AN OVERVIEW OF THE BUILDING ENERGY RETROFIT RESEARCH PROGRAM

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ABSTRACT

A relatively new program of the U.S. Department of Energy has been established to focus on the technical, financial, and behavioral barriers to improving the energy efficiency of existing buildings through retrofit. The program is organized by the three building sectors (single-family, multi-family, and commercial) and is implemented with expertise from four national laboratories, Princeton University, and the Alliance to Save Energy in cooperation with a large number of state, utility, and local agencies. This paper summarizes the objectives, approach, and accomplishments of the program.

INTRODUCTION

The Office of Buildings and Community Systems (OBCS) of the U.S. Department of Energy (DOE) directs a variety of programs to support public and private efforts to increase energy efficiency of the nation's buildings and communities. One of these programs, Building Energy Retrofit Research (BERR) within the Building Services Division, focuses on the technical, financial, and behavioral issues that require resolution to increase the use of retrofits that improve the energy efficiency of existing buildings. The BERR program is divided into three building sectors: single-family (SF) and commercial building research led by Oak Ridge National Labora- [illegible] include Princeton University, the Solar Energy Research Institute, the Alliance to Save Energy (ASE), and Pacific Northwest Laboratory.

The program was formally established in December 1984, and the private sector participated in identifying and assessing the barriers to energy conserving retrofit measures and the areas in which DOE sponsored research could be effective (1-4). The program has maintained active participation of the building retrofit "industry" in planning, reviewing, and conducting research and is looking for opportunities to expand and broaden this involvement. This overview paper describes the scope and approach of the program, examples of current projects, major accomplishments, and types of industry involvement as a means to encourage inquiry and additional cooperative efforts.

WHY FOCUS ON EXISTING BUILDINGS?

The largest potential for energy savings in the next 10-15 years is in retrofit measures that improve the energy efficiency of existing buildings. There is a large stock of buildings, they are much less efficient than they should be, and replacement with new buildings is very slow. Table 1 shows the distribution of residential households in the various building types as of November 1982. About three-fourths of the total households are in single-family attached, detached, and mobile homes, which can be categorized as "single-family" with respect to occupant and building characteristics that affect energy use. About 15 percent of the households are in multi-family buildings, and the remaining 10 percent are in two to four unit buildings. These exhibit technical characteristics of single-family and institutional issues of multi-family.

For this program, "commercial" is considered to be any building that is not residential, industrial, or agricultural. About four million commercial buildings are estimated to exist in the United States (Table 1). Although the great majority of the number of buildings (about 95 percent) have less than 50,000 ft^2 of floor area, the total commercial building floor area of approximately 50 billion ft^2 is divided about evenly between those smaller than 50,000 ft^2 and those of larger floor area.

Replacement of existing buildings is slow, and they will remain a significant part of the stock for the next 30-40 years. It is estimated that the stock [illegible] million (89 percent) of the 1985 stock will still exist in 2010. The 1985 residential stock will be over half the total for the next 40 years, and many buildings built after 1985 will be candidates for energy conserving retrofits during that period. For commercial buildings, 83 percent of the 1985 stock is expected to exist in 2010 and will represent over half the total stock for the next 30 years.

Table 1. Stock of existing buildings by type as of November 1982

Residential Households (millions)	
SF[a] detached	53.8
SF[a] attached	3.9
Mobile homes	3.7
2-4 units	10.1
5 and more units	12.2
Total	83.7
Commercial	
Number of buildings	4.0 million
Floor area	50.0 billion sq ft

[a]SF = single family.

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Overall, the remaining potential for energy savings from cost effective retrofit measures is still impressive. Results are shown in Table 2 of an estimate of potential annual energy savings from retrofit of the envelope and mechanical equipment to reduce energy used for heating, air conditioning, and domestic water heating in residential buildings (SF and MF). Because mechanical equipment retrofit includes the replacement of water heaters and HVAC systems with more efficient units, which is much more economical when systems need repair, these savings might require a 20 year period to be realized. At a linear implementation rate, this would amount to 17 Q energy end-use saved over 20 years, which is equivalent to an energy cost saving of $173 billion (1982 dollars): an average $8.7 billion per year saving during implementation and $17 billion per year thereafter (1).

End use energy consumption in the commercial sector was about 5.9 Q/yr in 1984 (11.3 Q/yr primary energy) which represented an expenditure of almost $70 billion/yr. Estimates indicate that $15-20 billion/yr (2.5-3.5 Q/yr primary) might be saved in commercial buildings through full penetration of energy retrofits with paybacks of 3 years or less.

