Building System Integration Research

**Recommendations for a
U.S. Department of Energy
Multiyear Program Plan**

January 1986

**Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830**

**Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute**

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RLO 1830

Printed in the United States of America
Available from
National Technical Information Service
United States Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

NTIS Price Codes
Microfiche A01

Printed Copy

Pages	Price Codes
001-025	A02
026-050	A03
051-075	A04
076-100	A05
101-125	A06
126-150	A07
151-175	A08
176-200	A09
201-225	A010
226-250	A011
251-275	A012
276-300	A013

3 3679 00058 5754

PNL-5696
UC-95d

BUILDING SYSTEM INTEGRATION RESEARCH

RECOMMENDATIONS FOR A
U.S. DEPARTMENT OF ENERGY
MULTIYEAR PROGRAM PLAN

January 1986

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Richland, Washington 99352

FWL 3028
JUL-98

BUILDING SYSTEM INTEGRATION RESEARCH
RECOMMENDATIONS FOR A
U.S. DEPARTMENT OF ENERGY
MULTIYEAR PROGRAM PLAN

January 1998

Prepared for
the U.S. Department of Energy
under contract number AC05-84OR21400

Building Research Laboratory
Richland, Washington 99352

ACKNOWLEDGEMENTS

We would like to acknowledge the support of government and industry representatives who helped develop this plan and thank them for their participation.

APPENDIX

We would like to acknowledge the support of government and industry representatives who have helped us in our research.

EXECUTIVE SUMMARY

This document is intended to serve as a basis for the U.S. Department of Energy's (DOE's) multiyear plan for building system integration (BSI) research. In this document, the concept of system integration research is explained, its benefits are demonstrated, and methods for the DOE's conduct of research during FY 1987 through FY 1991 are recommended. The plan is an outgrowth of earlier planning activities conducted for the U.S. Department of Energy (DOE), and is in direct response to the DOE FY 1986 Authorization Report that requires such a plan (House of Representatives 1985).

BSI research refers to the study of the effect of the building envelope, equipment, lighting, people, and weather on the amount of energy that buildings are designed to use. The intent of the research is to maximize building performance by applying research findings that identify, analyze, and quantify the impact that the interaction of building subsystems, occupants and climate has on the energy performance of residential and commercial buildings.

BSI research was initiated in 1982 in support of the DOE's Building Energy Conservation Standards Program, where the need for additional knowledge on systems integration became apparent. Although significant information was available on the relative efficiency of individual building materials and components, little was known about selecting and combining building materials, components, and systems for an optimum combination of energy conservation, first cost, occupant comfort and occupant productivity. To provide such information, the DOE initiated a series of residential and commercial building research projects. The results of these efforts convinced the DOE that substantial energy could be saved through a major research program in system integration.

The BSI research plan is divided into residential and commercial research areas. Residential buildings include site-built attached and detached homes, manufactured housing, and multifamily structures of three stories and less. Commercial buildings include all remaining buildings, including larger multifamily buildings, but excluding industrial buildings and commercial buildings with significant process loads. This separation of research recognizes that buildings in each sector are designed and constructed differently, serve different

functions, concern different members of the building community, and are driven by different financial/incentive practices, and therefore, present different research challenges.

The products of this research will be varied. They include end-use energy consumption and engineering data bases; knowledge-based design tools; building-specific design manuals; guidelines for constructing, operating, and maintaining buildings; algorithms and procedures for use in conservation standards; and prototypical demonstrations of advanced integration concepts.

The benefits of this research are projected to be substantial. Well-designed buildings can reduce energy consumption by up to 60% over buildings designed to standard practice, while reducing life-cycle and operating costs and often first costs as well. These benefits can be gained through optimal combination of proven building technologies, without increasing owner and occupant costs, and without the risks of reduced building productivity due to problems with unproven "high-tech" designs and equipment.

Several ancillary benefits will result from the research on building system integration. In the residential sector, decreased operating costs will decrease overall costs of ownership, thereby increasing both the number of families that qualify for home ownership and the discretionary income of homeownership families. A recent study by the Urban Land Institute (1982) indicates that affordable housing will continue to be one of the key economic issues of the 1980s and 1990s. In the commercial sector, lower energy costs will increase profit margins and market competitiveness.

Another benefit from BSI research will be the identification of component-specific research that can provide the greatest energy savings. This benefit is important because only through a "wholistic" cause-and-effect understanding of how a building works can the true value of any building element or design strategy be fully assessed. Finally, BSI research will develop a better understanding of how to maintain human comfort, health, and productivity, and will identify cost-effective ways to provide these requirements.

