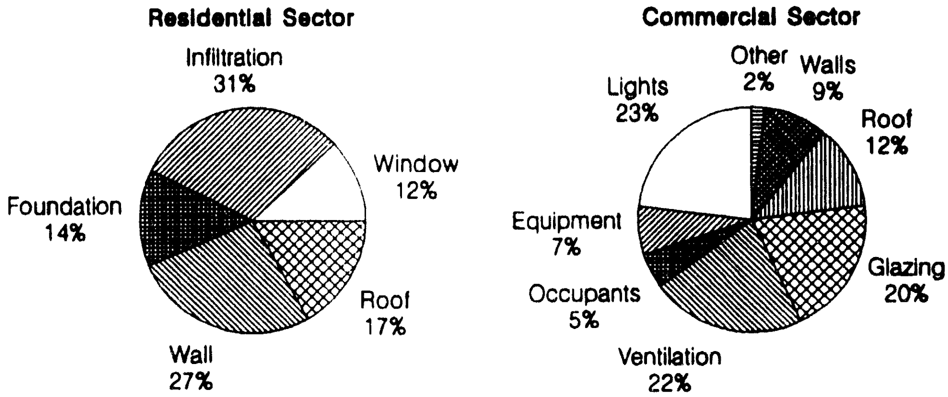
The Databook contains current information on energy consumption, building and equipment characteristics, and environmental and economic data. Sources of data include EIA surveys and forecasts, and OBT-generated data. The Databook will be updated regularly.

An example of OBT-developed data is the size of heating, ventilation, and air-conditioning (HVAC) loads in buildings, and the contributing components to these loads. These loads are intrinsic to any energy savings estimates for the building shell and equipment. OBT's Office of Building Energy Research (OBER) sponsored development of national, aggregate loads that are representative of the residential and commercial building sectors. Figure 5-1 shows building load components by percent.

Similarly, OBER supported an effort to examine energy use by end-use - heating, cooling, lighting, etc. (Belzer and Sands). Estimates of end-use consumption help to indicate the largest areas of potential energy savings for new conservation programs and initiatives. Researchers reviewed major sources of end-use estimates and examined their differences. Because energy consumption by end use is not actually measured, published estimates differ for a number of reasons, generally due to differing assumptions or statistical methods. Based on this evaluation, the researchers chose to combine the results from several sour-

Figure 5-1.

Building HVAC Loads by Component



ces to generate a consistent set of numbers that can be used throughout OBT. Partial results are shown in Figures 2-4 and 2-5 of this report.

Commercial Floorspace

Contact: Dave Belzer, PNL, (509) 372-4347

To support its commercial sector energy modeling activities, Pacific Northwest Laboratory has recently completed new estimates of historical commercial floorspace and projections of floorspace to the year 2010. Historical estimates of commercial building floorspace are essential to any evaluation of broad changes in commercial sector energy efficiency. Projected floorspace is a key element in determining the relative importance the commercial sector will have in the nation's future energy picture.

The four surveys of commercial buildings conducted by the Energy Information Administration (EIA) since 1979 have provided estimates of floorspace by building type for 1979, 1983, 1986, and 1989. Differences in sampling procedures make it difficult to make comparisons over time among the surveys. Neither EIA nor any other government agency publishes time series estimates of floorspace in the commercial sector.

Background

To support the first engineering-economic model of the commercial sector, Jerry Jackson and William Johnson at ORNL developed annual floorspace estimates for ten building types in 1978. The basic source of information for their study were the data on new additions of square footage collected by the F.W. Dodge division of McGraw-Hill. Using a perpetual inventory method, a floorspace stock was constructed from 1925 forward. Floorspace was assumed to leave the stock (demolitions) following a logistic retirement pattern with a 45-year half life (i.e. half the floorspace constructed in any year is expected to disappear from the stock in 45 years).

The first Nonresidential Building Energy Consumption Survey (NBECS) conducted by EIA in 1979 was a milestone in that it was the first comprehensive national survey of commercial buildings to be taken in the U.S.[1] EIA's estimate of 43 billion square feet as of January 1, 1980 was about 40 percent higher than the then best estimate by ORNL. The higher estimate was generally acknowledged to be largely the result of underreporting of new construction by F.W. Dodge.

In 1986, EIA sponsored SRA Technologies Corporation to construct historical floorspace estimates and to develop a methodology for forecasting future floorspace. SRA used the special demolition/conversion file created from the 1983 NBECS to construct retirement rates for six building classes and the four census regions. Using these rates, and annual vintages of floorspace as published in the 1983 NBECS, time series of floorspace were backcast from 1983 to 1960.

New Floorspace Estimates Benchmarked to 1989

The floorspace estimation procedure used by PNL combines elements of both of the above approaches. A demolition function was estimated from the special demolition/conversion file used by SRA. Additions data from F.W. Dodge were used to interpolate over time the vintage totals from the 1989 CBECS. In comparison to the SRA approach, the Dodge data were assumed to capture the year-to-year fluctuations in construction activity much better than the annual vintages totals reported by the NBECS. As in the SRA methodology, stocks for historical years were backcast from the benchmark totals in the 1989 CBECS.

The demolition function was based on a regression analysis of the observed demolition rates by vintage between 1979 and 1983. A logistic function was fitted to minimize the squared errors between predicted and actual demolition rates for five vintages: before 1900, 1901-1920, 1921-45, 1946-1960, and 1961-1979. Unfortunately, the sample size of the demolished commercial buildings was too small to allow separate functions to be estimated by building type. Accordingly, a single function was estimated for all buildings. Given the actual pattern of demolitions between 1979 and 1983, the estimated logistic function implies a considerably longer building life than previously assumed. The half-life implied by the estimated function is a little over 90 years.

The sample sizes in the NBECS/CBECS are not large enough to accurately estimate annual additions, either by building type or all buildings together. The annual construction data, by square footage, collected by F.W. Dodge were used to allocate the 1960-1989 vintage, by building type, reported in the 1989 CBECS. The reputed underestimation of the Dodge figures is not a serious weakness in this application, as long as the bias has remained fairly constant over this period. Excluding hotels, which are not part of the Dodge commercial data, total additions reported by Dodge from 1961-1989 are 29.1 billion

1 In 1989, the name of the survey was changed from the Nonresidential Buildings Energy Consumption Survey (NBECS) to the Commercial Buildings Energy Consumption Survey (CBECS).

square feet. The 1989 CBECS estimates a total of 36.1 billion square feet for the same period, for all building types excluding lodging.

For 1990, estimates of the Dodge additions data were not available for this study. To provide a preliminary stock estimate through 1990, the Dodge series were extrapolated using information on construction activity (in constant dollars) from the Bureau of Census.

With the estimated logistic function and recent floorspace additions, a historical floorspace series was then constructed. As in the SRA study, this is an iterative procedure, starting with the CBECS benchmark in 1989 and moving backwards to 1960. In general terms, the formulation employed is:

$$\text{Stock(t-1)} = \text{Stock(t)} - \text{Additions(t)} + \text{Demolitions(t)}$$

The first year of this procedure estimates the stock for 1985 (year t-1).

As mentioned above, the stock in year t (1989) is taken from CBECS. Additions are based on the F.W. Dodge information, calibrated to 1960-1989 vintage totals. Demolitions are based on the detailed stock by annual vintage from the 1986 NBECS. They are calculated by using the logistic function to calculate, in effect, the level of the stock in each vintage that would have existed one year earlier. Floorspace series were constructed for the twelve building types used in the PNL commercial sector model.

Table 5-1 shows the estimates of total commercial floorspace stock, additions, and demolitions from 1960 through 1990. As in the NBECS/CBECS, the floorspace stock are end-of-year estimates. The 1989 stock of 63,183 million square feet differs from the published CBECS figure of 63,184 million square feet due to the rounding error (stemming from the allocation of missing building type-vintage totals in the published 1989 CBECS).

The average annual growth rate from 1960 through 1990 is 2.5 percent. This estimate can be contrasted with the previous estimate by PNL made in 1989 that used essentially the same methodology with the 1986 NBECS (Energy Use and Conservation Trends: 1972-1986, PNL-6714, February 1989). In that study the 1960-1986 annual growth rate was estimated to be 2.7 percent for total floorspace. As compared to the 1986 NBECS, the 1989 CBECS estimated that older building (i.e. pre-1920) buildings comprise a higher proportion of the stock. Accordingly, new additions yield a lower growth rate of the total stock.

Table 5-2 uses the time series estimates of floorspace to calculate an overall measure of energy intensity in the commercial sector (in thousand Btu per square foot). Energy consumption is measured on a primary basis (includes electricity generation and transmission losses), as reported in EIA's 1991 State Energy Data Report. Consistent with the behavior in other end use sectors (residential and transportation) energy intensity increased markedly during the 1960s. Peak intensity was observed in 1973 at 213 KBtu/square foot.

Between 1978 and 1986, intensity fell by 7.1 percent, with most of the decline occurring in the first half of the period. Since 1986, however, the intensity has increased slightly, per-

Table 5-1.
Estimates of Total Commercial Floorspace,
Additions and Demolitions, 1960-1990
(Million Square Feet)

Year	Total Stock	Additions	Demolitions
1960	30,798		
1961	31,593	945	-150
1962	32,441	1,001	-153
1963	33,341	1,057	-157
1964	34,268	1,088	-161
1965	35,313	1,210	-165
1966	36,402	1,258	-169
1967	37,453	1,225	-174
1968	38,600	1,326	-178
1969	39,839	1,422	-183
1970	40,933	1,282	-188
1971	42,070	1,330	-193
1972	43,326	1,453	-198
1973	44,714	1,592	-203
1974	45,878	1,372	-208
1975	46,707	1,043	-214
1976	47,542	1,053	-218
1977	48,542	1,224	-224
1978	49,771	1,458	-229
1979	51,097	1,561	-235
1980	52,207	1,350	-241
1981	53,326	1,365	-246
1982	54,205	1,132	-252
1983	55,207	1,260	-258
1984	56,447	1,504	-264
1985	57,897	1,720	-270
1986	59,268	1,648	-277
1987	60,642	1,658	-284
1988	61,940	1,589	-291
1989	63,183	1,540	-298
1990	64,382	1,504	-305

Source: Pacific Northwest Laboratory, September 1991.

Total 1989 stock is benchmarked to the 1989 Commercial Building Energy Consumption Survey (CBECS), as published in Commercial Building Characteristics 1989, Energy Information Administration, DOE/EIA-0249(89), June 1991. Stock estimates are for end of year.
Additions based on new construction data from F.W.Dodge division of McGraw-Hill, Inc. F.W. Dodge data was calibrated to match vintage totals from 1989 CBECS.
Demolitions based on logistic demolition function estimated from special demolition file from the 1983 CBECS.

Table 5-2.
Commercial Floorspace, Energy Use, and Energy Intensity

Year	Total Floorspace (10^9 s.f.)	Total Energy (Quads)	Energy Intensity (KBtu/s.f.)
1960	30,798	4,749	154.2
1961	31,593	4,846	153.4
1962	32,441	5,154	158.9
1963	33,341	5,333	160.0
1964	34,268	5,531	161.4
1965	35,313	5,900	167.1
1966	36,402	6,386	175.4
1967	37,453	6,946	185.5
1968	38,600	7,361	190.7
1969	39,839	7,859	197.3
1970	40,933	8,344	203.8
1971	42,070	8,694	206.7
1972	43,326	9,166	211.6
1973	44,714	9,532	213.2
1974	45,878	9,357	204.0
1975	46,707	9,443	202.2
1976	47,542	10,019	210.7
1977	48,542	10,171	209.5
1978	49,771	10,477	210.5
1979	51,097	10.615	207.7
1980	52,207	10,586	202.8
1981	53,326	10,644	199.6
1982	54,205	10,857	200.3
1983	55,207	10,951	198.4
1984	56,447	11,413	202.2
1985	57,897	11,517	198.9
1986	59,268	11,592	195.6
1987	60,642	12,009	198.0
1988	61,940	12,642	204.1
1989	63,183	12,867	203.6

Sources:
Floorspace is described in Table 5-1.
Energy consumption data is from *State Energy Data Report, 1960-1989*, Energy Information Administration, DOE/EIQ-0214(89), May 1991.

haps in response to lower energy prices. From 1986 to 1989, overall intensity increased by 4.1 percent.

Floorspace Projections

The historical time series of floorspace can be used to develop a methodology to project future floorspace. Ideally, either floorspace or changes in floorspace would be linked to key determinants of investment--the level of activity (e.g employment, school age population, total population, etc.), interest rates, and perhaps the existence of special government programs. Separate econometric equations would be developed for each building type.