Table 2. Total annual U.S. energy use subject to retrofit in residential buildings and remaining savings potential

Function	Annual residential energy use (Q/year)[a]		Potential for annual savings (Q/year)[a]	
	End use	Primary	End use	
Space heating	3.5	4.9	Shell retrofit	0.2
			Mech. retrofit	0.9
Space cooling	0.7	2.1	Shell retrofit	0.01
			Mech. retrofit	0.2
DHW[b] heating	1.3	2.2	Insulation	0.09
			Mech. retrofit	0.26
Total	5.5	9.2		1.7

[a]1 Quad (Q) - 10^{15} Btu.
[b]DHW - Domestic hot water.

BARRIERS TO RETROFIT

Private, utility, and government agency activities, coupled with sharp increases in fuel costs, have been modestly successful in implementing energy conserving measures in single-family homes. However, there is still a large potential for energy and dollar savings in this sector, and there has been much less accomplished in the multi-family and commercial sectors.

There are a variety of barriers that must be addressed if marked improvements are to be made in the rate of adoption of energy conserving measures Private sector actions and market mechanisms alone have had limited effectiveness. Factors that limit achievable energy savings include:

- Neither owners nor occupants have financial incentives to retrofit rented buildings.
- Retrofit investments are risky because energy savings are less than expected on average and essentially unpredictable for individual buildings.
- The recent reductions in natural gas and fuel oil prices have reduced interest in conservation.
- Most conservation programs apply cold climate retrofit measures to the building envelope without realizing potential benefits from mechanical system retrofits, measures especially appropriate for hot climates, and operation and maintenance improvements.

The second item listed above ranked as one of the highest priority research needs for each of the building sectors and was especially appropriate for DOE activities. The performance of individual and combined energy-conserving retrofits and their effect on the performance of heating and cooling systems, comfort conditions, and occupant behavior are areas that have seen little systematic research. Most programs in the private sector are based either on results of computer simulations or on rules of thumb developed over years. Some of the retrofits work; others do not. Average energy savings of a large sample of retrofit homes is generally lower than that predicted by audits. Figure 1 shows a comparison of actual average savings (estimated from billing data) to predicted savings for three programs involving several hundred homes each. Actual savings range from 58 percent to 70 percent with an average of 64 percent of predicted values. This difference could be acceptable and planned for in state or utility conservation programs in which retrofit incentives are provided and the main interest is in overall performance of the program. However, comparison of actual to predicted energy savings for individual homes in any one sample, as shown in Figure 2, shows a wide range of scatter and only a slight correlation (r-0.33). About 20 percent of the homes

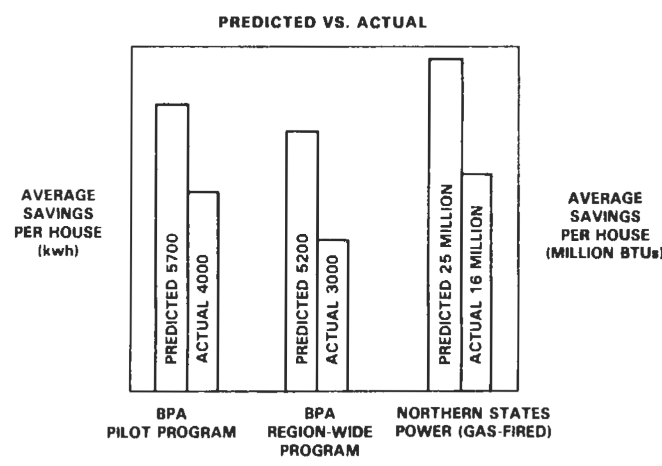

Fig. 1 Average single-family retrofit savings compared to predicted values

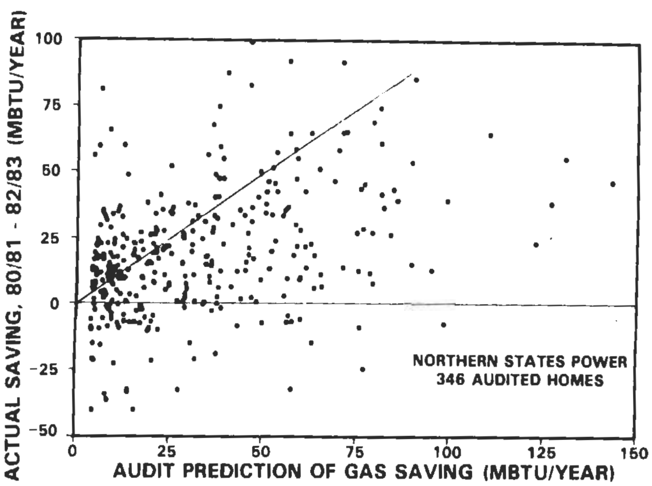

Fig. 2 Comparison of actual and predicted retrofit savings for individual homes

had zero or negative savings and less than half would fit within ±50 percent of the predicted values. The lack of expected savings and large uncertainty in retrofit performance has been identified as a barrier to other potential investors.

