Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

APPLIED SCIENCE DIVISION

BUILDING ENERGY RETROFIT RESEARCH
Multifamily Sector, Multiyear Plan
FY 1986-FY 1991

R. Diamond, C. Goldman, M. Modera,
M. Rothkopf, M. Sherman, and E. Vine

August 1985

APPLIED SCIENCE
DIVISION

Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

DISCLAIMER

LBL - 20165
EEB-epb-85-10

BUILDING ENERGY RETROFIT RESEARCH
Multifamily Sector

Multiyear Plan

FY 1986 - FY 1991

prepared for

Applications Research and Development
Building Services Division
Office of Buildings and Community Systems

U.S. Department of Energy

prepared by

Richard Diamond, Charles Goldman, Mark Modera
Michael Rothkopf, Max Sherman, Edward Vine

Applied Sciences Division
Lawrence Berkeley Laboratory
University of California
Berkeley, Ca. 94720

August 1985

This work was funded by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Energy Research and Development, Buildings Systems Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

ACKNOWLEDGMENTS

This multiyear plan was prepared by researchers in the Applied Sciences Division, Lawrence Berkeley Laboratory. The individuals listed below wrote or reviewed sections of the document.

Rick Diamond, Chuck Goldman, Mark Modera, Mike Rothkopf, Max Sherman, and Ed Vine.

We would like to acknowledge the contribution of Gautam Dutt and David Harrje of Princeton University for their section on private sector activity.

We would also like to acknowledge the major contribution of Rebecca Vories in preparing the extensive section on government activity.

The following individuals and organizations reviewed and made comments on an earlier draft:

Energy Resource Center, St. Paul, Minnesota
Karen Griffin, California Energy Commission
Robert Groberg, U.S. Dept. of Housing and Urban Development
Pradeep Gupta, Electric Power Research Institute
Charles Haun, Community Development Consultant
Mike MacDonald, Oak Ridge National Laboratory
Gerald Pine, Gas Research Institute

The individuals and organizations listed in Appendix A are also thanked for their contributions to this document.

BUILDING ENERGY RETROFIT RESEARCH
Multifamily Sector

Multiyear Plan
FY 1986 - FY 1991

CONTENTS

EXECUTIVE SUMMARY

Introduction

This document sets out a multiyear plan for research and development activities to accelerate, complement, and support private sector efforts to improve the energy efficiency of the existing *multifamily* housing stock. The plan was developed after extensive review of ongoing and planned activities in DOE and the private sector, and consideration of the potential for improved energy efficiency of this building stock. The plan will be revised periodically as a result of changes in private sector activity and needs, as well as changes in the planning assumptions.

Sector Characteristics

The multifamily sector differs from the remainder of the nation's housing stock in certain key respects: number and size of units, geographic distribution, heating system type, age distribution, fuel use, energy end use, and occupancy patterns. Sector characteristics include the following:

- 27% of the existing U.S. housing stock are in multifamily units--22.3 million households.
- Median floor area for multifamily units (790 ft^2) is nearly half the floor area of single-family units (1520 ft^2).
- 32% of these multifamily units are in the Northeast.
- 41% of multifamily buildings are heated by central heating systems.
- One-third of the multifamily stock is over 40 years old.
- New multifamily construction is primarily in the south and west--45% of the new multifamily units are located in California, Texas, and Florida.
- 85% of the multifamily stock is occupied by renters.
- Median rental income ($11,400) is about half median homeowner income ($21,800).
- Almost half of all renters remain in their residence for only one year or less. The same fraction of homeowners reside in their homes for more than ten years.
- The multifamily stock includes 1.25 million units of Public Housing, and about another 1.96 million units of federally-assisted housing.

Importance of Multifamily Sector

Buildings represent 36% of the total U.S. primary energy end use--about 26 quadrillion Btu (quads). The multifamily sector accounts for 2.8 quads, or $19.9 billion in 1983 dollars. The 1982 study conducted by the Office of Technology Assessment on energy efficiency in cities estimates that while retrofit activity in the multifamily sector could save 1.0 quad of energy per year by the year 2000, (43% of the total sector), the likely savings are only 0.3 quad (13% of the total sector). The potential dollar savings are $7.1 billion per year by the year 2000, but the likely savings are only $2.1 billion (in 1983 dollars).

Private Sector Activity

The limited retrofit activity that has taken place in multifamily buildings by the private sector can be broken into four categories:

- o Traditional businesses
- o Utility companies
- o Non-profit energy companies
- o For-profit energy companies

Traditional businesses sell to multifamily building owners such products as replacement burners, boiler controls, and thermostatic radiator valves. Projects targetted to single-family markets--attic insulation, window replacement--have been less successful.

Utility companies have recently set up programs to reach multifamily customers. Previous efforts by utilities including Pacific Gas and Electric, Consolidated Edison, Northeast Utilities, and Mass Save, have reached several thousand multifamily units.

The non-profit energy service companies are set up to provide a wide range of services directed at the tenant and owner of low-income multifamily properties. Individual companies are targetting to retrofit several thousand units in their cities over the next few years.

There are very few for-profit energy service companies in the multifamily sector--most concentrate in commercial buildings. A few companies offer one-stop services including audit, retrofit installation, and follow-up services. Several thousand multifamily households have been retrofit by private companies.

The Institute for Real Estate Management manages about one-third of the units in multifamily buildings. They estimate that 10-20% of the large, professionaly managed multifamily buildings have received some retrofit activity. This corresponds to a sector wide activity level of only 3-6% of the multifamily building stock receiving some capital retrofits.

Government Activity

Emphasis on programs specifically dealing with multifamily housing issues is a fairly recent occurrence at the federal, state/local, and utility levels. Initially, all residences were treated together, and no special emphasis was placed on multifamily buildings or tenants. The earliest federal work attempted to understand how investment decisions were made by owners of these properties. Except for research done in the late '70s on how to allocate energy costs to tenants in master-metered buildings, it has only been in the last three or four years that programs were specifically designed to reach both owners and tenants of multifamily dwellings.

The federal agencies that have played the largest role in multifamily programs are the Department of Energy (DOE) (primarily technical assistance and weatherization), the Department of Housing and Urban Development (HUD) (primarily grant programs for the rehabilitation of low- and- moderate-income housing), the Department of Health and Human Services (HHS) (low-income energy assistance) and the various armed services in improving the energy efficiency of their housing stock by 20% over 1977 energy consumption. Due to the large portion of lower income residents in many multifamily structures, programs have been aimed at reaching owners of buildings which house primarily lower income tenants.

State and local governments, frequently using federal funds, have taken a lead role in this area, and have devised a wide variety of programs to address upgrading of multifamily structures. The most active have been the states of California, Connecticut, Illinois, Indiana, Maryland, Massachusetts, Michigan, Minnesota, New York, Ohio, Pennsylvania, Wisconsin, and the cities of Baltimore, Boston, Chicago, Minneapolis, New York City and Pittsburgh.

Barriers

The barriers to retrofit activity are both technical and non-technical. The technical barriers are due to the lack of information on the cost and performance of individual retrofits, as well as the more complex issues of how individual retrofits interact with each other and perform over time. The non-technical barriers include institutional, financial, informational, and behavioral characteristics that have hindered retrofit activity in multifamily buildings. These barriers include the split incentives between tenants and owners for saving energy, the limited information on the performance of retrofits in multifamily buildings, the diverse characteristics of the multifamily building stock, and the limited channels of communication for transfering the cost, savings, and performance information to the millions of tenants, owners, and small businesses that could undertake retrofit activity in multifamily buildings.

Federal Role

Two factors that underly the federal role can be summarized as follows:

- Even though the potential for making cost-effective energy savings in the multifamily sector is great, very little conservation activity is taking place. The need to encourage this sector to conserve energy does not appear to be adequately addressed by existing private and government activities. The private sector has been hampered by a number of institutional, informational, and technical barriers.
- The federal government has a special role in the multifamily sector, both as an owner of a large number of multifamily buildings, and as supporter of numerous programs directed at the multifamily sector. Federally-assisted housing, both in HUD-supported public housing and in Section 8 subsidized housing, houses several million low-income and elderly Americans. Federal agencies need building energy data in order to manage effectively and upgrade the energy-efficiency of this large number of public-sector multifamily units. Over 25% of the residents in multifamily housing are eligible for assistance under the DOE Weatherization Assistance Program. Federal weatherization and energy assistance programs addressing low-income households all require the knowledge of retrofit performance in multifamily buildings, as well as the basic energy-use characteristics of this stock.

Research Program

Criteria for establishing Federal role

The basis for defining the Federal and Divisional role is a necessary first step in the identification of specific Federal actions to achieve energy savings through the retrofit of multifamily buildings. Based on the criteria and assumptions described below, a full range of program functions and activities were identified. These activities were then placed in priority order based on a systematic review process. The end result is the research program described in Section 5.0, and summarized here.

The following specific criteria or objectives were used in developing a definition of the Federal and Divisional role in support of the retrofit of multifamily buildings:

- A potential for significant net energy and economic savings must exist. This criteria emphasizes the ultimate objective of any energy conservation research program: the achievement of both energy and economic savings. Unless a significant opportunity exists, no Federal action can be considered.
- Potential savings are not being realized by the private sector because of identifiable market imperfections or failures. This criterion emphasizes the importance of avoiding Federal actions that duplicate private efforts or which otherwise interfere with normal market forces. Market imperfections or failures include, among others, an inability or unwillingness of private firms to undertake long term, high risk research (even though the results of such research might have major national benefits); especially fragmented or non-existent support

industries; tenant/landlord conflict; and inadequate market incentives because of depressed economic conditions or other constraints.

- o Anticipated benefits should be national or regional in nature, rather than local. Local concerns should be generally addressed by State and local governments or other non-Federal entities.
- o Federal research support or other actions should not impair the operations of the free market. Not only must there be a potential for significant net energy and economic savings, but the actions should not adversely affect the operation of the free market system.
- o Retrofit research support or other actions by the Building Services Division should be fully consistent with established legislative and organizational responsibilities and should not duplicate or conflict with the actions of other DOE offices and Federal agencies.
- o Specific program activities should be identified and reviewed in cooperation with private businesses, utilities, State and local

Criteria for setting project priorities

Assigning priorities for any research program is not an easy task. It is almost impossible to quantify every aspect of a project that could be taken into consideration, and then apply appropriate weighting factors to each of those aspects in order to obtain an unequivocal rank order of all projects considered. Even when such approaches are attempted, professional judgements and budget constraints often are the key determinants of the final rankings.

Probably the most important factors in any ranking system are: the establishment of the particular criteria that projects must meet in order to be considered for ranking; the establishment of differentiating criteria that will be used to determine the relative importance of the projects that are considered; and, the establishment of a consistent method of presenting information about projects that are being ranked. In this way, intelligent discussions can be held among reviewers to establish the final ranking of projects.

The approach used here, after looking at several simple and computer-based systems, was to develop a list of criteria and an extensive description form to be filled out on each project that was to be considered for final ranking.

Specific projects were suggested by experts from DOE, other Federal agencies, DOE laboratories, private firms, utilities, state and local governments, and user groups. Using projections of future energy consumption developed for DOE by PNL for each existing building sector, DOE laboratories filled out forms for each project and assigned initial rankings. These initial rankings were then reviewed by DOE and by knowledgeable representatives of the groups cited previously and final rankings were assigned by DOE.

The specific criteria which were used in the ranking process were divided into two groups--screening or threshold criteria, and differentiation criteria. Screening criteria are used to determine if a project should receive further consideration, and if so, whether or not it should be treated as a support, research and development, technology transfer or basic research project. The differentiation criteria were then used on those projects categorized as R&D and/or technology transfer projects. This provided an in-depth analysis of their potential to produce energy savings in existing buildings. The other project categories--support and basic research--were analyzed using fewer and more qualitative factors. It was assumed that over the life of the multi-year plan, support projects would receive 5-15% of the allotted funds, advanced technology projects 5-15%, and research and development the majority of the funds.

Research needs

The research needs, based on the responses of the forty organizations contacted, are broken down as follows:

Summary of Research Activity Needs in Multifamily Sector

Analysis and Evaluation:

- evaluate existing computer models; how useful are they for multifamily stock?
- develop models for electric buildings
- need improved utility bill analysis techniques
- what is importance of vacancy/turnover rates?
- need better air leakage models
- what are needs of additional groups, e.g., builders, investment criteria people, building owners, tenants, managers?

Characterize Building Stock:

- need better description of stock, low-rise vs high rise, infiltration/ventilation rates
- need characteristics of owners and rental industry
- what are energy use patterns? idiosyncrasies?

Retrofit Performance Data:

- need monitoring protocols
- what is performance of heating system retrofits--vent dampers, balancing, outdoor resets, etc.?
- what is performance of shell retrofits--insulating problem buildings, masonry walls, flat attics?
- what is the performance of hot-water retrofits?
- what is the performance of cooling retrofits?
- what are selection criteria? costs and savings?

Information and Technology Transfer:

- how can existing organizations be used?
- what other sources are useful--direct contact, technical reports, data bases, workshops?

Case Studies:

- demonstrate new technologies for existing buildings
- show how to retrofit old buildings
- how to implement major capital improvements
- show what works in actual implementation

Operations and Maintenance:

- how effective are energy management systems?
- what are implications of fuel switching?
- what are effective temperature controls--thermostats vs resets?

Marketing and Financing:

- what are long-term effects of shared savings?
- what are innovative sources of financing?
- what are building owners investment criteria?

Health and Safety:

- what are indoor air quality issues related to retrofits?
- what moisture problems result from retrofits?

Audits and Design Tools:

- how to improve audit accuracy and reliability
- need design tools to estimate costs and paybacks

Institutional Issues:

- how to address tenant/owner barriers
- need for regulatory elements
- how to increase public awareness
- how to design retrofits to have non-energy benefits as well for owners and tenants

Behavior and Metering:

- what is cost-effectiveness of sub-metering?
- what is effect of metering on future retrofits?
- what is appropriate feedback for tenants? rebates?
- what are effective educational tools?

Special Buildings:

- what are special needs for Federally-assisted housing?
- what can be done in oil-heated buildings?
- what are special needs for small multifamily buildings?

Research projects

Specific research projects were developed to address these needs, often combining needs which overlapped, and creating new areas where appropriate. Over one-hundred project areas were identified. A preliminary screening eliminated projects that did not meet the threshold criteria discussed above. The remaining project areas were reviewed and combined into the thirty-eight areas presented below.

The project areas are listed below by their major sub-headings. In addition to the preliminary ranking score computed by the criteria above, a review panel made up of fifteen individuals from DOE, National Labs, and other institutions gave an initial review score for each project. Where the review ranking differed from the preliminary ranking, both are given, with the preliminary ranking given first. The numerical rankings have been converted to HIGH, MEDIUM, and LOW scores and are given in the table below:

Retrofit Research Project Areas for Multifamily Sector

A. Planning and DOE Support
1. Survey user needs (HIGH)
2. Planning updates (HIGH)
3. Evaluate ARD projects (HIGH)
4. Stock characterizations (MEDIUM)

B. Analysis, Modeling, and Tool Development
5. Energy end use patterns (MEDIUM)
6. Peak & diversified load analysis (LOW/MEDIUM)
7. Evaluate existing multifamily models (MEDIUM)
8. Evaluate & develop utility bill analysis (MEDIUM)
9. Evaluate & develop air infiltration models (HIGH/MEDIUM)
10. Develop simulation models [included in #7]
11. Behavioral studies (HIGH/MEDIUM)
12. Data acquisition system (MEDIUM)
13. Audit diagnostics & techniques (HIGH)
14. Monitoring protocols & techniques (HIGH)

C. Retrofit Performance
15. Heating system retrofits (HIGH)
16. Shell retrofits (HIGH/MEDIUM)
17. Cooling system retrofits (MEDIUM/HIGH)
18. Hot water retrofits [included in #19]
19. Hot water systems (HIGH)
20. Lighting & appliances (MEDIUM/LOW)
21. Low cost/no cost (MEDIUM)

D. Interactions & Strategies
22. Operation and maintenance (HIGH)
23. Temperature control strategies (HIGH)
24. Load management techniques (LOW)
25. Retrofit interactions (HIGH)
26. Metering strategies (MEDIUM)
27. Low cost packages [included in #21]
28. Public housing strategies (HIGH)

E. Technology Adoption
29. Marketing strategies (LOW)
30. Innovative financing (LOW)
31. Acceptability of retrofits (HIGH)
32. Air quality and moisture [moved to section D] (MEDIUM)

F. Technology Transfer
33. Data Bases & Information Network (HIGH)
34. Workshops (HIGH/MEDIUM)
35. Case studies (HIGH)

G. Advanced Technology
36. Advanced window materials & systems (LOW/MEDIUM)
37. Solar cooling/heating (LOW)
38. Thermal storage, hybrid systems (LOW/MEDIUM)

These projects areas provide the basis for the research program. Additional planning will be required to select the optimal choice of projects to ensure a balanced program of multifamily retrofit research. All of the project areas are consistent with the mission of the Building Services Division described in the Introduction. However, a number of the project areas described encompass activities which might also be supported by other divisions within the office of Buildings and Community Systems, other offices within the Department of Energy, or, in a few cases, other federal agencies. For this reason, specific projects to be funded by the Building Services Division will be closely coordinated with the other appropriate federal offices.

Section 1.0
INTRODUCTION

IN THIS SECTION: Mission statements for Building Energy Retrofit Research; purpose of plan; importance of multifamily sector; overview of planning process.

1.0 Introduction

This document sets out a multiyear plan for research and development activities to accelerate, complement, and support private sector efforts to improve the energy efficiency of the existing multifamily housing stock. The plan was developed after extensive review of ongoing and planned activities in DOE and the private sector, and consideration of the potential for improved energy efficiency of this building stock. The plan will be revised periodically as a result of changes in private sector activity and needs, as well as changes in the planning assumptions.

1.1 Mission Statements

1.1.1 BCS Mission

The mission of the Office of Buildings and Community Systems (BCS) is to provide overall direction for a balanced program of technology planning, research and development, and testing and evaluation to provide effective support to non-governmental efforts to increase the energy efficiency of the Nation's residential, commercial and industrial buildings. BCS encourages efficient, cost-effective use of energy in buildings and community systems through the conduct of research and development on those technologies and programs that will increase the energy efficiency of the built environment and the implementation of DOE's statutory responsibilities in the building end-use area.

1.1.2 BSrD Mission

The mission of the Building Services Division (BSrD) is to develop and manage a balanced program of research, development, testing, and evaluation that will advance the efficient delivery and use of energy in community-wide systems, and in single-family, multifamily, and commercial buildings. The Division augments and enhances private sector energy conservation activities by helping to remove barriers to the use of efficient, community-shared energy systems, developing new technologies, determining the impacts of conservation technologies on existing buildings and utility loads, and testing new approaches for delivery of energy conservation information and services.

1.1.3 ARD Mission

The Applications Research and Development Branch (ARD) includes two major areas of responsibility: Utility Applications Research and Building Energy Retrofit Research (BERR). Utility Applications Research assesses the impact of building conservation technologies on utility loads and economics and develops analytical tools for utilities to incorporate the research results into their planning processes. BERR identifies technical, financial, behavioral, and other barriers that restrict the adoption or use of energy-efficient technologies and practices in existing buildings. BERR conducts research to determine methods for overcoming or eliminating these barriers, and conveys the results of research to the public and private sector organizations involved in building

retrofit. The BERR program covers three broad building categories: single-family residences, multifamily residences, and commercial buildings.

1.1.4 Multifamily Building Retrofit Research Mission

The mission of *multifamily* building retrofit research is to identify technologies and practices with retrofit potential, to test these measures in occupied buildings, and to define the impact on energy consumption of the measures, the quality of their installation, and occupant behavior after the retrofit. In addition, the program identifies the cost of retrofit measures and correlates this to the value of energy savings. For cost-effective retrofits, the program identifies problems which restrict their adoption or use, conducts research to determine methods of overcoming or eliminating these problems, and conveys the results to public and private organizations involved in the retrofit of multifamily buildings.

1.2 Purpose

The purpose of this plan is to set out a multiyear research and development agenda for accelerating and supporting private sector efforts to improve the energy efficiency of the existing multifamily building stock. Particular emphasis is given to buildings with low-income and federally-assisted residents (public housing). The plan provides a basis and rationale for funding decisions and is intended to solidify and provide direction for the research by integrating the needs of constituency groups into the research and development process.

The residential building stock is not easily split into single-family and multifamily sectors. While the 12.2 million households living in buildings having five or more units are clearly identified as multifamily, the 10.1 million households living in buildings having two-to-four units share many characteristics with single-family houses. Where appropriate, these two-to-four unit buildings are included in the plan, chiefly when there is research directed to the institutional barriers resulting from owner/tenant conflicts. For cases where the retrofits are more characteristic of the single-family sector, the units are included in the plan for the single-family sector.

1.3 Importance of Multifamily Sector

Table 1.1 gives the fraction of total U.S. primary energy use for buildings (residential and commercial), industry, and transportation.

Table 1.1. Total U.S. Energy Use by Sector [1982]

	Quads	
Buildings	25.7	36%
Industrial	26.1	37%
Transportation	19.1	27%
Total	70.9	100%

source: 1982 Annual Energy Review DOE/EIA-0384(82)

Breaking the building sector down into its three principle parts, (single-family, multifamily, and commercial), and separating fuel use (natural gas, oil, etc.) and electricity shows the multifamily sector consuming 2.8 quads of the total sector energy use of 21.6 quads (Table 1.2).

Table 1.2. Primary Building Energy Use by Sector [April 1982 - March 1983]

	Fuel	Electricity	Total (quads)
Single-family	4.62	1.86	10.2
Multifamily	1.42	0.46	2.8
Commercial	2.36	2.09	8.6*
Total			21.6

*NBECS doesn't include all non-residential energy use

source: 1982 Annual Energy Review DOE/EIA-0384(82)

The energy costs for the building sectors are shown in Table 1.3. The multifamily sector accounts for $19.9 billion in 1983 dollars.

Table 1.3. Total U.S. Energy Costs by Sector [April 1982 - March 1983]

	Billion $
Single-family	64.6
Multifamily	19.9
Commercial	32.5
Total	117.0

source: 1982 Annual Energy Review DOE/EIA-0384(82)

The conservation potential in the multifamily sector--perhaps more than any other building sector--is determined not only by the technical potential, but by the likelihood of its being achieved. The 1982 study conducted by the Office of Technology Assessment on energy efficiency in cities estimates that while retrofit activity in the multifamily sector could save 1.0 quad of energy per year by the year 2000, (43% of the total sector), the likely savings are only 0.3 quad (13% of the total sector). This translates to a potential dollar savings of $7.1 billion per year by the year 2000, but the likely savings are only $2.1 billion (in 1983 dollars).

1.4 Overview of Planning Process

The planning process was initiated by ARD in order to systematically review the need for federally-supported research in all building sectors. The goal was to establish comprehensive and long-term research programs to address these needs. Individual projects were identified by sector, and then analyzed, and ranked.

In order to review the work that had been done already in multifamily retrofits, LBL contacted individuals and organizations involved in diverse aspects of multifamily energy conservation throughout the country to find out what they were doing, what they perceived were the major research needs that could best be accomplished by a national retrofit research program, and to find out by what means the information gained from such a program could be transferred to the appropriate parties. Over 30 organizations were contacted by LBL and another seven were

reached by researchers at Princeton University. The organizations represented architects and engineers, consumer and public interest groups, federal, state and local governments, real estate and financial institutions, research and testing labs, trade associations, utilities and their associations, as well as individual consultants. A list of the organizations contacted and a summary of their responses are given in Appendix A and Appendix B. The research needs identified by this group is given in section 2.6.3.

Concurrent with the survey work, LBL was also reviewing the available literature characterizing the multifamily sector. The data resources are quite limited in this sector, not only in characterizing the physical stock, but in the energy end-use, retrofit potential, and tenant and owner characteristics as well. A summary of the available data is presented in section 2.0, *Multifamily Sector Profile*. Part of the section on retrofit activity in the private sector (section 2.5) was written by Princeton University. The extensive section reviewing government activities (section 3.0) was prepared by ARD.

Based on the research needs expressed by the contacted organizations, and the characterization of the multifamily sector, LBL evaluated the individual projects using the criteria summarized in section 4.3. The result of these project evaluations is the multiyear plan for research activities, summarized in section 5.0.

As in any major planning process, this plan will be revised and updated periodically to ensure that the research activities are meeting the overall objectives of the program. An earlier version of this plan was circulated to a limited number of reviewers for comment in July, 1985. Their comments have been incorporated into the present version.

Section 2.0

MULTIFAMILY SECTOR PROFILE

IN THIS SECTION: Building characteristics--number and size of multifamily units, regional distribution, heating system type, age distribution, trends in new construction; energy use data and trends--choice of heating fuel, aggregate energy use, end-use estimates; occupant and building owner characteristics--owners and renters, income, education, age, tenancy, behavior, building owners and managers; conservation potential; private sector activity; barriers; needs.

2.0 Multifamily Sector Profile

This section characterizes the multifamily building sector. It describe the major physical characteristics, energy use patterns, conservation potential, private sector retrofit activity, barriers to retrofit activity, and identifies research needs to overcome them.

Data on the physical characteristics of the multifamily stock are drawn from a number of sources, principally the American Housing Survey (AHS) and the Residential Energy Consumption Survey (RECS). The barriers and needs material are based on the responses of the 40 organizations contacted who are actively involved in multifamily retrofit activity. The organizations contacted and their complete responses are included as Appendix A and Appendix B, respectively.

Because the multifamily sector covers a wide range of physical structures--garden apartments, low-rises, high-rises--some judgements have been made in how to characterize the units. Previous attempts to categorize the sector have used number of stories, heating-system type, and a variety of different indices. The two principle data sources listed above, RECS and AHS, divide the sector into two categories of 2-4 units and 5 units and above. Despite its limitations, this usage has been followed throughout, except as noted.

In some instances where there was no information on multifamily housing, data on rental housing was used, and indicated in the text when this was done. This information is valid for the 86% of the multifamily stock that is renter occupied. The difficulties in defining the multifamily sector give some indication of the problems that are associated with all aspects of this sector.

2.1 Building Characteristics

The multifamily sector differs from the remainder of the nation's housing stock in certain key respects: geographic distribution of units, age of buildings, ownership patterns, type of heating system, and principal heating fuel. A detailed discussion of these characteristics, both physical and demographic, helps to identify the significant retrofit potential of multifamily buildings and also highlights some of the key barriers that limit investments in energy-efficient technologies.

2.1.1 Number and Size of Multifamily Units

Multifamily buildings vary widely in complexity, from single-family style of construction to large office-building type structures. These buildings comprise almost 27 percent of the existing U.S. housing stock (in terms of household units) although, due to their smaller size, they represent approximately 17 percent of the U.S. total heated floor space (see Table 2.1.1).

Table 2.1.1.
Existing Housing Stock*
[Total Residential Units: 83.8 Million Households]

	# units (millions)	% of Total Units	Median Heated Floor Area (ft^2)
Single-family detached	53.8	64.2%	1525
Single-family attached	3.9	4.6%	1513
2 - 4 units	10.1	12.1%	843
5 or more units	12.2	14.6%	733
mobile homes	3.8	4.5%	-

*Source: Residential Energy Consumption Survey: Housing Characteristics 1982 DOE/EIA-0314 (82), August 1984.

The median size of individual dwelling units tends to decrease as the number of units in a building increases. It is worth noting that the size of individual units is also strongly correlated with ownership. Owner-occupied units are larger on average than renter-occupied units (1347 vs 735 ft^2 for buildings with five or more units).

2.1.2 Regional Distribution

Nearly one-third of all the nation's multifamily units is located in the Northeast (see Figure 2.1.1).
In addition, a significant fraction (40%) of the nation's largest multifamily buildings (20 or more units) are located in this region. The other three regions (West, North Central, and South) each have between 20-24 percent of the nation's multifamily units. In each of these regions, more households live in buildings with five or more units.

2.1.3 Heating System Type

A large fraction of multifamily buildings (41%) are heated by central heating systems. Typically, central systems supply conditioned water, steam, or air through pipes or ducts for heating and cooling of individual apartments from a furnace, boiler, chiller, or air conditioner. Larger apartment buildings have a higher fraction of central steam and hot water systems (see Table 2.1.2).
Almost half of the households in buildings with five or more units and roughly one-third of the households in buildings with 2-4 units utilize central heating systems. Most multifamily buildings heated by individual heating systems rely on warm air furnaces (55 percent), of which 23 percent are electric resistance devices.