To support the 1991 baseline commercial energy projections for OBT, the approach to projecting future building stocks is much simpler than that described above. One equation is estimated to predict changes in total floorspace. Floorspace additions by building type are then based on an allocation procedure that essentially holds the shares of total additions by building type at the observed values for the 1980s. In part, this simple methodology was dictated by available time and resources for the task. However, the end result is one that is consistent with historical trends and which provides reasonable results for a long-range projection to the year 2010. Many of the short-term econometric specifications of nonresidential building investment presently used in some of the macroeconomic models would not display these long-term properties.

The first element of the projection procedure links changes in total floorspace to changes in Gross National Product. Based on the time series of total floorspace benchmarked to the 1989 CBECS, the following equation was estimated over the period 1963-1989.

$$\Delta\ln(S) = \underset{(8.3)}{0.106}\ \Delta\ln(GNP) + \underset{(45.3)}{0.861}\ [\Delta\ln(S)]_{t-1} \qquad R^2 = 0.882 \ \text{(t-statistics)}$$

The change in the logarithm of the floorspace stock (S) closely approximates the percentage change in the stock. Any change in the growth rate of GNP translates into a change in the growth of total stock. The first estimated coefficient implies, for example, that a recession that depressed the growth in GNP by 4 percent would reduce the growth in stock in the same year by nearly one half percent (4 * 0.106). The presence of the lagged (log) change in stock is derived from the assumption that any change in GNP growth would change the growth rate in stock with a time lag.

The sluggishness of the adjustment of nonresidential building investment owes largely to the long planning cycles required for large commercial projects. In addition, historically, some components of nonresidential construction have tended to be countercyclical. Table 5-3 below contrasts the behavior of total building stock and GNP during the last two severe recessions.

The R^2 of the equation suggests that this simple model captures much of cyclical behavior of net additions to the stock. The coefficients of the equation can be also be used to estimate the long-run response in the growth rate of floorspace to any step change in the growth rate of GNP. The long-run response is approximately 0.76. (This value, based on

Table 5-3.
Annual Percentage Changes in GNP and Total Floorspace
1973-1974 and 1981-1982

	1973	1974	1981	1982
GNP ($1982)	5.2	-0.6	2.2	-2.5
Total Floorspace	3.4	2.8	2.2	1.7

a "partial adjustment" specification with a lagged dependent variable, is computed as 0.106/(1.0 - 0.861). Thus, for example, if GNP is projected to grow at 2.0 per year in the coming decades, total floorspace by this model would grow at 1.5 percent per year.

The actual projection of total floorspace was based on the growth rate of GNP made by DRI, Inc. and published in the 1991 Annual Energy Outlook (Reference Case). GNP projections were published to 2000. Beyond 2000, GNP was assumed to grow at a constant 2.1 percent per year. Using the estimated equation and starting at the 1989 CBECS benchmark of 63.2 billion square feet, total floorspace was projected to rise to 77.7 billion square by 2000 and 92.2 billion square feet by 2010.

Forecasting

Contact: Jonathan Koomey, LBL, (510) 486-5974

Researchers at Lawrence Berkeley Laboratory have been compiling and documenting data for computer models that forecast energy use in residential and commercial buildings. The group has also been using these models, and the data upon which they are based, to assess the potential energy and economic savings that may accrue from policies that improve energy efficiency in buildings. These activities are summarized below under the following headings: residential baseline data, residential forecasting, residential conservation supply curves, commercial baseline data and forecasting, and consumer behavior.

Residential Baseline Data

The purpose of this activity is to compile, document, and analyze data used in forecasting models, and to store these data in a computerized form that is easily accessible to researchers. These data include unit energy consumptions for 12 end uses compiled from 65 studies, historical appliance shipments, historical appliance saturations, historical shipment-weighted efficiencies, cost versus efficiency relationships for appliances and building shells, and summaries of all current appliance efficiency standards for every end-use affected by the standards.

The database is internally documented: for each piece of data in the database, there is accompanying documentation available at the click of a button. Too often in the past it has been difficult or impossible to decipher the methods and the sources used to derive input data for forecasting models. This data compilation project has advanced the state-of-the-art and allowed easy access to LBL's extensive residential data for DOE and others.

Residential Forecasting

The information from the database described above is used in computer models that forecast residential sector energy use. These models rely upon empirically derived cost-efficiency relationships, fuel price and housing projections, and other parameters that characterize the way consumers choose the efficiency of their appliances and equipment. The models are a convenient way to organize and manipulate the detailed data necessary for assessing the effects of polices at the end-use level.

The Electric Power Research Institute's (EPRI's) REEPS model is used. It is a user friendly system that is widely accepted by forecasters in the electric utility industry. It is extremely flexible, allowing the user to change functional relationships without having to change the underlying computer code. There is currently a national model, as well as models that explicitly represent heating and cooling in the U.S. for North and South regions. The input data for the residential forecasting model are extensively documented.

Residential Conservation Supply Curves

The first part of this project assessed the technical potential for improving the efficiency of electricity use in the U.S. residential sector. This potential is expressed in terms of cost and electricity savings. The results for a given year are presented in a supply curve of conserved electricity, which has total electricity savings (TWh) on the x-axis and cost of conserved energy (/kWh) on the y-axis.

The supply curve of conserved electricity consists of roughly 300 energy conservation measures, which fall into four distinct categories:

- retrofitting of existing building shells,
- improving the thermal performance of new building shells,
- raising the efficiency of equipment and appliances as they are replaced, and
- switching from electricity to natural gas.

The vast majority of the conservation measures affect energy use in space conditioning, because of the sophistication with which building shells and equipment are analyzed. The conservation supply curves framework is somewhat more detailed than the REEPS model in characterizing building shell technologies.

The supply curve documented in Koomey et al. 1991, which estimates the technical potential for efficiency improvements, is currently being revised to reflect the latest technology data. It also serves as the basis for analysis of the achievable conservation potential. The work documented in Brown (1993) attempts to compensate for some of the limitations of the technical potential framework by adding factors to account for real-world constraints on program implementation, for program and administrative costs, and for other effects that limit potential energy savings (including persistence of savings and the "takeback" effect).

Commercial Baseline Data and Forecasting

Data and modeling is less advanced in the commercial sector than in the residential sector. This is true in part because of the heterogeneity of the commercial sector compared to the residential sector, in part because of the greater complexity of commercial buildings, and in part because most utility and government programs were first implemented for residences (and therefore estimates of the impacts of these policies were developed first for residences).

In the commercial sector, we rely on EPRI's COMMEND modeling framework. While not currently as flexible as REEPS, LBL is working with the designers of COMMEND to improve its accuracy and usefulness for policy analysis.

There are 11 building types and 10 end uses in COMMEND. The default data for lighting in all the building types have been revised, using work done by Atkinson et al. (1992), as compiled in Sezgen et al 1993b. The HVAC data for two of the building types (large and small offices) have also been revised using prototypes developed from the 1989 CBECS and other sources (Sezgen et al. 1993a).

Data development is continuing for the commercial sector, with the medium-term goals of (1) completing revisions for HVAC in all remaining building types and for office equipment, refrigeration, and water heating in all building types; and (2) creating an internally documented commercial forecasting database analogous to that for the residential sector.

Consumer Behavior/Market Failures

The forecasting group has been investigating issues of consumer choice as they relate to forecasting and policy analysis. All forecasting models embody in the algorithms used to forecast energy use some representation of how consumers make choices. The projected effects of different policies can depend critically on whether the algorithms accurately represent these choices. Sanstad et al. 1993 and Sanstad 1993 treat these issues in detail.

INTERNATIONAL ENERGY STUDIES

Contact: Lee Schipper, LBL, (510) 486-5057

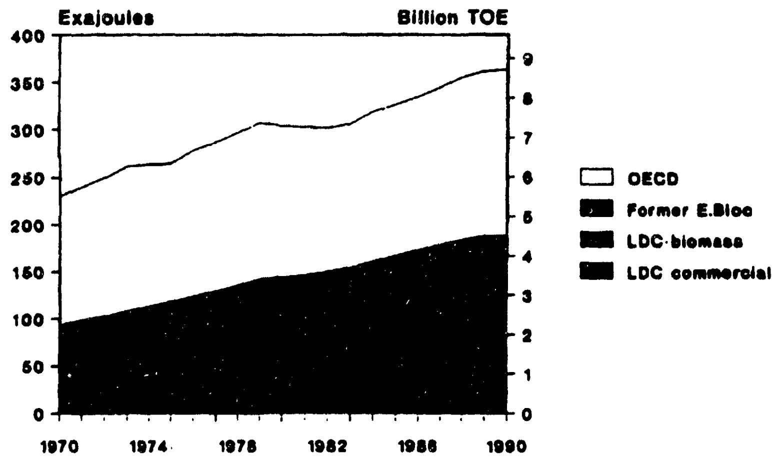
Information on technology development and the results of policies and programs outside the U.S. can expand the range of possible energy efficiency options for buildings in the U.S., and provide advance notice of export market opportunities for U.S. products and services. Tracking the progress of other industrial, developing, and transition economies toward improved efficiency and solar/renewable-based building energy systems can also provide needed perspective on global climate change mitigation strategies involving energy use. For these reasons, OBT assists in supporting analyses of energy use in other countries.

The summaries below are taken directly from the references listed at the end of this chapter.

World Energy Use

World energy use has risen by more than one-third since 1970, and grew steadily between 1983 and 1989 (Figure 5-2). The forces of activity, structural change, and energy-intensity have shaped energy use in different ways in the industrial, developing, and transitional

Figure 5-2. World Primary Energy Use



Source: Schipper and Meyers, p. 74

countries. In the industrialized countries, whose share of world energy use declined from 60 percent to 48 percent between 1970 and 1990, activity pushed moderately upward on energy demand. Structural change pushed upward on demand in passenger travel (more reliance on cars and air), freight transport (greater use of trucks), and households (more living area and appliances per person), but pushed downward in manufacturing (shift toward less energy-intensive industries).

Energy-intensities declined significantly in most areas. In manufacturing, there was considerable decline in energy-intensity in all countries, largely due to ongoing technological innovation. For automobiles, changes toward greater size and power partially offset improvement in technical energy-efficiency in Europe and Japan; intensity fell greatly in the United States, but remained above the level in other Organization for Economic Cooperation and Development (OECD) countries. Increase in size and features also balanced efficiency improvement for home appliances. In home heating, there was significant reduction in intensity in the United States, but growth in use of central heating offset improved efficiency somewhat in Europe. On average, decline in energy-intensities caused a reduction in OECD primary energy use of around 20 percent between 1973 and 1988. Since 1982, however, there has been a marked leveling off in most energy-intensities, especially in households and automobiles outside the United States.

In the developing countries, growth in energy use averaged nearly 5 percent per year between 1970 and 1990, and their share of world energy use rose from 20 percent to 31 percent. Increase in activity levels pushed strongly upward on energy use, although the pace of growth has varied among regions. Structural change also contributed to increase in energy use. In manufacturing, there has been some shift toward energy-intensive industries, especially in countries with abundant energy resources. In passenger travel, the role of automobiles has grown, and the share of trucks in freight transport has risen. In the residential sector, growth in the penetration of electric lighting and appliances contributed to rising electricity use. Change in energy-intensities is difficult to judge. In manufacturing, the largest energy-using sector, there has been decline in some countries resulting mainly from adoption of more modern processes. There are signs of some improvement in other areas as well, but in general the degree of change appears to be much less than in the OECD countries.

In the transitional countries, energy use grew at a moderate pace in 1970-1988, but has declined since as the economies struggle to reform on a new basis. Activity increased in all sectors in these countries, but there was less change than in other parts of the world in sectoral structure and energy-intensities. In manufacturing, the largest energy-use sector, there are signs of a modest decline in energy-intensity in some Soviet industries. In this and other sectors, however, the improvement in energy-efficiency was small compared to the improvement that occurred in the West.

The analysis of past trends summarized here holds many lessons for understanding how energy use may evolve in various parts of the world, and how governments might influence that evolution. Among sectors and countries, activity, structure, and energy-intensities have pushed energy use in different directions, and have been influenced by different factors. Considering these forces separately can help to illuminate more aggregate trends, and also provides a framework for evaluating the role of different forces and policies. Energy-intensities have declined in many areas due to technological innovation and explicit response to higher energy prices, but increases in the levels of service have also counteracted improvements in technical energy-efficiencies. In "producer" energy-use sectors, competition and the resulting drive to increase productivity has proven to be an important force in improving the efficiency of energy use. In "consumer" sectors, where energy costs are often not a major (or lasting) consideration, efficiency gains have been more connected to government policies and subsidies.