There are at least two approaches for addressing this uncertainty of benefits from investment in retrofit:

1. Retrofit proponents (states, utilities, shared savings firms, contractors, etc.) could share in the risks and/or savings of the investment in order to get significant participation of owners and/or occupants.

2. Reduce risk by completing research required to provide the private sector with knowledge and predictive tools to confidently select and install appropriate retrofits.

The DOE has selected the latter approach as the long term program goal and is currently focusing on the following technical objectives:

- Provide reliable data on retrofit performance and means of collecting such data.

- Maintain national capability for analyzing and updating retrofit performance data.

- Measure and analyze the influence of human and other factors on the effectiveness of retrofits and post-retrofit O&M.

- Make the results of retrofit research widely available to the building industry in active technology transfer activities.

The following sections summarize major accomplishments to date for each building sector.

SINGLE-FAMILY RETROFIT RESEARCH

MONITORING PROTOCOL

One high priority project area was "Improved Field Performance Monitoring Methods and Systems" to improve and standardize field data acquisition methods, instrumentation, and data handling so that retrofit performance monitoring can be carried out efficiently and yield comparable results from project to project. A Data Specification Guideline (5) was developed to identify the minimum data set required to measure energy savings of retrofit measures with corrections for changes in indoor temperature, weather, and internal heat gain. Optional data sets were also included to address additional issues. Activities were initiated with the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and the American Society for Testing and Materials (ASTM) to address broader issues related to monitoring protocols.

MANUALS AND GUIDES TO AID MECHANICAL RETROFITS

The ASE developed detailed manuals for natural gas heating systems (6) and for oil heating systems (7) that would serve as guides to inspecting existing systems, analyzing their efficiencies, and installing appropriate retrofits. They are intended for use by contractors, auditors, state energy office personnel, and utility staff members. These manuals have been used at training seminars and as "how-to" guides in the field. A "Warm Room Manual" to suggest ways to heat only a portion of a home's living space has also been published.

A guide for evaluation of gas heating system retrofit programs (8) was developed to provide detailed guidance for identification of households, screening for data quality, assignment of households to retrofit or control groups, assembling cost data, weather data, and pre and post retrofit fuel use data, and data analysis. As the ASE gas heating retrofit program for low-income households has been adopted in pilot programs in various states, this evaluation guide was made available to state agencies to help validate program savings. The guide was followed in evaluation of two state programs.

COOPERATIVE FIELD MONITORING PROJECT

The project was completed in Wisconsin to determine the combined energy savings of building envelope and mechanical heating system retrofits installed according to a newly developed audit procedure. The audit determined the most cost-effective combination of building envelope and mechanical heating system retrofits for a group of houses. Different retrofits were selected for individual houses and different amounts of money were spent in each house, although an average expenditure per house was maintained for the group. To provide results in a timely fashion and to reduce costs, new field measurement and analysis methods were developed: pre-retrofit data were collected during the first half of the winter and post-retrofit data were collected during the second half. The results show that larger average energy savings at a lower average cost can be achieved by an optimized combination of envelope and heating system retrofits than just envelope retrofits installed according to a "priority list." On the average, $2200 was spent per house under the 1982 Wisconsin Low-Income Weatherization Assistance Program to achieve 100 therms of energy savings per year. Using the audit and expanded retrofit options, only $1600 was spent per house to obtain approximately 200 therms of energy savings per year. The audit procedure selected a very different pattern of retrofits than normally installed following a "priority list." Wall insulation and replacement condensing furnaces were the principle retrofits selected most often. Participants in the project included DOE, ORNL, ASE, the State of Wisconsin, Wisconsin Power and Light, Wisconsin Gas, and Madison Gas and Electric.

SHORT TERM BUILDING ENERGY MONITORING

Monitoring techniques have been developed and field tested to reduce the cost and time required for measuring retrofit performance. The Wisconsin field monitoring project demonstrated the feasibility of measuring pre- and post-retrofit energy use in one winter season with weekly meter readings. The Building Energy Vector Analysis procedure (9) was also field tested in Wisconsin. BEVA uses a few days of hourly data with co-heating to measure the overall thermal integrity (or UA value) of the building envelope and the change due to retrofit. A users' guide for BEVA is in preparation.