Residents of buildings with central heating or domestic hot water systems often have their energy costs included in the rent; such households do not feel the immediate effect of energy price increases or reduced energy consumption. Approximately 62 percent of the 12.7 million households that have the cost for one or more fuels included in their rent live in buildings with central heating systems. With a central system, special devices are required to measure how much heat each of the serviced households is using, further decreasing the likelihood of directly linking the household with the energy it uses.

2.1.4. Age Distribution of Multifamily Units

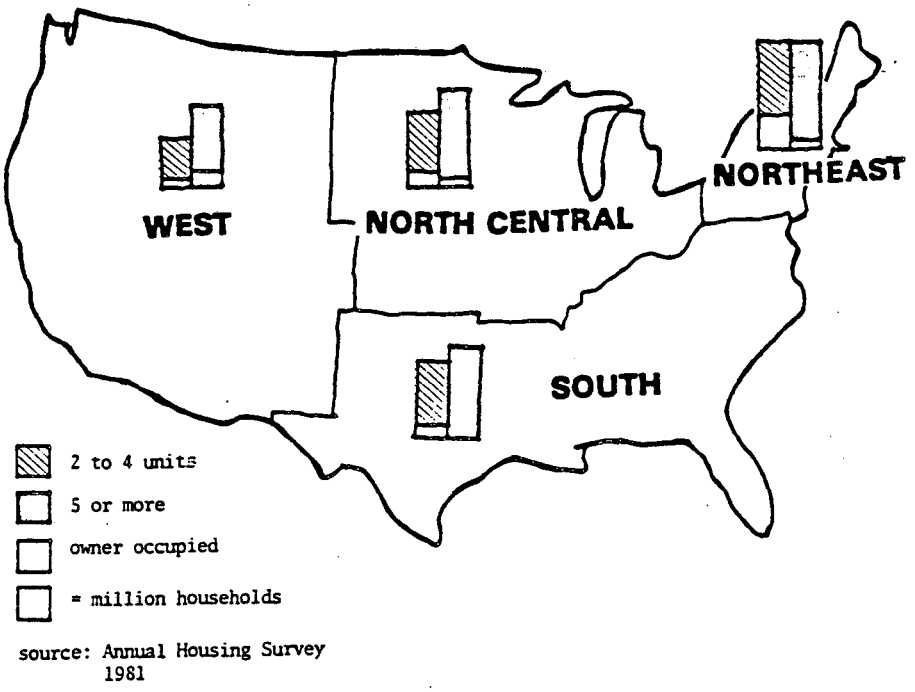


Figure 2.1.1. Distribution of Multifamily Units by Region

Table 2.1.2
Number of units with Central Heating and Hot Water Systems.*

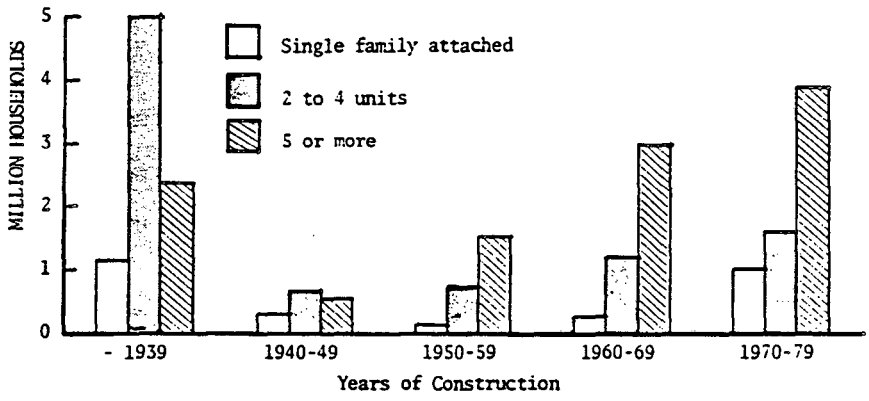
	Central Heating System	Central Hot Water System
	Millions of Units[a]	
Total Households in 2-or-more Unit Buildings	22.4	
2-4 units	3.4 (34%)	3.8 (38%)
5 or more units	5.7 (47%)	7.1 (58%)

[a] Fraction of buildings in that sub-sector.

*Source: RECS: Housing Characteristics, 1982

Approximately one-third of the multifamily stock is over 40 years old, having been constructed before 1939 (see Figure 2.1.2).

The multifamily sector has been characterized by sporadic and sometimes intensive periods of construction activity. Over 50 percent of the buildings with 2-4 units were constructed before 1939. During the 1940's and 1950's, relatively few multifamily units were constructed. Construction activity increased again during the 1960-70's, with approximately 400-500 thousand units of new multifamily construction starts each year.



source: Annual Housing Survey, 1981

Figure 2.1.2. Age Distribution of Multifamily Units

2.1.5 Trends in New Multifamily Construction

New privately-owned multifamily construction is concentrated principally in the the southern and western regions of the U.S. (see Table 2.1.3).

Table 2.1.3.
1983 Multifamily Building Characteristics*

Location	% of New units
Northeast	8
North Central	13
South	57
West	22

*HUD Construction Reports (25-83-13) June 1984

Much of this activity occurred in just three states (California, Florida, and Texas). For example, in 1983, 45 percent of all units built in buildings with five or more units were located in these three states.[1] Over the last decade, multifamily housing starts account for a significant fraction (30-40%) of total housing starts. Seventy-five percent of all multi-family units built each year are in buildings with more than four units. Most newly-constructed multifamily units are equipped with air conditioners (89%) and heat pumps are increasingly popular. For example, in 1983, 28% of new multifamily units installed heat pumps.

2.2 Energy Use Data and Trends

2.2.1 Choice of Heating Fuel

Choice of principal heating fuels in existing multifamily buildings parallels trends in the existing stock of single-family homes. In particular, the fraction of existing multifamily dwellings heated by natural gas (52-54%) is similar to that found in single-family dwellings. The share of existing multifamily units heated by oil dropped from 25 percent in 1975 to 21 percent in 1981. The fuel mix is quite different in new multifamily units, as electricity is the dominant heating source (66%). Few newly-constructed units are heated by fuel oil (see Table 2.2.1).

Table 2.2.1.
Fuel Mix in New and Existing Multifamily Housing Units*
(thousands)

Year	Total	Gas	Oil	Electricity
1975				
Existing	19,428	10,492 (54%)	4,942 (25%)	3,631 (19%)
New	442	145 (33%)	30 (7%)	260 (59%)
1981				
Existing	22,387	11,553 (52%)	4,727 (21%)	5,712 (26%)
New	447	142 (32%)	7 (2%)	293 (66%)

*Source: EIA *Energy Conservation Indicators 1983 Annual Report*

Natural gas is a particularly popular heating fuel in buildings with 2-4 units (see Figure 2.2.1).

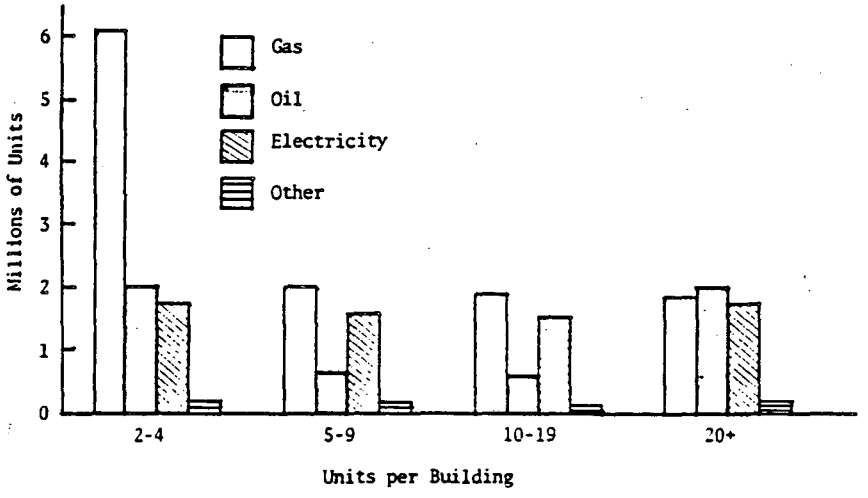


Figure 2.2.1. Heating Fuel in Multifamily Buildings

Significant changes in the relative mix of principal heating fuels will occur in the next decade if the trend towards electrification continues in new multifamily buildings.

2.2.2 Aggregate Energy Use

Multifamily buildings consume more than 20 percent of the energy consumed by residential buildings (see Table 2.2.2). This energy use directly or indirectly cost U.S. households approximately $20 billion annually in 1982-83. Over 50 percent of the energy consumed was natural gas, although, 55 percent of the $20 billion outlay was for electricity because of the higher $/Btu cost of electricity.

Table 2.2.2.
U.S. Residential Energy Consumption*
(1982 - 1983)

Housing Type	Annual Energy Usage Quads	Fraction of Total (%)
Single-family detached	6.04	70.0%
Single-family attached	0.43	5.0%
2 - 4 units	1.00	11.6%
5 or more units	0.89	10.3%
Mobile homes	0.027	3.1%
TOTAL	8.6	100

*Source: RECS: Consumption and Expenditures, April 1982 - March 1983.

The annual average consumption per household is lower in multi-unit buildings than in single-family dwellings but it is important to note that energy use per floor area exceeds that found in single-family dwellings (see Table 2.2.3). The average expenditure per household was $974 in buildings with 2 to 4 units and $818 in buildings with 5 or more units.

Table 2.2.3.
Average Energy Consumption per Household by Housing Type*

Housing Type	Annual Energy Use (MBtu)	Energy Intensity ($kBtu/ft^2$)
Total Households	103	71.1
Single-Family detached	112	65.2
2-4 units	93	90.8
5 or more units	73	93.1

*Source: Residential Energy Consumption Survey

On average, existing multi-family buildings have higher energy intensities despite the fact that they typically have a smaller amount of exposed building surface area/household due to shared interior walls. Studies that have identified significant potential for cost-effective energy-efficiency improvements often point to the relative energy-inefficiency of multi-unit buildings as well as the lower saturation of installed measures.

2.2.3 Energy Consumption by Region

Energy consumption patterns differ not only by type of building structure but also according to region. For example, multifamily housing in the Northeast consumes more than twice the energy per unit than is consumed annually by similar housing in the West. The higher energy use levels of the Northeast may be a result of factors such as climate, building size, and age of heating equipment.

2.2.4 End-use estimates

It is generally accepted that space conditioning accounts for a smaller fraction of total usage in multi-unit buildings than single-family dwellings because of their physical configuration (e.g. lower exposed building surface/household, common walls). Yet, it is difficult to obtain reliable and accurate end-use estimates for multi-unit buildings. The Energy Information Administration used regression analysis to develop end-use estimates based on the RECS survey, but the results for multi-family buildings suffer from severe data limitations. In particular, the percentage of usable fuel records was extremely low in multi-unit buildings. In buildings with five or more units, none of the households that used fuel oil had usable records, only 13% of the households that used natural gas, and 52% of the households that used electricity had usable billing data. In these cases, consumption data was imputed from results from other building types.

The Gas Research Institute has also conducted research on this topic for gas-heated dwellings. They concluded that space conditioning accounts for roughly 53-55 percent of total energy use in multi-unit low and high-rise buildings compared to 65-70 percent in single-family detached structures (see Figure 2.2.2).

2.3 Occupant & Building Owner Characteristics

2.3.1 Occupants: Owners and Renters

The ownership pattern in the multifamily sector is quite different from the rest of the housing stock. Eighty-five percent of multifamily units are renter occupied, in contrast to single-family households, where nearly two-thirds of all units are owner-occupied (see Table 2.3.1). The highest concentration of renters (93%) is found in buildings with five or more units. Owner-occupied units are concentrated among 2-4 unit buildings in all regions of the nation.

The rental and multifamily housing stocks are not identical. One-third of the rental households in the U.S. (9.8 million) live in single-family units (both attached and detached). The Northeast has the fewest single-family rentals, the South has the most.

2.3.2 Income

Because the Annual Housing Survey and the RECS data differentiate by owner- and renter-occupied units the following sections will characterize rental housing, not exclusively multifamily. The assumption is only valid for the 86% of the multifamily stock that is renter occupied. The profile of a typical renter is quite different from the profile of a typical homeowner. Renters tend to have much lower annual incomes than owners; in 1981, the median rental income was only $11,400, while the median homeowner income was $21,800. The monthly housing cost as a percentage of income is also significantly different for renters and owners. Renters in 1981 paid a median value of 27% of their income for housing costs compared to the median values of 12% (no mortgage) and 19% (with mortgage) for owners.

2.3.3 Education and Age

The 1981 Annual Housing Survey showed no significant difference in the median number of years of school completed by occupant of renter- or owner-occupied units. The median number of years of school completed for renter-occupied households was 12.5, and for owner occupied, 12.7.

Data from the same survey reported that 26% of the owner-occupied households have one or more residents 65 years old or over compared to 17% of the rental occupied households. Contrary to popular assumptions, the elderly, for the most part, own their own homes.

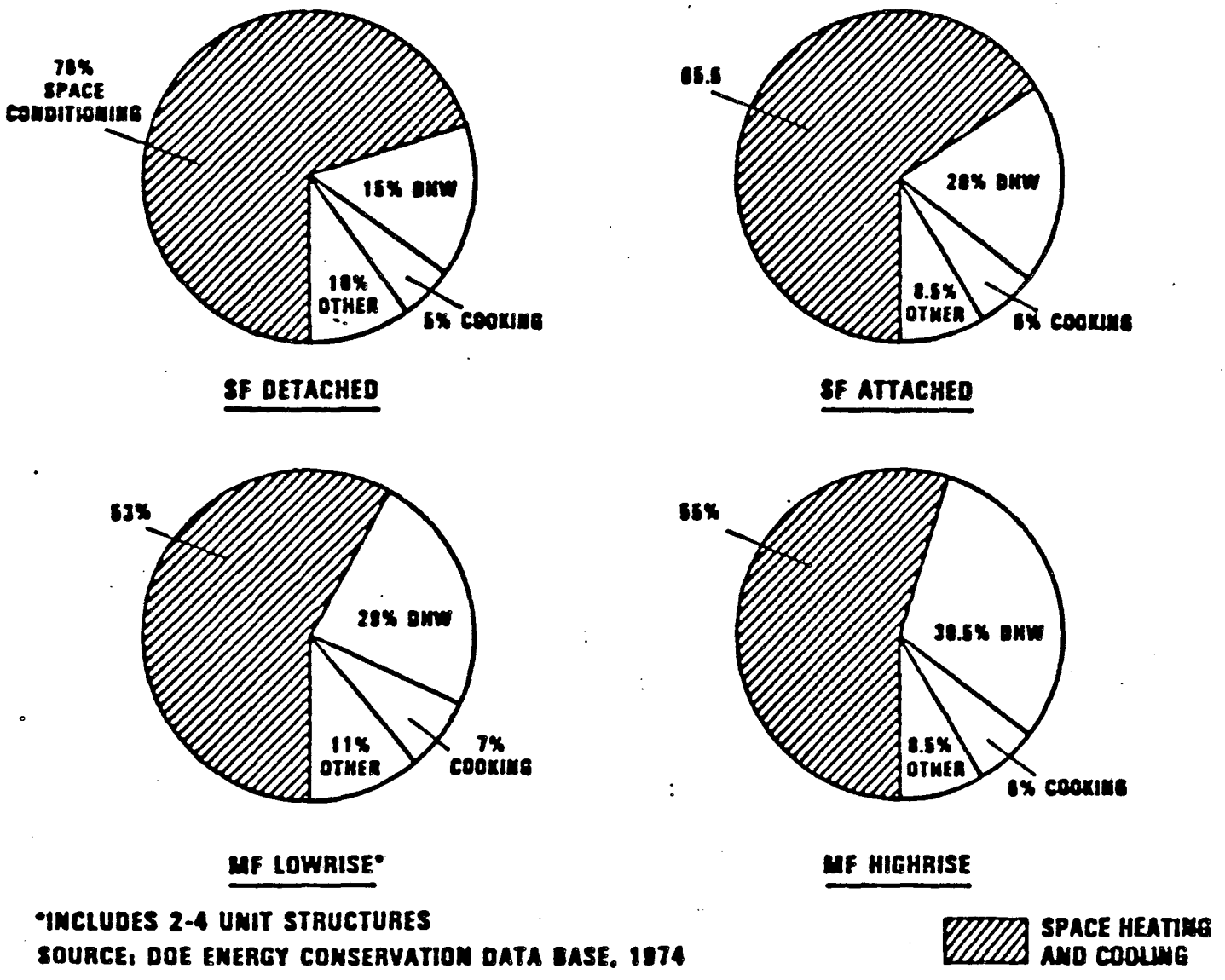


Figure 2.2.2. Functional End-use of Energy By Residential Structure Type

2.3.4 Tenancy

Tenants move more frequently than homeowners. Almost half of all renters remain in their residence for only one year or less. The same fraction of homeowners reside in their homes for more than ten years.

2.3.5 Behavior

There is no national information on the behavioral characteristics that differentiate multifamily dwellers from other residents. Anecdotal evidence suggests some differences, but these must be taken with caution. Apartment dwellers who do not pay for their centrally heated units frequently control the temperatures in over heated units by opening windows. Some studies have shown that energy use does go down when tenants pay directly for their energy use, but this, too, is a complex phenomenon, and is not well understood.

2.3.6 Building Owners

Table 2.3.1 Multifamily Housing Stock, Owners and Renters

	Million Households		
Housing Structure	*Own*	*Rent*	*TOTAL*
Buildings with 2 to 4 units:	2.1	8.0	10.1
Buildings with 5 or more:	1.0	11.3	12.2
TOTAL	3.1 (14%)	19.3 (85%)	22.3

source: RECS 1982

Table 2.3.2 Average Household Tenure

	Rental Units	Owner-occupied Units
% 1 year or less	42	12
% 2 to 5 years	33	26
% 6 to 10 years	12	18
% more than ten years	13	44

Source: U.S. Census quoted in Bleviss et al.

Building owners can be classified in two general categories, those who own units occupied by moderate- to high-income residents, and those who own units occupied by low-income residents. The distinctions made between these two groups is due in part to the different economic constraints associated with the two income levels.

2.3.6.1 Owners of moderate- to high-income housing

This subsector includes owners of apartments, condominiums, and cooperatives. Ownership types include:

- individuals
- members of condos and cooperatives
- local partnerships
- syndicated partnerships
- corporations—developers, insurance companies, pension funds

The ownership trend is toward investment partnerships, especially large syndications, which are now the most common form of ownership. Partnerships can support energy retrofit activities, but usually only at the time of syndication or refinancing. The short period of time which these partnerships hold the buildings (5-7 years), however, means economic payback on investments must be rapid.

There is stratification in the sector between large building owners and smaller building owners. Corporations and syndicates tend to own larger buildings, and have a strong edge in technical expertise and financial resources. Smaller building owners tend to be individuals with limited access to both of these.

One of the first energy retrofits sought by owners in this subsector is to install individual unit sub-meters in centrally-supplied buildings in order to remove energy costs from their direct responsibility. The trend toward tenant metering (almost half of all units) means that the incentives for owner investment in energy conservation retrofit are shrinking.

There is also a trend towards owners in this subsector hiring professional property managers (currently managing 30,000 to 40,000 buildings). In professionally managed buildings, building managers appear to be the key to implementing low-cost/no-cost measures, and can influence owners to make cost-effective capital retrofit measures.

The most influential organizations of building owners in this subsector appear to be the trade associations, such as the Institute for Real Estate Management (IREM), with 30,000 to 40,000 members, who manage about one-third of the privately owned multifamily buildings.

2.3.6.2 Owners of low-income housing

The types of low-income housing ownership are equally diverse, falling in four general categories:

- Established Owner/Manager: this type of landlord purchases property as a long-term investment for financial security;

- Trader: the trader purchases buildings with the idea of making a profitable and often quick resale;

- Operator: this landlord often cuts back on maintenance to increase profits. While the building deteriorates, the rents usually remain stable;

- Rehabilitator: this landlord upgrades deteriorated buildings and increases rents as the building improves.

Of these four, the established owner/manager is the most likely to engage in energy retrofits without displacing low-income residents afterwards; this ownership category is the most representative of low-income multifamily housing.

There are virtually no detailed data on multifamily building ownership. Most of what is known about ownership of buildings is known from real estate trade literature and the expertise of real estate analysts and operators. In some states ownership is hidden by various devices permissible under State law.

2.3.6.2 Federally-Assisted Housing

A major owner of multifamily housing is the Federal government. The federally-assisted housing stock includes 1.25 million units of public housing, 1.75 million units of subsidized section 8 housing, plus another 0.66 million units covered under other programs. HUD spends approximately $2 billion each year to pay all or part of the energy bills for these 3.6 million housing units.

Like the multifamily sector in general, federally-assisted housing is a mix of low-rise, high-rise, family units, centrally-heated systems, individually-metered, new and old building types. Energy use, however, is higher on a per dwelling unit basis than private sector housing. This can be accounted for, in part, by the generally older housing stock and the lack of energy conservation measures that have been installed to date.

2.4 Conservation Potential and Retrofit Issues

2.4.0 Conservation Potential

The conservation potential in the multifamily sector--perhaps more than any other building sector--is determined not only by the technical potential, but by the likelihood of its being achieved. The OTA estimate of the **likely** energy savings compared to the **possible** energy savings for this sector underscores the complex barriers to conservation in multifamily buildings (see table 2.4.1).

Table 2.4.1 Conservation Potential in Multifamily Housing
YEAR 2000

Multifamily Building Type	Trend energy use	Technical savings potential	Likely savings
	(quads of Btus)		
o Low-income	0.6	0.2	0.1
o Moderate & upper income master-metered	0.9	0.4	0.1
o Moderate & upper income tenant-metered	0.8	0.4	0.1
TOTAL	2.3	1.0	0.3

source: OTA

The assumptions in Table 2.4.1 are that energy use in the multifamily sector remains constant through the end of the century due in part to the cumulative effect of demolition and addition of new stock. Of the total sector (2.3 quads), OTA estimates that current cost-effective retrofit technology could save 1.0 quad (43%) a year by the year 2000. The likely savings, however, are only 0.3 quads, or 13% of the sector's energy use. (The willingness or lack of willingness on the part of owners to carry out retrofits is discussed in section 2.6.)

Several caveats are in order in presenting the data summarized in the table since there are few data on the actual effects of building retrofits in multifamily buildings. The data that we do have show, on average, that considerable savings are possible from low and moderate cost retrofits, but that savings achieved in individual buildings may be considerably higher or lower. Because each structure is a unique combination of design, siting, construction, and previous retrofits, and due to the often unpredictable behavior of occupants and weather, the actual performance of retrofits may vary substantially from that predicted.

While a large potential for energy savings in multifamily buildings does exist, there is less likelihood of its being achieved here than in any other building sector, given current conditions of availability of capital, retrofit information, and public programs.

2.4.1 Saturation of retrofits in the multifamily sector

The RECS national data on multifamily housing are lacking critical areas with respect to retrofit activity. Information is limited to certain shell retrofits--storm windows and doors--with nothing on insulation, weatherstripping, or caulking. Nor is there any information on retrofits to mechanical systems, as well as low-cost/no-cost measures. Hittman Associates reviewed the limited data available on energy conservation activity in the multifamily sector in a report prepared for DOE's Office of Conservation Policy in 1981. The report identifies and catalogues the available data which can be used to assess the current status of weatherization in multifamily housing and the current trends in adding weatherization measures to this housing. The conclusions of this report were that the current status and trends of retrofits in multifamily buildings with 2-4 units could be estimated from the available data, but to estimate the status of energy conservation in the

entire sector would require some questionable assumptions.

2.4.2 Retrofit options

Retrofits for multifamily buildings have been grouped in different ways, one of the more comprehensive lists was prepared for the International Energy Agency Annex XI: Energy conservation opportunities for multifamily buildings. The retrofits are organized under ten headings:

- building envelope
- hvac controls
- heating plant
- cooling plant
- air distribution and ventilation
- piping for steam and hot water distribution
- domestic hot water
- lighting
- miscellaneous
- occupancy

A list of the retrofits is given in Appendix C. OTA, IREM, among others, have estimated costs and savings using standard energy calculations for various retrofits that were the basis for their calculations.

2.4.3 Retrofit issues: priorities, interactions, load management, rehab

Priorities. While each multifamily building will need an audit to determine which retrofits are most cost effective, certain characteristics of the buildings will indicate likely strategies. Three physical characteristics identified by OTA that are pertinent for retrofit selection in the multifamily stock are building size, wall and roof type, and mechanical system type. Shell retrofits--insulation and window treatment--are generally more cost effective for small buildings than for large ones because of the greater surface area through which conditioned air can escape. On the other hand, shell retrofits in very large buildings may be cost effective due to economies of scale, as in the case of the Housing Authority of New York which recently installed several thousand storm windows in their buildings.

Wall and roof type will determine the ease of installation for insulation. Features common to much of the multifamily stock--masonry walls, flat roofs--are difficult to insulate except at great expense.

Mechanical system types can be either centralized as is common with water or steam systems, or decentralized, with individual space heaters. Combinations occur in buildings with centralized heating and decentralized cooling such as individual air conditioning units.

Which retrofits are suited for a given building and in which order they should be performed involves a complex series of issues apart from the technical optimum of cost-effective measures. Availability of funding for certain measures, other actions such as rehabilitation, which may include specific measures as retrofits, and peculiarities of the given building are all factors that may preclude installation of a cost-effective retrofit.

Interactions. When individual retrofit options are combined into retrofit packages, the cumulative savings can be significantly less than the sum of the savings from individual retrofits. If retrofits are installed in a series, the savings of each will depend on which retrofits have already been installed. Interactive effects may result from all types of retrofit measures:

- o Measures that act on the same feature of the building envelope save less when combined than the sum of each alone
- o Measures to improve mechanical system efficiency may have a mutually reducing effect
- o Improving the building envelope efficiency may decrease the seasonal efficiency of the heating system

- Domestic hot water measures may reduce each others' effects.

These interactive effects, as well as the site-specific nature of retrofits in the multifamily sector, make it particularly difficult to accurately estimate energy savings.

Load Management. Many electric utilities in addition to encouraging energy conservation to reduce demand are interested in load management to shift peak load and lower the need for new generating capacity. Different utilities face different peak loads for their region, and specific retrofits can reduce daily peaks or summer and winter peaks. While retrofit technologies exist for multifamily buildings that can shift peak load, e.g., storage space and water heaters, interlock devices, heat pump hot water heaters, it is likely that utilities will concentrate on commercial buildings and new multifamily construction, especially as new construction in this sector is predominantly heated and cooled by electricity.

Rehabilitation. The choices facing most multifamily building owners or developers are to do nothing, retrofit, rehabilitate, or demolish. Rehabilitation refers to the major restoration of a building, including structural, mechanical, and architectural features. Most cities operate programs to rehabilitate and conserve existing housing. Usually these programs are tied to code enforcement, and are designed to preserve the safety and health of building residents. Rehab programs are generally funded out of federal programs--primarily Community Development Block Grants. Regulations encourage the use of such programs in part for energy conservation. Energy is usually not the top priority, but is more likely to follow exterior repairs and code enforcement.

The combination of retrofit and rehab is especially important for multifamily buildings where the funding ceiling on rehab financing is much higher than for energy conservation repairs alone. Retrofit measures such as upgrading heating systems become feasible under rehab programs whereas they could not be attempted with lower level energy loans and grants. More importantly, retrofit activity cannot be isolated from major repairs in some of the most seriously deficient housing. What good is insulation or storm doors on a building that has a dilapidated roof? Typically, weatherization programs cannot touch such major deficiencies. Ideally, the time to install many retrofits is during major building rehabilitation.

2.5 Private Sector Activities

2.5.0 Overview

The relatively few documented studies of energy conservation in multifamily buildings indicate that retrofits can be very cost effective. Thus conservation investments by landlords should represent a good investment and energy conservation companies should be eager to service this market. This has not been the case however. While single-family houses and large commercial buildings have been serviced traditionally by the conservation industry, multifamily buildings have been largely ignored.

There has been no systematic analysis of private sector energy conservation activity in multifamily buildings; most available information is anecdotal. It is nonetheless clear that most of the major energy conservation companies have stayed out of the multifamily building sector. The National Association of Energy Service Companies (NAESCo), a group that serves as a focus of major companies in the energy conservation industry, reports that most of its members are involved almost entirely with commercial (and institutional) buildings.

The limited conservation effort currently taking place in privately-owned multifamily buildings can be broken up into four categories: (a) activities promoted by vendors of specific products (traditional businesses); (b) activities of utility companies; (c) activities of non-profit corporations; and (d) activities of private for-profit companies.