Many of the basic forces that shaped energy use in the 1970s and 1980s will also be at work in the 1990s, but the context in each country group and the larger global environment will be different. The 1970-1988 period was one of large increase in energy prices in much of the world. Most observers expect little growth in prices in the 1990s, except of course in the transitional countries, where the price subsidies of the past are being lifted rather quickly. On the other hand, environmental problems, including the threat of global warming, are emerging as factors that seem likely to shape energy policy, especially in the industrialized countries. In addition, rising international economic integration and the growing adoption of market-oriented economic polices throughout the world should facilitate adoption of more energy-efficient technologies. At the same time, increasing levels of activity and structural changes will push energy use upward, especially outside the OECD countries.

Energy Intensities in OECD Countries

Researchers are continuing a long-term effort to track energy use in OECD countries. In this case, energy intensities are examined in nine countries that account for about 75 percent of total OECD energy use: the United States, Japan, West Germany, France, the United Kingdom, Italy, Sweden, Norway, and Denmark. Energy intensities are evaluated in five sectors (manufacturing, passenger travel, freight transport, residential, and services) between the early 1970s and the late 1980s.

The importance of each sector in total energy use varies among the U.S., Japan, and the "Europe-7." Manufacturing accounted for 52 percent of primary energy use in Japan in 1988, but for 35 percent in Europe-7 and only 27 percent in the U.S. In contrast, the residential sector accounted for 26 percent of primary energy use in the U.S., 30 percent in Europe-7, but only 13 percent in Japan. These differences reflect the Japanese climate, the importance of manufacturing exports in the economy, lifestyle, and other factors. Passenger travel is most significant in the U.S. due to the high ownership and use of automobiles.

Between 1973 and 1989, fuel intensities fell considerably in manufacturing, air travel, residential space heating, and in the service sector. There was also a strong decrease in automobile fuel intensity in the U.S., but not in Europe and Japan. Higher energy prices, autonomous trends in technology (especially in manufacturing and air travel), and in some cases energy efficiency programs and policies caused the declines in intensities. Electricity intensity behaved rather differently, increasing in some cases (the service sector and manufacturing in some countries) or remaining relatively unchanged. An index of aggregate (primary) energy intensity based on the intensity changes in each subsector shows a decline of 14-19 percent between 1973 and 1988 in the three largest OECD countries. This was less than the decline in the ratios of energy use to GDP.

The rate of decline in energy intensities eased in the mid-1980s, in large part because energy prices fell. However, since most new technologies are less energy intensive than those in the stock, replacement or expansion of activity virtually assures a reduction in average energy intensities for many years, albeit at slower rates than in the 1973-88 period. The gap between new and stock-average intensities is partially due to policies such as thermal performance requirements for new buildings and energy efficiency standards for new household appliances, or incentives for purchase of energy-efficient equipment. However, the rate of *decline* in the energy intensity of new systems has slowed, which in turn slows the rate of decline in average energy intensities. While there are many very energy-efficient technologies on the market, their market share is relatively small. While ample evidence suggests that the potential for further cost-effective reductions in energy intensities may be as great in the 1990s as it was in the 1970s, the actual realization is well short of the potential. Accelerating the pace of intensity decline to the levels experienced in the 1973-88 period will require higher energy prices, stronger energy-efficiency policies, and a general economic environment conducive to modernization and investment.

Residential Sector Energy Use and CO_2 Emissions

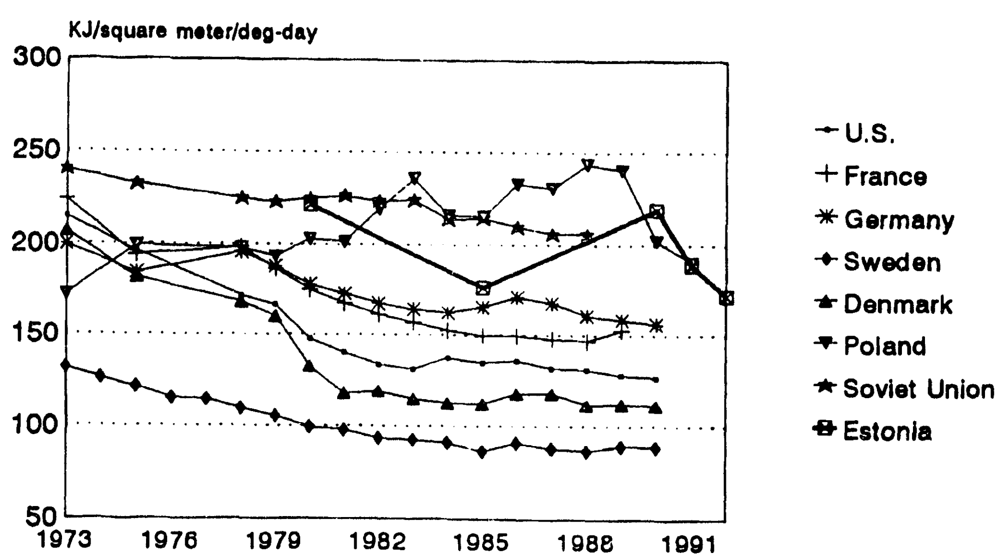
In the late 1970s and for most of the 1980s, household energy use in the OECD underwent significant changes. Many of these changes were a result of more efficient energy use, in response to higher energy prices, energy efficiency programs, and the appearance of new technologies for saving energy. Some changes occurred in response to demographic or other pressures not related to energy.

Household oil use shrank dramatically in most countries, while the rise in electricity use has slowed. The efficiency of household energy uses improved in all countries. Figure 5-3 shows this for space heating. CO_2 emissions per capita were lower in 1990 in almost all of the countries studied. Although the changes in these indicators varied widely from country to country, it appears that the goals of successive energy policies were met in most countries.

Real prices for most household energy sources stopped rising or fell after 1985. The decline in the share of oil in total energy use slowed, but did not stop or reverse significantly in most countries. Slower growth in electricity use appears to be permanent, too. However, there was a distinct slowdown in the rate of improvement of household energy use overall after 1985. And a sustained reversal of any of these changes could raise per capita CO_2 emissions from the residential sector. Hence, there is concern about the evolution of household energy use after 1985.

The level of household energy services (home size, numbers of appliances, etc.), energy efficiency, fuel mix, and power generation fuels all play an important role in determining the level of per capita CO_2 emissions. Space heating is the most important source of CO_2

Figure 5-3. U.S. and European Space Heating Intensities



emissions, but increasing electricity use for appliances and lighting is growing in importance. The U.S., Denmark, the former West Germany, and the U.K. have the highest CO_2 emissions per capita of the nine OECD countries examined; significantly, coal dominates power production in these four countries.

Per capita CO_2 emissions from residential energy use were reduced in all countries except Japan and Italy. There were many reasons for this decline. In Sweden and France, where the largest drop in per capita emissions occurred, the increased share of nuclear in power generation and increased use of electricity for space and water heating were the largest contributors. In Norway, hydro-based electricity and wood drove emissions down in this sector. In Denmark and the U.S., improved energy efficiency was the main reason for the decline. In Great Britain and Germany, reduced use of coal in homes was the predominate reason for lower CO_2 emissions.

The main source of growth in emissions from residential energy use has been electric appliances, where, in spite of important improvements in energy efficiency, the number of appliances grew so rapidly that electricity use (and subsequent emissions) were increased for these end uses. For Norway, Sweden, and France, emissions from appliances were mitigated by the supply of nuclear and hydro-electric power. In the other countries, CO_2 emissions per capita from electric appliance use grew between 1973 and 1989. Overall, population and structure effects push up the CO_2 emissions in the nine countries, and the intensity effect pushes both energy use and CO_2 emissions down in all the countries except Japan.

Transitional Economies

Concern over the release of greenhouse gases into the atmosphere, particularly those related to fossil-fuel use, has focused interest on energy use in countries that are major fuel consumers. Because of the importance of the Former Soviet Union (FSU) and Eastern European countries to the world energy balance (see Figure 5-2), future fuel-use patterns in these countries will have a major impact on global emissions of greenhouse gases, as well as the emissions of other pollutants that may have more localized effects. This section briefly summarizes efforts to understand the structure of energy use in the FSU and in Poland.

The structure of energy use in the FSU economy, with its emphasis on raw materials production, leads to a pattern of use radically different from those in the West. The low level of consumer amenities (built space per capita, automobile ownership and use, passenger travel) also contributes significantly to this important difference. When proper disaggregation of demand is made, Soviet energy-use intensities vary from being roughly on par with those in the West in a few sectors to significantly greater (i.e., less efficient) in many other sectors. The investigation shows that energy/GNP ratios or other measures of aggregate economic performance are virtually useless for analyzing the energy economy of the FSU. The problems with this indicator make it impossible to gain information about how energy efficiency has changed in the economy or how energy might be used differently in the future. Finally, increases in the level of consumer amenities could have significant upward impact on future energy demand, possibly even offsetting the downward impact of reduced raw materials production.

Based on their analysis of available data, researchers conclude that energy-use in the FSU is extremely inefficient, both in the technical sense as well as in the economic sense. International comparison suggests that the greatest inefficiency is in space heating. While there is enormous potential for improved energy-use efficiency in the FSU, that potential is presently limited by both the lack of a market-based pricing system of energy and lack of personal and institutional experience with using information, such as prices, to develop economic criteria for rationalizing energy use. Since these barriers are similar to those faced by virtually all other sectors of the economy, the energy dilemma faced by the FSU republics is in many ways embedded in the more fundamental problems of a transition to a more market-based economy and an open society. Current work is exploring what this means for those in the West who wish to provide assistance and improve energy efficiency in the FSU.

Findings in Poland are similar to those for the FSU. The industrial sector accounts for a larger share of energy use than in the West, and living space per capita and appliance ownership are low compared to Western countries. Space heating efficiency is generally very low, and electricity use in the buildings sectors is small.

As the structures of the energy-using sectors change in the transitional economies, for example to more living space per capita and greater appliance saturation, tremendous opportunities exist for improving the efficiency of energy use. Improvements depend as much on economic restructuring as on improving technologies. There are many ways in which international cooperation can assist, but this assistance should be geared to the human and social structure in these countries, and not rely too heavily on technology or programs from the West.

APPLIANCE AND BUILDING ENERGY STANDARDS

DOE is charged by legislative mandate to develop energy standards for both appliances and buildings. This responsibility resides within OBT. Although not funded through the Evaluation and Planning activity, summaries of DOE activities in these areas are provided here because understanding the energy characteristics of new buildings and appliances is essential to forecasting building energy use and planning OBT's R&D activities.

Analysis of Federal Appliance Efficiency Standards

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The Energy Policy and Conservation Act (P.L. 94-163), as amended by the National Energy Conservation Policy Act (P.L. 95-619) and by the National Appliance Energy Conservation Act of 1987 (P.L. 100-12) and by the National Appliance Energy Conservation Amendments of 1988 (P.L. 100-357), provides energy conservation standards for 12 of 13 types of consumer products[2] and authorizes the Secretary of Energy to prescribe amended or new energy standards. The Energy Policy Act of 1992 (P.L. 102-486) adds five products: (14) general service fluorescent lamps and incandescent reflector lamps; (15) showerheads; (16) faucets; (17) water closets; and (18) urinals, for which test procedures and labels will be developed. This Act sets standard levels for lamps, motors, commercial heating and cooling equipment, and commercial water heaters, and includes a schedule for possible amendments to the standards.

Initiated in 1979, LBL's assessment of the standards is designed to evaluate their economic impacts according to the legislated criteria (see the Figure below).

The economic impact analysis is performed in five major areas:

- *Engineering Analysis,* which establishes the technical feasibility and product attributes including costs of design options to improve appliance efficiency.
- *Consumer Analysis* at two levels: national aggregate impacts (forecasts) and impacts on individuals (life-cycle cost analysis). The national aggregate impacts include forecasts of appliance sales, efficiencies, energy use, and consumer expenditures. The individual impacts are analyzed by life-cycle cost, payback periods, and cost of conserved energy, which evaluate the savings in operating expenses relative to increases in purchase price.
- *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.
- *Utility Analysis* that measures the impacts of the altered energy-consumption patterns on electric utilities.
- *Environmental Analysis* that estimates changes in emissions of carbon dioxide, sulfur oxides, and nitrogen oxides, resulting from reduced energy consumption in the home and at the power plant.

This year, based on the analysis, DOE is considering possible updated standards for eight products: room air conditioners, water heaters, mobile home furnaces, direct heating equipment, kitchen ranges and ovens, pool heaters, televisions, and fluorescent light ballasts. Data collection and analysis continued for possible updated standards for refrigerators and freezers, furnaces, central air conditioners, and heat pumps.