SF RETROFITS FOR HOT CLIMATES

Most early retrofit programs emphasized space heating measures that were more appropriate for cold climates than warm ones. A recent report (10) identified conservation measures that would be appropriate for hot humid climates. The effectiveness of each of six shell retrofit measures and of replacing the air conditioner with a high-efficiency unit was analyzed using a building simulation model (DOE-2.1B) for a prototype ranch-style house. During the cooling season, the measure producing the greatest energy savings is the replacement air conditioner, but the measure is cost effective only if the existing unit needs major repair or replacement. A subsequent study outlined a pilot program for electric system retrofit in the South. Findings of this study were presented at an "Electric Retrofit Roundtable" co-sponsored by ASE and Edison Electric Institute.

RADIANT BARRIER RESEARCH

A major component of summer heat gain and winter heat loss in single-family housing is that which occurs through the ceiling. DOE and the Tennessee Valley Authority (TVA) jointly funded tests of a low-cost, easily installed material that promises significant reduction in ceiling heat transfer and in cooling and heating energy requirements. This material, an aluminum foil product with two reflective surfaces, reduces the radiant component of heat transfer between the ceiling (and its insulation) and the underside of the roof.

The ORNL experiments on radiant barriers were conducted in three unoccupied houses. One was used as the control house with no barrier, while the other two houses were used to test two different methods for installing radiant barriers. In one house, the radiant barrier was laid on top of the attic fiberglass batt insulation, and in the other house, the barrier was attached to the underside of the roof truss. The attics of all three houses were insulated with kraft paper faced R-19 fiberglass batt insulation. The result for a summer test (11) showed a cooling energy savings of 17 percent when the radiant barrier was laid on top of ceiling insulation and 9 percent with the radiant barrier attached to the underside of the roof trusses. The winter test with the radiant barrier showed that the horizontal barrier was able to save space heating energy amounting to 10 percent. The roof truss radiant barrier increased consumption by about 3 percent. Preliminary estimates indicate a potential for 0.2 Quads primary energy savings annually if installed in the 22 million southern homes.

MULTI-FAMILY RETORFIT RESEARCH

MONITORING PROTOCOL

A protocol was developed to provide a standardized set of procedures for monitoring the performance of retrofit measures in MF buildings. The draft protocol was tested in field tests in Chicago and Minneapolis/St. Paul and experience gained was incorporated into the final protocol (12). A primary goal for the protocol work is the development of ASTM and ASHRAE standards for building monitoring.

RETROFIT MONITORING

Monitoring was initiated to evaluate the installation and performance of specific retrofits in occupied buildings, the effects of building operation and maintenance, and potential health and safety hazards associated with the retrofits. An important aspect of this research is collaboration with local groups and agencies, which currently includes the San Francisco Public Housing Authority, the Center for Neighborhood Technology in Chicago, the Energy Resource Center in St. Paul, the Minneapolis Energy Office, and the Minnesota Department of Energy and Economic Development. These groups provide buildings to be retrofit, coordinate field activities, assist in maintaining data collection, and frequently provide data from parallel measurements.

The buildings range from seven units to 26 units, and are two or three stories high. The buildings are all heated by natural gas, with different distribution systems, including individual space heaters, central boilers with single-pipe steam, and central boilers with hot water distribution systems. The buildings have flat roofs, with various combinations of attic insulation and venting. The domestic hot water is provided by gas-fired central boilers, with both pumped loop and demand distribution systems. Four of the buildings are managed by a public housing authority, two are cooperatively owned, and the rest are tenant occupied. The buildings are all between forty and sixty years old, and are representative of a significant fraction of the multi-family building stock in their areas.

The retrofits to these buildings involve changes to the building shell, the heating system, and the domestic hot water system. The shell measures include insulating and sealing attics and adding storm windows. Heating system retrofits include adding vent dampers, new air vents to the steam radiators and distribution lines, furnace derating, boiler tune-up, new steam cycle controllers, outdoor cut-outs, new high-efficiency boilers, front-end boilers, and steam to hot water conversions. The retrofits to the domestic hot water systems include new high-efficiency boilers and active solar systems. Descriptions of these retrofits are given in Ref. 13.

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NEW DIAGNOSTIC TECHNIQUES

Techniques included the development of a short-term diagnostic test to understand the characteristics of the building shell and mechanical systems. The first diagnostic demonstration project focused on a one-week investigation of a 7 unit apartment building in Minneapolis, working in conjunction with the Minneapolis Energy Office. Simultaneous measurements with six blower doors were used to investigate air leakage in the apartments both between units and to the outside. The building's original steam boiler was evaluated to quantify energy losses, and a short-term measurement using tracer-gas was made of a vent damper retrofit installed on the boiler (14).