2.5.1 Traditional Businesses

Vendors of specific products typically offer multifamily building owners such items as replacement burners, separate boilers for domestic water heating, boiler controls for both steam and hot water heat distribution, distribution system controls based on outside temperature, thermostatic radiator valves for apartment temperature control for steam and hot water radiators. These are generally the same products available to the commercial building sector. Products generally targeted to single family buildings have been less successful in multifamily buildings. Examples include attic insulation, replacement of single glazed windows and patio doors with double-pane units, replacement boilers, etc. In addition, vendors have successfully sold products and services that reduce the landlord's direct costs for energy. Examples include Btu meters or other heat metering devices which allow each apartment to be billed according to the amount of heat "used", furnace and/or boiler in each apartment to replace a central heating or water heating system, etc.

Another response to energy cost awareness in multifamily buildings has come from trade and professional groups. Architects and engineers, both groups with a major impact on building energy use, have undertaken to train themselves to provide improved energy design and engineering services. The American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) is developing standards for the efficient use of energy in existing buildings. Two proposed standards are of importance to the multifamily sector, Standard 100.1P-Low Rise Residential, which includes multifamily dwellings not more than three stories in height, and Standard 100.2P-High Rise Residential, for all multifamily dwellings having more than three stories. Each of the proposed ASHRAE standards covers efficient energy use in the building's exterior envelope, heating, ventilating, air conditioning, domestic water heating, and lighting systems.

The Institute for Real Estate Management (IREM) has 30,000-40,000 members who manage about one-third of the units in privately owned multifamily buildings. They have produced workbooks on energy conservation measures for apartments and handbooks on metering conversion strategies, as well as a number of articles for their members on energy-related issues. Their estimate for the level of retrofit activity is that 10-20% of the larger, professionally managed buildings have received capital retrofits; the rate is much lower in other multifamily buildings. This corresponds to a sector wide activity level of 3-6% of the multifamily building stock receiving some capital retrofits.

2.5.2 Utility Companies

[The utilities discussed here are private, i.e., investor-owned utilities. Public, or government utilities, are covered in section 3.0]

Utility companies have been involved in multifamily retrofits at various levels. An increasing number of utilities are offering energy audits to apartment tenants and building owners. While some of these are related to CACS, some utility companies have already had ongoing programs. In Massachusetts, home energy audits of the RCS program are administered by Mass Save in a large part of the state. The audit procedure and algorithm were developed by Xenergy, a private company which also carries out the audits for Mass Save. As an example, Xenergy's XENCAP audit procedure is a mainframe program that is also in use by other utilities interested in auditing multifamily buildings. These utilities include Pacific Gas and Electric and Northeast Utilities who administer the audits in house. Since 1981, PG&E has audited 8,000 units in buildings of five units or more, and has weatherized 140,000 units of low-income multifamily housing.

In addition to direct involvement in energy conservation, utility companies have also been instrumental in financing the activities of some non-profit corporations, discussed below. Utility involvement in energy conservation in multifamily buildings has, however, been very small compared to their activity in the single-family sector.

2.5.3 Non-profit Energy Service Companies

A few non-profit corporations have recently become major actors in providing energy conservation services to multifamily buildings. They are often formed out of a need to retrofit housing of lower income tenants and have been able to generate financial assistance through utilities, state and/or federal government funds, or from other private sources. One of the main features of these organizations is that they take an integrated approach and provide a one-stop delivery mechanism for energy conservation, thus reducing the marketplace confusion created by the diversity of products and services. They look at a wide spectrum of energy conservation opportunities and generally address institutional obstacles as well through a number of innovative arrangements such as tenant education and rebate programs, and shared savings. Although they hold forth much promise, there are only a handful of such non-profit organizations, and none have so far been able to break even financially without significant financial assistance.

Non-profit energy service companies, because they need not worry about generating profits, have been able to concentrate on retrofitting lower income and smaller unit housing, areas often avoided by the for-profit companies. In addition to the groups described below, active leaders in the field are the Community Energy Development Corporation (CEDC) in Philadelphia, Pennsylvania, and Action Housing, Inc., in Pittsburgh, Pennsylvania.

The Citizens Conservation Corporation (CCC) in Boston, Massachusetts, is the oldest non-profit energy service company serving multifamily clients in the country. CCC offers a comprehensive one-stop shop approach aimed at rental housing with moderate and low-income residents. Their program now covers 2500 lower income housing units, with reported savings between 20 and 50%. An important aspect of the CCC program is that it is not oriented just towards landlords, but that tenants are recognized as equally important in developing energy conservation strategies. Consequently, tenant involvement and education is a large component of their work.

In 1983, the Energy Resource Center (ERC) in St. Paul, Minnesota, started an energy service company similar in many ways to the CCC. The Center incorporated in 1981 as a joint venture between the city of St. Paul and Northern States Power Company to provide conservation services. The ERC program has two components, one aimed at 1-4 unit housing, the other at 5 units or more. The Center relies on RCS audits for the 1 to 4 unit buildings, and uses in-house staff for the audits of the larger structures. Several innovative retrofits have been carried out on the heating systems of the buildings involved, but it is too soon to know the effectiveness of all these measures.

The Center for Neighborhood Technology (CNT) in Chicago, Illinois, began in 1978 with the goal of ensuring the available and affordability of basic needs among low and moderate income households in Chicago. They offer a range of energy related services which are targetted for the 5 to 49 unit, centrally heated and metered, low-rise structures, which account for nearly one quarter of

the city's housing. CNT has developed their own audit for these buildings, and plans to monitor their retrofitted buildings to confirm their accuracy.

To date they have audited and financed 18 buildings. Retrofit costs average $1500 to $1800 per unit, and are expected to result in 30 to 40 percent savings. Plans are already in effect to scale the program considerably. They anticipate reaching 7000 units over three years.

2.5.4 For-profit Energy Service Companies

There are relatively few private, for-profit, energy conservation companies. Some engineering firms do energy audits but offer no follow-up work. Vendors of individual items have already been discussed. A very few companies offer one-stop services including audit, conservation implementation, and follow-up service. Although some have had shared savings or guaranteed savings programs, we do not know of any for-profit company still offering them.

An example of a for profit energy service company is Benec Industries in New York City. They have been involved in energy conservation in multifamily buildings for many years. They do energy audits as well as act as general contractors on retrofit implementation. A Benec representative stated that heating system upgrading and balancing are the two areas where most of the energy savings are realized, and reported savings in heating energy ranging from 19 to 60 per cent.

Benec has been working in multifamily buildings ranging in size from 20 units to 100s of units. Buildings vary in height from 6 to 30 or more stories. They are currently doing 27 of the smaller buildings in a shared savings project for New York City's Department of Housing Preservation and Development.

Energy Retaining Systems (ERS), another energy service company, is located in New Jersey, and specializes in saving energy through low-level monitoring of hundreds of boiler rooms throughout the state. Their concept is based on sensitizing the right individuals in the buildings to what energy is being used and why. Monitoring is limited to energy billing data but the concept is based on keeping records of the system configuration in the boiler rooms and mailing postcards to ERS whenever settings are changed. Initially, ERS demonstrates the settings both to boiler room or building operator and the building owner. ERS staff also make site visits to spot check that the settings have been correctly reported. ERS is monitoring 300 boiler rooms in this way. Building owners pay a monthly flat fee based on the number of rooms working out to about 1% of the annual fuel cost.

A third for-profit company is Princeton Energy Partners (PEP), an energy conservation services company that serves both single-family and multifamily buildings. It is a franchise with a parent company and about fifteen franchises, mostly in the Mid-Atlantic states. PEP specializes in instrumented energy analysis using blower doors, infrared scanners, furnace analyzers, etc. The PEP companies also perform retrofits through their own staff or act as general contractor in managing retrofits installed by other contractors according to PEP specifications. Thus PEP acts as a one-stop energy audit and retrofit service. So far PEP has performed audits and retrofits on several thousand multifamily housing units.

2.6 Barriers to Multifamily Retrofit and Research Needs

2.6.1 Barriers to Retrofits

The lack of private sector activity--as summarized in the previous section--is due to a number of complex and interrelated barriers. These barriers exist for a variety of reasons, and while there are no simple solutions, understanding these barriers and identifying the research needs to overcome these barriers is an essential step in furthering energy conservation for this sector. These barriers have been broken down into four general categories: technical, informational, legal and regulatory, and economic, behavioral, and institutional.

Technical barriers

Technical problems in retrofitting multifamily buildings tend to be more complex and harder to solve than the problems in single-family residences because the multifamily stock on the average is older, in poorer condition, and more variable in building technology than the single-family stock. A major technical barrier is that owners are unwilling to invest in the costly retrofits to their buildings without guaranteed savings, and retrofit installers cannot afford to undertake the necessary research to demonstrate the performance of their products.

Technical expertise on multifamily retrofit performance is less available because technical efforts to date have concentrated in the past on the larger single-family and commercial building market. Single-family retrofits tend to be shell dominated, i.e., insulation and storm windows, while retrofits in commercial buildings are usually system dominated, i.e., boiler and burner retrofits. Multifamily buildings fall somewhere between the two, and because there has been less demand for services from this sector, contractors and energy auditors have less experience with these buildings.

Information barriers

Information barriers to energy conservation in multifamily buildings exist at several levels. Little information about the multifamily stock is available to planners and policy makers for making effective programs to further energy conservation. Conflicting information about the performance and costs of retrofits prevent building owners from making informed decisions. The lack of reliable, credible information about financing programs--particulary alternative financing methods--and on the reliability of companies and practitioners is another information barrier. Reliable information is required to motivate retrofit investments and this implies reliability with respect to particular building types, and not just multifamily buildings in general.

In addition to the lack of reliable information is the general inadequacy of effective means of information transfer. While owners and managers of large properties may read trade journals on building management, the large percentage of small building owners are not effectively informed. Existing means of information transfer are summarized at the end of this section.

Legal and Regulatory Barriers

An apparently important but hard to measure and little discussed barrier to multifamily retrofit is the presence of unenforced building code violations and other illegalities. Owners of buildings with building code deficiencies, unassessed and possibly unauthorized improvements, or altered meters have reason to fear that energy auditing and retrofit activity will lead to discovery and unfavorable consequences. It is the stock with the greatest need for retrofit that is most likely to have building code deficiencies.

Other legal and regulatory barriers include rent control laws that do not have provisions for rent increases reflecting the value to tenants of energy efficiency improvements, legal restrictions on metering individual apartments, and regulations that allow utility declining block rate structures that artificially make such metering uneconomic. Time-of-transfer requirements are another regulatory means for bringing the building stock to meet a higher level of energy performance. Little evaluation has been done on the effectiveness of such efforts, particulary where enforcement is not vigorous.

Economic, Behavioral and Institutional Barriers

Generally, a major barrier to retrofits and energy conservation in multifamily buildings is the split in economic interest between landlords and tenants. If the tenant pays for energy, then the landlord has little incentive to make physical improvements; while if the landlord pays, then tenants have little incentive to control usage. This split incentive is often complicated by the independent interests of building managers who do not pay energy costs but who wish to lower the effort involved in building maintenance and of lenders who get little benefit from successful retrofit projects, but who may incur risks associated with unsuccessful ones. Furthermore, the major split in incentives between landlords and tenants sometimes occurs in the context of conflict over other issues making cooperation with respect to energy conservation particularly difficult.

Metering is another important institutional barrier. When buildings are converted from master meters where the owner pays bills to individual meters where the tenant pays, the resulting reductions in energy costs are not always proportional to the reductions in energy usage due to rate structures that favor single large users. Under these circumstances owners may retain the master meter and install check meters for each unit and bill the tenant for their usage. This practice is illegal in certain states that prohibit individuals from "re-selling" fuel and electricity, the rationale being that unscrupulous owners could charge more for the energy than they are paying. The physical characteristics of multifamily buildings pose additional complications in metering conversions, for example, one unit may be maintaining low thermostat settings in order to borrow heat from adjacent units. An interesting question about metering conversions is the impact they have on future retrofits. Potentially cost-effective measures such as solar hot water and district heating schemes are all more amenable to central space conditioning and domestic hot water systems. Perhaps the most significant institutional barrier concerning metering conversions is that it is widely regarded as the single panacea for multifamily buildings in spite of its limitations.

Access to capital for improvements is also a major barrier to multifamily retrofits. A substantial fraction of multiunit owners are financially strapped. Lenders are reluctant to absorb the risks--especially long-term risks.

A large fraction of multifamily buildings are approaching the end of their economic life. In order to be financially attractive, improvements to buildings that may be approaching a major rehabilitation due to physical deterioration or abandonment due to physical or neighborhood deterioration or for which destruction to make way for new land uses is a possibility, must pay off more rapidly than improvements to otherwise similar buildings. Thus building and neighborhood deterioration and changing land use patterns all act as barriers to retrofitting.

To the extent that the rental housing resale market does not reflect the value to the owner of energy conservation improvements, this market failure is also a barrier to energy conservation since it limits the liquidity of the owner's retrofit investments and discourages such investment.

Tax laws also pose a barrier to retrofit activity in multifamily buildings. Energy conservation tax credits available for single family homes are not available for multifamily rental buildings. Under the U.S. tax code, landlords may deduct the annual energy costs of their properties from their income as business expenses. They receive no parallel benefit for investments in energy conservation. In addition, concern about property tax increases based upon reassessments triggered by energy efficiency improvements may also deter such improvements.

Concerns about security and privacy can make both tenants and landlords reluctant to have buildings open to strangers associated with retrofit activities. Fear of vandalism--whether aimless or a purposeful part of landlord tenant conflict--can act as a barrier to efficiency improvements potentially subject to vandalism.

Finally, property managers can hinder or support energy conservation efforts. Unlike owners or tenants, they tend to be isolated from paying energy costs. They define their jobs as working to minimize tenant and landlord complaints. A tenant complaint about lack of heat is more likely to be addressed by turning up the furnace than by insulating the apartment. Property managers may be reluctant to approach landlords with proposals for energy retrofits lest they appear as having failed in their maintenance duties or as adding to owners' expenses.

Table 2.6.1: Summary of Barriers to Conservation in Multifamily Housing

Technical Barriers

- owners unwilling to invest in retrofits with unknown performance and savings
- retrofit installers unsure how to retrofit certain building and equipment types
- performance of individual retrofits and packages of retrofits unknown
- evaluation and audit uncertainties
- health and safety issues

Informational Barriers

- lack of knowledge about building stock and retrofit measures already installed
- lack of knowledge about retrofit cost and performance
- lack of knowledge about occupant effects on retrofits
- few channels for dissemination
- few knowledgeable people
- conflicting information

Legal and Regulatory Barriers

- Existing building code violations
- rent control without pass-through
- utility and block-rate structure

Economic, Behavioral, and Institutional Barriers

- split incentives
- tax laws
- access to capital
- risk of uncertain savings
- hidden market value
- security and privacy
- property managers' incentives
- tenant/landlord relationships
- metering practices
- high turnover of tenants
- codes

2.6.2 Research Needs

Research in multifamily retrofits over the past five years, while successfully addressing some problems, has more often uncovered new problems that had not been anticipated. Significant advances have come from pioneering efforts of private sector practitioners who have been retrofitting buildings, relying on often crude engineering estimates (as well as seat-of-the-pants intuition), university studies that have evaluated metering conversions and other behavioral patterns, and research labs that have identified appropriate multifamily retrofits as well as developed instrumentation and analysis techniques for quantifying their energy savings. Nevertheless, the consensus of all parties contacted is that we know very little about how to advance the energy efficiency of multifamily buildings.

Research and Measurement

There are a number of research and measurement activities that can help overcome the barriers to multifamily retrofit. Basic to any research efforts would be a full characterization of the multifamily sector, including physical description, installed energy efficiency measures, ownership and occupancy. Additional information is needed on energy end-use patterns and trends in future energy use.

In order to reduce the uncertainty that makes multifamily retrofit investments risky, a careful program of monitoring and evaluation of retrofit activities is needed. The effectiveness of both physical measures and of entire retrofit programs need to be measured under a variety of circumstances. The measurement should be coupled with an effort to model nominal energy requirements in multifamily buildings. Such models can be used to help identify the most attractive candidates for retrofit activity, identify economically promising measures, and play a role in landlord-tenant dialogue, cooperative efforts, and devising equitable cost-sharing formulas.

In addition to evaluation and modeling, technical barriers can be overcome by research directed at developing new ways of dealing with particular problems. Among the candidate technology development projects are ones directed at improved ways of metering gas and hot water, at developing insulation materials that can be installed on the exterior of buildings, and at measures for building types identified as particularly difficult.

Possible research activities to overcome technical barriers are listed below.

Energy Use Patterns: How is the energy budget distributed to meet heating, cooling, domestic hot water, cooking, and other appliance needs in different parts of the country?

Evaluation: Very few retrofit activities have been evaluated as to performance and cost-effectiveness. The evaluations that have been done use different methodologies, so that a comparison of different projects is nearly impossible. Standard evaluation methods which would allow researchers and practitioners to compare and profit from each others' experience need to be developed.

Domestic Hot Water: Although it is suspected that domestic hot water accounts for a larger share of energy use in a multifamily building as compared with a single family structure, little is known about how domestic hot water is used in such a structure and about which technologies deliver hot water with the least waste of energy.

Tenant Behavior/Check Metering: Tenants play a major role in the energy use of a multifamily building, yet little is known about how to motivate them to conserve. Moreover, little is known about check metering and its implications for giving tenants specific information on their individual energy use.

Measuring Results: It is often quite difficult to determine how much a specific retrofit saves because the baseline keeps changing as tenants move out, maintenance practices vary, and often other retrofits are added in addition to the one being measured. The issue of estimated savings then becomes much harder.

Upgrading vs. Repairing Heating Plants: Determining when a heating plant should be scrapped rather than upgraded is an issue that is poorly understood at this point, but has major implications for the cost-effectiveness of the measure chosen.

Maintenance vs retrofit: Many retrofits combine maintenance and hardware installation, determining savings attributable to one or the other is difficult. Yet, once again, this information is necessary to determining the cost-effectiveness of the retrofit.

Building Idiosyncrasy: Are buildings so idiosyncratic that energy savings analyses must by their very nature address each building separately when addressing savings potential or are there some technologies whose applicability extend to a whole class of multifamily buildings?

Specificity of Savings Projections: Is it necessary to know the savings attributed to individual retrofit technologies or is the savings attributed to a group of retrofits generally applied to multifamily buildings sufficient?

Data Analysis Tools for Personal Computers: While predictive and analytic computer programs using main frame computers are useful to researchers who can often take advantage of university computers, they are limited in application to field practitioners who have neither the sophistication nor the equipment to support such programs. Translating these programs for use on personal computers and hand-held calculators has considerable potential for making these programs more useful.

Predictive Models for Energy Use: Models still do not exist that reasonably predict the heat loss characteristics of multifamily buildings.

Mechanical System Retrofits: Do vent dampers yield cost-effective savings, and, if so, how much? Do outdoor resets save energy when used in conjunction with steel-fired boilers, and, if so, how much energy do they save? How can systems be balanced to correct for over heating?

What Works in Actual Implementation: Do technologies and programs that look good in the lab or on paper actually work in practice?

Indoor Air Quality/Moisture: What effects do energy efficiency retrofits have on air quality and moisture condensation on building materials, and how can these be controlled?

Central vs. Individual Plants: Is it more energy efficient, particularly in very tight buildings to have a central heating, cooling, and/or hot water plant, or separate plants in each unit?

Property Manager-Compatible Retrofits: Since property managers ultimately will have responsibility for building maintenance, how should retrofits be designed to make them compatible to manager abilities and needs, and what type of training should accompany installation of these retrofits?

New technologies: How effective are air-to-air heat exchangers in limiting energy loss while ventilating as compared with ordinary fans? What is the potential for earth-coupled heat pumps in multifamily buildings, particularly in cold climates where conventional heat pumps are not very attractive? What is the potential for advanced window materials? Passive and active solar retrofits? Thermal storage and hybrid systems?

Information Dissemination

Both new and existing technical information on multifamily retrofits needs to be made more available to retrofitters, both those in public sector programs as well as the private sector contractors, energy service companies, and A&E firms. Reliable economic information on retrofits is needed by owners, lenders and tenants. Building operation information is needed by tenants, building managers and owners. Marketing strategy and program management information is needed by retrofit program managers. Some state and local government officials could benefit from information on model provisions for energy efficiency cost pass through for inclusion in rent control laws.

There is a major need for inexpensive auditing procedures and reliable labeling systems so that owners can identify attractive retrofit measures, so that prospective tenants can discriminate between energy efficient and energy inefficient apartments, so that building owners can recoup retrofit investments from tenants and from building purchasers, and so that risks to lenders are

reduced.

Mechanisms to support information exchange and technology exchange that were identified by LBL and others are discussed below:

Existing Organizations: Information should be disseminated through existing channels: Institute for Real Estate Management (IREM), state apartment associations/housing councils, lending institutions, secondary market owners, banks, association of apartment owners, and rent control boards are all possible candidates. HUD could handle information on Federally-assisted housing.

Direct Contact: One-to-one communication is one of the most effective means of transferring information. Experienced auditors and neighborhood groups are potential means of facilitating on-site information exchange.

Lending libraries: Practitioners could turn to lending libraries for diagnostic or evaluative equipment that they would otherwise not be able to afford, as well as technical advice on specific technologies. In exchange, they would provide needed field information on what works (and incorporate evaluative efforts to assess this information) to the research community. In addition, having a pool of consultants to whom program operators can turn for technical consultation and exchange would promote technology transfer needs.

Technical Reports and Case Studies: Documenting the types of retrofits that have been tried, where, by whom, and what the results were, if any, would be very helpful to many practitioners who find they spend considerable time reinventing the wheel.

Media: Newspapers, television, utility bill stuffers, accurate mailing lists, are all potential sources of information to reach a wide range of users. Newsletters on what types of retrofits are being done presently and what types of workable technologies are available could also be helpful. Several existing newsletters or publications might already fill some of these needs; these include *Energy and Housing, Energy Auditor and Retrofitter,* and *Energy User News.*

Trade Journals: such as *Journal of Property Management* or *Multifamily Quarterly, Buildings, The Wholesaler, Consulting Engineer,* and others, are important sources for practitioners, building owners and managers who aren't likely to read journals exclusively on energy concerns.

Data bases could be expanded to meet some of these needs. The LBL data base, BECA, which has compiled information on energy savings resulting from retrofits, is one such data base. Though it has relatively few data points on multiunit structures, BECA could prove increasingly useful if the results from in-field retrofits were added to the data base. Another useful data base is the DOE RECON, which is an extended bibliography on conservation-related publications and articles.

Workshops: can involve all the methods discussed above. They provide a setting for one-to-one communication which can be complemented by the presentation of technical reports and case studies.

Unknown: This listing is by no means exhaustive. Several groups contacted felt that we still haven't reached critical sectors, e.g., small building owners, with information because we lack the proper channels for doing so. On-going efforts to determine effective means for information exchange should be a high priority.

Legal and Regulatory Changes

A number of legal and regulatory changes could reduce barriers to retrofitting. Among these are modifying or eliminating rent control laws that do not contain energy efficiency improvement cost pass through provisions, improving the income and property tax treatment of energy efficiency improvements in rental housing, and enacting and enforcing minimum standards in local building codes.

Electric utility regulations that allow declining block rates not reflective of cost differences for multifamily dwellings, provide a barrier both to retrofitting and to individual metering. Other regulations that restrict individual apartment metering also interfere with potential schemes for allocating retrofit costs in accordance with benefits.

Regulations related to subsidized rehabilitation of multifamily buildings could require that such rehabilitation include all cost effective energy conservation measures.

Vigorous enforcement of existing building codes and assessment laws can help eliminate undiscovered illegalities that make building owners reluctant to allow audits or undertake retrofits.

Financial Incentives

Financial incentives can reduce or eliminate economic barriers to retrofit and may help overcome other barriers. Such incentives could include loans, loan guarantees, loan interest subsidies, tax credits, grants or assessment breaks. Case studies on where these have been used successfully would be useful.

Summary of Research Needs

The table below gives a summary of the research needs based on the literature review and the information gathered from the organizations contacted. A more extensive listing of the research needs is given in Appendix B.

Summary of Research Activity Needs in Multifamily Sector

Analysis and Evaluation:

- evaluate existing computer models; how useful are they for multifamily stock?
- develop models for electric buildings
- need improved utility bill analysis techniques
- what is importance of vacancy/turnover rates?
- need better air leakage models
- what are needs of additional groups, e.g., builders, investment criteria people, building owners, tenants, managers?

Characterize Building Stock:

- need better description of stock, low-rise vs high rise, infiltration/ventilation rates
- need characteristics of rental industry and building owners
- what are energy use patterns? idiosyncrasies?

Retrofit Performance Data:

- need monitoring protocols
- what is performance of heating system retrofits—vent dampers, balancing, outdoor resets, etc.?
- what is performance of shell retrofits—insulating problem buildings, masonry walls, flat attics?
- what is the performance of hot-water retrofits?
- what is the performance of cooling retrofits?
- what are selection criteria? costs and savings?

Information and Technology Transfer:

- how can existing organizations be used?
- what other sources are useful--direct contact, technical reports, data bases, workshops?

Case Studies:

- demonstrate new technologies for existing buildings
- show how to retrofit old buildings
- how to implement major capital improvements
- show what works in actual implementation

Operations and Maintenance:

- how effective are energy management systems?
- what are implications of fuel switching?
- what are effective temperature controls--thermostats vs resets?

Marketing and Financing:

- what are long-term effects of shared savings?
- what are innovative sources of financing?
- what are building owners investment criteria?

Health and Safety:

- what are indoor air quality issues related to retrofits?
- what moisture problems result from retrofits?

Audits and Design Tools:

- how to improve audit accuracy and reliability
- need design tools to estimate costs and paybacks

Institutional Issues:

- how to address tenant/owner barriers
- need for regulatory elements
- how to increase public awareness
- how to design retrofits to have non-energy benefits as well for owners and tenants

Behavior and Metering:

- what is cost-effectiveness of sub-metering?
- what is effect of metering on future retrofits?
- what is appropriate feedback for tenants? rebates?
- what are effective educational tools?

Special Buildings:

- what are special needs for Federally-assisted housing?
- what can be done in oil-heated buildings?
- what are special needs for small multifamily buildings?

How these needs have been addressed by government activity is the subject of the following section.

Section 3.0

GOVERNMENT ACTIVITY

IN THIS SECTION: Overview of government activity in multifamily housing: sector characterization and analysis; research on existing building measures and approaches; research on new retrofit measures; technology transfer and information dissemination; financial incentives; regulatory activities.

3.0 Government Activity

The purpose of this section is to highlight government-supported research and technology transfer activities whose main focus is to address barriers that have delayed improved energy efficiency in the existing multifamily housing stock. While this is not a comprehensive survey, it is intended to cover a broad spectrum of activities which have been supported. The majority of activities that will be covered will be federal programs. Exemplary state and local programs and public utility programs will be covered, as appropriate. No attempt was made to make a broad search for example programs beyond DOE and only readily available materials were used.

This section will provide an overview of the kinds of activities that have been supported in the past, and the major results of those activities.

In order to better highlight specific research concerns, this section has been organized around major research and technology transfer issues rather than around program descriptions. The major issues are: Sector Characterization (3.1); Determining and Monitoring the Impact of Conservation Measures (3.2.1); Modeling and Audit Systems (3.2.2); User/Occupant Behavior and Decision-Making (3.2.3); Evaluation of Delivery Mechanisms (3.2.4); and Basic Research (3.3). Any research work that has been sponsored by programs in these categories will be discussed in the sections indicated. Program description information is provided on Technology Transfer (3.4); Financial Incentive (3.5); and Regulatory (3.6) activities in the sections indicated.

3.0.1 Overview of Government Activities in Multifamily Housing

Emphasis on programs specifically dealing with multifamily housing issues is a fairly recent occurrence at the federal, state/local, and utility levels. Initially, all residences were treated together, and no special emphasis was placed on multifamily buildings or tenants. The earliest federal work attempted to understand how investment decisions were made by owners of these properties. Except for research done in the late '70s on how to allocate energy costs to tenants in master-metered buildings, it has only been in the last three or four years that programs were specifically designed to reach both owners and tenants of multifamily dwellings.

Because multifamily buildings cover a wide range of physical structures (garden apartments, low-rises, and high-rises), they can benefit from retrofit measures common to both single-family homes and commercial buildings, as well as representing problems and solutions unique to multifamily buildings. Multifamily building ownership varies from single individuals to large, corporate investment funds, to government agencies. The majority of tenants are middle and upper income, but multifamily buildings represent a major source of housing for many low-income people. All of these factors contribute to the problematic nature of devising programs which address the multifamily sector.