Also completed were data collection and modeling of alternative policies for improving energy efficiency of lighting equipment in buildings, including residential and commercial applications. Results show energy and economic savings for a wide range of policies, including component standards, building codes, incentive programs (rebates and tax credits),

2 Products covered: (1) refrigerators, refrigerator-freezers, and freezers; (2) room air conditioners; (3) central air conditioners and heat pumps; (4) water heaters; (5) furnaces and boilers; (6) dishwashers; (7) clothes washers; (8) clothes dryers; (9) direct heating equipment; (10) kitchen ranges and ovens; (11) pool heaters; (12) television sets; and (13) fluorescent-lamp ballasts.

and education. The policies differ in magnitude, timing, and certainty of savings, as well as ease of enforcement and administrative burden. Further discussion of the lighting analysis can be found below.

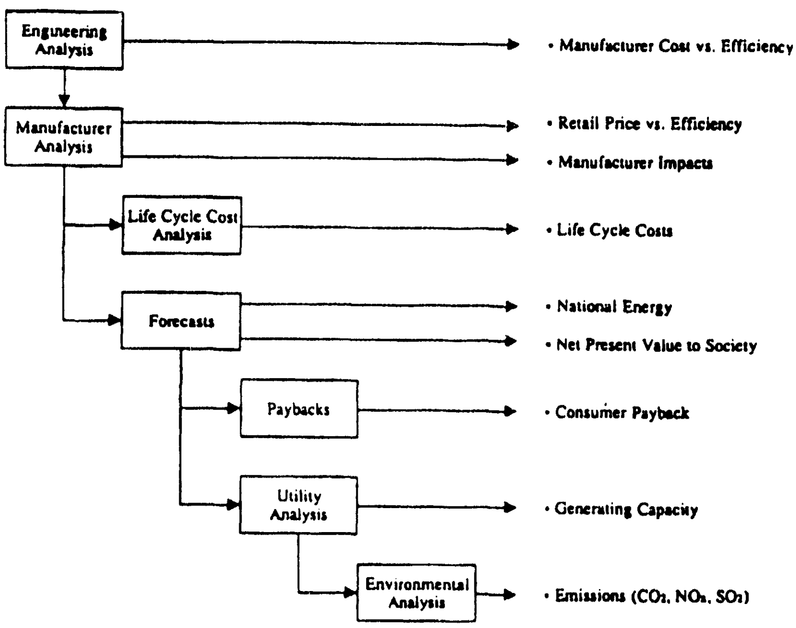
Next year's activities will include the analysis of possible energy efficiency standards for eleven products. Data collection and analysis for possible updated standards for refrigerators and freezers, furnaces, central air conditioners, and heat pumps will also continue. The Energy Policy Act of 1992 expands the appliance efficiency program at DOE to include lamps, motors, commercial heating and cooling, and commercial water heating. Analysis of these products will be performed, as directed by DOE in 1994.

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. The engineering analysis seeks to identify this cost-consumption relationship for selected appliances.

In 1992, analyses for eight products were modified: water heaters, pool heaters, direct heating equipment, mobile home heaters, fluorescent ballasts, room air conditioners, ranges/ovens, and televisions. An analysis for lighting products was reviewed and revised in 1992. The advantages and drawbacks of lighting standards and of other lighting energy-conservation policies were addressed. Engineering analyses were initiated for three products: central furnaces and boilers, refrigerators and freezers, and central air conditioners and heat pumps.

Figure 5-4
Analytic Framework for the Appliance Standards Analysis



In 1993, we completed engineering analyses for three products: central furnaces and boilers, refrigerators and freezers, and central air conditioning and heat pumps. This work involved extensive meetings with industry and government task force working groups.

The engineering analysis consists of the following steps: select appliance classes; select baseline units for each class; select design options for each class; and determine the maximum technologically feasible design, the efficiency improvement, and the cost for each option for each class. Data are obtained through contacts with trade organizations and manufacturers, from suppliers of purchased parts and materials, and from computer simulations.

In 1994 we plan to write the technical support documentation for the engineering analysis of three products: central heating, central air conditioning and heat pumps, and refrigerators and freezers. We will analyze public comments on an advance notice of proposed rulemaking on the three products. We will also respond to comments on, and revise, our report on the analysis of eight products (water heaters, pool heaters, direct heating equipment, mobile home heaters, fluorescent ballasts, room air conditioners, ranges/ovens, and televisions), after receiving review comments.

Assessing the 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 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 collected economic and financial data as inputs. Outputs include price, rate of profit, shipments, revenues, net income, and the standard errors of these estimates. LBL-MIM also provides estimates of retail prices used by the Residential Energy Model (LBL-REM) and the life-cycle cost analysis.

This year the LBL-MIM was used to perform an analysis of the impact of standards on water heaters, direct heating equipment, room air conditioners, kitchen ranges and ovens, pool heaters, mobile home furnaces, televisions, and fluorescent lamp ballasts. The results are contained in a technical support document submitted to DOE, to be published in 1994.

Data collection and preliminary analysis for the next round of products were also begun. The products considered include refrigerators and freezers, central heating equipment (furnaces and boilers), and central air conditioners and heat pumps. We have submitted questionnaires to firms, industry associations, and industry consultants; received and followed-up on data; and prepared to generate retail prices for the next steps in the analysis.

We have also reviewed an alternative analytical model for the manufacturing analysis, the Government Regulatory Impact Model (GRIM). The GRIM was a joint effort among industry trade associations (Association of Home Appliance Manufacturers, Gas Appliance Manufacturers Association, and Air-Conditioning and Refrigeration Institute) and the consulting firm Arthur D. Little. We developed a proposed method for modifying the

LBL-MIM to include GRIM for the cost analysis, but without displacing industry return on equity as the primary impact variable.

In 1994, we expect to analyze public comments on the initial eight product analysis, begin a reanalysis of the eight products based on those comments and any new data that is received, complete a preliminary analysis of the next three products, and begin the next analysis of clothes washers, clothes dryers, and dishwashers.

Building Energy Standards Program

Contact: Jeffrey A. Johnson, PNL, (509) 375-4459

The Building Energy Standards Program is conducted for the Department of Energy's Office of Codes and Standards, within the Office of Building Technology. The Energy Policy Act of 1992 (EPAct) requires that the Department of Energy support the voluntary energy standards development process, advocate the use of model energy codes, and provide technical support to states and the federal government in adopting energy efficiency standards for new buildings. The Pacific Northwest Laboratory's multidisciplinary approach provides both scientific and technology deployment strategies that advance the efficiency of new buildings through codes and standards as directed by the EPAct legislation.

The goals of the program are:

- To facilitate the construction of energy efficient, cost-effective, and environmentally sound new buildings through the application of energy efficiency codes and standards;
- To base codes and standards on the application of sound scientific principles; and
- To work with the federal government, states, code development organizations, and the buildings community to provide a path for energy efficient technologies and practices to be deployed into the design and construction process.

The Laboratory is playing an active role in supporting the building industry's development of new codes and standards. This includes supporting the development of the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) standards for new buildings, and working with Council of American Building Official's (CABO) Model Energy Code (MEC) for residential buildings. This support includes the analytical work required to develop cost-effective codes and needs assessments to determine the implementation needs at the state and local level.

The program is divided into three major areas of research and development: residential codes and standards, commercial codes and standards, and state and federal code support. The codes and standards research occurs within the residential and commercial portions of the program. Products include standards research, federal codes, and implementation materials. These products are transferred to the state and federal sectors through the support portion of the program. Activities include working with the DOE Regional Support offices, state energy offices, stakeholder organizations, and the Federal Energy Management Program.

The DOE provides an annual Report to Congress identifying the state-by-state actions taken and recommendations to improve ıe implementation of EPAct.

Commercial Buildings

Contact: Rich Quadrel, PNL, (509) 375-5933

The EPAct requires that before October 24, 1994, each State, shall "Certify to the Secretary that it has reviewed and updated the provisions of its commercial building code regarding energy efficiency." This certification must "include a demonstration that such State's code provisions meet or exceed the requirements of ASHRAE/IES Standard 90.1-89." In addition, DOE is to provide technical assistance to help States meet these EPAct requirements. In order to efficiently provide such assistance, PNL will develop a Technical Support Document (TSD) that will describe a comparative analysis to show which of the States meet or exceed ASHRAE/IES Standard 90.1-89. This analysis can then be used by the States to submit their certification reports to the Secretary of DOE. There are also several other products available that were developed with assistance from DOE and PNL that will help the States meet the mandate. These are listed below:

1. Energy Code for Commercial and High-Rise Residential Buildings (90.1 Code);

2. ASHRAE and Federal versions of Standards Compliance Software (ENVSTD and LTGSTD) and their user guides;

3. ASHRAE and Federal versions of the 90.1 Users Manual; and

4. BESP Hotline (1-800-270-CODE) and BESP Newsletter.

In addition to these products, plans are underway to develop training materials and workshops that will then be offered around the States to aid them in adopting and enforcing the State energy codes and ensure their application to building design and construction practices.

On the updating of the federal version of the Commercial Building Standards (10 CFR 435), EPACT requires that DOE issue a Federal Register Notice of Proposed Rulemaking (NOPR) by October 1994 that will be available for public review and comments. This will be done in parallel to the update and revision of the ASHRAE/IES Standard 90.1-89 that is underway. Following a specific period for review and comments and having addressed all the comments, a Final Rule will be issued in 1995/96 which will be mandatory for all commercial buildings built in the Federal sector.

Residential Buildings

Contact: Craig Conner, PNL, (509) 375-2538

The EPAct requires that before October 24, 1994, each State shall "certify to the Secretary that it has reviewed and updated the provisions of its residential building code regarding energy efficiency and made a determination as to whether it is appropriate for such State to revise such residential building code provisions to meet or exceed CABO Model Energy Code, 1992." This certification must "include a demonstration that such State's code provisions meet or exceed the requirements of ASHRAE/IES Standard 90.1-89." In addition, DOE is to provide technical assistance to help States meet the EPAct requirements. It will also support the Department of Housing and Urban Development (HUD) in implementing EPAct provisions that require the Model Energy Code to be included in HUD Minimum Property Standards (MPS). There are also several other products available that were developed with assistance from DOE and PNL that will help the States meet the mandate. These are listed below:

1. Technical Support Document (TSD) that will describe a comparative analysis to show which of the States meet or exceed the CABO Model Energy Code, 1992;

2. Implementation guides for use by HUD field offices in enforcing MPS guidelines;

3. Model Energy Code tradeoff software; and

4. BESP Hotline (1-800-270-CODE) and BESP Newsletter.

In addition to these products, plans are underway to develop training materials and workshops that will then be offered around the States to aid them in adopting and enforcing the State energy codes and ensure their application to building design and construction practices.

On the updating of the federal version of the Residential Building Standards (10 CFR 435), EPACT requires that DOE issue a Federal Register Notice of Proposed Rulemaking (NOPR) by October 1994 that will be available for public review and comment. This will be done based on the recently published ASHRAE Standard 90.2-93. Following a specific period for review and comment and having addressed all the comments, a Final Rule will be issued in 1995/96 which will be mandatory for all residential buildings built in the Federal sector.

State and Federal Code Support

Contact: Diana Shankle, PNL, (509) 372-4350

The EPAct requires that the DOE "shall provide technical assistance to States to implement the requirements of this section, and to improve and implement State residential and commercial building energy efficiency codes or to otherwise promote the design and construction of energy efficient buildings." This assistance includes providing assistance to States for certification, code advocacy and adoption, implementation, training and technical support. There will be several activities undertaken this year to fulfill these requirements including:

1. Coordination with DOE's Office of Technical and Financial Assistance and their EPAct Working Group;

2. Regional workshops at selected DOE Regional Offices for States and other stakeholder groups to discuss EPAct requirements;

3. Direct support to States in providing adoption assistance;

4. Code implementation planning materials;

5. Transfer of implementation materials produced in the Residential and Commercial portions of the program to States; and

6. Secure codes and standards information from States identifying the current status of codes.

A variety of mechanisms will be used to address the requirements of the different audiences involved in code adoption and implementation. The mechanisms will be modified as we learn from our experiences of working with the various stakeholders in the states and Federal sector. The mechanisms that will be employed during FY94 are based on the successful experiences some states have already had using them as well as building on successes the building energy standards program (BESP) has experienced during FY93.

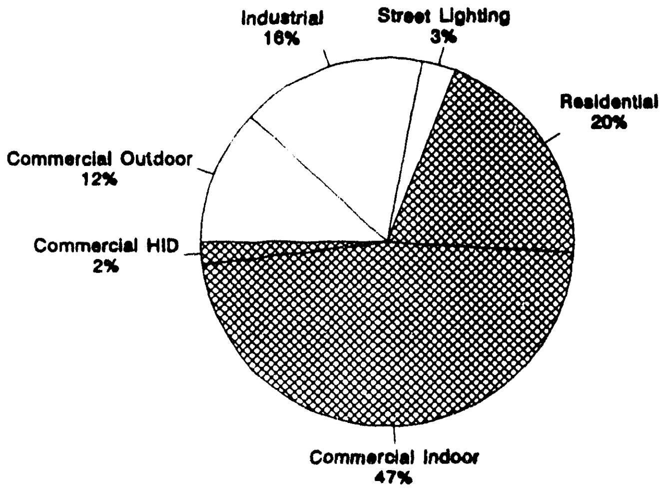
HIGHLIGHTS

Lighting

Lighting accounts for about 19 percent of all U.S. electricity use and 7 percent of total U.S. primary energy use. In 1990, consumers spent $36 billion on lighting. OBT's Office of Codes and Standards sponsored an analysis of the benefits and costs of various Federal policies designed to promote energy-efficient lighting (Atkinson, et al.). Figure 5-5 shows how lighting is used; the shaded areas indicate the end uses that were included in the analysis.