The air leakage diagnostic procedures were further tested in apartment buildings in Massachusetts, California, and Illinois. The tests have been simplified so that only two blower doors are needed, but the measurement procedure is still fairly complex. Data from these tests have been used to calculate the infiltration rates for the apartment buildings, which have shown the different ventilation patterns for different sides of the building and the different stories (15-16).

OCCUPANT BEHAVIOR SURVEYS

Surveys were conducted to determine effects of behavior on retrofit performance in multi-family buildings in California and Illinois. Forty-eight households in low-income apartments in San Francisco were interviewed about their energy and hot water consumption. Data from these surveys were used in a model to predict hot-water consumption that was in close agreement with the measured hot-water consumption (17). Residents in two Chicago apartment buildings were surveyed about their behavior relating to ventilation and energy use, and this information was used to understand the large temperature variations occurring in the different apartments. Such findings are useful in adjusting the central heating system so that apartments can be heated more uniformly and the system operated more efficiently (18).

ANALYSIS OF RETROFIT PERFORMANCE FROM UTILITY BILLING DATA

Performance analysis and information on building characteristics and retrofit strategy was completed for over forty public housing projects. The study shows the energy savings and cost-effectiveness of the conservation retrofits. Particular indicators include resource energy savings, the cost of conserved energy, and the internal rate of return (19).

Baseline energy use was analyzed for over 40,000 public housing units, and utility billing data from 19 multi-family complexes in New Jersey were used to determine normalized annual consumption (NAC) of fuel used for space heating using the Princeton Scorekeeping Method (PRISM).

COMMERCIAL RETROFIT RESEARCH

SECTOR CHARACTERIZATION

Characterization continued to provide information on commercial building retrofit activity and energy use. A review of existing data sources on the commercial buildings retrofit market (20) showed that information on retrofit activity is not extensive when compared to new construction, but retrofit is growing in importance as a construction activity. Another report is being prepared to show information in the NBECS (Non-residential Buildings Energy Consumption Survey) data that is not developed in the standard NBECS reports and to indicate how more detailed estimates of where the energy savings potential exits in commercial buildings might be developed with extensions to the NBECS data and analysis.

MONITORING PROTOCOL

A protocol is under development to improve the standardization of experimental design, data collection, and analysis to allow the experience gained from each new study to build more fully on previous work. The intent is also to increase the future usability of such data in analyses of the results from groups of experiments. Standardization activities will be pursued with national organizations such as ASHRAE and ASTM. First drafts have been completed and are under review.

OPERATION AND MAINTENANCE (O&M)

A survey of commercial sector resources for O&M training and services was completed (21). The report identified significant problems: training needs to be improved and more qualified personnel are needed, some buildings have design and/or installation problems in the as-built condition, better O&M diagnostics and check-up procedures are needed, and credible, general information on the expected savings from improved O&M is lacking. It appears significant improvements in building energy efficiency is possible if some of these areas can be addressed.

RETROFIT MONITORING

Field studies have been initiated to study the overall retrofit process for commercial buildings. The key results are the energy and dollar savings for the retrofits, but there are many issues related to how retrofits are installed, how buildings are operated and maintained, and any effects that retrofits have on the comfort and productivity of the occupants that must also be considered.

A field study is being conducted in Tennessee to measure the performance of retrofits in small commercial buildings. TVA assisted ORNL in selecting the buildings to study, the buildings were inspected, energy use profiles were analyzed, and one was selected for monitoring. Preretrofit data are currently being collected.

AUDITS AND DIAGNOSTICS

A study is in progress by ASHRAE to assess perceptions of the areas where audits can be improved. A new approach to air flow measurement has been developed that uses several orifices with changing area ratios to extrapolate to a zero pressure drop condition across the orifice. The technique provides ±1 percent accuracy in the lab, with expected field accuracy of ± 5 percent. This technique was reported at an ASME conference and received much interest.

A combined audit and installation field test has been conducted, and the results are being analyzed. One interesting retrofit was included in this test: lighting levels were reduced to 50 fc in a retail store using color-enhancing fluorescent lamps, and the occupants liked the change. This retrofit may offer interesting opportunities for the future. These audit and diagnostic techniques are being developed for use in an approach to small commercial buildings in which packages of effective retrofits can easily be recommended and installed.

RETROFIT GUIDEBOOK

A guide for commercial buildings has been developed together with the Energy Committee of the American Consulting Engineers Council that provides a general description of the overall process of achieving energy efficiency.

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