The federal agencies that have played the largest role in multifamily programs are the Department of Energy (DOE) (primarily technical assistance and weatherization), the Department of Housing and Urban Development (HUD) (primarily grant programs for the rehabilitation of low- and- moderate-income housing), the Department of Health and Human Services (HHS) (low-income energy assistance) and the various armed services in improving the energy efficiency of their housing stock by 20% over 1977 energy consumption. Due to the large portion of lower income residents in many multifamily structures, programs have been aimed at reaching owners of buildings which house primarily lower income tenants.

State and local governments, frequently using federal funds, have taken a lead role in this area, and have devised a wide variety of programs to address upgrading of multifamily structures. The most active have been the states of California, Connecticut, Illinois, Indiana, Maryland, Massachusetts, Michigan, Minnesota, New York, Ohio, Pennsylvania, Wisconsin, and the cities of Baltimore, Boston, Chicago, Minneapolis, New York City and Pittsburgh.

Programs of the four federal utilities and municipal and rural utilities will be covered in this section. (Activities of private investor owned utilities and their various research arms have been covered in the private sector section). Among the major public utilities in the country, the Tennessee Valley Authority and the Bonneville Power Administration have been the most active.

Internationally there has been a greater emphasis on savings in multifamily buildings. Residents in countries like Switzerland and Sweden occupy primarily multifamily housing, and the buildings sector represents the largest energy use for those countries. Sweden has developed incentives to encourage landlords to make improvements that will have mid- to long-term payoffs. Switzerland has concentrated on studying improvements to hydronic heating systems. Under the auspices of the International Energy Agency's Annex ll, a sourcebook is being produced for member countries that will provide information on diagnostic procedures, target values for building performance, lists of energy conservation opportunities, and the impacts those opportunities represent, either singly or in concert with others. This sourcebook should be available in early 1986.

The following sections will describe work that has been performed by all public sectors to understand and address the barriers to improve the efficiency of multifamily housing (both from a structural and a behavioral point of view), the types of technologies that have been developed or modified to address multifamily structures, and the types of technology transfer, financial incentive, institutional support, and regulatory programs that have been put in place to make the impact of these barriers on greater energy efficiency in multifamily buildings.

3.1 Sector Characterization and Analysis

Activities included under this heading are:

- Collection of basic statistics on multifamily building stock--number of buildings, square footage, income distribution of residents, type of construction, age, energy consumption, ownership, regional distribution.
- Compilation of specialized data bases (e.g., retrofit performance).
- Development of simulation models to predict aggregate impacts of different policy approaches.
- Identification of information and incentive needs of occupants and owners.

This kind of information is used to assist in determining the quantity of energy that could be saved in the multifamily sector, the potential importance of programs addressing specific areas of potential savings, general conservation program planning, evaluation, and utility load and future energy demand forecasting.

Sector characterization has received more attention than other research efforts regarding multifamily housing, but much of the data is very superficial and not easily comparable.

3.1.2 Federal Government Activities

The separation of multifamily issues from residential issues in general did not take place until well after most federal energy programs had been underway to respond to the 1973 energy crisis. Some early characterization studies were conducted, but the majority of efforts began with the 1980s.

- The first attempt to address this sector as a separate issue was a study prepared by Booz-Allen-Hamilton in 1979 for the DOE Buildings and Community Systems Office called *Achieving Energy Conservation In Existing Apartment Buildings*. This was a hurried document needed to fulfill requirements of the National Energy Conservation and Policy Act (NECPA). Much of the data for this study was taken from the 1976 Bureau of the Census housing data. The main purposes of the report were to determine the investment criteria of apartment owners and ways of providing owners with information on cost-effective energy conservation measures.
- In 1978, Honeywell conducted a study of Automated Energy Management Systems for Small Buildings for DOE to determine which types of buildings were most conducive to these types of controls and the market acceptability of them. Apartment buildings, schools and small commercial buildings under 75,000 square feet were targeted. The study identified the need to develop cost-effective integrated control systems and specified the types of controls needed for each type of building and a strategy for marketing to them.
- Between 1978 and 1982, the Energy Information Administration conducted the $1 million survey called *Residential Energy Consumption Survey* on a yearly basis and issued reports on household characteristics and national and regional data on energy consumption and expenditures. This probability sample of 4500-5500 households includes households that live in multifamily units (approximately 10 percent of the sample) but does not provide much separate analysis of this sector. The 1981 survey has a larger sample of multifamily respondents and more information on apartment buildings, and the 1982 study does provide limited analysis of the location, type of mechanical equipment, and income of people who live in units where energy costs are included in their rent. Data was gathered in 1984 and the results of that analysis will be available in 1986. BERD has provided funds for further analysis on a variety of multifamily issues. 1987 is the next year that another survey is likely to be conducted.
- The Residential Utility Billings System project begun in 1979 provided some sector characterization information. This project is described in more detail in Section 3.2.4.2.
- In December 1980, the DOE Office of Policy and Evaluation supported a workshop organized by the Federation of American Scientists on *Multifamily and Rental Housing* to address the problems in this area through discussions between federal agencies and some local government representatives. It was concluded that financial barriers (both access to capital and lack of financial incentives) were the primary problem, though addressing these alone would not be sufficient. Other areas of major importance were: better and more wide-spread availability of technical information, involvement of community groups, identification of cost-effective improvements, determination of the amount of savings possible due to remetering as opposed to retrofitting, developing alternatives to expensive retrofit procedures, and guidelines for when to replace all or part of an HVAC system. Information was tabulated on the characteristics of multifamily housing in the jurisdictions of participants.
- In 1980, Hittman Associates undertook an *Analysis of Institutional Mechanisms Affecting Residential and Commercial Building Retrofits* for the DOE Office of Policy and Evaluation to identify and evaluate the impact of barriers for occupants and owners. The main barriers identified were fuel pricing policies, high finance costs, inability to evaluate contractor and retrofit product performance, lack of one-stop marketing systems, lack of customized information, lack of non-economic incentives, and use of first-cost criterion as the major basis for decision-making.

- *BECA-B Data Base.* Begun in 1980 by BERD funding to Lawrence Berkeley Laboratory (LBL), this effort has gathered in one place as much information as possible regarding the measured results of weatherization efforts by utilities, low-income programs, research studies, and multifamily retrofit programs. The data base contains information gathered using many different methodologies, on approximately 60,000 households regarding level of expenditures, types of measures installed, measured changes in energy use, and payback results. This information is then used to determine the energy savings of different measures. A wide variation in savings has been reported, with average savings of about 20-30% above pre- retrofit usage, resulting in a real rate of return between 13% and 31%. More information is contained in *Technical Performance and Cost- Effectiveness of Conservation Retrofits in Existing US Residential Buildings: Analysis of the BECA-B Data Base.* LBL-17088.
- In 1981, Market Facts prepared *Situation Analysis--Multifamily Housing* for DOE, summarizing available federal data, disincentives, and opportunities in this sector. It reaffirmed much of the anecdotal information on disincentives voiced at the 1980 conference, and identified information programs, elimination of energy costs as a tax deduction, and implementation of a 20 percent investment tax credit as the most cost-effective approaches for Federal involvement in the multifamily area.
- In 1981, SERI undertook two studies to understand the perception of landlords regarding energy conservation and solar energy. One investigation described general real estate investment criteria and how these would affect landlords' investments in energy efficiency. The other conducted thirty-five (35) in-depth interviews with landlords in Boston, Chicago, Denver, and San Francisco. In addition to characterizing the rental housing of those cities, the study found that the type of metering employed was the single most important indicator of a landlords' propensity to invest in energy conservation measures with those having master-metered buildings or subsystems being the most inclined to invest. Other findings showed that the size of the landlords' holdings indicated the types of barriers that were perceived, with large holders having easier access to information, capital and loans. Most landlords preferred to finance measures out of current cashflow which led to primarily inexpensive measures being installed. Interest in packaged auditing and installation services was of most interest to landlords of master-metered buildings who did not have enough property to employ a regular maintenance crew.
- In 1982, the Office of Technology Assessment issued a seminal report for the House Committee on Banking, Finance and Urban Affairs entitled *Energy Efficiency of Buildings in Cities.* This report covered all types of buildings. It provides information on the total amount of energy consumed in multifamily buildings, the structural and mechanical characteristics of multifamily buildings, the amount of energy it would be technically feasible to save, the amount that is likely to be saved, the types of measures that appear to have the best payback, and the types of buildings and building ownership most likely to adopt energy conservation measures. It pointed out the very important role of building operation and maintenance in achieving savings. Major barriers to increased activity appeared to be the lack of data on how retrofits perform in individual buildings; the inability to predict with reasonable accuracy how measures would perform in a particular building, making such retrofits appear quite risky; and the high cost of borrowing money. It made recommendations on how to overcome those barriers.
- The Department of Housing and Urban Development sponsored workshops conducted by the Brookings Institution in 1980 and 1981 and subsequent analysis of *Energy Costs, Urban Development and Housing.* This effort was a broad policy look at all forms of energy and how their future use and cost would impact the urban environment. A chapter on "Energy and the Existing Stock of Housing" looked at the engineering evidence for reducing energy use, the effects of rising prices on householders, occupants and owners, and concluded that the United States economy can adjust to higher prices without massive Federal programs. In another chapter on "Home Energy Costs and the Housing of the Poor and Elderly", information is provided on weatherization activities and energy expenditures undertaken by this

sector, adjustment to price increases, and the impact of public weatherization programs. It concluded that in 10-15 years most buildings would be weatherized and that only the poor living in individually metered buildings or master-metered buildings in declining neighborhoods would still be impacted.

- In 1984, an in-house DOE task force, with contractor assistance, put together *Multifamily Buildings: A Draft Technology Transfer Analysis and Plan* to define specific target audiences within the multifamily sector. It provides information on: number of units, energy consumption, characteristics of low-income households, the amount of conservation that has taken place already, and barriers to adoption of techniques. The report includes an extensive bibliography of information about multifamily housing.
- Also in 1984, Lawrence Berkeley Laboratory (LBL) undertook a literature and data *Review of Energy Use and Conservation in Public Housing* for BERD/ARD and HUD. This report looked at data available which described building characteristics and end uses for public housing in different geographic and climatic zones. It also described information available on: retrofit activity to data, measured results of some of that activity, review of behavioral and institutional issues, methods of choosing conservation measures to be implemented, and identified areas that deserved additional research attention. It pointed out several differences regarding energy use and tenant profiles of public housing units and other multifamily dwellings.
- As part of the draft (1980) and final (1983) regulatory analysis for the Commercial and Apartment Conservation Service (CACS) attempts were made to analyze the energy saving potential of five unit plus apartment buildings and provide average data on: ownership characteristics, who pays the utility bill, location of buildings within differing climate zones, building age, unit square footage, heating fuels, and use of air conditioning.
- Two conferences were co-sponsored by DOE's Office of Building Energy Research and Development's (BERD) Applications Research and Development Branch (ARD) during 1985 to continue the exploration of issues and solutions to multifamily housing problems. These conferences address building owners and managers, city and state public housing agencies, utilities, and non-profit agencies.

  The first conference was held in February in Philadelphia to learn about what makes programs successful in the areas of marketing, finance, performance contracting, audits, technologies, and how to deal with problem housing. Proceedings will be available later in 1985 and will include a series of case studies that will help others replicate successful programs.

  The second conference was held in California in May and will focus on elements of successful marketing programs, setting up a multifamily program at the state and/or local level, day-to-day management of conservation programs including resident participation, public housing programs, utility programs, financing opportunities, and private sector experience.
- The BERD Architectural and Engineering Branch has recently awarded a contract to the National Association of Homebuilders (NAHB) with the Institute of Real Estate Management (IREM) to analyze and determine the most important energy conservation strategies in mid-rise and high-rise multifamily buildings. A total of 15 "base case" buildings will be modeled in five climates and for four past and future time periods to assist with providing detailed design guidance on major rehabilitation and new construction of such buildings for architects, engineers, and developers. The project is expected to be completed by the end of 1985.
- Military Multifamily Housing: LBL and others are currently developing a computerized standard for new construction for both single-family and multifamily dwellings. It can also be used to determine what additional action would be needed to meet a particular standard if information on original measures are known. It optimizes life-cycle cost and calculates net present worth.

- Also at LBL there is an on-going effort to develop computer models of representative low-rise (less than 4 story) multifamily buildings, and to analyze their energy conservation needs by conducting parametric analyses using DOE 2.

3.1.3 State/Local Government Programs

As part of their planning process for multifamily programs, a few states have gathered some information informally about the characteristics of this housing sector, but we do not have information on any major efforts that have been completed. The need for this kind of information may be less at the state level, given already in-place information sources such as state housing departments and property tax records. The quality and availability of this information is uneven at best, however. Some state utility commissions do maintain their own energy forecasting models, but we are not aware of any that focus specifically on this sector.

Some efforts that have been completed or are about to begin are:

- A 1985 study by LBL for the California Energy Commission and DOE providing information on Low-Income Households and Energy Use in California. While the majority of the information relates to transportation energy, there is information on the characteristics and home energy use of these households including dwelling unit characteristics, type of fuel used, saturation of certain appliances and energy conservation measures. The CEC also separates multifamily from single-family in their energy forecasting
- The North Carolina Alternative Energy Corporation (NCAEC) will soon be releasing an RFP to conduct market research in rental housing to obtain demographics on the units and their owners and tenants, to obtain attitudinal information, and to assist in determining appropriate incentives. Results are expected by the end of 1985.

3.1.4 Public Utility Programs

There are four major federal utilities–the Tennessee Valley Authority (TVA), the Bonneville Power Administration (BPA), the Western Area Power Administration (WAPA), and the Southeast Power Administration. In addition, there are a large number of public utilities that serve regional, state, and local areas. Many of these started as part of the Rural Electrification Program (REP). Almost all of them carry out conservation programs of some kind due to federal, state or local mandates or to meet their own load management needs.

Both TVA and BPA maintain survey and modeling staffs that frequently undertake studies or updates of previous studies to understand physical, demographic, and attitudinal aspects of residential housing and energy consumption. This kind of information is used to develop information and other technology transfer programs and to estimate the impact of those programs on saving energy and on peak load requirements. None of these are specifically aimed at multifamily housing, but do include relevant information. For instance:

- BPA is currently compiling a comprehensive data base to support its assessment and load-forecasting activities. It will contain survey data collected from its Pacific Northwest Residential Energy Survey (PNWERS), U.S. Census and other federal demographic and economic data, as well as using internally generated inputs and out-puts from the model. It is expected to be operational by the Spring of 1985. The PNWERS survey was first conducted in 1979, and will be conducted every five years.
- End-Use Load and Conservation Assessment Program (ELCAP): This program will collect and analyze hourly electricity loads for each of the major end uses in samples of residential and commercial buildings to assist in providing better system-wide forecasts. About 700 single-family residences, 25 multifamily residences, and 250 commercial buildings will be monitored. Instrumentation should be complete by the Spring of 1985. The data gathered will be used to: characterize electricity demand and peak by end use; characterize the penetration of energy conservation measures and explain the differences in observed savings; and support estimates of the costs associated with selected energy conservation measures.

3.2 Research on Existing Building Measures and Approaches

Most building research to date has sought specific answers to specific problems often by finding new applications for existing technologies, or seeking improvements in existing technologies. A wide range of research approaches has assisted in finding these answers.

This section covers such activities as: determining and monitoring the impact of potential measures for multifamily housing, improved modeling and auditing systems, occupant behavior and user decision-making, and evaluation of delivery mechanisms. The majority of work has been in the modeling and auditing areas, and in occupant behavior and user decision-making, especially as it regards building owners.

3.2.1 Determining the Impact and Potential of Retrofit Measures

Such activities as laboratory testing, monitoring building equipment in operation in the field and analysis of utility bills are covered here. Although DOE has sponsored a large amount of research directed at determining the impacts of various conservation measures, little has been directed specifically toward multifamily buildings.

3.2.1.1 Federal Activities

DOE and others have sponsored some programs to monitor performance of retrofits in multifamily housing. Sometimes these have looked at specific sectors–low-income housing; or at specific measures–added insulation. Most have been very small scale–under 20 units; the number and kind of data points monitored have also varied. Much of the work has been done to support the needs of CACS. Some examples of activities are:

- Although no documentation has been found, it appears a study was conducted for DOE in 1976 of several "twin" apartment buildings around the country of which one was master-metered and the other was individually metered, and consumption comparisons were made.
- Information gathered under the RUBS program described in Section 3.2.4.2 is the largest data set with information on 2600 units.
- A 1977 effort by the Institute of Real Estate Management for the Federal Energy Administration, *Energy Cost Reduction for Apartment Owners and Managers*, a combination report and workbook, presented data taken from individual apartment projects on the performance of a variety of conservation measures–replacement of showerheads, reduction of hot water temperatures, timers on hot water circulating pumps, relamping, balancing of heating systems, setback thermostats, boiler maintenance, storm windows, pipe and tank insulation, and roof insulation.
- Also in the eighties, Princeton University undertook some work for DOE to monitor the performance of retrofit work in multifamily buildings. They selected a small number of several different multifamily building styles, conducted an audit aimed primarily at identifying air leakage paths, made improvements to seal off those paths and then measured the energy savings. They also looked at several different types of equipment for monitoring the performance of multifamily buildings comparing them for cost, installation time, ease of programming and flexibility.
- Starting in 1980, NBS carried out a number of studies aimed at providing a more consistent way of measuring the costs and benefits of buildings and building systems. Methodologies were developed to address life-cycle costing, benefit/cost and savings-to-investment ratios, net benefits and internal rates-of-return, and simple and discounted paybacks. These techniques were developed to help designers and decision-makers select more cost-effective overall building designs and a variety of both energy and non-energy building systems. This information is being used to develop a Building Economics Standard by the American Society for Testing and Materials (ASTM). These methods are primarily applicable to large buildings.
- NBS work to establish criteria for insulation, vapor barriers, storm windows/doors, caulking and weather-strippin, clock thermostats, replacement windows/glazing which would be used in the WAP.

- 1978-81 work by LBL for DOE and BPA to understand the impact of retrofits on indoor air quality. A mobile lab was developed to measure air quality before and after retrofits. A number of pollutants from heating, cooking, and other sources were identified in concentrations higher than those recommended for health and comfort.
- In 1981, Hittman Associates prepared *Evaluation of Estimated Energy Conservation Measure Costs and Benefits in the Multifamily Sector* for DOE's Office of Conservation Policy. This literature review tried to quantify the potential impacts of retrofitting multifamily buildings and estimating the impacts of occupant behavior on energy use. Using primarily engineering estimates, the report developed a classification scheme for multifamily buildings, identified per unit energy savings and installation costs associated with retrofits of space and water heating and space cooling, and calculated savings-to-cost ratios for retrofitting different building types in different climate regions.
- Also in 1981, HUD Region I prepared an internal study, *Cutting Costs by Cutting Consumption: Solving the Energy Problem in Multifamily Housing in New England.* The study documents the energy consumption of almost 500 projects in the region according to various factors such as building type, size, age, management and savings from conservation improvements in selected projects.
- In 1982, Argonne National Laboratory (ANL) conducted the *Apartment Building (Multifamily) Use Study (ABUS-1)* to gather information on the energy use characteristics of multifamily buildings that qualify under the CACS program. The information was used to help develop an appropriate audit and determine the applicability of various energy conservation and renewable energy measures and O&M procedures. To do this, energy use surveys were conducted at 63 sites in seven cities representing six climate zones. On-site walk-through audits were conducted, including determining awareness of energy conservation. The report gives information on annual energy use by fuel type, floor area, structural characteristics, equipment in use, and the types of energy improvements that could be made. It indicates that most had not taken any conservation steps. A 1984 study took a closer look at seven of these buildings and compared audited results with computer-simulated data to determine the most appropriate measures for low-rise buildings. ANL is now looking at the impact of vent dampers in apartment buildings.
- Since the first ABUS study, Oak Ridge National Laboratory (ORNL), has undertaken more in-depth studies (ABUS II) and developed models of one low-rise and one high-rise prototypical building based on the sixty-three (63) sites studied earlier. These buildings have been simulated in different climate zones, using three different infiltration rates, and with a variety of different utility rate structures. After a base case is established, CACS measures are "added" individually or in combination, and energy savings and paybacks calculated. The results of this study will be available during 1985. They will be used to provide general guidelines and methods for estimating annual energy savings from CACS retrofit measures.
- For the Weatherization Assistance Program (WAP), the National Bureau of Standards (NBS) used existing standards and engineering estimates to determine: the potential impact of conservation modifications to boilers/furnaces, burners, and controls, energy management systems, tune-ups or repairs, maintenance methods, damper modifications, turbulators and waste heat recovery devices for multifamily buildings.
- On-going data collection by LBL under ARD's Retrofit Performance Monitoring Program. The two main aspects of this program, which is DOE's first major effort supporting multifamily field monitoring, are: 1) establishment of standard monitoring protocols to gather detailed data before and after retrofit measures have been installed. DOE hopes to encourage others to use this protocol once it has been finalized so that data collected by many different entities can be compared easily. 2) on-site monitoring of federally assisted housing projects in San Francisco, Denver, and New Jersey.

- The BERD/Building Energy Sciences Branch is supporting ongoing research into the development of inexpensive devices for measuring infiltration and detecting the presence and concentration of indoor air pollutants in buildings. Passive samplers, as they are called, have been developed to detect formaldehyde (now commercially available), and to measure infiltration (a perfluorocarbon tracer). Refinements have been made to existing radon, nitrogen dioxide, and water vapor samplers and work is progressing on a carbon monoxide sampler. These passiver samplers require no on-site instrumentation, allowing a large number of sites to be inexpensively monitored in the field with analysis conducted later in a laboratory.
- The Navy also carries out an extensive research program aimed at meeting the needs of its facilities for reduced energy consumption. Their $7 million yearly budget covers both building and industrial conservation projects and is overseen primarily by the Naval Civil Engineering Laboratory (NCEL) at Port Hueneme, California. Their work is primarily applicable to multifamily-type buildings and covers such things as: a test and evaluation program on the thermal performance of concrete block and metal buildings; instrumented data gathering on some multifamily buildings; exploration of moisture problems in exterior walls; methods of air infiltration reduction in family housing; compilation of generic information on the thermal properties of insulation materials; fire and weather testing of sprayed foam insulations; evaluation of infrared, radiometer tracer gas and passive monitors for gathering data on insulation coverage, air leakage and moisture penetration; testing of lighting products for retrofit; evaluation of high-efficiency space heating, domestic hot water, ventilating and air conditioning equipment; impacts of whole house fan installations; evaluation of boiler controls; and evaluation of solar domestic hot water systems. Most of their work is published as Technical Notes to enable facilities personnel to put the information into practice on individual bases.

3.2.1.2 State and Local Government Activities

Although a few states and cities have been very active in developing programs to address the needs of this sector, they have not sponsored much monitoring of the impacts of these programs. One exception is the City of Minneapolis, which has monitored a number of rental housing units to determine which measures work best in 5-50 unit buildings and looked at the savings associated with use of outdoor resets in hydronically heated buildings.

3.2.1.3 Public Utility Programs

Public utilities have the capacity to obtain a fair amount of information through their billing records, and have done so for general customer classes. However, since multifamily buildings are usually part of a larger customer class, there has been little separate information gathered on this sector.

BPA does have one project underway which will gather some information specifically on multifamily buildings. As part of its overall End Use Load and Conservation Assessment Program (ELCAP) BPA will collect and analyze hourly electricity load data for each of the major end uses in samples of residential and commercial buildings. Twenty-five multifamily residences will be monitored to characterize electricity demand and peak by end-use; penetration of energy conservation measures; savings associated with selected measures; and estimated costs associated with selected measures.

3.2.3 Improved Modeling/Audit Systems

Both building models and audits attempt to understand how energy is used in buildings. Models are usually employed to simulate energy use for existing buildings or buildings under design on an hourly, daily, or yearly basis, whereas audits are used to characterize the energy-related components of existing buildings and to determine opportunities for more efficient energy use. Both activities have developed a variety of tools ranging from mainframe computer programs to simple checklists.

Many different organizations have developed and used audits. Until the advent of the Residential Conservation Service (RCS), most audits were developed by professional engineers or utility organizations and were primarily used for larger buildings or industrial processes. With the implementation of the RCS and the Commercial and Apartment Conservation Service (CACS) and the development of the model audits, both the public and private sector have developed audits for multifamily buildings.

Because of the wide diversity of building characteristics in the multifamily sector, it is hard to develop a single model or audit that can apply to all of these situations. Generally, this sector is treated in an aggregate manner in models that deal with total residential energy consumption. With regard to audits, smaller buildings have been treated as single-family dwellings, and larger buildings as commercial buildings requiring professional engineering audits.

3.2.3.1 Federal Activities

The main efforts here have been to modify the Residential Conservation Service (RCS) audit to accommodate small apartment buildings and to provide validation services to support the Commercial and Apartment Conservation Service (CACS).

Oak Ridge National Laboratory (ORNL) has modified the original RCS audit to apply to buildings containing four or more units which are individually heated or cooled. The key modifications are for estimating infiltration rates, buffer space correction factors for unit dwellings, and estimating heat gain from solar radiation. This is a walk-through audit that can be used by utilities or building owners. DOE reviews the programs submitted by private firms, states, and utilities for the CACS program to determine their applicability to centrally heated and/or cooled multifamily and commercial buildings, the assumptions and calculations used, and their consistency with accepted practice. So far, five such audits have been received and two have been validated for national use.

Although there are no building simulation models which address only multifamily buildings, the federal government has sponsored the development of a large number of models with different purposes. Some are still in use and others have been superceded by later efforts. Among the better-known modeling efforts are:

- DOE-2 - Developed by LBL to provide energy-use analysis of residential and commercial buildings. This mainframe computer system requires a large amount of computer storage. DOE-2 calculates hour-by-hour energy end use of a building by determining the dynamic heating, cooling, and lighting loads and simulating the response of primary energy conversion and secondary HVAC equipment to those loads. It predicts annual consumption and can be used to analyze existing buildings or design new ones. It is intended to be used by architects and engineers with a basic knowledge of the thermal performance of buildings. It can also calculate the life- cycle costs of buildings and/or equipment. The latest version is the DOE-2.1B.
- In another effort, LBL has developed a Program for Energy Analysis of Residences (PEAR) to make the capabilities of DOE-2 more accessible through a microcomputer program. It covers 5 residential building prototypes in 800 locations, and allows the user to make adjustments based on the characteristics of the actual house being analyzed or designed. It can then analyze the energy and cost-effectiveness of a variety of conservation and solar measures. Additional development will allow a similar analysis of two low-rise apartment building prototypes.
- BLAST 3.0 - Developed by the U.S. Army Construction Engineering Research Laboratory (CERL) and LBL. This mainframe computer system can provide sequential hourly calculation of space loads. HVAC system operation, whole building energy costs, and life-cycle economics by the interaction of four in-line subprograms. Its main advantage is its capability to analyze the energy use of a variety of passive solar systems.

- SERI Residential Energy Simulation (SERIRES) – this hourly simulation program was originally developed at the National Center for Appropriate Technology as SUNCAT and was later modified and expanded by SERI. Its main advantage is that it uses much simpler inputs than either DOE-2 or BLAST and is particularly suitable to residential-scale buildings.
- NBS/TARP - Thermal Analysis Research Program is a whole building energy simulation program used primarily by researchers. It has developed some of the more sophisticated algorithms for analyzing the flows of energy within a building.
- DEROB - Dynamic Energy Response of Buildings was originally developed at the University of Arizona and later supported by DOE and SERI to simulate thermal performance of architectural structures. Its main advantage is its ability to assess trade-off questions during the design process. It is primarily useful for new building design and for integration of passive and active solar features into building design.
- BEVA - Building Energy Vector Analysis is a new, simplified approach to yearly hour-by-hour building energy simulations. It was developed by SERI for the DOE Passive and Hybrid Programs and uses parameters calculated from short-term monitoring of specific building elements or calculated from a building description. It requires fewer inputs than other simulation models and is more useful for analyzing actual building performance data and predicting building performance before and after retrofit measures have been installed.
- Also, the Navy has sponsored the development of two computer simulation programs. One is for use in designing or redesigning buildings to take advantage of natural cooling and ventilation; the other (CEL-1.1) deals with conservation of electric lighting through daylighting, task lighting, and more efficient lighting products.
- DOE and NBS have sponsored many refinements in the use of infrared thermography which has played a large role in providing qualitative images of the sources of heat losses in buildings. While used extensively as a research tool, utilities and some private energy consultants use it as an aid in their auditing programs, either through on-ground inspection of individual structures or aerial inspection of a large number of buildings.
- Another diagnostic technique which has received federal research support has been the development of Pressurized Blower Door testing which allows for greater accuracy in determining the sources of air infiltration and leakages, and in assisting contractors to seal off those sources.