Figure 5-5.

U.S. Lighting Use, 1990



Source: Atkinson, et al.

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Types of policies evaluated in the analysis include mandatory component and system performance standards, voluntary component standards, incentives, and information programs. Eleven lamp product classes and four fixture product classes are examined for the commercial sector and four lamp product classes for the residential sector. Detailed engineering performance and life-cycle cost data are given for each technology, and national demand for lighting is modeled for eleven commercial building types and three residential building types.

A number of scenarios are modeled, including minimum life-cycle cost combinations of technologies (representing the maximum economic savings potential), and a research and development combination of technologies (representing the technical potential). Savings which would be achieved from the fluorescent and incandescent lamp standards included in the Energy Policy Act of 1992 are also modeled. Several baselines are used to measure savings due to alternative policies.

Figure 5-6 shows the range of cumulative lighting energy savings for the commercial sector by 2030. Savings from building codes are similar to those from single-component (lamp) standards. The minimum life-cycle cost combination includes the effects of the minimum life-cycle cost technologies for each component (lamps, ballasts, fixtures, controls) used in combination with the others. The research and development combination is similar, and includes the effects of technologies now in the research and development stage that could be commercialized after 1995. These combination standards have the greatest potential for savings. Figure 5-7 shows the range of possible energy savings for the residential sector.

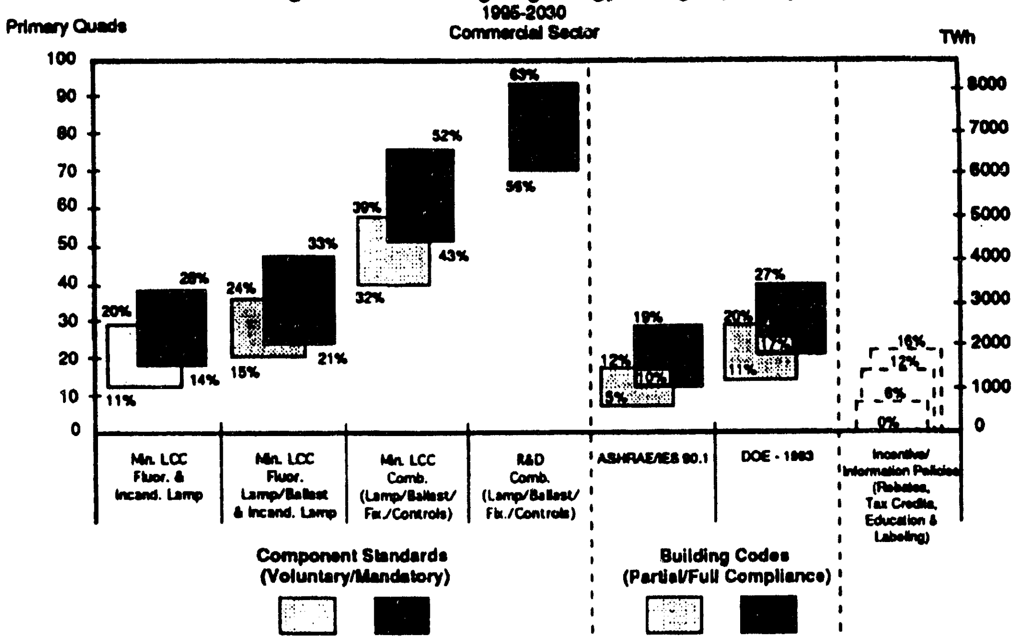
Results for both sectors show that new federal policies offer significant cost-effective opportunities for reducing lighting energy demand beyond what is currently projected to occur due to existing programs. Potential savings range from up to 15 percent for incentive/information policies to almost 65 percent for comprehensive mandatory standards. Voluntary standards achieve approximately two-thirds as much savings as do mandatory standards; economic benefits and emission reductions are also greater for mandatory standards.

Savings from the Energy Policy Act of 1992 (lamp standards) achieve one-quarter of the potential commercial energy savings from prospective comprehensive standards (the Minimum Life Cycle Cost Combination case) and one-seventh of the prospective savings for the residential sector. For the commercial and residential sectors combined, the difference in net present value for the two cases is approximately $50 billion.

New federal policies would reduce uncertainties for utilities in projecting future energy demand and for lighting equipment manufacturers in anticipating demand for their products. The policy options considered here are generally complementary; a mixture of strategies promises to be the most technically and institutionally sound approach. Continued research and development is essential for a continued supply of conservation resources.

Figure 5-6.

Range of Cumulative Lighting Energy Savings by Policy
1995-2030
Commercial Sector

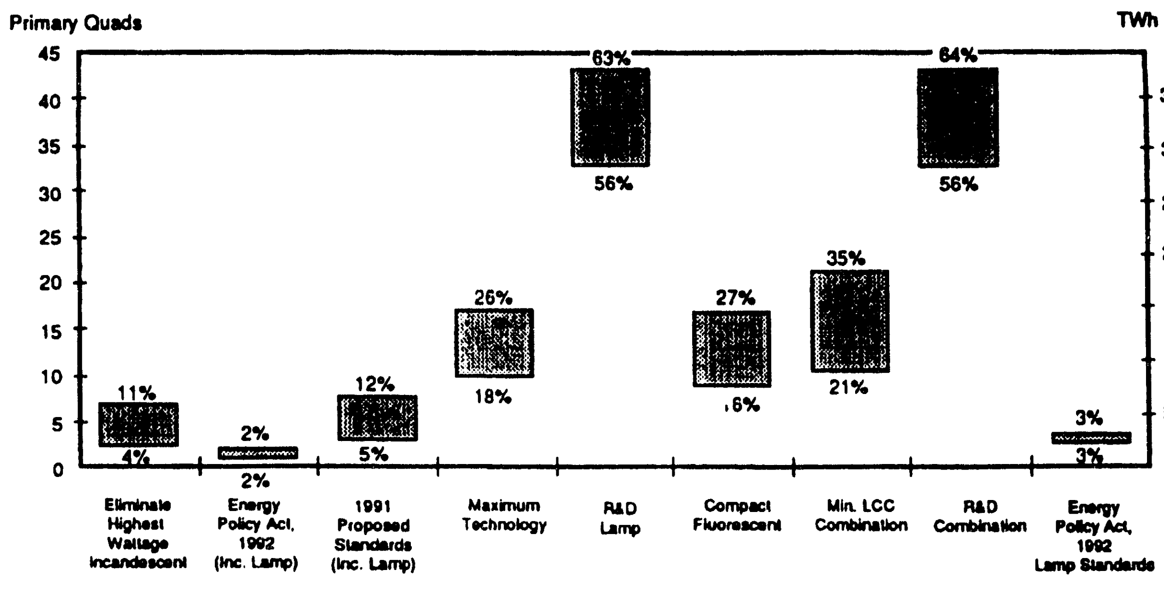


Note: Percentages are portion of respective baseline lighting energy.
Tops of bars represent savings under Low-Efficiency Baseline; bottoms of bars represent savings under High-Efficiency Baseline.

Source: Atkinson, et al.

Figure 5-7.

Range of Cumulative Lighting Energy Savings from Lamp Standards
1995 to 2030
Residential Sector



Note: Percentages are portion of respective baseline lighting energy.
Tops of bars represent savings under Frozen-Efficiency Baseline; bottoms of bars represent savings under High-Efficiency Baseline.

Source: Atkinson, et al.

Thermal Distribution

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Thermal distribution systems are the ducts or pipes that transport the heat or cooling effect from equipment to the building spaces in which it is used. The goal of this activity is to determine what is known about thermal distribution systems and to evaluate the potential for energy savings due to improvements in such systems. This work has been sponsored by the Building Equipment Division within OBT.

Andrews and Modera (1991) estimated the energy savings potential of improved efficiency of thermal distribution systems in residential and small commercial buildings. Taking into account the region, type of distribution system, and location of ducts in forced-air systems, the authors projected the amount of energy that will enter thermal distribution systems in 2020, and estimated the savings that could be achieved by improving thermal distribution efficiency. Savings of 11 to 31 percent (0.87 to 2.38 quads) can be achieved in both existing and new (built by 2020) small buildings. Most of the savings are in forced-air systems. The smaller number represents savings that can be achieved using current technologies and practices, such as reducing leaks and increasing duct insulation. Achieving greater savings requires new technology development and research to better understand the processes involved in duct losses and interactions.

In 1992, DOE sponsored a conference on thermal distribution. Researchers and representatives of the homebuilding and air distribution industries discussed research needs and possible roles for DOE and industry. Four separate panels developed research recommendations. All four panels called for development of a standardized "figure-of-merit" efficiency rating system comparable to those used for furnaces, boilers, and air conditioners. All four panels also called for efforts in education and training, and at least two panels cited the need for developing better data on housing characteristics relevant to thermal distribution and for developing design guidelines and specifications for thermal distribution systems.

Current work is developing a framework for categorizing measurement protocols and approaches to the figure of merit. One of the difficulties in developing an efficiency rating system is to account for the interactions of the distribution system with the heating/cooling equipment and with the building envelope. The relative advantages and costs of top-down measurement approaches, which evaluate overall thermal distribution efficiency, and bottom-up approaches, which measure individual loss mechanisms, are being evaluated. Particular attention is being given to distribution systems in partially conditioned spaces such as basements.

Research and Marketing

The Senate Committee on Appropriations requested in its Committee Report on the FY 1991 Appropriations for Interior and Related Agencies (P.L. 101-534) that the Department of Energy (DOE) prepare a report on the "feasibility of coupling research and marketing strategies more closely, especially for the buildings and community systems program." The report prepared in response to that request focused on OBT activities.

The goal of marketing is to know the needs of one's customers so thoroughly that the product or service fits them and sells itself. Within the Department of Energy, marketing is not a static, one-time event that occurs at some particular point in the evolution of a new technology; rather it is integrated into the process of developing a technology from concept to commercialization. The mechanisms by which the marketing of DOE research and development is conducted include cost-shared research projects with private-sector companies, ongoing cooperation with State and local government offices and organizations as well as private, public interest groups, use of industry advisory groups, cooperation with trade associations, solicitations for research and development (R&D) proposals, workshops and conferences, technical papers, technology demonstrations, operation of user facilities, market and analysis studies, and publication and dissemination of outreach information products.

R&D marketing efforts are carried out through four primary activities:

- Planning. Several programs have been using government-industry planning mechanisms for years. Others have used this marketing strategy infrequently or not at all. All the programs can benefit from increased use of industry and consumer input during the planning phase of energy R&D. The opportunities are greatest in areas where technology advances and/or increased public attention are reviving industry interest in jointly-funded activities. These include solar technologies, lighting and appliances, and indoor environment subprograms.

- Monitoring. Government and industry researchers currently do a satisfactory job of keeping each other informed about their research findings. The primary opportunity for enhanced marketing during the research monitoring stage is in the analysis of the research-in-progress to obtain insights into the direction of the findings. This opportunity is present in all the subprogram areas. A regular, structured government-industry review of research in progress could help establish a basis for later commercialization efforts.

- Cost-Sharing. By far the most beneficial coupling of research and marketing occurs through industry participation and cost-sharing in Federal research and development activities. Current strategic planning guidelines place significant emphasis on the importance of cost-sharing and industry participation, and the recent shift toward more application-oriented activities has increased the potential for attracting industry participation. Further improvement in this area of coupling can be achieved.

- Transferring. There is an effective technology transfer program, with activities tailored to the particular needs of each of the end-use sectors. These efforts can be expanded in direct proportion to the availability of funding for such activities, with a high probability that even greater benefits will accrue. One area of technology transfer that could be expanded, especially within the Buildings research program, relates to consumer (end-user) education. Achieving a better understanding of consumer decision processes, and providing the educational information necessary to increase awareness of the benefits associated with energy efficiency, could substantially improve the ultimate marketability of Federally funded research results.

Program Review

In 1992, the Building Energy Efficiency Program Review (BEEPR) Group was organized to review and recommend improvements to OBT's research and development program. The BEEPR Group included representatives from industry, utilities, universities, national laboratories and government.

The Group found much to praise in OBT's program, particularly in the development of a number of new technologies and tools. The Group also felt that OBT has been less successful in stimulating large-scale changes in building energy efficiency. To that end, the program needs to work more closely with the building industry and needs to expand its efforts to educate building decision-makers.

The review identified three key themes that could serve as a new foundation for the OBT program. These are:

- Making Energy Efficiency Happen. Promote the implementation of, and stimulate the market for, cost-effective energy efficiency and renewable energy measures and practices.
- Creating New Technology Options. Develop new technologies and tools through the close involvement and cooperation of the building industry.
- Educating Energy Professionals. Place greater emphasis on education and training for energy efficiency professionals.

Reviewers also identified 13 major initiatives developed around these three themes, and recommended increased funding to support these activities.

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APPENDIX. DATA TABLES

U.S. Primary Energy Consumption, by Sector, 1960–1991
(Trillion Btu)

Year	Residential	Commercial	Industry	Transportation	Total
1960	8,284.0	4,749.2	20,162.9	10,598.5	43,794.6
1961	8,582.1	4,845.5	20,253.0	10,774.6	44,455.2
1962	9,102.3	5,153.8	21,049.6	11,224.9	46,530.6
1963	9,366.6	5,332.5	21,984.0	11,658.6	48,341.7
1964	9,684.4	5,530.6	23,292.5	11,999.4	50,506.9
1965	10,118.8	5,900.4	24,243.6	12,434.0	52,696.8
1966	10,654.0	6,385.7	25,527.9	13,102.8	55,670.4
1967	11,142.4	6,945.5	25,754.7	13,748.6	57,591.2
1968	11,864.7	7,360.6	26,915.2	14,859.1	60,999.6
1969	12,716.7	7,858.5	28,101.4	15,497.4	64,174.0
1970	13,310.0	8,344.2	28,593.4	16,086.5	66,334.1
1971	13,841.8	8,693.8	28,534.8	16,718.1	67,788.5
1972	14,528.6	9,166.4	29,871.4	17,708.9	71,275.3
1973	14,642.2	9,532.0	31,570.1	18,607.1	74,351.4
1974	14,361.5	9,356.7	30,693.7	18,115.6	72,527.5
1975	14,453.6	9,442.9	28,428.6	18,244.2	70,569.3
1976	15,008.4	10,019.4	30,263.7	19,100.9	74,392.4
1977	15,214.1	10,171.4	31,111.0	19,820.7	76,317.2
1978	15,625.7	10,476.5	31,442.7	20,613.5	78,158.4
1979	15,196.6	10,615.0	32,635.7	20,473.0	78,920.3
1980	15,069.3	10,586.1	30,635.0	19,694.9	75,985.3
1981	14,606.2	10,644.2	29,264.0	19,508.0	74,022.4
1982	14,736.8	10,857.4	26,141.1	19,071.0	70,806.3
1983	14,654.6	10,950.6	25,745.9	19,135.0	70,486.1
1984	14,963.9	11,452.3	27,855.3	19,801.2	74,072.7
1985	15,193.4	11,530.8	27,261.3	20,068.3	74,053.8
1986	15,182.9	11,644.4	26,648.8	20,813.5	74,289.6
1987	15,541.5	12,026.1	27,821.4	21,451.0	76,840.0
1988	16,320.5	12,614.3	29,028.0	22,306.6	80,269.4
1989	16,563.2	12,834.6	29,357.1	22,561.9	81,316.8
1990	15,888.5	12,815.3	29,901.5	22,537.3	81,142.6
1991	16,377.2	13,019.8	29,600.7	22,121.2	81,118.9

Source: State Energy Data Report 1991, Energy Information Administration, DOE/EIA 0214(91), May 1993.

Residential Energy Consumption Estimates, 1960–1991 (Trillion Btu)

Year	Fuel Type: Coal	Fuel Type: Natural Gas	Fuel Type: Oil	Fuel Type: Electricity	Net Energy	Electrical System Energy Losses	Total
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	8,582.1
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	4,843.2	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	1,337.1	2,661.7	8,766.1	6,197.8	14,963.9
1985	69.3	4,566.1	1,483.4	2,708.9	8,827.7	6,365.7	15,193.4
1986	69.2	4,432.3	1,456.7	2,794.7	8,752.9	6,430.0	15,182.9
1987	65.6	4,435.7	1,508.5	2,901.6	8,911.5	6,630.0	15,541.5
1988	65.9	4,757.4	1,562.8	3,046.5	9,432.6	6,887.9	16,320.5
1989	58.3	4,925.4	1,559.6	3,089.7	9,632.8	6,930.4	16,563.2
1990	61.9	4,518.7	1,266.3	3,152.8	8,999.6	6,888.9	15,888.5
1991	56.3	4,685.0	1,293.4	3,259.9	9,294.5	7,082.7	16,377.2

Source: State Energy Data Report 1991, Energy Information Administration, DOE/EIA 0214(91), May 1993.

Commercial Energy Consumption Estimates, 1960–1991 (Trillion Btu)

Year	Fuel Type: Coal	Natural Gas	Oil	Electricity	Net Energy	Electrical System Energy Losses	Total
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	3,452.8	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	859.1	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	2,918.1	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	5,947.1	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	5,868.0	4,989.4	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	1,198.1	2,266.7	6,185.3	5,279.0	11,452.3
1985	107.2	2,503.3	1,038.9	2,352.4	6,001.9	5,528.9	11,530.8
1986	107.0	2,382.6	1,098.6	2,440.4	6,028.7	5,615.8	11,644.4
1987	99.4	2,499.1	1,078.4	2,541.5	6,218.4	5,807.7	12,026.1
1988	102.3	2,743.7	1,036.9	2,677.4	6,560.4	6,053.9	12,614.3
1989	87.7	2,799.5	965.7	2,769.3	6,622.2	6,212.5	12,834.6
1990	92.9	2,698.1	906.8	2,862.3	6,560.1	6,255.1	12,815.3
1991	84.5	2,808.5	861.0	2,920.4	6,674.3	6,345.5	13,019.8

Source: State Energy Data Report 1991, Energy Information Administration, DOE/EIA 0214(91), May 1993.

Residential Sector Primary Energy Consumption per Household, 1960 – 1991

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	2,398.7	45.4	8,284.0	156.9
1961	53.6	6,066.1	113.2	2,515.9	46.9	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	6,464.4	116.9	2,902.3	52.5	9,366.6	169.4
1964	56.2	6,546.7	116.5	3,137.8	55.8	9,684.4	172.3
1965	57.4	6,753.9	117.7	3,364.9	58.6	10,118.8	176.3
1966	58.4	6,976.9	119.5	3,677.0	63.0	10,654.0	182.4
1967	59.2	7,207.8	121.8	3,934.7	66.5	11,142.4	188.2
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	7,861.2	124.0	5,448.9	85.9	13,310.0	209.9
1971	64.8	8,014.0	123.7	5,827.8	89.9	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	7,930.9	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	205.5
1975	71.1	7,603.7	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	7,693.0	103.8	7,521.2	101.5	15,214.1	205.3
1978	76.1	2,704.5	35.5	7,934.3	104.3	15,625.7	205.3
1979	77.3	7,239.6	93.7	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	82.6	6,265.7	75.9	8,340.5	101.0	14,606.2	176.8
1982	83.5	6,267.4	75.1	8,469.4	101.4	14,736.8	176.5
1983	84.3	5,952.5	70.6	8,702.0	103.2	14,654.6	173.8
1984	86.0	6,104.4	71.0	8,859.5	103.0	14,963.9	174.0
1985	86.8	6,118.8	70.5	9,074.6	104.5	15,193.4	175.0
1986	88.8	5,958.1	67.1	9,224.7	103.9	15,182.9	171.0
1987	90.0	6,009.8	66.8	9,531.6	105.9	15,541.5	172.7
1988	91.5	6,386.1	69.8	9,934.4	108.6	16,320.5	178.4
1989	92.8	6,543.3	70.5	10,020.1	108.0	16,563.2	178.5
1990	93.3	5,846.9	62.7	10,041.7	107.6	15,888.5	170.3
1991	94.3	4,741.3	50.3	10,342.6	109.7	16,377.2	173.7

Sources: State Energy Data Report
Statistical Abstract of the United States

Residential Sector Energy Prices, 1970–1991
(Current Dollars Per Million Btu)

Year	Coal	Natural Gas	Distillate Fuel	Kerosene	LPG	Electricity *	Average
1970	1.13	1.06	1.39	1.54	2.12	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	8.77	9.10	21.66	11.14
1986	3.11	5.67	6.35	7.14	8.57	21.75	10.99
1987	2.76	5.39	6.05	6.61	8.64	21.82	10.95
1988	2.64	5.32	6.11	6.74	8.45	21.92	10.90
1989	2.67	5.47	6.76	7.36	10.38	22.41	11.26
1990	3.01	5.63	8.01	8.86	10.94	22.96	12.14
1991	3.09	5.66	7.65	8.44	10.94	23.57	12.34

* Electricity converted at 3,412 Btu per kWh.

Source: State Energy Price and Expenditure Report 1991, DOE/EIA–0376, September 1993, and earlier editions.

Commercial Sector Energy Prices, 1970–1991
(Current Dollars Per Million Btu)

Year	Coal	Natural Gas	Distillate Fuel	Kerosene	LPG	Motor Gasoline	Residual Fuel	Electricity*	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	6.94	8.59	9.01	4.50	21.31	11.71
1986	1.66	4.94	4.59	5.90	8.22	6.77	2.70	21.10	11.35
1987	1.54	4.64	4.52	5.69	7.67	7.22	3.11	20.45	11.05
1988	1.54	4.51	4.33	4.72	7.80	7.33	2.53	20.34	10.90
1989	1.54	4.61	5.10	5.55	7.33	8.03	2.93	20.77	11.38
1990	1.61	4.70	6.10	6.75	8.61	9.15	3.41	21.20	12.03
1991	1.56	4.69	5.60	6.03	9.02	8.98	2.61	21.73	12.21

* Electricity converted at 3,412 Btu per kWh.

Source: State Energy Price and Expenditure Report 1991, DOE/EIA–0376(91), September 1993, and earlier editions.

Value of New Construction, 1970–1991
(million current $)

	Residential	Commercial	Total	Percent of GDP
1970	36,969	34,250	71,219	7.05
1971	49,650	36,207	85,857	
1972	61,567	38,830	100,397	
1973	66,026	45,109	111,135	
1974	56,973	49,226	106,199	
1975	52,936	46,684	99,620	6.28
1976	69,535	46,335	115,870	
1977	93,482	48,402	141,884	
1978	111,221	59,090	170,311	
1979	118,100	73,325	191,425	7.69
1980	102,364	82,008	184,372	6.81
1981	101,588	91,491	193,079	6.37
1982	86,953	96,571	183,524	5.83
1983	127,459	92,907	220,366	6.47
1984	156,500	112,084	268,584	7.11
1985	161,367	130,620	291,987	7.23
1986	190,177	128,832	319,009	7.47
1987	197,924	114,160	312,084	6.87
1988	201,393	122,177	323,570	6.60
1989	199,992	128,708	328,700	6.27
1990	186,634	134,499	321,133	5.82
1991	161,672	119,146	280,818	4.95

Source: Value of New Construction Put In Place, U.S. Department of Commerce, Current Construction Reports, C30–9105, May 1993.
GDP: 1992 Statistical Abstract Table 673

Notes: Value of new construction does not include expenditures for public utilities, highways and streets, or water supply facilities.
New construction includes additions, alterations, and major replacements, as well as some types of equipment.