3.2.3.2 State and Local Government Activities

For the most part, state and local governments have not gotten involved in modeling and audit development. A few exceptions are:

- The City of Minneapolis has developed an audit for buildings in the 5-50 unit range as part of its regulatory requirements that multifamily buildings be upgraded at the time of sale.
- The New York State Energy Research and Development Administration (NYSERDA) has undertaken a wide range of activities aimed at understanding energy in multifamily buildings. It has: developed an audit, identified institutional barriers to energy conservation in multifamily housing, determined the cost of undertaking an energy conservation program for the 291 state-assisted public housing authorities, demonstrated the use of energy management systems in high-rise multifamily complexes, studied the reliability and accuracy of electrical submetering systems, and studied the effectiveness and acceptability of low-flow showerheads.

3.2.3.3 Public Utility Activities

Many utilities will provide audits to their customers on request, but do not necessarily advertise this availability, nor have they developed audits specific to multifamily buildings. A 1983 survey by ORNL did not uncover any utilities that had developed audits specifically for this sector, although it appears at least one has been developed since then.

With the advent of the CACS program, utilities and states have proposed methods for auditing multifamily housing. Many are relying on privately developed audits to address this sector. Each state or utility can develop its own list of measures that will be covered by its audits within the CACS guidelines.

3.2.4 Occupant Behavior and User Decision-Making

Issues covered here are decision-making criteria and information needs of occupants, owners, and managers; energy use behavior of occupants; and motivational factors of both tenants and owners. This area, relative to multifamily housing, has not been studied to the same degree as have similar issues in single-family housing. Several studies have looked at the investment criteria and financing sources available to owners, and a few studies have looked at tenant behavior. In general, it has been concluded that owners have little incentive and difficult access to capital to make improvements, and that tenants use less when they have to pay directly for the energy they use.

3.2.4.1 Federal Activities

DOE has sponsored several studies of apartment building owner criteria for investing in energy improvements. A typical one was a literature review in 1981 in conjunction with some workshops by Market Facts, entitled *Energy Retrofit Decision-Making in the Commercial and Multi-Family Sectors.* The study found: owners and managers have a need for expert unbiased advice on energy products and services; product guarantees and assurance of vendor viability were more important than current financial incentives, which were deemed insignificant; many apartment owners expected to convert to condos; obtaining funds was a significant hurdle, whether they were from banks or from owner associations; energy-efficient retrofits are not perceived as improving market value.

The most extensive study of tenant energy use was conducted as part of the RUBS program described below.

3.2.4.2 Residential Utility Billing Systems Program (RUBS)

This eight-year project, conducted by the Institute for Behavioral Sciences at the University of Colorado, produced two reports and a variety of tenant information materials with a variety of purposes. The primary purpose of the effort was to identify and evaluate methods of encouraging energy conservation in master-metered buildings and to inform those involved in multifamily housing of these results. The first report, published in 1980, *Encouraging Energy Conservation in Multifamily Housing: RUBS and Other Methods of Allocating Energy Costs to Residents,* contained information about the number of units that are master-metered or sub-metered, their energy consumption patterns, results of different approaches to obtaining energy savings in master-metered and sub-metered buildings, and problems associated with achieving savings in this sector. Pilot projects using the mathematical formula developed by RUBS for allocating costs were conducted in Denver, and in Providence, Rhode Island. Similar information was gathered from private sector participants in four other cities. Energy use was studied in 2600 units, along with resident reactions, cash flow for the property and potential abuses of the program. A *Cost Allocation and Decision Guide* and a *RUBS Operation Manual* for property managers and owners were also developed.

Overall average savings were less than had been predicted and varied considerably depending on the end-use being addressed, e.g., 5 percent for space heating, and 22 percent for lights and appliances.

Another RUBS report issued in 1983, *Tenant-Paid Energy Costs In Multifamily Rental Housing: Effects on Energy Use, Owner Investment and the Market Value of Energy,* is a comprehensive look at tenant payment of energy costs, especially heating costs in multifamily housing by examining records of 83 properties between January 1979 and November 1981 in ten states. In addition, a survey was conducted by the Institute of Real Estate Management showing that: tenants who pay separately for energy use less energy; owners of buildings where tenants pay the energy bill are only slightly less likely to make improvements compared to owners of other properties; energy costs are topics of rental advertising; prospective tenants do inquire about energy costs; frequently the rents of energy-efficient properties are lower than those of energy-inefficient

properties, but not by the full amount of the energy cost difference; mode of payment greatly affects how building owners and tenants interact to affect energy use; and that tenant payment for energy use can reduce consumption over the long term. The report also examined the implications for policy-making regarding: mode of payment, the implications for programs that seek to encourage owner investment in energy improvements, and the appropriate role for formula billings in distributing tenant energy costs.

3.2.4.2 State and Local Government Activities

There has been some work carried out by state and local governments in this area, although we are unaware of any major studies. While there may be some regional differences in building stock and the proportion of low-income residents, it is assumed that national studies addressing these issues, have widespread applicability.

NYSERDA and NCAEC have conducted some small projects and NCAEC is currently sponsoring a major study of multifamily housing that will address some of these issues, along with many others.

3.2.4.3 Public Utility Activities

Both TVA and BPA have conducted research into user behavior and decision-making. Both TVA's and BPA's regular residential surveys include renters and some special analysis on this sector. They have not yet done special studies specifically aimed at the multifamily sector. Generally other public sector utilities have not sponsored this type of research.

3.2.5 Delivery Mechanisms Research and Evaluation

Activities covered here are efforts aimed at determining ahead of time which delivery mechanisms would be most effective for specific programs or audiences, and at evaluating delivery programs already in place.

Because there has been relatively little emphasis on separate programs to address this sector until recently no one has done a major assessment of the effectiveness of programs that are in place.

A number of general program reviews such as that conducted for the CACS regulatory analysis have pointed out the lack of concerted effort, the fragmentation of the effort between many federal and state agencies, and the lack of interest by the private sector in these buildings except for the largest complexes.

3.2.5.1 Federal Activities

Work sponsored by DOE includes:

- A study that was conducted to look at private sector involvement with multifamily and commercial buildings was carried out for DOE in 1981 by Market Facts for the Building Conservation Services Division, *Situation Analysis--Energy Retrofit Industry.* This report characterized the energy retrofit industry for both the commercial and multifamily sectors and concluded that it did not yet provide very convincing services or products to these sectors.
- As part of the Technology Transfer Working Group on Multifamily Housing described earlier, an "Analysis of the State Role" was made underlining the important role states could play, especially if support were provided to assist them in: identifying out-of-state resources; sharing accomplishments; receiving information on the latest technical developments; translation of material for local use; marketing assistance, and assistance in training and staff capability building.

  The overall report further concluded that savings are not being realized due to lack of information credible to building owners and managers on the effectiveness of conservation measures, available financing and reliable contractors; lack of an information network to disseminate information to owners and managers; poor timing and expensive availability of financing for retrofit measures; and lack of coordination among agencies involved. The report made recommendations for improving efforts in all these areas.

It also prepared guidelines for how to develop different kinds of technology transfer programs by presenting analytic models for how to effectively carry out technology transfer, and then by providing guidelines for product-oriented technology transfer programs, user-oriented programs, and provider-oriented programs.

3.2.5.2 State/Local Government Activities

None known.

3.2.5.3 Public Utility Activities

None known.

3.3 Research on New Retrofit Measures

Until recently, there has been little emphasis on research directed towards new retrofit measures for multifamily buildings. It has generally been assumed that measures that apply to either single family or commercial buildings will also apply to multifamily buildings.

At the time of the 1973 oil embargo, very little was known about energy use in buildings beyond the broadest overview. Although there were a variety of products on the market—primarily insulation and storm windows—this was not an area in which industry research dollars were being concentrated or new products being introduced.

Since 1973, a large number of new and improved products (as well as some of suspect usefulness) have reached the marketplace; no-cost/low-cost techniques for reducing energy use have been refined, and much has been learned about what happens to fuel once it leaves the distribution lines and enters building usage.

The concept of basic research is usually associated with the understanding of physical processes as opposed to the development of specific products which is more in the domain of applied research. The construction and operation of buildings incorporate many different technologies, and it is difficult to characterize them in terms of a research stage. It is even more difficult to characterize any building's research as being pertinent to a particular building sector. Nonetheless there are examples of generic research which is much broader in scope but which will affect the development of building products. Much of this research has been a joint venture between the government and private industry.

3.3.1 Federal Activities

The Department of Energy has supported major research programs ranging from basic physics research on energy phenomena to demonstration programs employing new products or techniques. In some cases, research has been carried out by government laboratories, in other cases, by private industry or universities.

Major programs have been carried out in the areas of roof systems, wall systems, infiltration and ventilation, window systems, and other building components. Other programs have been more product-oriented, concentrating on thermally activated heat pumps, refit of oil furnaces, and development of improved insulation materials. Initially, this work concentrated on understanding basic energy flows in buildings and how they impacted energy consumption. Current work is looking more at impacts such as generation and control of humidity. While much of this work has some applicability to multifamily buildings, most of it has concentrated on single-family structures. Some examples of the kind of work that has been funded specifically on multifamily buildings are:

- HUD is providing information on indoor air quality in super-insulated multifamily buildings to local rehab officials.
- The DOE Passive and Hybrid Solar Energy Group has had a program for the last several years on Retrofit and Multifamily Issues that has looked at hybrid solar systems, active charge/passive discharge systems and the use of phase change materials with sensible storage for this end use sector. In addition, much of the work in the Solar Thermal Transport area is aimed at solving retrofit and multifamily building problems.

Some of the broader building and equipment research programs that study issues applicable to all building sectors are:

- Envelope Programs:

  Roof Systems--Improvement in the scientific and technical basis for the development and construction of more energy-efficient low slope roof systems, including identification of heat loss source and methods of reduction.

  Infiltration and Ventilation--Development of techniques for detecting, monitoring, and modeling infiltration and air change rates in residential and commercial buildings.

  Wall Systems--Development and improvement of the scientific and technical basis for the development and construction of more efficient wall systems, including identification of heat loss sources and establishment of standard test measures.

- The Energy Conversion Equipment Program has provided over $103 million since FY78 to develop new heat pump concepts, new lighting devices and ballasts, new refrigeration and appliance technology, and study combustion system technology. Some specific accomplishments in these programs are:

  Heat Pumps and Refrigeration and Appliance Technologies--Developing of several new approaches to improved heat pump performance and alternative heat pump technology. Areas of interest have been ground and water coupled heat pumps, dynamic losses and field performance of refrigeration systems, novel cycles and refrigerants, absorption heat pumps, internal combustion heat pumps, and heat- engine-driven heat pumps.

  Combustion Systems Technology--Developing the technical basis for substantially increased energy conservation in gas, liquid, and solid-fueled space heating equipment. A number of prototype burner systems with low firing rates for modulating oil burners have been developed. Also, corrosion agents have been identified in condensing systems that have serious implications for the longevity of the materials used in these systems.

  Lighting Technology--Developing the technical basis for reducing the electrical energy consumption of lighting by 50% by the year 2000 without compromising illumination requirements through studying such areas as low-pressure and high-pressure lamps, and developing lighting controls and efficient lighting system design methods. Several products for both residential and commercial use have been developed, including a solid state ballast for gas discharge lighting, which has enjoyed good market success. It also funded the development of the CONTROLITE computer program for lighting design.

  Equipment Integration--Looking at improvements that can be made in the distribution of energy from the equipment source, interactions among equipment subsystems, and impacts on health and productivity.

  Energy Conversion and Utilization Technologies (ECUT)--Conducting research in four disciplines: thermal sciences, materials sciences, biocatalysis, and tribology in order to improve the efficiency of energy conversion and end use for all energy areas. It also solicits proposals for development of innovations and has awarded several for developing building materials relating to daylight concentrators, holographic window films, and lightweight insulating concrete.

  LBL/Windows and Daylighting Program since 1977 has undertaken an extensive research effort on many aspects of the impact of windows on energy use in buildings and the potential for using daylighting in buildings. Work that is particularly applicable to existing buildings concerns the thermal performance of insulating systems for windows and regression analysis of residential window performance.

  f2Materials/Components Research An objective of SERIs passive research program is to develop new materials and mechanisms that will enhance the efficiency of passive components (and systems) in residential and commercial buildings. Research is being performed on electrocromic windows and solid-phase change materials. The control of light transmission through glass panes using electrocromic coatings will allow designers to tune glazing systems to changes in light levels. Working to improve the thermal insulation of windows by

incorporating a vacuum between the glazing layers and by depositing an infrared reflective coating on one of the glass surfaces is also being performed. Storage research is aimed at improving the control and efficiency of passive components and systems.

In addition, much of the research carried out by DOE's Solar Thermal and Passive and Hybrid Programs has studied issues that are relevant to retrofit in existing buildings.

3.3.2 State/Local Government Activities

Most states have not funded much research in the area of developing new conservation measures for buildings. There are some major exceptions, however. Widely varied programs doing research not only in conservation, but frequently in alternative and traditional energy sources, as well, are carried out by the California Energy Commission (CEC), the Florida Solar Energy Center (FLSEC), The Montana Department of Natural Resources (DNR), several New Mexico research institutes associated with universities in the state, the New York State Energy Research and Development Administration (NYSERDA), the North Carolina Alternative Energy Corporation (NCAEC), And the South Carolina Energy Research and Development Corporation (SCERDA). It is not known which of these may be addressing multifamily issues.

3.3.3 Public Utility Activities

Very little research except as noted below has been carried out by public utilities, and none of what has been carried out is specifically oriented to multifamily buildings.

- BPA has undertaken several major conservation-related research efforts. Their areas of concentration have been on understanding the sources and impacts of indoor air contamination and identifying ways to mitigate this. They have supported space-heating heat pump research and testing of energy conservation techniques for water heaters.
- TVA has carried out considerable technology-oriented research in the heat pump and solar areas.

3.4 Technology Transfer and Information Dissemination

The kinds of activities utilized in this area include workshops, conferences, technical publications, user publications, "hot lines", clearing- houses, exhibits, articles in the trade and general press, audiovisual presentations, workbooks, public service announcements, personnel exchange, and direct technical assistance. It also covers demonstration programs aimed at providing information to owners and residents, or building industry participants on how to undertake certain kinds of retrofits.

The major multifamily activity on the federal level has been the co-sponsorship of conferences that allow practitioners to learn from each other about designing programs that are more effective in meeting the needs of this sector.

For the most part, a number of state and local governments have been the most active in developing programs to address this sector.

3.4.1 Federal Activities

The main actors have been DOE and HUD. DOE's activities have consisted of demonstrations, practitioner conferences, and dissemination of self- help information. HUD has engaged primarily in demonstration programs.

There are two general DOE technology transfer programs which states have used to undertake some activities in the multifamily area. Those programs are:

- State Energy Conservation Program (SECP)--This program was legislated in 1975-1976 to promote energy efficiency and reduce growth in energy demand by helping states and territories to implement their comprehensive plans for state operations.

- States are provided with energy education materials, training manuals, technical reports, and seminars and workshops in general energy topics.
- Energy Extension Service (EES)--This legislated program kicked off most of the outreach efforts undertaken by the states. The program has been active in all states since 1980, and was developed to provide small-scale energy users such as homeowners, small businesses, local governments, and public institutions with specific information and technical assistance to use conservation measures and renewable resources (EES is working to develop new technology transfer activities to help promote knowledge about the best ways to conduct energy audits and provide small business services to low-income groups).
- In addition, based on Section 509 of the ECPA legislation, DOE had planned to implement an Innovative Delivery Mechanism Demonstration project which would provide motivation to renters and building owners similar to that provided by the residential energy tax credit. A good deal of background work was performed before the project was cancelled.

In the area of information dissemination, a wide variety of printed materials have been developed through DOE and/or HUD sponsorship:

- The RUBS program produced two reports and a variety of renter materials that were aimed at helping building owners institute effective energy conservation programs, including a variety of ways to bill for tenants' share of energy costs.
- The Federal Energy Management Program (FEMP) has producted books and workshops for architects and engineers, *Energy Conservation in Existing Buildings* and, with the AIA, *Energy in Redesign*. These are currently being updated. Although not aimed specifically at the multifamily sector, both of these provide generic information useful to retrofit situations.
- Each of the armed services has carried out extensive programs to educate their facilities' personnel and contractors on retrofitting the housing on their bases.
- With DOE funding in 1980, the Greater Washington Board of Trade produced the *Energy Conservation Manual for Multifamily Dwellings* for use by apartment owners.
- In 1982, HUD produced the most extensive workbook in this area *Energy Conservation for Housing* covering a step-by-step energy conservation survey that Public Housing Authorities should use and a list of energy conservation opportunities which could be considered for multifamily buildings.
- DOE also sponsored, with IREM, the *Energy Cost Control Guide for Multifamily Properties*, which provides information on low-cost/no-cost measures, as well as more capital-intensive activities.
- The Weatherization Assistance Program has produced a handbook for rental property owners and managers on effective measures for multifamily buildings.
- In 1984, the HUD Energy Division undertook an initiative to "Reduce Heating Costs in Multifamily Rental Housing." The purpose of this initiative was to bring greater coordination between all HUD programs and other programs in making rental housing more energy efficient as part of on-going rehabilitation efforts, HUD organized a series of meetings in cities to help those responsible for assisted housing identify problems and solutions. City and state HUD recipients are being encouraged to develop specific programs. Meetings were held in New York, Chicago, and Boston. HUD field offices are setting up additional meetings. Cities have continued with the following: the development of energy conservation case studies, energy use targets for different building sizes, awards programs, preparation of educational materials, testing of energy analysis procedures, training courses for managers, research on resident behavior, use of Solar Bank funds to make improvements, and plans to improve audits, explore shared savings potential with energy service companies, and increase loan availability.

- FEMP has established a Clearinghouse on Federal Energy Shared Savings Contracting to provide bibliographies, a referral network, and sample procurement documents to public sector organizations interested in using alternative financing for conservation efforts.

In addition, there are a number of general federal information programs that are used by renters, building owners, program managers and researchers.

- Conservation and Renewable Energy Inquiry and Referral Service (CAREIRS) - This service responds to public inquiries over a toll-free number and provides general information about these energy sources. The service develops consumer publications and distributes these, as well as providing referral to other programs and people for additional information.
- Office of Scientific and Technical Information/-Technical Information Center (OSTI/TIC) - Operated by ORNL for DOE, this office maintains a number of national and international data bases regarding energy- related technical reports on completed projects as well as research in progress. It maintains mailing lists for automatic distribution, responds to inquiries, and provides on-line searching capability through RECON. ANL maintains the National Energy Software Center for TIC, which provides information and support services for and copies of a wide range of energy software.
- National Technical Information Service (NTS) - This Department of Commerce service sells copies of technical reports generated by most federal agencies. Reports are available in either microfiche or hard cover.
- National Energy Information Center (NEIC) - The Energy Information Administration's arm for responding to inquiries regarding a wide variety of statistics on all aspects of energy use and production in the country.
- Solar Technical Information Program (STIP) - Operated by SERI, it provides solar and conservation information to the scientific and technical communities.

3.4.2 State and Local Government Activities

Although most state and local governments have not yet addressed this area, there are a number of notable exceptions which have set the standard for effective multifamily programs. Some of these are:

- New York City which has developed brochures and training services for building superintendents, landlords, and tenants to save some of the $27-million energy bill for 35,000 repossessed units managed by the City's Department of Housing Preservation and Development. They have also awarded a few "shared savings" contracts for these units.
- City of Minneapolis which has developed information, research and regulatory programs, as well as special financing programs with HUD funding.
- The States of Minnesota, California, and Connecticut all provide information in conjunction with their special financing programs which will be described in Section 3.5.2. In addition, several states have been active in providing workshops and counseling to multifamily building owners and managers as part of their EES activities.
- NYSERDA has an on-going program aimed at demonstrating the energy savings that can be achieved through performance contracting at a variety of multifamily buildings in the state. It has spent approximately $700,000 on this effort so far and has published some reports on the initial phases of the project.
- In addition, the federally funded, state-run Energy Extension Service kicked off most of the outreach efforts undertaken by the states. The program has been active in all states since 1980, and was developed to provide small-scale energy users such as homeowners, small businesses, local governments, and public institutions with specific information and technical assistance to use conservation measures and renewable resources. Many states have conducted workshops for renters and for multifamily building owners under this umbrella program.

- States and localities have formed a number of organizations to assist them in sharing information about their programs. Some of the most active are the Council of Local Energy Officials, the National Governor's Conference Energy Committee, and the Housing and Urban Development Community Association Directors.

3.4.3 Public Utility Activities

Public utilities have not attempted special programs aimed at this sector. A few exceptions are described below:

- TVA has been actively addressing rental units for almost three years. For 1985, this effort has targeted the performance of 42,000 audits in the 760,000 rental unit population. TVA is working closely with community organizations, PHA's, and property managers to increase interest in having audits conducted, and they hope that 27% of those audited will undertake recommended measures. The number of rental units in multifamily buildings is unknown.
- One innovative response to audit delivery for the RCS program has been MASS SAVE. The majority of investor-owned and public utilities in the State of Massachusetts set up this non-profit organization to deliver the required audits and to market retrofits to customers throughout the state. In 1982, MASS SAVE began a multifamily program and by 1983 had reached 484 buildings.

3.5 Financial Incentives

This has been the area of greatest activity, particularly at the state and local level. Some are expansions of single-family programs, and others are aimed directly at the multifamily sector. The types of incentives used are quite varied--e.g., tax credits, loans, grants, reduced-interest financing through loan insurance, municipal bonds, "shared savings," and payments for energy saved. One often cited problem is the lack of coordination among the providers of these programs.

3.5.1 Federal Activities

Although there are a variety of federal tax credits available, their use is severly restricted in the case of multifamily buildings. Both DOE and HUD have been active in financing programs which can reach multifamily housing. Most DOE programs are extensions of single-family programs aimed at meeting the needs of low-income households. Most HUD programs are basic housing and urban development financing programs which can be used for energy purposes if local recipients so desire.

Examples of the tax credits, DOE and non-HUD programs are described below. HUD programs are covered in Section 3.5.1.1.

- Investment tax credits and other tax incentives available to building owners are:
  - The regular investment tax credit of 10% (however, this credit does not apply to buildings and structural components considered to be real property, except for oil and gas boilers, (meaning that very few improvements to multifamily buildings would qualify).
  - The rehabilitation credit of 15-25% depending on the age, and historical nature of the building (only certified historical residential buildings could qualify).
  - The energy investment credit of 10-15%, depending on the type of investment. No conservation measures apply, however, solar and wind properties qualify for a 15% credit.
  - Accelerated depreciation (ACRS) of 5 years (because most energy savings measures are considered to be real or structural property, they must be depreciated over 15 years or more).
- Renters can use the residential 15% tax credits for energy improve- ments made to their apartments, but the IRS has not conducted an analysis that would indicate the level of use by renters. It is assumed to be fairly small.

- Similarly, DOE's Weatherization Assistance Program (WAP), provides funds to furnish cost-effective conservation measures for the dwellings of low-income families, and some of this is used in rental and publically-assisted housing.

  To be eligible for this assistance, a household must be at or below 125% of OMB's poverty guidelines or meet one of a variety of other federal income tests. Maximum expenditure per household is $1600. There are an estimated 12.6 million households eligible for this assistance. For a multifamily building to be eligible, 66% of the units must meet low-income requirements. The majority of programs are run by non-profit community development organizations.

  Through 1984, $1.037 billion had been spent by DOE on this program, reaching over 1.3 million households. Average cost of weatherizing has been $769 per home. Currently, funding is about $190 million per year. An estimated 125,000 multifamily units have been reached by this program since its inception at a total estimated expenditure of $96 million.

- In mid-1984, WAP instituted a weatherization Innovative Financing project to test three different approaches to financing retrofits in low-income multifamily housing. These pilots are being conducted in New York, Pennsylvania, and Minnesota, and are testing the following models:

  - Shared savings--State assists landlords in identifying and negotiating agreements with shared savings companies and monitors the project during the contract term

  - Bank participation--Reduced interest loans for subgrantee who packages the loan and the improvements for eligible landlords

  - Development of energy services companies (ESCo) by a local agency--Local agency establishes an ESCo which performs energy conservation retrofit for a fee or a share of the savings. companies establish such businesses by arranging financing for the buildings with the companies being paid out of energy savings

  All models will prepare "how-to" guides to assist others who wish to replicate this program.

- Through state agencies, the Department of Health and Human Services administers the Low-Income Home Energy Assistance Program, (LIHEAP) which provides direct cash payments to people unable to pay their utility bills. Fifteen percent of the money can be used for weatherization at state discretion. Although there are no restrictions on the use of these funds per se, many states have chosen to funnel this money through the WAP program, where restrictions do apply. An agreement must be reached between the landlord and the tenant as to the length of time before the rent can be raised due to weatherization improvements only. This has served as a major disincentive for using the funds in the multifamily sector.

- Energy Conservation Investment Program (ECIP)-- This program provides funding for energy improvements in DOD facilities. The majority of housing is made up of multifamily buildings although specific numbers of units are not known. An annual budget of about $210 million goes into energy upgrading all types of buildings. Overall in 1983, DOD claimed an 11.9% reduction in Btu/ft^2 since 1975 in all buildings and facilities. In addition, DOD has conducted several studies of innovative financing and has an aggressive third-party financing program underway.

- National Corporation for Housing Partnerships-- A federally chartered, privately owned corporation which provides capital and project management to preserve and develop single-family and multifamily housing for low- and moderate-income families.

3.5.1.1 Department of Housing and Urban Development (HUD) Programs

HUD has a number of programs that have been used by states and cities to address multifamily housing energy conservation programs. In general, there is nothing to prevent most of HUD's housing programs from being used for these purposes, as they are broadly aimed at providing funds to upgrade the private housing stock or improve public housing facilities.

It has been left up to local jurisdictions to request funds for energy conservation purposes. General HUD programs that can be used in this fashion are:

- Multifamily Rental Housing, Section 207--Provides mortgage insurance to construct or rehabilitate rental housing with 5 or more units in predesignated areas.
- Mortgage Guarantee and Home Improvement Loan Insurance--Provides insurance for major and minor improvements and most energy improvements are specifically allowed.
- Multifamily Rental Housing for Low and Moderate Income-- Finances construction or major rehabilitation for qualifying projects through mortgage insurance.
- Urban Development Action Grants (UDAG)--Helps cities and counties with severe economic distress to stimulate economic recovery in conjunction with the private sector.
- Community Development Block Grants (CBDG)--Provides annual grants to cities and large (over 50,000 population) counties on a formula basis to carry out a wide range of community development activities including building retrofit. Small cities are funded on a discretionary basis through their states.

Other HUD programs more specifically aimed at encouraging energy efficiency are:

- Comprehensive Improvement Assistance Program (CIAP)/HUD Modernization--Since 1980, this program has worked with public housing agencies to save energy. HUD uses a formula to determine how much to reimburse Public Housing Authorities (PHA) for energy costs as part of overall operating expenses. Additional costs/savings are split on a 50/50 basis. Through 1982, $112.4 million had been spent primarily in the Northeast, Midwest, and Southeast to address the $1 billion PHA national energy bill. In 1984, HUD began a $4 million study as part of this effort to determine the national cost of fixing, adding to, or redesigning the 11,000 buildings maintained by PHA's, including energy improvements. A sample of 1,000 buildings will be thoroughly studied to calculate these costs.
- Oil Heating Retrofit Program--This program was designed to modernize oil heating systems in public housing and to install and test new energy conserving devices. In 1980, $28 million had been spent on both of these programs to sixty-one PHAs.
- Solar Energy and Conservation Bank--Funded in 1983 for almost $30 million, it provides loan subsidies or grants to moderate and low- income individuals for conservation and solar improvements. States apply for and work with local financial institutions or other qualifying organizations to distribute the funds. In twenty-two states, apartment buildings with four units or less are included, and in twelve states, complexes with five or more units are included. The FY85 funding for this effort is estimated at $15 million. Most programs have no specific outreach to multifamily units. If Solar Bank funds are used, the recipient cannot also claim the residential or other energy tax credits.
- Energy-Financing Demonstration--In early 1985, HUD worked with sponsors of section 202 (housing for elderly) to enter into 10-year shared savings contracts in two high-rise projects. HUD hopes to use these examples to encourage others in assisted housing to enter into similar arrangements.
- Rental Rehabilitation Program (RRP)--provides cities with 50% of the rehabilitation costs for lower income properties and rent subsidy vouchers for Section 8 Certificate housing. Starting in 1984 $300 million is available over a two-year period and cities can design programs that best meet their needs.