Residential Property Expenditures
1985 to 1990
(Millions of Current Dollars)

	Total Expenditure	Maintenance & Repairs	Improvements			
			Total	Structural Alterations	Non-Building Alterations	Major Replacements
All Property Types						
1990	106,773	51,305	55,468	30,481	6,771	18,215
1989	100,891	42,689	58,202	29,957	9,828	18,415
1988	101,117	40,885	60,232	34,036	9,303	16,893
1987	94,082	38,229	55,853	31,198	8,779	15,875
1986	91,274	35,971	55,303	28,569	10,040	16,695
1985	80,267	35,358	44,909	21,565	7,211	16,134
All Owner Occupied Properties						
1990	63,287	22,850	40,463	24,454	5,350	10,632
1989	62,838	19,886	42,952	24,100	8,573	10,278
1988	65,445	19,918	45,527	27,563	8,091	9,873
1987	58,094	18,374	39,720	24,486	7,513	7,721
1986	57,722	17,506	40,216	22,868	8,350	8,999
1985	50,810	17,475	33,335	16,932	6,515	9,887
All Rental Properties						
1990	43,487	28,454	15,032	6,028	1,421	7,584
1989	38,053	22,803	15,250	5,857	1,255	8,137
1988	35,672	20,967	14,705	6,473	1,213	7,019
1987	35,992	19,856	16,136	6,714	1,267	8,155
1986	33,551	18,465	15,087	5,701	1,689	7,697
1985	29,457	17,883	11,574	4,632	695	6,247

Sources: U.S. Bureau of the Census, Current Construction Reports, Expenditures for Residential Improvements and Repairs Second Quarter 1990, C50−90Q2

U.S. Bureau of the Census, Current Construction Reports, Expenditures for Residential Improvements and Repairs Fourth Quarter 1990, C50−90Q4

Regional Residential Property Expenditures
1986 to 1990
(Millions of Current Dollars)

Year & Region	Total Expenditures	Maintenance & Repairs	Total Improvements
1990			
All Regions	106,773	51,305	55,468
Northeast	26,039	12,731	13,309
Midwest	23,757	10,676	13,081
South	29,141	13,853	15,288
West	27,835	14,045	13,791
1989			
All Regions	100,891	42,690	58,201
Northeast	28,883	12,981	15,901
Midwest	21,643	8,160	13,483
South	26,607	12,220	14,388
West	23,759	9,330	14,429
1988			
All Regions	101,117	40,885	60,232
Northeast	31,022	12,478	18,545
Midwest	21,352	8,301	13,051
South	27,101	12,870	14,231
West	21,642	7,237	14,405
1987			
All Regions	94,082	33,932	52,147
Northeast	25,737	10,448	14,179
Midwest	21,178	7,447	12,193
South	30,061	9,545	16,789
West	17,111	6,493	8,986
1986			
All Regions	91,274	35,970	55,302
Northeast	25,688	9,571	16,116
Midwest	18,594	7,543	11,050
South	29,215	10,712	18,502
West	17,778	8,145	9,635

Source:
U.S. Bureau of the Census, Current Construction Reports Fourth Quarter 1990, C50–9OQ4 and Second Quarter 1990, C50–90Q2.

Energy Consumption in U.S. Households, 1990

Characteristics	Total Households (mil.)	Residential Buildings: Total Number (million)	Residential Buildings: Total Floorspace (bill. sq.ft.)	Consumption (1): per Building (million Btu)	Consumption (1): per Square Foot (thous. Btu)	Consumption (1): per Household (mill. Btu)	Consumption (1): per Household Member (mill. Btu)
Total U.S. Households	94.0	74.2	169.2	124	54	98.1	38
Urban Status							
Urban	72.9	54.6	131.8	132	55	99.2	38
Rural	21.1	19.6	37.4	102	53	94.2	35
Climate Zone (2)							
Under 2,000 CDD and Over 7,000 HDD	10.1	8.3	21.0	136	53	110.6	45
5,500 to 7,000 HDD	26.7	21.2	54.5	155	60	123.3	47
4,000 to 5,499 HDD	20.9	16.3	39.3	131	54	101.6	39
Under 4,000 HDD	19.3	14.8	28.6	95	49	72.9	28
2,000 CDD or More and Under 4,000 HDD	17.0	13.7	25.7	93	50	75.2	28
Type of Housing Unit							
Single-Family	64.4	64.4	140.9	111	51	110.9	39
Mobile Home	5.2	5.2	4.9	78	83	78.0	29
Multifamily	24.4	4.6	23.5	364	71	68.5	34
Heated Floorspace (sq.ft.)							
Fewer than 1,000	30.6	16.1	24.4	121	80	63.6	30
1,000 to 1,999	39.1	34.9	66.4	111	58	98.5	36
2,000 to 2,999	16.9	15.9	45.9	133	46	125.2	42
3,000 or More	7.4	7.3	32.5	180	40	176.4	59
Ownership of Unit							
Owned	62.3	58.9	135.8	117	51	110.5	41
Rented	31.7	15.2	33.4	153	70	73.7	31
Public Housing	2.5	0.6	2.1	254	66	57.4	24
Not Public Housing	29.2	14.7	31.3	150	70	75.1	31
Year of Construction							
1939 or Before	21.5	16.7	40.8	153	63	119.7	47
1940 to 1949	7.0	6.1	11.6	122	64	105.2	41
1950 to 1959	13.4	11.9	24.7	123	59	109.5	43
1960 to 1969	14.8	11.4	26.2	124	54	95.4	39
1970 to 1979	21.4	15.3	36.3	119	50	85.1	32
1980 to 1984	8.0	6.2	13.6	93	42	71.9	26
1985 to 1987	5.1	4.1	9.2	83	37	67.6	26
1988 to 1990 (3)	2.8	2.5	6.9	114	42	103.1	35
Household Size							
1 Person	23.4	15.1	31.1	110	53	71.1	71
2 Persons	30.6	24.0	57.0	124	52	97.6	49
3 to 5 Persons	36.4	31.9	74.0	130	56	113.6	30
6 or More Persons	3.6	3.2	7.2	134	60	119.7	18

1) Energy sources are electricity, natural gas, fuel oil, kerosene, and liquefied petroleum gas.
2) Climate zones are based on annual degree-days that are averaged over 30 years from 1951 to 1980.
3) Does not include all new construction for 1990.
Source: Residential Energy Consumption Survey, DOE/EIA-0321(90), February 1993.

Commercial Buildings 1989, by Census Region
Number of Buildings (Thousands)

	U.S.	Northeast	Midwest	South	West
All Buildings	4,528	783	1,046	1,847	851
Activity					
Assembly	615	96	134	275	109
Education	284	38	54	108	84
Food Sales	102	Q	Q	45	Q
Food Services	241	54	59	87	41
Health Care	80	12	21	30	17
Lodging	140	21	24	50	44
Mercantile/Service	1,278	259	303	523	193
Office	679	108	139	275	157
Parking Garage	45	16	13	7	8
Public Order & Safety	50	Q	Q	Q	Q
Warehouse	618	95	177	243	104
Other	62	12	8	29	14
Vacant	333	45	82	158	49
Year constructed					
1899 & Before	172	58	50	47	Q
1901 to 1919	242	67	86	51	38
1921 to 1945	680	170	156	238	116
1946 to 1959	868	159	195	354	159
1960 to 1969	821	114	210	318	179
1970 to 1979	884	109	191	404	181
1980 to 1983	317	31	55	161	70
1984 to 1986	329	38	56	181	55
1987 to 1989	215	37	46	94	37
Energy Sources					
Electricity	4,297	751	1,001	1,726	819
Natural Gas	2,439	358	737	815	530
Fuel Oil	586	305	90	158	33
District Heating	105	30	16	35	23
District Chilled Water	25	1	3	14	7
Propane	348	85	76	146	42
Other	130	31	34	53	Q

Q = Data withheld.
Source: Commercial Buildings Characteristics 1989. DOE/EIA-0246(89).

Commercial Buildings 1989, by Census Region
Floorspace (Million Square Feet)

	U.S.	Northeast	Midwest	South	West
All Buildings	63,184	13,569	15,955	22,040	11,620
Activity					
Assembly	6,838	1,507	1,408	2,750	1,174
Education	8,148	1,888	2,221	2,404	1,634
Food Sales	792	Q	Q	278	Q
Food Services	1,167	284	339	370	173
Health Care	2,054	378	912	472	292
Lodging	3,476	549	982	1,215	730
Mercantile/Service	12,365	2,647	3,059	4,778	1,882
Office	11,802	2,703	2,281	3,817	3,001
Parking Garage	983	160	384	245	194
Public Order & Safety	616	Q	Q	Q	Q
Warehouse	9,253	1,811	2,639	3,422	1,381
Other	1,529	161	178	821	369
Vacant	4,161	905	1,349	1,326	581
Year constructed					
1899 & Before	1,654	743	445	308	Q
1900 to 1919	4,245	1,408	1,602	628	606
1920 to 1945	8,098	2,574	2,401	2,250	873
1946 to 1959	10,511	2,196	2,250	4,089	1,975
1960 to 1969	12,167	2,736	3,286	4,057	2,089
1970 to 1979	13,329	2,030	3,160	5,217	2,923
1980 to 1983	4,274	439	893	1,926	1,015
1984 to 1986	5,670	849	1,218	2,437	1,166
1987 to 1989	3,235	593	700	1,127	816
Energy Sources					
Electricity	61,587	13,326	15,710	21,233	11,318
Natural Gas	41,593	8,583	12,923	11,883	8,205
Fuel Oil	12,684	5,158	3,261	2,852	1,412
District Heat	6,856	2,356	1,546	1,694	1,259
District Chilled Water	2,101	407	318	911	465
Propane	4,695	1,073	1,061	1,738	Q
Other	1,542	370	552	456	Q

Q = Data withheld.
Source: Commercial Buildings Characteristics 1989. DOE/EIA-0246(89).

Commercial Buildings Energy Consumption for 1989, 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
All Buildings	4,528	63,184	5,788	2,773	2,073	357	585
Region							
Northeast	783	13,569	1,354	586	353	237	179
Midwest	1,046	15,955	1,659	609	831	61	159
South	1,847	22,039	1,648	975	498	50	126
West	851	11,620	1,126	604	391	Q	121
Year Constructed							
1899 or before	172	1,624	128	25	53	17	Q
1900 – 1919	242	4,245	239	75	123	26	15
1920 – 1945	680	8,098	636	211	244	69	Q
1946 – 1959	868	10,511	988	379	411	77	Q
1960 – 1969	821	12,167	1,275	589	458	73	156
1970 – 1979	884	13,329	1,342	730	441	61	110
1980 – 1983	317	4,274	432	295	117	10	Q
1984 – 1986	329	5,670	464	303	141	Q	Q
1987 – 1989	215	3,235	284	167	85	Q	Q
Principal Activity	617	6,909	441	186	174	31	49
Assembly	282	8,076	704	217	323	71	Q
Education	102	792	139	105	27	Q	Q
Food Sales	241	1,167	255	113	128	Q	Q
Food Service	80	2,054	449	154	186	17	92
Health Care	140	3,476	425	138	187	10	Q
Lodging	1,278	12,365	1,048	550	417	75	Q
Mercantile/Service	679	11,802	1,230	781	238	43	167
Office	50	616	78	29	25	Q	Q
Public Order/Safety	618	9,253	536	243	206	53	Q
Warehouse	107	2,511	386	219	102	Q	Q
Other	333	4,161	98	39	49	Q	Q
Vacant							

Q = data withheld.

* End–use electricity converted at 3,412 Btu per kWh.

Source: NBECS: Commercial Buildings Energy Consumption and Expenditures 1989, DOE/EIA–0318(89).

Commercial Buildings Energy Expenditures for 1989, 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
All Buildings	4,528	63,184	70,826	55,943	9,205	1,822	3,857
Region							
Northeast	783	13,569	17,505	13,188	1,807	1,225	1,287
Midwest	1,046	15,955	16,468	11,697	3,381	310	1,081
South	1,847	22,039	21,759	18,409	2,293	241	816
West	851	11,620	15,093	12,649	1,724	Q	Q
Year Constructed							
1899 or before	172	1 654	1,214	603	270	96	Q
1900 – 1919	242	4,245	2,448	1,676	527	138	107
1920 – 1945	680	8,098	7,033	4,776	1,135	377	Q
1946 – 1959	868	10,511	10,334	7,333	1,809	404	788
1960 – 1969	821	12,167	14,894	11,667	1,975	349	903
1970 – 1979	884	13,329	17,807	14,815	1,939	288	766
1980 – 1983	317	4,274	6,194	5,570	502	50	Q
1984 – 1986	329	5,670	7,184	6,363	665	26	Q
1987 – 1989	215	3,235	3,718	3,143	382	Q	Q
Principal Activity							
Assembly	617	6,909	5,986	4,648	809	180	349
Education	282	8,076	6,589	4,391	1,309	331	Q
Food Sales	102	792	2,163	1,992	137	Q	Q
Food Service	241	1,167	3,282	2,520	675	Q	Q
Health Care	80	2,054	4,052	2,670	712	72	Q
Lodging	140	3,476	4,014	2,593	818	52	Q
Mercantile/Service	1,278	12,365	13,527	11,116	1,931	430	Q
Office	679	11,802	18,323	15,757	1,128	232	1,207
Public Order/Safety	50	616	875	582	120	Q	Q
Warehouse	618	9,253	6,085	4,836	853	234	Q
Other	107	2,512	4,709	3,915	420	Q	Q
Vacant	333	4,161	1,218	924	237	Q	Q

Q = data withheld.
Source: NBECS: Commercial Buildings Energy Consumption and Expenditures 1989, DOE/EIA–0318(89).