3.5.2 State/Local Government Activities

States have developed a wide variety of programs and funding sources for increasing financial incentives to improve the energy efficiency of multifamily buildings. Local governments have been the most active in using these incentives, primarily in city-owned housing. Some examples are:

- One of the most often used sources of funding for these programs is what is known as Warner Amendment funds or oil overcharge settlement funds. Each state gets a share determined by the volume of refined petroleum products consumed in each jurisdiction during the 1973-1981 time period. The states have wide authority to use the funds through the State Energy Conservation Program (SECP), the Energy Extension Service (EES), the Institutional Conservation Program (ICP), the Weatherization Assistance Program (WAP) or the Low-Income Home Energy Assistance Program (LIHEAP).
- In 1984, the Michigan Energy Department undertook a survey of energy efficiency financing programs in the United States and found that 23 states had or were planning some type of energy efficiency financing program, of which 17 served multifamily clients. Eighteen of these programs offer financial assistance, while others undertake demonstrations or provide written materials and training.
- The State of New York has chosen to use its oil overcharge allocation to provide low-interest loans for multifamily retrofits. Its research arm, NYSERDA, has developed thirty case studies of "Performance Contracting", two of which cover multifamily buildings.
- The City of New York reduces a landlord's city tax obligation if qualifying conservation measures are installed.
- Minneapolis, Baltimore, and Jersey City have all floated municipal bonds to subsidize private retrofit expenditures. Minnesota and Connecticut have had similar state programs.
- Since 1978, Minneapolis has tried a variety of programs aimed at addressing this sector. It currently provides a subsidized audit and financing to landlords to undertake retrofits. It uses Solar Bank funds for buildings of five units or more, and has established a special fund with UDAG and utility backing to finance smaller unit improvements. There has been a brisk demand for audits and loans in the larger buildings.
- Minnesota has developed a loan insurance program to provide help to properties that meet certain requirements to get financing from lending institutions. This effort is currently being pilot tested in Minneapolis.
- California has used $200,000 of its oil overcharge money to allow private and public entities to offer energy consulting services for 2-10 unit properties. Another $500,000 is being used in a variety of ways to leverage financing for interested landlords.
- The State of Connecticut provides loans at 4 percent interest (or free, if 50 percent of tenants are low income) on conservation improvements up to $10,000 in buildings of 5 units or more. The money comes from a bond-financed state loan fund. Loans are depen- dent on a CACS audit being performed. Since 1979, interest has been high, and the state expects to reach 2500 units under current funding before increasing the fund. It has also dedicated a large portion of its LIHEAP funds to provide weatherization of multifamily units.

3.5.4 Public Utility Activities

A number of financing programs have been attempted by this sector as described below. In addition, many of these utilities provide rebates to people who allow the utilities to use a variety of load management devices on their property and equipment.

- TVA has had an active program in this area since 1977 and has tried a number of approaches to get consumers to reduce their electrical consumption. Programs have ranged from 25 percent rebates for three months to tenants who saved 25 percent or more of their previous bills, to zero or low-interest loans. Of the 760,000 rental units in the TVA service area, 27 percent have received audits, and 7 percent have been weatherized using TVA loans.
- In 1984, BPA contracted for a study of *Financing Conservation Resource Development Through A Regional Finance Corporation* to help it determine how to provide financing for all end-use sectors. The study looked at the market for conservation financing in each sector, and made recommendations for the types of financing mechanisms that would be most effective for each sector.

- In 1983, BPA awarded contracts to demonstrate shared savings in five buildings, two of which were multifamily--one privately owned, and one PHA. A volume of case studies on the experience of these programs was published in 1984 as *Demonstration Financing Field Tests for Commercial, Industrial, and Multifamily Buildings*. These studies point to many physical and institutional difficulties in the multifamily sector.
- The Los Angeles Municipal Utility offers below-market financing to individual apartments that have electric heating, domestic hot water, or air conditioning.
- The Springfield Illinois Public Power Association offers a 10% rebate up to $250 for adding insulation to multifamily buildings as part of its program to reduce summer peaks.

3.6 Regulatory Activities

Most regulatory activities have concentrated on two approaches-- requiring the availability and promotion of special audits for this sector, or requiring the upgrading of multifamily housing units to specified standards by a certain date or at the time of sale of the building.

3.6.1 Federal Activities

The main regulatory activity has been the establishment of the Residential Conservation Service (RCS) and the Commercial and Apartment Conservation Program (CACS). The requirement for DOE to establish these programs was contained in the NECPA '78 legislation and the Energy Security Act Amendments. The RCS program, which covers all residences up to four units and multifamily buildings with individually heated and cooled units has been in effect since 1982. The CACS program is in the process of being implemented.

The primary purpose of CACS is to provide owners and tenants with energy audits which give reliable cost/benefit information on measures and practices with a seven-year payback or less. A variety of activities has been carried out in support of establishing such a program. Some of the reports covered in earlier sections were supported by the CACS program. To date, some 36 states have submitted state plans. Fifteen have been approved, and at least one (Michigan) has been implemented.

The practices and measures to be covered under the CACS program are: measures such as air conditioner replacement; automatic energy control systems; caulking and weatherstripping; energy recovery systems; furnace or utility plant modifications such as flue dampers and replacement burners; distribution system modifications; ceiling, duct, floor, pipe, wall and water heater insulation; replacement or modification of lighting systems; window and door system modifications such as storm window and glazing enhancers or retardants; and several active and passive solar systems. In addition, a number of operations and maintenance procedures are covered: maintenance of air conditioners, furnace and distribution systems; closing off of unoccupied areas; use of shading; plugging infiltration leaks; furnace and water heater temperature reductions; and use of flow restrictors.

HUD has required that all PHA's must audit their housing projects. If housing management people do not comply, they will not get rent increases. In addition, Energy Management Requirements have been promulgated for all HUD-insured projects, including an annual energy survey and a plan for implementation.

3.6.3 State/Local Government Activities

A small number of states and cities have passed ordinances dealing with energy savings in rental units. Some examples are:

- As part of the Zero Interest Program (ZIP), the California Public Utilities Commission has required its member utilities to submit programs for approval to encourage energy saving in rental units.

- Programs are initiated by the utilities themselves, and a wide variety of approaches have been proposed. Several utilities have met with success and are enthusiastically expanding their programs; others are petitioning for suspension on the grounds that the programs have not been cost-effective for the ratepayer base.
- In 1976, Minnesota passed a rental code which required that buyers of multifamily buildings be given information about the energy efficiency of the buildings they buy, and requiring that a series of prescriptive measures with a payback of 10 years or less be implemented at the time of sale or by 1983. The code has not been well enforced, and its prescriptive nature has led to only minor improvements in energy efficiency. The state is moving to a performance approach with random inspections and penalties for non-compliance.
- The cities of Portland, Minneapolis, and Madison and the State of Wisconsin have passed similar codes. The Wisconsin code, which becomes effective in 1985, requires that measures with a five-year pay-back be completed by the time of sale. A certificate of compliance must be filed with the deed and appraisers deduct lacking improvements from the value of the buildings. All of these codes seem to be experiencing compliance problems.
- Berkeley and San Francisco, California have a code that applies to all residential property at the time of sale. It prescribes 5 measures and uses lenders and realtors as the main source of information about the code. Compliance has been difficult to verify.
- In another arena, Connecticut already had in place a program similar to CACS when the Federal legislation was passed.

3.6.4 Public Utility Programs

None known.

Section 4.0

FEDERAL ROLE, PLANNING ASSUMPTIONS AND PRIORITY SETTING

IN THIS SECTION: Criteria for establishing the federal role; multiyear planning assumptions; criteria for setting project priorities.

4.0 Federal Role, Planning Assumptions and Priority Setting

As part of the multiyear program plan for multifamily retrofit research to be implemented by the Building Services Division, it is essential to establish clear criteria upon which the role of the Federal government in this area should be based, state the assumptions used in determining the scope of this role, and describe the method by which project priorities will be ultimately set. The basis for defining the Federal and Divisional role is a necessary first step in the identification of specific Federal actions to achieve energy savings through the retrofit of multifamily buildings. Based on the criteria and assumptions described in this section, a full range of program functions and activities were identified. These activities were then placed in priority order based on a systematic review process and the method outlined in Section 4.3. The end result is the specific program plans described in Section 5.0.

4.1 Criteria for Establishing the Federal Role

The following specific criteria or objectives were used in developing a definition of the Federal and Divisional role in support of the retrofit of multifamily buildings:

- A potential for significant net energy and economic savings must exist. This criteria emphasizes the ultimate objective of any energy conservation research program: the achievement of both energy and economic savings. Unless a significant opportunity exists, no Federal action can be considered.
- Potential savings are not being realized by the private sector because of identifiable market imperfections or failures. This criterion emphasizes the importance of avoiding Federal actions that are duplicative of private efforts or which otherwise interfere with normal market forces. Market imperfections or failures include, among others, an inability or unwillingness of private firms to undertake long term, high risk research (even though the results of such research might have major national benefits); especially fragmented or non-existent support industries; tenant/landlord conflict; and inadequate market incentives because of depressed economic conditions or other constraints.
- Anticipated benefits should be national or regional in nature, rather than local. Local concerns should be generally addressed by State and local governments or other non-Federal entities.
- Federal research support or other actions should not impair the operations of the free market. Not only must there be a potential for significant net energy and economic savings, but the actions should not adversely affect the operation of the free market system.

- Retrofit research support or other actions by the Building Services Division should be fully consistent with established legislative and organizational responsibilities and should not duplicate or conflict with the actions of other DOE offices and Federal agencies.
- Specific program activities should be identified and reviewed in cooperation with private businesses, utilities, State and local governments and other researchers and potential users.

4.2 Multi-Year Planning Assumptions

In order to ensure that the specific program sub-elements and project areas described in this plan might realistically receive Federal support over the next 5 years, a number of assumptions were used in their development and review. Specifically, it was assumed that:

- The annual budget available for Building Energy Retrofit Research during the planning period may change from the FY 1985 level, but it will *not* increase or decrease so substantially as to change the character of the activity suggested.
- The major objectives of the retrofit research program plans must be achieved during the multiyear planning period.
- The program plan must be able to be implemented effectively on a year-by-year basis, with most projects being funded to completion at the time of project start. It must also be sufficiently flexible to adjust to significant changes in program priorities or funding levels.
- No legislative, regulatory, organizational *changes* are necessary to implement the plan and the plan is consistent with the general direction and type of activity envisioned in the Energy Conservation Program Planning Document, FY 1986 - FY 1990 (May 1984).

4.3 Criteria for Setting Project Priorities

Assigning priorities for any research program is not an easy task. It is almost impossible to quantify every aspect of a project that could be taken into consideration, and then apply appropriate weighting factors to each of those aspects in order to obtain an unequivocal rank order of all projects considered. Even when such approaches are attempted, professional judgements and budget constraints often are the key determinants of the final rankings.

Probably the most important factors in any ranking system are: the establishment of the particular criteria that projects must meet in order to be considered for ranking; the establishment of differentiating criteria that will be used to determine the relative importance of the projects that are considered; and, the establishment of a consistent method of presenting information about projects that are being ranked. In this way, intelligent discussions can be held among reviewers to establish the final ranking of projects.

The approach used here, after looking at several simple and computer-based systems, was to develop a list of criteria and an extensive description form to be filled out on each project that was to be considered for final ranking.

Specific projects were suggested by experts from DOE, other Federal agencies, DOE laboratories, private firms, utilities, state and local governments, and user groups. Using projections of future energy consumption developed for DOE by PNL for each existing building sector, DOE laboratories filled out forms for each project and assigned initial rankings. These initial rankings were then reviewed by DOE and by knowledgeable representatives of the groups cited previously and final rankings were assigned by DOE.

The specific criteria which were used in the ranking process were divided into two groups--screening or threshold criteria, and differentiation criteria. Screening criteria are used to determine if a project should receive further consideration, and if so, whether or not it should be treated as a support, research and development, technology transfer or basic research project. The differentiation criteria were then used on those projects categorized as R&D and/or technology transfer projects. This provided an in-depth analysis of their potential to produce energy savings in existing buildings. The other project categories--support and basic research--were analyzed using fewer and more qualitative factors. It was assumed that over the life of the multi-year plan, support projects would receive 5-15% of the allotted funds, basic research projects 5-15%, and research and development the majority of the funds.

Among the most important criteria used were:

Screening/Threshold Criteria

- o the project meets the criteria for receiving federal support if:
  - it primarily accelerates improvements in the energy efficiency of existing buildings
  - its benefits are more than local in scope
  - insufficient support is being provided currently
  - little is being done in the area due to identifiable market imperfections or barriers
  - it doesn't duplicate other Government activities
- o the expected benefits from the project significantly exceed their costs

Differentiation Criteria Most of the criteria included here were selected to help quantify in a variety of different ways the potential energy savings impact of the project and the combined Federal, private and other costs for achieving those savings. This information was used to perform two calculations—a net present incremental benefit, and a savings to cost ratio. Both of these calculations attempt to determine how much impact Federal involvement will have in the project area, and the cost-effectiveness of that involvement, *above* what would take place under "normal market conditions." In general, the more positive both of these factors, the higher priority assigned to the project.

Other criteria considered were:

- o support for the project by industry and user groups
- o the importance of the project for the completion of other projects
- o the probability that the project will meet its goals
- o the possible secondary impacts of the project on health, safety, and the environment
- o the ability of the project to strengthen market forces and reduce the need for future Federal assistance.

Section 5.0

PLANNED RETROFIT RESEARCH PROGRAM

IN THIS SECTION: Summary table of project areas with preliminary ranking; project area descriptions.

5.0 Planned Retrofit Research Program

Over one-hundred project areas were identified, both by the organizations and individuals contacted, and by the review of the literature. A preliminary screening eliminated projects that did not meet the threshold criteria discussed in the previous section (4.3). The remaining project areas were reviewed and combined into the thirty-eight areas presented below. Table 5.1 lists the project areas by their major sub-headings. In addition to the preliminary ranking score computed by the criteria given in the previous section (3.4), a review panel made up of fifteen individuals from DOE, National Labs, and other institutions gave an initial review score for each project. These scores are on a scale from 1 to 10, with 10 being the highest. Where the review ranking differed from the preliminary ranking, both are given, with the preliminary ranking given first. The numerical rankings have been converted to HIGH (9-10), MEDIUM (7-8), and LOW (1-6) scores and are given in the table below:

Table 5.1 Retrofit Research Project Areas for Multifamily Sector

A. Planning and DOE Support
1. Survey user needs (HIGH)
2. Planning updates (HIGH)
3. Evaluate ARD projects (HIGH)
4. Stock characterizations (MEDIUM)

B. Analysis, Modeling, and Tool Development
5. Energy end use patterns (MEDIUM)
6. Peak & diversified load analysis (LOW/MEDIUM)
7. Evaluate existing multifamily models (MEDIUM)
8. Evaluate & develop utility bill analysis (MEDIUM)
9. Evaluate & develop air infiltration models (HIGH/MEDIUM)
10. Develop simulation models [included in #7]
11. Behavioral studies (HIGH/MEDIUM)
12. Data acquisition system (MEDIUM)
13. Audit diagnostics & techniques (HIGH)
14. Monitoring protocols & techniques (HIGH)

C. Retrofit Performance
15. Heating system retrofits (HIGH)
16. Shell retrofits (HIGH/MEDIUM)
17. Cooling system retrofits (MEDIUM/HIGH)
18. Hot water retrofits [included in #19]
19. Hot water systems (HIGH)
20. Lighting & appliances (MEDIUM/LOW)
21. Low cost/no cost (MEDIUM)

D. Interactions & Strategies
- 22. Operation and maintenance (HIGH)
- 23. Temperature control strategies (HIGH)
- 24. Load management techniques (LOW)
- 25. Retrofit interactions (HIGH)
- 26. Metering strategies (MEDIUM)
- 27. Low cost packages [included in #21]
- 28. Public housing strategies (HIGH)

E. Technology Adoption
- 29. Marketing strategies (LOW)
- 30. Innovative financing (LOW)
- 31. Acceptability of retrofits (HIGH)
- 32. Air quality and moisture [moved to section D] (MEDIUM)

F. Technology Transfer
- 33. Data Bases & Information Network (HIGH)
- 34. Workshops (HIGH/MEDIUM)
- 35. Case studies (HIGH)

G. Advanced Technology
- 36. Advanced window materials & systems (LOW/MEDIUM)
- 37. Solar cooling/heating (LOW)
- 38. Thermal storage, hybrid systems (LOW/MEDIUM)

These projects areas provide the basis for the research program. Additional planning will be required to select the optimal choice of projects to ensure a balanced program of multifamily retrofit research. All of the project areas are consistent with the mission of the Building Services Division described in the Introduction. However, a number of the project areas described encompass activities which might also be supported by other divisions within the office of Buildings and Community Systems, other offices within the Department of Energy, or, in a few cases, other federal agencies. For this reason, specific projects to be funded by the Building Services Division will be closely coordinated with the other appropriate federal offices.

The descriptions of the projects below are summaries of the proposed work with explanations of how they fit into the overall program. Detailed evaluations of the projects and their priority ratings are given in Appendix D.

5.1 Determine User Needs (preliminary score: 10; review score 10)

This support project consists of ongoing contact with individuals and groups who are involved in energy activities in the multifamily sector (e.g., building owners and managers, appliance manufacturers and distributors, architects and engineers, contractors, utilities, tenants, and federal, state, and local government agencies). These contacts will be used to find out what needs to be done in the multifamily sector. The results will provide guidance to DOE policy-makers in the multifamily sector. Each year, the results will indicate how effective DOE's programs are by seeing how these needs are being met by government programs.

The primary audience for the results of this project is DOE. The secondary audiences for project results are all groups involved in energy issues in the multifamily sector. This project is important for it addresses the requests of user groups (e.g., architects and engineers, consumers and public interest groups, research and testing groups, government, and utilities) that DOE respond to their needs in the government's selection of energy programs in the multifamily sector. It also addresses an important barrier to greater energy efficiency in the multifamily sector: the lack of understanding of and response to the most critical energy issues facing individuals and groups in the multifamily sector. No other national effort is planned, and the project is essential for the completion and continued support of other ARD projects.

5.2 Planning Updates (preliminary score: 10; review score 10)

This support project updates the DOE's Multiyear Plan in the multifamily sector every year, based on user needs and the evaluation of on-going ARD/BERD projects. The results of the updates will be used by DOE policy-makers in selecting projects in the multifamily sector for the Multiyear Plan.

The primary audience for the results of this project is DOE. The secondary audiences for project results are all groups involved in energy issues in the multifamily sector. This project is important for it addresses the requests of all user groups: that the DOE Multiyear Plan should be relevant and responsive to user needs. Also, it addresses an important barrier to greater energy efficiency in the multifamily sector: the lack of a comprehensive and systematic review of on-going DOE programs in the multifamily sector on a regular basis (yearly). No other national effort is planned, and the project is essential for the completion and continued support of other ARD projects.

5.3 Evaluate ARD projects (preliminary score: 10; review score 10)

The support project consists of the evaluation of on-going ARD projects in the multifamily sector by measuring economic and non-economic costs and benefits of the projects, and by determining if DOE's "mission" is being efficiently and effectively supported. The results of this evaluation will be used by DOE policy-makers in supporting on-going projects and selecting new projects in the multifamily sector for DOE's Five Year Plan.

The primary audience for the results of this project is DOE. The secondary audiences for project results are all groups involved in energy issues in the multifamily sector. This project is important for it addresses the requests of all user groups: DOE's multifamily projects should be relevant and responsive to user needs. Also, it addresses an important barrier to greater energy efficiency in the multifamily sectors: the lack of detailed, quantitative information on which DOE projects "work" and are "cost-effective" (and, therefore, should be supported) and which DOE projects "don't work" and are not cost-effective (and, therefore, should be discontinued). No other national effort is planned, and the project is essential for the completion and continued support of other ARD projects.

5.4 Stock Characterization (preliminary score: 8; review score 8)

This support project would provide a baseline portrait of the multifamily housing stock, including distribution by building type, age, location, etc. Other characteristics would include heating/cooling equipment and level of retrofit activity. Two levels of activity are envisaged, the first to collect and analyze existing data, mostly regional or state (e.g., California, Pacific Northwest) and the second to work with EIA to over sample multifamily buildings in the next RECS (1987) survey to provide the first comprehensive multifamily data on a national level.

The primary audience for the results of this project is DOE and other government agencies, as well as national labs and research institutions. The secondary audiences for project results are utilities and their associations. This project is important for it addresses the needs of user groups (e.g., A&E firms, AIA, utilities, state energy offices, etc.). It also addresses an important barrier to energy efficiency in the multifamily sector: no national effort has characterized this sector, hampering marketing and planning efforts. No other national effort is planned, and the project is essential for the completion of nearly 25 other projects.

5.5 Energy End-Use Patterns (preliminary score: 7; review score: 8)

This support project will develop a portrait of end-use consumption patterns in the multifamily housing stock. It will attempt to determine the fraction of total energy use in this sector used for space heating, domestic hot water, cooking, lighting, and appliances. Project will include more detailed analysis of particular subsectors (e.g., Federally-assisted housing).

The primary audience for the results of this project are government agencies and researchers. The secondary audiences for project results are utilities, and architects and engineers. This project is important for it addresses the requests of user groups (e.g., community energy groups, utilities, and research institutions). It also addresses an important barrier to energy efficiency in the

multifamily sector: limited information, that has hampered retrofit, marketing, and planning efforts. Information on energy end-use patterns are needed to plan retrofit efforts and project expected savings.

5.6 Peak and Diversified Load Analysis (preliminary score: 4; review score: 8)

This R&D project will develop models and analysis tools to examine peak load impacts of various energy conservation measures in multifamily buildings. Project will also explore load-shifting strategies, their technical potential and cost-effectiveness. Results include assessment of peak demand reductions with implementation of retrofits for utilities with different system characteristics (e.g., summer peaking vs winter peaking).

The primary audiences for the results of this project are utility companies and government agencies. The secondary audiences for project results are researchers and building owners. The project addresses technical and information barriers to greater energy efficiency in multifamily buildings, namely, the limited knowledge of peak load impacts of various conservation measures. There is a need for peak load modelling in order to characterize demand impact of various measures.

5.7 Evaluate existing multifamily models (preliminary score: 8; review score: 8)

This R&D project will evaluate existing building energy analysis models that are used on multifamily buildings. The project will review detailed hourly simulation models (e.g., DOE-2) as well as simplified building simulation models. The project will help determine the level of need for additional modeling and tool development specific to the multifamily sector.

The primary audiences for the results of this project are government agencies and research institutions. The secondary audiences for project results are utilities and architects and engineers. The project addresses technical barriers to greater energy efficiency in multifamily buildings. No national effort is otherwise planned, federal or private.

5.8 Develop Utility Bill Analysis (preliminary score: 8; review score: 8)

This R&D project will evaluate and extend techniques used to analyze utility billing data to multifamily buildings. Score-keeping has been used extensively on single-family homes; special problems particular to multifamily buildings need to be examined (e.g., changes in occupants, occupancy rates, frequency of O&M actions, metering configuration). Score-keeping provides methods to weather-adjust energy use, calculate energy savings attributable to retrofits, and gives parameters that provide indicators of the sources of conservation. The effectiveness of retrofit projects in many multifamily buildings will be evaluated with utility billing data; thus, it is important to determine viability of existing analytic techniques and expand models to handle problems found in master-metered buildings.

The primary audiences for the results of this project are building owners, utilities, government agencies and research institutions. The secondary audiences for project results are architects and engineers. The project addresses technical and information barriers to greater energy efficiency in multifamily buildings. Regression analysis can provide more accurate estimates of energy savings from retrofit activity. In addition, more detailed knowledge of consumption by various end-uses will allow better planning efforts. No national effort is otherwise planned, federal or private and the project is important to insure that retrofits are compared using consistent energy analysis framework.

5.9 Develop Air Infiltration Models (preliminary score: 9; review score: 8)

Air infiltration represents approximately one-third of the energy load on the heating and cooling systems in multifamily buildings. Air infiltration also affects the temperature balance (and therefore temperature control between apartments), and it affects the indoor air quality in the apartments, as well. The object of this project is to develop simplified mathematical models for predicting the air infiltration in multifamily buildings. The present multi-zone infiltration models are excessively complex, and require long, iterative calculations, to determine the flow rates. This project would develop and verify models to predict both outdoor air flow and total air flow through apartments, using local weather data, and a one-time measurement of air tightness to

characterize the building. These flow rates will be used to determine the cost-effectiveness of retrofits to improve air tightness, as well as provide input for control strategies that are designed to balance the temperatures between apartments.

5.10 Develop Simulation Models (preliminary score: 8; review score: 8)

This R&D project will involve the simulation of energy models (e.g., DOE-2) on prototypical multifamily buildings for estimating energy savings and cost-effectiveness of various retrofit measures for different buildings in different climates. Results will be used for planning of retrofits, and by energy auditors and others interested in estimating energy savings and cost-effectiveness of retrofits in multifamily buildings. Microcomputer applications of the methodology will also be examined for possible development.

The primary audiences for the results of this project are utility and energy service companies. This project is important for it addresses the requests of several user groups (e.g., architects and engineers, utilities, and government). Also, it attempts to overcome an important barrier to greater energy efficiency in the multifamily sector: the lack of accurate information on the cost-effectiveness of retrofits in different multifamily buildings in different climate zones. No other national effort is planned, and the project is essential for ARD planning of retrofits in the multifamily sector.

5.11 Behavioral Studies (preliminary score: 9; review score: 8)

This R&D project will conduct surveys in different types of multifamily buildings (master metered, individually metered, and check metered; 2-4 units and 5 or more units; etc.) and with different demographic groups (e.g., by income and ethnicity) to document how people affect the performance of energy retrofits. The focus will concentrate on key end uses: e.g., space heating, space cooling, and water heating. Where energy use data are available, energy use models will be developed that examine the direct and indirect effects of tenant behavior. These surveys will examine how tenant behavior affects energy conserving activities and why they do or do not pursue such activities. This project is related to #31 *Acceptability of Retrofits*, which focuses on the decision-making behavior of owners.

5.12 Data Acquisition Systems (preliminary score: 7; review score: 7)

The object of this project is to identify and describe data acquisition systems that are appropriate for monitoring retrofit performance in multifamily buildings. Systems ranging from single-variable monitoring all the way to multichannel and power line carrier systems would be reviewed. The project would match appropriate sensors with data acquisition systems, size systems for various monitoring needs, and provide a list of compatible sensors, data acquisition units and data analysis hardware (i.e., printers, plotters, storage mediums). This project would provide a compendium of available instrumentation for groups monitoring retrofit performance in multifamily buildings.

5.13 Audit Diagnostics and Techniques (preliminary score: 10; review score: 10)

The object of this project is to evaluate current auditing techniques and to identify new auditing techniques for evaluating multifamily buildings. Both instrumented and walk-through audits would be analyzed. Results of this project will be incorporated into new, more effective, auditing procedures, making full use of current technology and the experience of the public and private sectors. Because of the central role of auditing in determining retrofit activity, technology transfer would be an important part of this project.

5.14 Monitoring Protocols and Techniques (preliminary score: 9; review score: 9)

The object of this project is to develop a standard set of procedures for evaluating (i.e., monitoring) different types of multifamily buildings and retrofits. These protocols would specify the variables to be monitored, provide methods for measuring them, and give techniques for analyzing the collected data. It is expected that the results of this project will be used to help develop consensus standards for multifamily building monitoring, similar to standards already developed for single-family buildings, e.g., fan-pressurization standards.

5.15 Heating System Retrofits (preliminary score: 10; review score: 10)

This R&D project consists of measuring the performance of heating system retrofits as installed in multifamily buildings, looking at the whole spectrum of mechanical systems and building types. Specific areas of research will cover performance and cost-effectiveness of vent dampers, power burners, upgrading vs replacing boilers, etc. The work will be performed in conjunction with established retrofit organizations in order to share cost, equipment, and field expertise, as well as to further technology transfer. Preliminary planning will determine sites meeting criteria for type of construction, retrofit, and geographic location.

The primary audiences for the results of this project are contractors, energy service companies, and A&E firms. The secondary audiences for project results are utilities, apartment owner associations, and government policy makers. It also addresses an important barrier to energy efficiency in the multifamily sector: the numerous contractors and retrofit installers do not have the resources to evaluate the performance of heating system retrofits installed in buildings. The project has a high benefit-cost ratio and addresses a need voiced by the user community.

5.16 Shell Retrofits (preliminary score: 9; review score: 8)

This R&D project consists of measuring the performance of shell retrofits as installed in multifamily buildings, looking at the whole spectrum of building types. Shell retrofits will be evaluated using billing data analysis, and where necessary, additional monitoring of interior temperatures. Specific areas of research will cover performance and cost-effectiveness of insulating flat roofs, masonry walls, and improved window retrofits. The work will be performed in conjunction with established retrofit organizations in order to share cost, equipment, and field expertise, as well as to further tech transfer. Preliminary planning will determine which sites meet criteria for type of construction, retrofit, and geographic location.