Electricity Consumption in Commercial Buildings, 1989

	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	4,294	61,563	813	189	13.2	2,217	43,532	661	15.2
Region									
Northeast	751	13,326	172	288	12.9	446	10,052	143	14.2
Midwest	1,001	15,704	178	178	11.4	482	11,040	151	13.7
South	1,723	21,215	286	166	13.5	942	15,179	239	15.7
West	819	11,318	177	216	15.6	347	7,262	129	17.8
Building Floorspace									
1,001 – 5,000	2,360	6,409	95	40	14.9	999	2,777	60	21.6
5,001 – 10,000	855	6,297	72	84	11.5	468	3,469	53	15.3
10,001 – 25,000	622	9,989	112	180	11.2	406	6,649	89	13.4
25,001 – 50,000	243	8,671	97	399	11.2	176	6,309	79	12.5
50,001 – 100,000	125	8,918	127	1,018	14.2	94	6,707	108	16.1
100,001 – 200,00	60	8,222	113	1,884	13.8	49	6,768	94	14
200,001 – 500,00	23	6,996	107	4,617	15.3	17	5,103	95	18.6
Over 500,00	7	6,062	89	12,681	14.7	7	5,751	85	14.8
Principal Activity									
Assembly	614	6,851	55	89	8.0	263	4,086	42	10.3
Education	282	8,070	64	225	7.9	167	6,122	52	8.5
Food Sales	102	792	31	302	39.0	69	662	28	42.3
Food Service	241	1,167	33	137	28.3	164	935	25	26.7
Health Care	80	2,054	45	565	22.0	35	1,642	39	23.8
Lodging	140	3,476	40	289	11.6	94	2,834	35	12.4
Mercantile/Service	1,276	12,361	161	126	13.0	604	7,948	119	15.0
Office	679	11,796	229	337	19.4	384	9,291	193	20.8
Public Order/Safety	50	608	8	168	13.8	19	473	7	14.8
Warehouse	543	8,850	71	131	8.0	274	6,202	58	9.4
Other	107	2,511	64	1,074	43.8	64	1,720	4	2.3
Vacant	182	3,027	11	63	3.8	81	1,618	9	5.6

Q = data withheld.

Source: NBECS. Commercial Buildings Energy Consumption and Expenditures 1989, DOE/EIA–0318(89).

Commercial Lighting Equipment as of 1989
Number of Buildings
(thousands)

	All Buildings	All Lit Buildings	Lighting Equipment Used (Solely or in Combination): Incandescent Bulbs	Fluorescent Lamps	High-Intensity Discharge Lamps	Other Lighting	High Efficiency Ballasts
All Buildings	4,528	4,269	2,404	3,920	456	24	1,074
Region							
Northeast	783	748	460	686	98	Q	234
Midwest	1,046	987	602	907	123	Q	255
South	1,847	1,718	876	1,572	146	Q	363
West	851	816	466	755	90	Q	222
Year Constructed							
1919 & Before	414	379	297	338	Q	Q	20
1920 to 1959	1,548	1,446	870	1,301	130	Q	292
1960 to 1969	821	773	435	729	68	Q	213
1970 to 1979	884	851	435	790	88	Q	218
1980 to 1983	317	305	127	283	54	Q	98
1894 to 1987	329	315	149	288	45	Q	109
1987 to 1989	215	200	91	190	38	Q	94
Principal Activity							
Assembly	615	612	472	512	78	Q	115
Education	284	284	136	274	41	Q	101
Food Sales	102	102	47	102	Q	Q	28
Food Services	241	241	182	228	23	Q	61
Health Care	80	80	50	78	13	Q	28
Lodging	140	140	130	121	7	Q	31
Merc/Service	1,287	1,275	598	1,237	124	Q	337
Office	679	679	375	663	46	Q	217
Parking Garage	45	45	19	37	12	NC	10
Public Order & Safety	50	50	27	48	Q	NC	Q
Warehouse	618	538	256	430	79	NC	78
Other	62	62	28	52	16	Q	20
Vacant	333	162	83	137	Q	NC	35

NC = No Cases in Sample.
Q = Data withheld.
Source: NBECS: Commercial Buildings Characteristics 1989, DOE/EIA-0246(89).

Commercial Buildings 1989
Heat Production Equipment
Number of Buildings
(1000)

			Heat Production Equipment Used				
	All Buildings	All Heated Buildings	Boilers	Warm-Air Furnaces	Individual Space Heaters or Electric Baseboards	Packaged Heating Units	Air-Source Heat Pumps
All Buildings	4,528	3,877	704	1,619	1,389	859	453
Census Region							
Northeast	783	711	276	322	220	65	59
Midwest	1,046	920	195	527	330	125	30
South	1,847	1,512	131	503	592	456	238
West	851	734	101	267	248	212	127
Year Constructed							
1899 or before	172	154	50	72	69	Q	Q
1900 - 1919	242	204	62	85	81	22	15
1920 - 1945	680	585	167	255	225	72	35
1946 - 1959	868	758	162	352	283	134	59
1960 - 1969	821	686	113	307	220	166	63
1970 - 1979	884	771	87	291	289	223	93
1980 - 1983	317	267	21	91	94	93	52
1984 - 1986	329	277	18	99	84	97	73
1987 - 1989	215	174	25	68	45	31	45
Principal Activity							
Assembly	615	589	130	264	212	123	71
Education	284	279	106	73	69	69	24
Food Sales	102	89	Q	45	Q	33	Q
Food Service	241	228	32	95	42	73	Q
Health Care	80	75	17	27	22	14	18
Lodging	140	134	45	38	67	22	12
Mercantile/Service	1,278	1,219	158	582	513	226	too
Office	679	663	122	280	169	176	122
Public Order/Safety	50	50	16	Q	21	Q	Q
Warehouse	618	340	32	122	176	72	49
Other	107	74	13	16	33	12	Q
Vacant	333	137	19	47	52	33	13

Q = data withheld.

Source: NBECS: Commercial Buildings Characteristics 1989, DOE/EIA-0246(89).

Commercial Building Shell Conservation Features
Number of Buildings
(thousands)

	All Buildings	Buildings With Shell Conservation Features: Any Building Shell Conservation Features	Roof or Ceiling Insulation	Wall Insulation	Storm or Multiple Glazing	Tinted or Reflective Shading Glass or Film	Exterior or Interior Shadings or Awnings	Weather Stripping or Caulking
All Buildings	4,528	3,819	3,057	2,026	1,440	944	1,473	2,774
Region								
Northeast	783	664	521	363	360	86	241	501
Midwest	1,046	890	715	521	492	178	298	694
South	1,847	1,551	1,269	807	428	448	633	1,100
West	851	714	551	334	160	232	301	479
Year Constructed								
1919 & Before	414	323	203	106	172	49	125	210
1920 to 1959	1,548	1,239	916	487	408	214	451	865
1960 to 1969	821	697	549	337	221	154	274	493
1970 to 1979	884	778	672	480	277	252	306	578
1980 to 1983	317	286	253	220	118	92	106	231
1894 to 1987	329	303	272	239	138	114	127	237
1987 to 1989	215	193	181	157	105	70	84	162
Principal Activity								
Assembly	615	555	426	274	243	155	160	421
Education	284	268	221	136	76	64	136	205
Food Sales	102	87	73	54	38	Q	27	62
Food Services	241	224	186	127	108	60	125	176
Health Care	80	78	63	48	45	21	39	59
Lodging	140	132	100	73	56	25	72	119
Merc/Service	1,278	1,084	873	559	363	220	407	730
Office	679	657	559	422	327	240	309	508
Parking Garage	45	34	24	Q	Q	Q	Q	23
Public Order & Safety	50	42	32	16	14	Q	13	34
Warehouse	618	382	288	175	78	79	101	240
Other	62	52	41	29	16	16	14	42
Vacant	333	225	171	101	68	31	63	154

Q = Data withheld.

Source: NBECS: Commercial Buildings Characteristics 1989, DOE/EIA–0246(89).

Energy Management for Commercial Buildings in 1989
Number of Buildings
(thousands)

	All Buildings	Computerized Energy Managment and Control Systems					
		All Buildings	H.V.A.C Controls	Lighting Controls	Other Controls	Regular H.V.A.C Maintenance	Participated in Utility Sponsored Conservation Program
All Buildings	4,528	264	251	51	32	2,102	324
Region							
Northeast	783	44	43	9	6	455	101
Midwest	1,046	63	60	6	8	460	58
South	1,847	85	81	15	9	756	66
West	851	73	68	21	8	430	99
Year Constructed							
1919 & Before	414	Q	Q	Q	Q	159	Q
1920 to 1959	1,548	52	52	Q	Q	647	137
1960 to 1969	821	56	53	10	9	398	69
1970 to 1979	884	55	50	15	13	460	66
1980 to 1983	317	23	20	9	Q	162	19
1894 to 1987	329	33	33	5	Q	167	18
1987 to 1989	215	31	29	8	Q	109	7
Principal Activity							
Assembly	615	36	35	Q	Q	328	54
Education	284	53	53	6	9	230	60
Food Sales	102	Q	Q	Q	Q	51	Q
Food Services	241	21	21	Q	Q	133	Q
Health Care	80	7	7	Q	Q	46	6
Lodging	140	to	9	Q	Q	104	16
Merc/Service	1,278	43	35	10	10	511	70
Office	679	62	59	15	4	411	65
Parking Garage	45	Q	Q	Q	NC	7	Q
Public Order & Safety	50	Q	Q	Q	NC	24	Q
Warehouse	618	9	9	Q	Q	170	19
Other	62	7	7	Q	Q	34	Q
Vacant	333	Q	Q	Q	NC	53	Q

NC = No Cases in Sample.
Q = Data withheld.
Source: NBECS: Commercial Buildings Characteristics 1989, DOE/EIA–0246(89).

1990 Estimates of Commercial End-Use Energy Consumption (QBtu)

End Use	Site Electric	Natural Gas	Dist. Fuel	Other Fuels	Site Total	Site %	Primary Electric	Primary Total	Primary %
Space Heat	0.52	1.80	0.45		2.77	39.1%	1.66	3.91	29.1%
Space Cooling	0.73	0.21			0.94	13.3%	2.33	2.54	18.9%
Lighting	1.14				1.14	16.1%	3.63	3.63	27.0%
Water Heat	0.040	0.519	0.147		0.71	10.0%	0.127	0.79	5.9%
Pool Heat		0.135			0.14	1.9%		0.14	1.0%
Refrigeration	0.227				0.23	3.2%	0.723	0.72	5.4%
Vending Machines	0.102				0.10	1.4%	0.325	0.32	2.4%
Water Coolers	0.033				0.03	0.5%	0.105	0.11	0.8%
Cooking	0.013	0.289			0.30	4.3%	0.041	0.33	2.5%
Laundry	0.076	0.122			0.20	2.8%	0.242	0.36	2.7%
Office Equipment	0.007				0.01	0.1%	0.022	0.02	0.2%
Electronics	0.013				0.01	0.2%	0.041	0.04	0.3%
Unallocated				0.52	0.52	7.3%		0.52	3.9%
TOTAL	2.90	3.08	0.60	0.52	7.09	100.0%	9.24	13.43	100.0%

Table Notes:
Other Fuels include residual fuel oil, LPG, coal, motor gasoline, and kerosene.
Source: Office of Building Technologies

1990 Estimates of Residential End-Use Energy Consumption (QBtu)

	Site Electric	Natural Gas	Fuel Oil	LPG	Kero-sene	Wood	Site Total	Site %	Primary		
									Electric	Total	%
Space Heat	0.48	2.86	1.00	0.19	0.07	0.58	5.18	50.5%	1.53	6.23	36.3%
Space Cooling	0.40						0.40	3.9%	1.27	1.27	7.4%
Lighting	0.41						0.41	4.0%	1.31	1.31	7.6%
Water Heat	0.58	1.57	0.14	0.06			2.34	22.9%	1.86	3.62	21.1%
Pool Heaters		0.05					0.05	0.4%		0.05	0.3%
Refrigeration	0.43						0.43	4.2%	1.37	1.37	8.0%
Freezers	0.12						0.12	1.2%	0.39	0.39	2.3%
Range	0.10	0.24					0.34	3.3%	0.32	0.56	3.3%
Oven	0.11	0.20					0.31	3.0%	0.35	0.55	3.2%
Microwave	0.06						0.06	0.5%	0.18	0.18	1.0%
Washer	0.03						0.03	0.3%	0.08	0.08	0.5%
Dryer	0.15	0.05					0.20	2.0%	0.48	0.53	3.1%
Dishwasher	0.02						0.02	0.2%	0.08	0.08	0.5%
Miscellaneous	0.19	0.08					0.27	2.6%	0.60	0.68	4.0%
Television	0.07						0.07	0.7%	0.22	0.22	1.3%
Unallocated				0.03			0.03	0.3%		0.03	0.2%
TOTAL	3.15	5.04	1.14	0.28	0.07	0.58	10.25	100.0%	10.04	17.14	100.0%

Source: Office of Building Technologies

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