The primary audiences for the results of this project are contractors, energy service companies, and A&E firms. The secondary audiences for project results are utilities, apartment owner associations, and government policy makers. It also addresses an important barrier to energy efficiency in the multifamily sector: the numerous contractors and retrofit installers do not have the resources to evaluate the performance of shell retrofits installed in buildings. The project has a high benefit-cost ratio and addresses a need ranked high by the user community.

5.17 Cooling System Retrofits (preliminary score: 8; review score: 9)

This R&D project examines the performance of retrofits to cooling systems (e.g., ceiling fans, heat pumps, etc.) by utility bill analysis, sub-metering, and detailed monitoring of interior temperatures and outdoor weather variables including solar radiation. Energy use before and after retrofits will be monitored and analyzed (normalizing for weather, occupancy, etc.).

The primary audiences for the results of this project are contractors, owners, and utility companies. This project is important for it addresses the requests of user groups (e.g., DOE, LBL, utility companies, IREM, and Florida Solar Energy Center). It also addresses an important barrier to greater energy efficiency in multifamily buildings where cooling demand is great: the lack of information on energy savings and cost-effectiveness of cooling retrofits in multifamily buildings. Many retrofits in this area are easy to install, appear to be quite favorable (high benefit-cost ratios), and should lead to greater tenant and building owner/manager satisfaction.

5.18 Hot Water Retrofits [combined with #19]

5.19 Hot Water Systems (preliminary score: 10; review score: 10)

The object of this project is to evaluate the numerous systems for supplying domestic hot water, as well as to evaluate retrofits to improve the energy consumption of these systems. Domestic hot water represents a much larger fraction of the total energy consumption for multifamily residences compared to single-family residences. The hot water options to be investigated will include: continuous circulation loops vs. cold pipe systems, large storage tanks vs. source heaters, and separation or integration of space heating and domestic hot water. The project will also evaluate the economics of retrofits such as installing more efficient heaters, installing low-flow showerheads, insulating pipes, as well as investigate the interactions of different hot-water retrofit

strategies.

20. Lighting and Appliances (preliminary score: 8; review score: 6)

This R&D project examines the performance of retrofits to lighting and appliances by careful field experimentation, focusing on measured energy savings. In addition to analyzing the energy savings of such lighting retrofits as replacing common area incandescent lighting with higher efficiency fluorescent lighting, reducing number of fixtures, etc., additional emphasis will be spent on understanding tenant and owner satisfaction with the retrofits and how their behavior affects the energy savings.

The primary audiences for the results of this project are building owners and managers, contractors, and energy service companies. The secondary audiences for project results are government and utility groups carrying out retrofit programs on lighting and appliance retrofits in multifamily buildings. This project is important for it addresses the requests of user groups (e.g., DOE, LBL, and utility companies). It also addresses an important barrier to greater energy efficiency in multifamily buildings: the lack of information on energy savings and cost-effectiveness of lighting and appliance retrofits in multifamily buildings. Many retrofits in this area are easy to install, appear to be quite favorable (high benefit-cost ratios), and should lead to greater tenant and building owner/manager satisfaction. No other national effort is planned, and the project is essential for the completion and continued support of other ARD projects in this area.

5.21 Low Cost Packages (preliminary score: 7; review score: 8)

This R&D project examines the performance and applicability of low-cost retrofits (e.g., low-flow showerheads, furnace tune-up, lighting conversions, O&M actions) to multifamily sub-sectors. This project will also analyze resident involvement in energy cost control as part of low-cost strategies. Results will include appropriate measures for various climate and building types.

The primary audiences for the results of this project are building owners and tenants, consumers and public interest groups, government agencies, and utilities. The project addresses technical and information barriers to greater energy efficiency in multifamily buildings. Owners and tenants are unwilling to invest in low-cost measures without knowing reliability and expected savings. In addition, the project will develop appropriate low-cost measures for particular multifamily building types. No national effort is otherwise planned, federal or private and the project has a very favorable cost-benefit ratio.

5.22 Operations and Maintenance (preliminary score: 9; review score: 9)

This R&D project looks at the long-term performance of retrofits to understand the effect of operation and maintenance procedures. Building managers will be surveyed to determine what O&M procedures are standard for different building and equipment types. A sub-set of these procedures will be monitored to show how critical O&M is for retrofit performance. An important aspect of this project will be in identifying the most effective means for communicating the findings to the building managers and operators.

5.23 Temperature Control Strategies (preliminary score: 10; review score: 9)

A widespread problem in multifamily buildings is the poor control of the temperatures in the apartments. Because the central system does not provide uniform heating, or because the building envelope is not uniform, or simply because the wind and sun do not affect the building in a symmetric manner, temperature control in multifamily buildings is often accomplished by opening and closing windows, resulting in excessive space-heating bills. In addition, the operation of many heating plants is optimized solely for considerations such as maintenance and tenant satisfaction, often resulting in large inefficiencies from an energy perspective. The object of this project is to examine the performance of various temperature control strategies and retrofits. The strategies to be examined will include: the addition of outdoor reset and cut-out to buildings heated with hot water systems, different types of steam-cycle controllers for steam-heated buildings, one-time balancing of steam systems to provide uniform heating, and strategies for extending night setback to an optimum length, as well as setting daytime temperatures to meet occupant needs. The evaluations will focus on field performance measurements of energy savings, but will also include measurements and interviews with tenants to evaluate the thermal comfort (and therefore

acceptability) of each strategy.

5.24 Load Management Techniques (preliminary score: 4; review score: 4)

Retrofits that reduce electricity use will be increasingly important as more multifamily buildings are being converted to individually metered apartments, often with electric resistance space heaters. This R&D project will evaluate specific retrofits that can shift peak electricity demand in either electric space or water heating. Specific retrofits could include interlock systems that prevent major electric appliances from operating simultaneously, heat pump hot water heaters, heat recovery from air conditioners, and storage water heaters.

5.25 Retrofit Interactions and Strategies (preliminary score: 8; review score: 9)

This R&D project consists of two parts, one that looks at the performance of groups of retrofit measures, and the other, related, task of determining which groups of retrofits are appropriate for different building types. The work would involve developing prototypical multifamily building types and modelling these generic types with different retrofit packages, using DOE-2 or some other simulation program. Field monitoring would be used to validate a subset of these simulations.

5.26 Metering Strategies (preliminary score: 7; review score: 8)

This R&D project examines the performance of different metering strategies (e.g., master-, sub-, and check-metering) by careful field experimentation, focusing on measured energy savings. Energy use before and after metering conversion will be monitored and analyzed (normalizing for weather, occupancy, energy behavior, etc.). In addition, reactions by tenants and building owners/managers will be examined. Results will be used by government agencies and building owners/managers and others interested in converting their metering systems.

The primary audiences for the results of this project are DOE, HUD, tenants, and building owners/managers. The secondary audiences for project results are utility companies, public interest groups, and researchers. This project is important for it addresses the requests of user groups (e.g., ORNL, LBL, PNL, California Energy Commission, New York State ERDA, and EPRI). It also addresses two important barriers to greater energy efficiency in multifamily buildings: uncertainty in expected energy savings and cost-effectiveness in selecting the appropriate metering conversion system, and possible negative reactions by tenants and/or building owners/managers. No other national effort is planned, and there is very little information available on the benefits and costs of meter conversion.

5.27 Low Cost Packages [included in #21]

5.28 Public Housing Strategies (preliminary score: 10; review score: 9)

This R&D project consists of examining the issues of retrofit performance as they apply to public housing, looking specifically at issues of building audit, retrofit selection, financing, installation and quality control, and operation and maintenance. Initial parts of this project would be to evaluate the existing billing data on buildings pre- and post-retrofit, and to analyze the existing energy-use data from selected multifamily buildings in 115 public housing projects. This data would be used in the development of simplified energy analysis methods that would allow HUD and local housing authorities better tools for predicting energy use and trends.

Evaluation of innovative financing and service delivery mechanisms for energy retrofits would include case studies of innovative private sector financing, e.g., utility zero interest loans, and energy service company approaches using third-party financing and shared savings. These case studies would provide housing authority managers with information on alternate methods of funding retrofits for their projects. Other case studies would be conducted to evaluate the effect of different energy management strategies. Such strategies as building temperature control, metering conversions, and tenant education, among others, would be evaluated in order to estimate the level of energy and cost savings that can be obtained through improvements in energy management.

5.29 Marketing Strategies (preliminary score: 4; review score: 4)

This R&D project examines appropriate marketing strategies for the multifamily sector. The project will explore components of marketing strategy, market segmentation of this sector, product/service design (e.g., one-stop shopping, warranties, ongoing servicing of equipment), and market penetration. Case studies of successful marketing efforts, as well as studies of where such efforts have been unsuccessful will be analyzed and made available to organizations involved in marketing multifamily retrofits.

The primary audiences for the results of this project are real estate and finance institutions, and government agencies. The secondary audiences for project results are utility companies, and trade associations. This project is important for it addresses the requests of user groups (e.g., IREM, ACEC, CEC). It also addresses economic and information barriers to retrofit activity in multifamily buildings.

5.30 Innovative Financing (preliminary score: 6; review score: 6)

This R&D project examines innovative methods for financing retrofits in multifamily buildings with different ownership patterns (e.g., privately-owned, cooperatives, federally-assisted). Alternative financing assistance programs will be analyzed and case studies of both successful and unsuccessful approaches will be documented. Methods of combining energy conservation with capital expenditures for rehabilitation and maintenance will be evaluated. The project will also explore ways to overcome economic barriers that prevent owners from implementing conservation measures.

The primary audiences for the results of this project are building owners. The secondary audiences for project results are utility companies and real estate and finance institutions, who need to be aware of the issues in cost savings from building retrofits. This project is important for it addresses the requests of user groups (e.g., IREM, AIA, NYSERDA, NCLC). It also addresses specific economic barriers to greater energy efficiency in multifamily buildings. These include the problems of lack of access to capital, inability to absorb risk of uncertain savings, and 'split incentives' that hinder energy-efficient investments.

5.31 Acceptability of Retrofits (preliminary score: 9; review score: 9)

This R&D project has two components. First, surveys of tenants and building owners/managers are conducted to learn about their attitudes towards potential retrofits (heating, cooling, hot water, etc.) in multifamily buildings, focusing on perceived barriers to the acceptance of retrofits. Second, surveys of tenants and building owners/managers are conducted after a retrofit in a multifamily building to learn about their attitudes and behavioral responses to retrofits. Results will be used, along with analysis of energy savings, for determining which retrofits have the best prospect of being installed in multifamily buildings.

The primary audiences for the results of this project are building owners/managers. The secondary audiences for project results are utility companies, public interest groups, researchers, contractors, and manufacturers. This project is important for it addresses the requests of user groups (e.g., LBL, EPRI, utility companies, Office of Technology Assessment, and DOE). It also addresses an important barrier to greater energy efficiency in multifamily buildings: retrofit dissatisfaction (once installed, the retrofit may be changed by tenant and/or building manager/owner to reduce discomfort, etc.). No other national effort is planned, and the project is essential for the completion and continued support of other ARD projects. Energy conservation in the multifamily sector is critically dependent on the acceptability of retrofits by tenants and building managers/owners.

5.32 Air Quality and Moisture (preliminary score: 7; review score: 8)

This R&D project consists of analyzing the potential health hazards associated with retrofits in multifamily houses, specifically those retrofits that reduce air infiltration rates. This project is related to the development of air infiltration models for multifamily buildings as well as the monitoring of shell retrofits in buildings. Past retrofit activity has shown that moisture and air quality problems can be significant particularly where air leakage is reduced by the installation of weatherstripping or storm windows, and where tenants use their gas stove for space heating. In

addition to the modelling of potential hazards, specific buildings that are known to have developed moisture and air quality problems will be evaluated to determine how such problems can be corrected and avoided in future retrofits of other buildings.

The primary audience for the results of this project are contractors and building owners who need to know the potential effects of retrofits on the health of the occupants and the building itself. The secondary audiences for project results are housing officials and utilities, as well as federal, state, and local health officials, who may be carrying out weatherization projects in multifamily buildings. This project is important for it addresses the results of user groups (e.g., non-profit energy service companies such as the Citizens Conservation Corp, the National Bureau of Standards, state energy offices, and others.

5.33 Data Bases (preliminary score: 9; review score: 9)

This technology transfer project will compile, analyze, and periodically publish data bases on the measured energy performance and cost-effectiveness of energy-saving technologies installed in existing multifamily buildings. This project will compare current practice with estimated technical potential, examine range of savings and costs in order to identify factors associated with successes and failures, and compare measured savings with predicted estimates. The project will maintain building and energy data collected as part of building retrofit research project and ensure that results are presented in a consistent, analytic framework. The data bases will be publicly accessible and are an important mechanism for making results available to the user community. Connections to international data bases through the International Energy Agency's Annex XI activities could also prove valuable.

The primary audiences for the results of this project are DOE and other government agencies, utilities, and building owners/managers. The secondary audiences for project results are architects and engineers, consumer groups, researchers, and contractors. This project is important for it addresses the requests of user groups (e.g., GRI, CNT, HUD, and national laboratories). It also addresses an important barrier to greater energy efficiency in multifamily buildings: lack of reliable information. A recent OTA study concluded that there is very little documented information on the results of actual retrofits on different types of buildings. The OTA report stresses that improved data on results of individual retrofits, retrofit packages, and actual savings compared to predicted estimates could help alleviate building owner's concerns regarding retrofit expense and outcome. No other national effort is planned, and the project will help transfer results from retrofit performance monitoring.

5.34 Workshops (preliminary score: 9; review score: 8)

This technology transfer project addresses the lack of a multifamily network to disseminate information on energy use and conservation to building owners, managers, tenants, practitioners, researchers, etc. Specialized, focused workshops are one of the most effective means of information transfer. This project would allow for planning, organizing, and carrying out of workshops on a national level.

The primary audience for the results of this project include all parties involved in multifamily retrofits.

5.35 Case Studies (preliminary score: 9; review score: 9)

This technology transfer project will conduct and report on case studies of retrofit performance in multifamily buildings. Initial case studies will help primarily in focusing retrofit research issues; final studies will transfer and demonstrate important technologies. The project will focus on either new technologies for existing buildings, problems in retrofitting specific sub-sectors (e.g., old buildings, buildings with clad walls, steam- heated buildings, 'problem' housing), or explore important issues (e.g., combining rehabilitation with retrofit activity). Case studies will include site visits, building energy diagnostics, occupant surveys, and monitoring, where appropriate. Case studies will yield a more thorough understanding of cause-and-effect relationships that influence building energy performance.

The primary audiences for the results of this project are architects and engineers, government agencies, utilities, and building owners/managers. This project is important for it addresses the requests of user groups (e.g., AIA). It also helps overcome important barriers to greater energy efficiency in multifamily buildings by demonstrating results from retrofits to private sector. Case studies are very important to user groups; they guarantee that results are transferred to user community and allow special issues and problems to be examined in sufficient depth.

5.36 Advanced Window Materials (preliminary score: 5; review score: 8)

This advanced technology project will explore the potential for developing new window materials that have much higher R-values than existing technologies, and determine how such windows can be used to replace the poor quality windows presently installed in most multifamily buildings. Because windows play such an important part of the energy inefficiency in multifamily buildings (representing a large fraction of the shell losses), improvements in this area could have significant energy savings.

The primary audience for the results of this project would be manufacturing companies. The secondary audiences for project results are contractors and energy service companies.

5.37 Solar cooling/heating (preliminary score: 5; review score: 6)

This advanced technology project will examine the potential for cost-effective solar retrofits in multifamily buildings, looking at the feasibility of such strategies as using south-facing masonry walls as trombe walls, south-facing porches as sunspaces, etc.

The primary audience for the results of this project are contractors, architects, and energy service companies. The secondary audiences for project results are building owners and managers.

5.38 Thermal storage, hybrid systems (preliminary score: 5; review score: 7)

This advanced technology project will examine the potential for cost-effective thermal storage retrofits in multifamily buildings, looking at the feasibility of using solar photovoltaics, solar ponds, and ice ponds, for generating electricity and/or providing space heating and cooling.

The primary audience for the results of this project are manufactures and contractors. The secondary audiences for project results are building owners and managers.

Bibliographies and Appendices

Bibliography for Section 2.0

1. M. Alvarez, R. Tavares, B. Tibbetts, T. Gray,and B. Eller, *Petroleum violation escrow account (PVEA) rental sector program*, California Energy Commission, September 1984.

2. American Council for an Energy-efficient Economy, *Proceedings of the 1984 Summer Study on Energy Efficiency in Buildings*, August 1984.

3. J. Beyea, D. Harrje, and F. Sinden, "Energy conservation in an old 3-story apartment complex," *Energy use management, 1*, Oct. 24, 1977.

4. D.L. Bleviss and A.A. Gravitz, *Energy conservation and existing rental housing*. Energy Conservation Coalition, Washington, D.C., 1984.

5. J.D. Bolton, "Cost effective methods of energy conservation in apartment complexes," *Energy Technology, 10*, pp. 289-298, Feb. 28, 1983.

6. Booz, Allen, and Hamilton, Inc., *Alternative metering practices, implications for conservation in multifamily residences*, prepared For U.S. Department of Energy, June 1979.

7. Coalition of Northeast Municipalities, *Multi-Family Energy Conservation: A Reader*. July 1981.

8. M.J. DeLaHunt, J. Hanford, L. Palmiter, *Consumption characteristics in the multi-family sector*, Ecotope, Seattle, WA, October 1984.

9. Energy Information Administration, Department of Energy, *Energy Conservation Indicators: 1983 Annual Report*, DOE/EIA-0441 (83), Washington D.C., 1984.

10. Energy Information Administration, Department of Energy, *Consumpton and Expenditures, April 1982 through March 1983: National Data*, DOE/EIA-0321 (82), Washington D.C., November 1984.

11. Energy Information Administration, Department of Energy, *Residential energy consumption survey: housing characteristics 1982*, DOE/EIA-0314 (82), Washington D.C., August 1984.

12. Federation of American Scientists, *Proceedings of the multifamily and rental housng workshop*", February 1981.

13. S.B. Friedman, "Multi-family energy conservation: owners' economic perspectives," *Energy efficiency in buildings: a state policy handbook*, pp. 69-75, 1982.

14. L.S. Galowin, "Criteria for mechanical systems in multi-family buildings for residential weatherization options," draft NBSIR report, National Bureau of Standards, 1984.

15. C. Gold, *The Page Homes demonstration project for the application of computers to energy conservation in public housing authority projects*, Bumblebee Energy Systems Inc., Trenton, NJ, February 1982.

16. C.A. Goldman, *Technical performance and cost-effectiveness of conservation retrofits in existing U.S. residential buildings: analysis of the BECA-B data base*, Lawrence Berkeley Laboratory, LBL-17088, October 1983.

17. Government of Ontario, *Study of the relative merits of bulk and individual electrical metering for apartment buildings in Ontario.*

18. J.R. Grossmann and C.L. Vaia, *Residential Sector Trends Reported In The Decennial Census and Annual Housing Survey With An Emphasis On the Natural Gas Statistics, Final Report*, Energy and Environmental Analysis, Inc., November 1983.

19. J. Harris and C. Blumstein ed., *What Works: Documenting Energy Conservation in Buildings*, American Council for an Energy Efficient Economy, Washington, DC, 1984

20. H.E. Hirschfeld, *Evaluation of the conservation potential of a refit energy management system in a large, high-rise apartment complex. Phase II*, September, 1981.

21. Honeywell, Inc., Energy Resources Center, *New York City Housing Authority radiator valve demonstration study.* Final report, May 1978.

22. M. Klepper and J. Sherman, *Innovative Financing for energy-efficient improvements*, January 1982.

23. R.D. Lipschutz, R.C. Diamond, and R.C. Sondregger, *Energy use in a high-rise apartment building*, Lawrence Berkeley Laboratory, September 1983.

24. L. McClelland, *Tenant-paid energy costs in multifamily rental housing: effects on energy use, owner investment, and the market value of energy*, November 1983.

25. J. Muller, *Energy conservation and the multifamily housing industry*, April 5, 1974.

26. R. Mullin, "Shared savings gets realtor new water heater," *Energy User News, 8(32)*, pg. 5, Aug. 8, 1983.

27. D.H. Nall, "Micro-computer control of a steam heating system in an older apartment building," *Proceedings, Intersociety Energy Conversion Engineering Conference, 5*, pp. 2019-2023, Aug. 21, 1983.

28. New York State Energy Research and Development Authority, *Semi-Annual Report*, August 1984.

29. New York State Energy Research and Development Authority, "Toward a Secure Energy Future", *A Multiyear Energy Research, Development and Demonstration Program Plan*, 1984 Update.

30. New York State Energy Research and Development Authority, "...An Investment in Research Now is a Commitment to Reliable and Affordable Energy in our Future.", *1983-84 Annual Report.*

31. Office of Technology Assessment, *Energy Efficiency of Buildings in Cities*, March 1982.

32. Perkins & Will, The Ehrenkrantz Group, *An Evaluation of the Physical Condition of Public Housing Stock: Energy Conservation*, U.S. Department of Housing and Urban Development, Washington DC, March 1980.

33. G. D. Pine, *Characteristics of the Multifamily Residential Sector*, Gas Research Institute, December 1984.

34. R.L. Ritschard and D. Dickey, "Energy Conservation in Public Housing: It Can Work", *Energy Systems and Policy 8*(3):269-291, 1984.

35. C. Patten, M. Sherman, and B. Shapiro, *Case Studies of Successful Energy Conservation Programs in PHA's: St. Paul, Minnesota*, Council of Large Public Housing Authorities, Boston, MA, December 1982.

36. K.J. Romanko and W. Rudoy, "Some effects of thermal mass in multifamily dwellings: Effects on heating and cooling loads," *ASHRAE* (American Society of Heating, Refrigerating, and Air-Conditioning Engineers) *Transactions, 87*, pp. 161-171, June 28, 1981.

37. J.M. Seisler, "Metering to conserve energy in multifamily residences," *Changing energy-use futures, 3*, Oct. 22, 1979.

38. J.C. Shaffer, *Evaluation of the Apartment Conservation Pilot Program*, Conservation and Solar Division, Seattle City Light, Seattle, WA, March 1984.

39. D. Tanz, "Electricity cost halved at Florida condominium," *Energy User News, 3(47)*, pp. 1 and 8, Nov. 20, 1978.

40. R.K. Thornton, *Performance of a major passive solar retrofit on a turn-of-the-century multi-family brick row house*, pp. 773-776, Aug. 30, 1982.

41. I. Turiel, R. Ritschard, and D. Wilson, *Low-Rise Multi-family Housing: A Preliminary Energy Analysis*, Lawrence Berkeley Laboratory, LBL-18823, December 1984.

42. U.S. Department of Commerce, Bureau of the Census, *Annual housing survey, 1981*, Washington, DC., 1983.

43. U.S. Department of Commerce, Bureau of the Census, *Characteristics of New Housing: 1983, Construction Reports*, Washington DC., June 1984.

44. U.S. Department of Energy, *Multifamily Buildings: A Draft Technology Transfer Analysis and Plan*, CE Technology Transfer Working Group, April 1984.

45. C.S. White and A.O. Converse, *Case Study of the 424 West 33rd Street Apartment House*, July 1981.

Bibliography for Section 3.0

Many of the reports listed below were prepared for government agencies by contractors and were never taken beyond the draft stage, or are internal agency working documents, so complete bibliographic information is not available.

1. ABT Associates, *Modernization Needs of the Public and Indian Housing Stock: Draft Energy Analysis Plan*, prepared for HUD, Nov. 1984.

2. American Council for an Energy Efficient Economy, "Financing Conservation: Energy Management Services, Shared Savings and other Mechanisms, Vol. L, 1984.

3. ACEEE, "New and Existing Multifamily Residences/Building Controls and Monitoring Systems," Vol. C, 1984.

4. ACEEE, *1984 Summer Study on Energy Efficiency in Buildings*, Vols. A-L, 1984.

5. American Institute of Architects Foundation, *Energy in Architecture*, Washington, DC, September 1983.

6. AIAF, *Energy in Redesign*, Washington, DC, 1983.

7. American Public Power Association, "Public Power Innovation, 1984," Washington, DC, 1984.

8. Applied Solar Inc., "Clearinghouse on Federal Energy Shared Savings Contracting," Washington, DC, 1984.

9. Arawak Consulting, *Multifamily Buildings: A Draft Technology Transfer Analysis and Plan*, prepared for DOE, April 20, 1984.

10. D.K. Benson, et al, *Evacuated Window Glazing Research and Development: A Progress Report*, SERI/PR-255-2578, (NTIS/DE85002025), Golden, CO, December 1984.

11. D.K. Benson, et al, *Laser Sealed Evacuated Window Glazings*, SERI/TP-255-2454, (NTIS/DE85000512), Golden, CO, October 1984.

12. D.K. Benson, et al, "Solid State Electrochromic Switchable Window Glazings", *Proceedings of the Passive and Hybrid Solar Energy Updates 1984, DOE/CONF-8409118, Washington, DC, October 1984.*

13. *D.L. Bleviss and A.A. Gravitz, Energy Conservation and Existing Rental Housing*, Energy Conservation Coalition, Washington, DC, October 1984.

14. D.L. Bleviss, *Proceedings of the Multifamily and Rental Housing Workshop*, December 4-66, 1980, Federation of American Scientists, Washington, DC, 1981.

15. Bonneville Power Administration, *Saving Power: 1984 Conservation Sourcebook*, Portland, OR, June, 1984.

16. Booz, Allen and Hamilton, *Alternative Metering Practices: Implications for Conservation in Multi-family Residences*, NTIS HCP/M 16 93-03, June 1979.

17. D.M. Burch, "Infrared Audits of Roof Heat Loss," ASHRAE *Transactions*, Vol. 86, Part 2, Atlanta, GA, 1980.

18. D.M. Burch, *The Use of Aerial Infrared Thermography to Compare the Thermal Resistances of Roofs*, NBS Technical Note 1107, prepared for DOE, Gaithersburg, MD, August 1979.

19. D.M. Burch and D.F. Krintz, "Using high-resolution hand-held radiometers to measure in-situ thermal resistance," National Bureau of Standards, Gaithersburg, MD.

20. Centaur Associates, "An Annotated Bibliography and Resource Directory on the Residential Conservation Service and Commercial and Apartment Conservation Service Programs," prepared for BERD/BCS, February 1983.

21. C.B. Christensen, "Advanced Phase-Change Storage for Passive Solar Heating: Analysis of Materials and Configurations," *8th National Passive Solar Conference Preprints*, Santa Fe, NM, American Solar Energy Society, Boulder, CO, 1983.

22. Department of the Army, excerpts from an unknown program plan entitled "V.Base Support, C. Facilities Energy," provided by Bernie Wasserman, DAEN-ZCF, Washington, DC.

23. Department of Energy, Office of Buildings and Community Systems, *Achieving Energy Conservation in Existing Apartment Buildings, Analysis and Recommendations*, Washington, DC, May 1979.

24. DOE, Office of Building Energy Research and Development, *Annual Operating Plan, 1985, Office of Building Energy Research and Development*, DOE/CE-0120, Washington, DC, December 1984.

25. DOE, Office of State and Local Assistance Programs, *Annual Operating Plan, 1985, Office of State and Local Assistance Programs.*

26. DOE, BERD, Division of Federal and Community Programs, *Annual Report on Federal Government Energy Management, FY 1983, Washington, DC, August 1984.*

27. *DOE, Office of State and Local Assistance, Department of Energy State and Local Assistance Programs, 1984 Report,* DOE/CS-0118, Washington, DC, 1984.

28. DOE, Federal Energy Management Programs, *Energy Conservation in Existing Buildings, (Architects and Engineers Guide to),* DOE/CS-0132, February 1, 1980.

29. DOE, *Energy Conservation Multi-Year Plan, FY 86-90,* Washington, DC, July 1984.

30. DOE, Policy and Evaluation, *Energy Projections to the Year 2000,* DOE/PE-0092/2, Washington, DC, October 1983.

31. DOE, *Energy Research Abstracts,* Vol.9, No. 23, December 15, 1984.

32. DOE, Office of Building Energy Research and Development, *Final Regulatory Impact Analysis: Commercial and Apartment Conservation Service Program,* DOE/CE-0051, July 1983.

33. DOE, Office of Building Energy Research and Development, *Guidelines for Technology Transfer Planning,* Washington, DC, April 1984.

34. DOE, Office of the Secretary, *The National Energy Policy Plan,* DOE/S-0014/1, Washington, DC, October 1983.

35. DOE, Office of the Secretary, *Secretary's Annual Report to Congress,* DOE/S-0010(84), Washington, DC, September 1984.

36. DOE, Office of the Controller, *United States Department of Energy, Fiscal Year 1986 Budget Highlights,* DOE/MA-0062/3, Washington, DC, February 1985.

37. Department of the Navy, *Navy Shore Facilities Energy R&D Plan for FY 1985,* Naval Civil Engineering Laboratory, Port Hueneme, CA.

38. A. Downs and K.L. Bradbury, (eds.), *Energy Costs, Urban Development and Housing,* The Brookings Institution, Washington, DC, 1984.

39. Department of Housing and Urban Development, "HUD launches Energy Financing Demonstration," HUD Press Release 85-6, Washinngton, DC, January 29, 1985.

40. Department of Housing and Urban Development, *Solar Energy and Energy Conservation Bank: Annual Report to the Congress, Fiscal Year 1984*, HUD-B-920, Washington, DC, December 1984.

41. A.R. Ehrenshaft, W.R. Mixon, and M.A. Karnitz, "Bibiliography of Resource Materials for the Residential Conservation Service and Commercial and Apartment Service Programs," Oak Ridge National Laboratory, Oak Ridge, TN, May 1983.

42. Energy Administration, Michigan Department of Commerce, *Energy Efficiency Financing Programs in the United States*, Lansing, MI, October 1984.

43. Energy Conservation Coalition, "Agenda, Conference of Practitioners in Multifamily Rental Housing Energy Conservation, Philadelpia, Feb. 11-14, 1985," Washington, DC, 1985.

44. Energy and Environmental Analysis, Inc., *Development of a Demonstration Program for Retrofit of ECRR Measures on Existing Dwelling Units*, DOE/CS/20203, December 1978.

45. Energy Information Administration, DOE, *Annual Energy Outlook*, 1983, DOE/EIA-0383(83), Washington, DC, May 1984.

46. EIA, DOE, Annual Energy Review, 1983, DOE/EIA-0384 (83), Washington, DC, April 1984.

47. EIA, DOE, *Characteristics of the Housing Stock--Households: Preliminary Findings from the National Interim Energy Consumption Survey*, NTIS-DOE/ EIA-0199/P, Washington, DC, October 1979.

48. EIA, DOE, *Energy Conservation Indicators, 1983 Annual Report*, DOE/EIA-0441-83, Washington, DC, October 1984.

49. EIA, DOE, *Energy Information Administration--Annual Report to Congress*, DOE/EIA-0173 (83), Washington, DC, 1983.

50. EIA, DOE, *Monthly Energy Review*, DOE/EIA-0035 (84/09), Washington, DC, December 1984.

51. Hagler, Bailly & Company, *Financing Conservation Resource Development Through a Regional Finance Corporation: Evaluating Potential Finance Activities*, Vol. I, prepared for BPA, May 1984.

52. Hagler, Bailly & Company, *Financing Conservation Resource Development Through a Regional Finance Corporation: Evaluating Alternative Organizational Structures*, Vol. II, prepared for BPA, May 1984.

53. J. Harris and C. Blumstein (eds.), *What Works: Documenting Energy Conservation in Buildings*, ACEEE, Washington, DC, 1984.

54. Hittman Associates, *Evaluation of Estimated Energy Conservation Measure Costs and Benefits in the Residential Multi-family Sector: Final Report*, prepared for DOE/Office of Conservation Policy, November 1981.

55. Institute of Real Estate Management and the Federal Energy Administration, *Energy Cost Reduction for Apartment Owners and Managers*, 1977.

56. Internal Revenue Service, "Investment Credit," Circular #572, November 1984.

57. H.R. Isakson and D.D. Kushner, *Making the Most of Energy in Real Estate: Relevant Energy Facts for Real Estate Developers, Builders, Lenders, Appraisers and Brokers*, HCP/M8696-01, for DOE/BCD, College of Business Administration, University of Georgia, Atlanta, GA, September 1978.

58. A.C. Jordan, *Buildings Energy Research: A Bibliography, Publications of the Building Systems Division*, ORNL/CON-122, Oak Ridge, TN, April 1983.

59. G. Kamp, et al, *Study of Currently Available Commercial and Apartment Building Energy Conservation Audits*, ORNL/CON-137, Oak Ridge, TN, September 1983.

60. M. Klepper, et al, *Demonstration Financing Field Tests for Commercial, Industrial and Multifamily Buildings Case Studies*, Vol I of Two, Lane and Edson, prepared for BPA, Washington, DC, November 1984.

61. J.O. Kolb and J.M. MacDonald, *CACS Apartment Energy Conservation Case Studies*, ORNL/CON-174, Oak Ridge, TN, December 1984.

62. Lawrence Berkeley Laboratory, "Publications of the Windows and Daylighting Group," WG-1, Applied Science Division, Berkeley, CA, March 15, 1985.

63. LBL, *Review of Energy Use and Conservation in Public Housing*, prepared for DOE/BERD/ARD, Berkeley, CA, December 1984.

64. A. Levine, et al, *Energy Conservation in Rental Housing: Landlords' Perceptions of Problems and Solutions*, SERI/RR-744-1308, Golden, Co, March 1982.

65. L. McClelland, *Encouraging Energy Conservation in Multi-family Housing: RUBS and other Methods of Allocating Energy Costs to Residences*, DOE/CS-20050-1, prepared for DOE/BERD, Institute of Behavioral Sciences, Boulder, CO, November 1983.

66. L. McClelland, *Tenant-Paid Energy Costs in Multifamily Rental Housing: Effects and other Methods of Allocating Energy Costs to Residences*, DOE/CS/20050-T2, prepared for DOE/BERD, Institute of Behavioral Sciences, Boulder, CO, November 1983.

67. H.A. McLain, et al, *Residential Conservation Service, Model Audit Manual Multi-family Audit Procedure, ORNL/CON-104, Oak Ridge, TN, April 1984.*

68. *N.J. Malik and K.N. Patel, Initial Assessment of Energy Conservation Opportunities for Low-Rise Apartment Buildings*, ANL/ENG-84-02, Argonne National Laboratory, Chicago, IL, October 1984. (Draft)

69. Market Facts, *Energy Retrofit Decision-Making in the Commercial and Multifamily Sectors, Draft*, prepared for DOE, October 14, 1981.

70. Market Facts, *Situation Analysis-Multifamily Housing*, prepared for DOE/Building Conservation Services Division, September 28, 1981.

71. Market Facts, *Subtask Report--Situation Analysis, Energy Retrofit Industry*, prepared for DOE/Building Conservation Services Division, September 31, 1981.

72. H.E. Marshall and R.T. Ruegg, *Recommended Practice for Measuring Benefit/Cost and Savings-to-Investment Ratio for Buildings and Building Systems, NBSIR 81-2397, Gaithersburg, MD, November 1981.*

73. *H.E. Marshall, Recommended Practice for Measuring Net Benefits and Internal Rates of Return for Investments in Buildings and Building Systems*, NBSIR 83-2657, Gaithersburg, MD, October 1983.

74. H.E. Marshall, *Recommended Practice for Measuring Simple and Discounted Payback for Investments in Buildings and Building Systems*, NBSIR 84-2850, Gaithersburg, MD, March 1984.

75. H.E. Marshall, "Subcommittee E06.81 on Building Economics," *Standardization News*, October 1982.

76. J.P. Millhone, J.A. Smith, and E.C. Freeman, Jr., *Applications Research and Development Program Plan for FY1983 through FY 1985*, Draft, Prepared for DOE/BERD/ARD, Washington, DC, December 3, 1982.

77. J.P. Millhone, Letter to Mike Bell at the Nationaal Association of Homebuilders regarding the status of the PEAR computer program, DOE/BERD, Washington, DC, May 1, 1985.

78. Myers Associates, Inc., *Energy Conservation Manual for Multi-Family Dwellings: A Guide to Reducing Energy Consumption in Apartments, Condominiums and other Multi-Family Residential Buildings*, prepared for the Greater Washington Board of Trade and DOE, Towson, MD, 1981.

79. National Bureau of Standards, "Applied Economics Group Publications 1973-1985," Gaithersburg, MD.

80. National Bureau of Standards, *Building Technology Publications*, Special Publication 457-1, Center for Building Technology, Gaithersburg, MD, 1976.

81. National Bureau of Standards, *Building Technology Publications*, SP457-3, Center for Building Technology, Gaithersburg, MD, July 1979.

82. National Bureau of Standards, *Building Technology Publications*, SP457-4, Center for Building Technology, Gaithersburg, MD, June 1980.

83. National Bureau of Standards, *Building Technology Publications*, SP457-7, Center for Building Technology, Gaithersburg, MD, June 1983.

84. National Bureau of Standards, *Building Technology Publications*, SP457-8, Center for Building Technology, Gaithersburg, MD, June 1984.

85. National Bureau of Standards, *Criteria for Mechanical Systems in Multifamily Buildings for Residential Weatherization Options*, NBSIR 84-2939, September 1984.

86. National Institute of Building Sciences, *Market Segmentation and Analysis: The Potential for Increasing the Energy-Efficiency of Existing Buildings*, Washington, DC, December 13, 1982.

87. North Carolina Alternative Energy Corporation, *North Carolina Alternative Energy Corporation, Quarterly Status Report, October- December, 1984*, Research Triangle Park, NC, 1985.

88. North East Solar Energy Center, sponsor, *U.S. Department of Energy Passive and Hybrid Solar Energy Program Update Meeting*, September 21-24, 1980, CONF-800972, 1980.

89. New York State Energy Research and Development Administration, *Toward a Secure Energy Future, A multi-year energy program plan*, NYSERDA, Albany, NY, June 1983.

90. Oak Ridge National Laboratory, *Expansion of the Residential Conservation Service Program to Multi-Family and Small Commercial Buildings, Draft Regulatory Analysis*, DOE/CS-0194, prepared for DOE/Office of Building and Community Services, Oak Ridge, TN, November 1980.

91. Office of Technology Assessment, *Energy Efficiency in Buildings in Cities*, OTA-E-168, Washington, DC, March 1982.

92. Pacific Northwest Laboratory, *Energy Conversion Equipment Program Summary*, prepared for DOE, Richland, WA, February 1985.

93. K. Patel, *Apartment Building (Multi-Family) Use Study-ABUS-1, Preliminary Energy Data Analysis, Final Report*, Argonne National Laboratory, prepared for DOE, Chicago, IL, October 1, 1982.

94. Perkins and Will, and the Ehrenkrantz Group, *Energy Conservation for Housing: A Workbook*, HUD-PDR-700(2), prepared for HUD/Office of Policy Development and Research, May 1982.

95. T.F. Potter, "Improvemennts in Glazings--SERI Materials Research in Progress," Vol. B, *ACEEE 1984 Summer Study on Energy Efficiency in Buildings*, ACEEE, Washington, DC, 1984.

96. R. Ritschard, et al, *Review of Energy Use and Conservation in Public Housing*, DRAFT-LBL-18822, prepared for DOE/BERD, Berkeley, CA, 1984.

97. W.J. Rossiter, Jr. and R.G. Mathey, (eds.), *Weatherization of Residences: Criteria for Retrofit Materials and Products*, NBS Technical Note 1201, Gaithersburg, MD, August 1984.

98. R.T. Ruegg, *Economic Evaluation of Building Design, Construction, Operation and Maintenance*, Seminar Workbook, NBS Technical Note 1195, Gaithersburg, MD.

99. R.T. Ruegg, et al, *Recommended Practice for Measuring Life-Cycle Costs of Buildings and Building Systems*, NBSIR 80-2040, Gaitersburg, MD, June 1980.

100. K. Subbarao and L. Flowers, "A Balanced Measurement/Calculation-Based Approach to Building Energy Analysis," *ACEEE 1984 Summer Study on Energy Efficiency in Buildings*, Vol. C, ACEEE, Washington, DC, 1984.

101. Technical Information Center, ORNL, "PEP Search on Energy Research in Existing Buildings," prepared for DOE/BERD/ARD, Oak Ridge, TN, February 11, 1985.

102. Tennessee Valley Authority, *Conservation Report, 1984*, Chattanooga, TN, 1984.

103. S.J. Treado and D.M. Burch, "Applications of Aerial Thermography for Residential Energy Analysis, ASHRAE *Transactions*, Vol. 89, Part 2, ASHRAE, Atlanta, GA, 1983.

104. Urban Systems Research and Engineering, Inc., *Guidebook for Space and Water Heating Measures: Multi-Family Housing*, prepared for DOE/ Weatherization Assistance Program, August 1984.

105. E.L. Vine and S.J. Gold, *Low-Income Households and Energy Use in California*, LBL-19127, prepared for the California Energy Commission and DOE, Lawrence Berkeley Laboratory Repoort, Berkeley, CA, March 1985.

106. E.L. Vine, *State Survey of Innovative Energy Programs and Projects*, LBL-19126, prepared for the California Energy Commission and DOE, LBL,, Berkeley, CA, March 1985.

107. B. Welch, "Energy Efficiency in Multifamily Buildings: An Outline," Alliance to Save Energy, Washington, DC, May 1983.

APPENDIX A
Organizations and Individuals Contacted

American Consulting Engineers Council (ACEC)
Alex Willman.....202/347-7474

American Institute of Architects (AIA)
M. Eichenberger.....202/626-7300

Argonne National Lab (ANL)
K. Patel.....FTS/972-5267

Association of Energy Engineers (AEE)
Romay Rupnow.....404/447-5083

Building Owners and Managers Assoc (BOMA)
Alton Penz.....202/289-7000

California Energy Commission
Karen Griffin.....916/324-3338

Center for Neighborhood Technology (CNT, Chicago)
Michael Freedberg
John Katrakis.....312/454-0126

Citizen's Conservation Corp (CCC Boston)
Roland Rowse.....717/398-7227

Ecotope
Larry Palmiter.....206/322-3753

Energy Resource Center (St Paul)
Thomas Griffen
Joyce Kerwin.....612/227-7947

Electric Power Research Institute (EPRI)
Pradeep Gupta.....415/855-2610

Florida Solar Energy Center
Subrato Chandra.....305/783-0300

Gas Research Institute (GRI, Chicago)
Gerald Pine.....312/399-8308

Institute of Gas Technology
Thomas Zawacki
Robert Macris.....312/890-6444

Institute for Real Estate Management (IREM)
Charles Achilles.....312/661-1938

Los Alamos National Laboratory (LASL)
Don Neeper.....FTS/843-3832

Minneapolis Energy Office
Ed Groody

George Peterson
Martha Hewett.....612/348-4835

Minnesota Dept. of Energy
John Armstrong
Greg Hubinger
Mary Fagerson.....612/296-1003

Minnesota Finance Housing Agency
Susan Haugan.....612/296-9848

National Bureau of Standards (NBS)
Esher Kweller
Larry Galowin.....301/921-3293

National Consumer Law Center
Steve Ferrey.....617/523-8010

National Institute of Building Sciences (NIBS)
Steve Biegel.....202/347-5710

New York State Energy Research Development (NYSERDA)
David Wolcott.....518/465-6257

Oak Ridge National Laboratory
Eric Hirst.....FTS/624-6304

Office of Technology Assessment
Dick Rowberg.....202/226-2144

Pacific Northwest Laboratories
Ray Reilly.....509/3764359

Pennsylvania Governor's Energy Council
Dan Desmond
Jim Gallagher.....717/783-9976

Princeton University
Meg Fels
David Harrje
Gautam Dutt.....609/452-4684

Queens College CBNS
Len Rodberg.....

Seattle City Light
Ed Holt.....206/625-3628

Society of Real Estate Appraisers
Robert Morn.....202/298-8497

Stockton State College (NJ)
Lynn Stiles.....609/652-1776

Sun Power Consumer Association
John Proctor.....303/973-8207

Technical Development Corp.
Steve Morgan.....617/523-7557

University of Chicago
John Porterfield.....312/996-4490

University of Pennsylvania Energy Center
Bob Wirtshafter.....215/898-7185

US Dept. of Housing and Urban Development (HUD)
Bob Groberg
Bernie Mannheimer
Mark Wynn.....202/755-5574

Wisconsin Gas Company
Brian Fay.....414/291-7000

Private Consultants:

Chaim Gold 609/392-6748
Charles Haun 717/398-7227
Gary Nelson 612/929-6949
David Robinson 612/646-1695

APPENDIX B
Responses of Individuals and Organizations Contacted
(December 1984 - January 1985)

In order to find out what retrofit activity was currently underway in the multifamily sector, and to assess research needs, researchers at LBL and Princeton University contacted individuals and organizations that were involved in a variety of aspects of multifamily retrofits. A list of the contacts is given in Appendix A. Their responses, listed below, are structured by the questions asked of each, and grouped by the type of organization, as indicated by the list below.

Type of Organization	Abbreviation	Number of Contacts
Architects & Engineers	A&E	4
Consumer & Public Interest	CPI	7
Government--Federal, State, & local	GVT	9
Real Estate & Finance	RFI	1
Research & Testing	R&T	8
Trade Associations	TRD	4
Utilities and their associations	UTL	5
Other (consultants, etc.)	ETC	4
TOTAL		42

II. What work or related work have you done on energy and multifamily buildings?

(number in parentheses are frequency of responses)

(16) Site Audits
(15) Specific Retrofits to Equipment
(13) Evaluation of Utility Billing Data
(11) Specific Retrofits to Shell
(11) Characterization of Physical Stock
(9) Simulation Models
(8) Detailed Monitoring
(7) Characterization of Energy End Use

(18) Other :

A&E:
- DOE-2 runs
- rank retrofits, optimize conservation package

CPI:
- codes, financing, metering, policy, and tax credits
- set up pilot shared savings programs
- using CIRA program to predict savings

ETC:
- tenant education
- control systems
- general, less-detailed monitoring of retrofit performance
- research definition and program management

GVT:
- study on energy and cities
- lighting measures
- technical assistance to owners
- third party loans, PVEA money for "rental problem"
- conferences on multifamily
- retrofit programs
- end-use metering
- innovative financing--shared savings
- field survey of public housing stock (ABT study for HUD)
- multifamily solar bank program
- third party financing, shared savings
- requirements for standards for mechanical retrofits

RFI:
- input to monitoring project

R&T
- passive solar retrofits in multifamily buildings
- modular hybrid systems: active collection, passive storage
- cogeneration opportunities
- cooling models
- programmatic issues
  research needs study for HUD
- working with neighborhood groups

TRD:
- developed educational materials for appraisers
- published national guidelines, building codes and rehab

III. What work are you currently doing or plan to do in this area?

(number in parenthesis is frequency of response)

(13) Site Audits
(12) Evaluation of Utility Billing Data
(12) Specific Retrofits to Equipment
(10) Specific Retrofits to Shell
(8) Simulation Models
(8) Characterization of Physical Stock
(8) Detailed Monitoring
(6) Characterization of Energy End Use

(11) Other :

A&E:
- spread sheet for savings by component
- monitoring of 100 units
- characterization of time of day energy end uses

CPI:
- utility financing of multifamily retrofits
- submetered data collection
- occupant surveys
- rentals vs co-ops

ETC:
- conference for multifamily practitioners
- control systems

GVT:
- update multifamily audits for CACS
- establish retrofit corp. for multifamily
- looking at what is cost-effective
- analyze decision making process on energy saving investments
- tenant metering study, vent damper study

TRD:
- energy rating systems

UTL:
- pre, post-retrofit study
- special financial programs
- define representative building types, calculate hourly loads, technology assessment

IV. What data, information, reports, etc. do you have that we can either get copies of or references to?

- Seattle City Light reports
- OTA report
- audit package (MEO)
- rental property standards (MEO)
- reports on rental program (CEC)
- five-year R&D plan (NYSERDA)
- IREM reports:
  1)energy cost control guide for multifamily properties ($22)
  2)alternatives to master-metering when you can't retrofit ($12)
  3)no cost/low cost for multifamily housing ($8)
  4)reprints from journal of property management ($8)
- HUD report on rehabilitation research needs
- programmatic evaluation, progress reports (ERC)
- field task proposal (LANL)
- project description of monitoring new multifamily building (FSEC)
- research agenda from ACEEE conference (ORNL)
- Philadelphia Housing Authority reports (Gold)
- characterization of multifamily sector (GRI)
- technical reports, research plans (MEO)
- project descriptions (CNT)
- reports on energy conservation in multifamily buildings (CBNS)
- many small reports (CCC)
- NBSIR 84-2939: Criteria for mech system options in multifamily buildings (NBS)

V. What do you perceive are the most critical research needs in promoting energy efficiency in multifamily buildings?

(number in parenthesis is frequency of response)

(15) What works in actual implementation
(14) Specification of savings projections
(10) Tenant behavior/Check metering
(10) Measuring results
(8) Energy-use patterns
(7) Distinguishing between savings due to maintenance and savings due to hardware installation
(6) Developing predictive methods to model energy use in multifamily buildings
(6) Central vs. individual plants
(5) Building idiosyncrasy
(5) Domestic hot water
(5) Balancing
(4) Evaluation
(4) Outdoor resets/Steel fired boilers
(4) Indoor air quality/Moisture
(4) Designing property manager-compatible retrofits
(3) Upgrading vs. repairing heating plants
(3) Vent dampers
(2) Adapting data analysis tools to personal computers
(1) Air to air heat exchangers
(1) Earth-coupled heat pumps

(20) Other:

A&E:
- evaluation of computer models, extent to which static models (LBL, Princeton) are good predictors
- infiltration ventilation rates, what is known?
- Princeton model based on gas; need data and models for electric buildings
- need to talk to builders and investment criteria people
- need description of stock
- design tools to estimate costs
- performance data
- case studies
- what is actually being done
- what kinds of investment criteria
- satisfying developers/ short-term investors vs long-term strategies
- how to best integrate new technologies with existing buildings
- where are information sources
- long term O&M implications
- low vs high-rise buildings

CPI:
- important needs on the side of landlord-tenant relationship
- financing market, landlord decision-making
- regulatory elements
- heating system retrofits

- problems in retrofitting flat attics
- overcoming tenant landlord barriers
- improved temperature controls
- infiltration research: air flows, retrofits, better models
- proper ventilation of attics in cold climates, cost of passive vents
- energy managements systems; demand charges; check metering, need tools to shed peak demand

ETC:
- marketing, financing
- energy audits, reliability of predictions
- tenant education/owner education
- public housing
- oil overcharge funds
- fuel switching from electric heat to gas/oil fired systems
- #1 need: funds to document what's already been done
- optimal piping design for heat production vs distribution
- front-end boilers for spring/fall and DHW
- lead (Pb) in DHW supplies (from solder joints)
- temperature controls in buildings (thermostat vs reset)
- commissioning of retrofits—how do they get implemented by contractors; quality control

GVT:
- reduce technical uncertainties; reason for under-investment
- cost savings potential
- prove payback on retrofit investment
- what retrofits appropriate
- accuracy of predictions
- effect of master vs individual metering on future retrofits
- what is effective feedback for tenant participation? rebates?
- what are most cost effective measures
- financing--high priority
- informational and educational aspects
- cooperation of housing authorities with innovative financing
- analysis of utility bills and implementing well-proven measures more useful than detailed monitoring
- public housing
- control strategies in steam buildings
- legal restrictions on derating gas boilers, stack heat recovery
- innovations in supplementary heating systems
- incentives to tenants

RFI:
- no cost/low cost retrofits
- needs for incentives
- enabling legislation from Federal government
- building temperature restrictions
- how to implement major capital improvements
- how to get retrofits installed: heating, a/c, passive solar

R&T:
- better glazing in windows
- analysis of performance of hybrid systems
- performance and cost-effectiveness documentation
- test procedures for rating ceiling fans
- owners/managers/tenants

TRD:

- demonstrate to owners that property values increase after retrofit and that measures are cost effective
- dollar return on dollar invested must be shown
- hardware measures

UTL:

- develop technology efficient for end use.
- relate end use to economics of utility and user.
- correct approach to help customer understand retrofits and energy use.
- how to estimate savings in multifamily buildings
- simulation model for multifamily housing
- costs of measures per square foot
- data base on multifamily buildings
- how to get tenants involved
- occupant behavior and awareness
- how to insulate around old wiring--knob and tube type
- what is decision making process for choice of appliance and energy systems
- characterize nature of appliances in multifamily sector

VI. What other research areas do you think are interesting but less critical?

A&E:
- economic motives for occupants/landlords
- vacancy/turnover rate; makes aggregate data inaccurate
- *infiltration*
- DOE-2 predictions for components
- meaning of model coefficients for electric buildings

CPI:
- innovative financing
- targetting multifamily sectors most conducive to retrofitting
- appropriate government involvement in brokering energy conservation investments
- oil-heated buildings: harder to reach and more difficult to monitor
- amenity issue: designing retrofits that have spin off benefits for management co., building owners, tenants. People are too myopic about energy savings

GVT:
- lack of information being disseminated; need to exchange experts
- understanding balance of heat and energy use in buildings
- finding and retrofitting small multifamily buildings (2-4 units); getting them interested
- general research into techniques to save energy
- cost effectiveness of sub-metering
- types of energy management systems
- data collection, feedback to tenants
- small multifamily--5-8 units, mixed commercial and residential
- masonry walls
- heat pipes

R&T:
- non-south insolation values for different climates

TRD:
- air-to-air heat exchangers, heat pumps

UTL:
- how do we make appliance market adopt new technologies?
- how to convince landlords of large-scale properties to insulate when tenants pay the bill
- how to increase public awareness

VII. How do you see this information most usefully disseminated? (workshops, technical reports, data bases, home videos, etc.?)

(16) Workshops
(12) Technical Reports
(10) Trade Publications
(7) Data Bases
(2) Direct Mail

(13) Other:

A&E:
- need to find where A&E firms get their information
- through existing organizations: BOMA
- private economic incentives; building owners not interested, have other problems besides retrofits

CPI:
- policy papers
- one-to-one communication
- accurate mailing lists
- face-to-face contacts
- technical reports on methods for calculating savings

ETC:
- HUD should disseminate information on federally-assisted housing
- private landlords don't read Trade Journals on energy use
- association of rent control boards

GVT:
- on-site information exchange
- neighborhood groups
- auditors
- workshops and technical reports coupled together
- credible groups needed; organizations with objective reputation
- associations of apartment owners
- focused research meeting
- demonstrations, person-to-person communication
- motivate owners (board of directors for co-ops) at local level
- HUD workbook has been difficult for some housing authorities
- need hands on practical approach
- person-to-person with technically competent personnel

RFI:
- Journal of Property Management
- newsletters to managers

R&T:
- utility bill stuffers

TRD:
- through lending institutions and secondary market owners, bankers
- TV for mass audience

UTL:
- needs to be found
- direct one-to-one contact
- newspaper
- BOMA associations

VIII. Would you be willing to participate further in the planning process? (another phone interview, fill out a written questionnaire, review draft of planning document, fund research, etc.)
yes: 38
no: 1
no answer: 3

IX. Can you suggest names of other individuals or organizations whom you think should be contacted?

*Monty Aaker (MFHA)
Ann Anderson (engineer)
Charles Ashmore, (HUD)
Doug Bauer, Tom Morron, (EEI)
Harvey Bernstein, (Applied Management Services)
*Don Boyson, (Columbia S&L)
*Debbie Bleviss (FAS)
Ron Ciotti (Pittsburgh)
Don Clark (engineer)
Jeff Cook (engineer)
*Dave Conover (NCSON)
*Gautam Dutt (and other Princeton people)
*Mark Friedrichs (DOE)
*Karen Griffin (CEC)
*Dick Grot (NBS)
*Martha Hewett (MEO)
*Eric Hirst (ORNL)
*John Katrakis (CNT)
Haunani Kekuna (Penn. Power and Light)
*Chris Kopp (MECC)
*Steve Morgan (TDC)
David Moulton (Energy and Power Subcommittee Staff)
*Ken Murphy (Energy and Environ. Study Inst., Wash. DC)
*Gary Nelson (researcher)
*George Parsons (Jersey City Housing Auth.)
*George Peterson (MEO)
*John Porterfield
*Mary Proctor (OTA)
*Dave Robinson (researcher)
Mitch Rosenberg (TDC)
Wally Rouse (CCC)
Mark Schuldt (United Industries, Bellevue, WA)
Hannah Shapira (ORNL)
Wayne Sherwood (CLAPHA)
Linda Shuck (PGE)
Steve Sim (Florida Power and Light)
Tom Smith (Univ. of Wisconsin)
Barbara Tillman (Grenadier Realty Corp)
*Ian Wallace (engineer)
*Bill Wisner (HUD)
Jim Wolfe (ASE)

*contacted

LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720