CONTENTS

1.0	INTRODUCTION	1.1
1.1	A DEFINITION OF BUILDING SYSTEM INTEGRATION RESEARCH	1.1
1.2	NEED FOR BUILDING SYSTEM INTEGRATION RESEARCH	1.1
1.3	HISTORY OF BUILDING SYSTEM INTEGRATION RESEARCH	1.4
1.4	PROGRAM SCOPE	1.6
1.5	PLAN DEVELOPMENT	1.7
2.0	THE BUILDINGS SECTOR	2.1
2.1	ENERGY USE IN THE BUILDINGS SECTOR	2.1
2.2	RESIDENTIAL BUILDING CONSTRUCTION AND ENERGY-USE TRENDS	2.2
2.2.1	Residential Building Construction	2.2
2.2.2	Residential Energy Consumption	2.2
2.3	COMMERCIAL BUILDING CONSTRUCTION AND ENERGY USE TRENDS	2.3
2.3.1	Commercial Building Construction	2.3
2.3.2	Commercial Building Energy Consumption	2.4
2.4	IMPLICATIONS FOR BSI RESEARCH	2.5
3.0	TECHNICAL PLAN	3.1
3.1	THE RESIDENTIAL RESEARCH PLAN	3.2
3.1.1	Residential Research Element #1: Subsystems Interaction Research	3.3
3.1.2	Residential Research Element #2: Regional/Site Research (Cooling)	3.6
3.1.3	Residential Research Element #3: Design Process Research	3.7
3.1.4	Residential Research Element #4: Construction Practice Research	3.9
3.1.5	Residential Research Element #5: Housing Innovation Research	3.13
3.2	THE COMMERCIAL RESEARCH PLAN	3.15
3.2.1	Commercial Research Element #1: Subsystems Interaction Research	3.17
3.2.2	Commercial Research Element #2: Building/Occupant Interaction Research	3.18
3.2.3	Commercial Research Element #3: Design Process Research	3.20
3.2.4	Commercial Research Element #4: Construction, Operation, and Maintenance Research	3.25

4.0	MANAGEMENT PLAN	4.1
4.1	MANAGEMENT RESPONSIBILITIES, STRATEGY, AND CONTROL	4.1
4.2	BUILDING INDUSTRY COORDINATION	4.1
5.0	RESOURCE PLAN	5.1
5.1	RESEARCH COSTS AND FUNDING	5.1
5.2	FACILITIES AND EQUIPMENT	5.1

LIST OF FIGURES

1.1	Building System Integration	1.1
1.2	Energy Research Roles and Products	1.5
2.1	Building Energy Consumption as a Fraction of National Energy Consumption	2.1
2.2	Profile of U.S. Residential Housing by Building Type in 1983	2.2
2.3	End-Use Disaggregation for Residential Building Energy Consumption in 1980	2.3
2.4	Commercial Building by Building Type in 1979	2.3
2.5	Commercial Building Floor Space by Year of Construction	2.4
2.6	End-Use Disaggregation for Commercial Building Energy Consumption in 1980	
3.1	Residential Building System Integration Research Structure	3.2
3.2	Schedule for Residential Building System Integration Research	3.4
3.3	Residential Subsystem Research	3.5
3.4	Residential Regional/Site Research	3.8
3.5	Residential Design Process Research	3.10
3.6	Residential Construction Practice Research	3.12
3.7	Residential Housing Innovation Research	3.14
3.8	Commercial Building System Integration Research	3.15
3.9	Schedule for Commercial Building System Integration Research	3.16
3.10	Example of Building-Specific Approach to Commercial Building System Integration Research	3.17
3.11	Commercial Subsystems Interaction Research	3.20
3.12	Commercial Building/Occupant Interaction Research	3.22
3.13	Commercial Design Process Research	3.24
3.14	Commercial Construction, Operation and Maintenance Research	3.26
4.1	Program Management	4.1

LIST OF FIGURES

1.1	Building System Integration	1.1
1.2	Energy Research Notes and Comments	1.2
1.3	Building Energy Consumption as a Fraction of National Energy Consumption	1.3
1.4	Profile of U.S. Residential Housing by Building Type in 1981	1.4
1.5	End-use Disaggregation for Residential Building Energy Consumption in 1980	1.5
1.6	Domestic Building by Building Type in 1979	1.6
1.7	Commercial Building Energy Use by Type of Construction	1.7
1.8	End-use Disaggregation for Commercial Building Energy Consumption in 1980	1.8
1.9	Residential Building System Integration Research Structure	1.9
1.10	Schedule for Residential Building System Integration Research	1.10
1.11	Residential Subsystem Research	1.11
1.12	Residential System/Style Research	1.12
1.13	Residential Design Process Research	1.13
1.14	Residential Construction Process Research	1.14
1.15	Residential Housing Energy Research	1.15
1.16	Commercial Building System Integration Research	1.16
1.17	Schedule for Commercial Building System Integration Research	1.17
1.18	Example of Building Specific Approach to Commercial Building System Integration Research	1.18
1.19	Commercial Subsystem Integration Research	1.19
1.20	Commercial Building Research Structure	1.20
1.21	Commercial Design Process Research	1.21
1.22	Commercial Construction Process Research	1.22
1.23	Commercial Building System Integration Research	1.23

1.0 INTRODUCTION

This multiyear (5-year) program plan for building system integration research was developed by Pacific Northwest Laboratory (PNL) with input from Lawrence Berkeley Laboratory, Brookhaven National Laboratory, and many representatives of the buildings industry. (See Appendix A for a list of participants.) The planning effort was directed by the Building Systems Division of the U.S. Department of Energy's (DOE's) Office of Buildings and Community Systems. The research will be managed by the Building Systems Division.

The primary purpose of BSI research is to better understand how buildings work as an integrated system; to take the knowledge gained in researching old and new technologies and apply it to building design, construction, operation, and maintenance; and to ensure that the research results are transferred to the buildings industry where they will result in more efficient and cost-effective buildings.

This plan describes the scope, technical content, and resources required to conduct the BSI research program during FY 1987 through 1991. In the following sections, system integration research is defined, the need for the research is discussed, its benefits are outlined, and the history of building system integration research is summarized. The program scope, the general approach taken in developing this program plan, and the plan's contents are also described.

1.1 A DEFINITION OF BUILDING SYSTEM INTEGRATION RESEARCH

Building system integration research is the study of the effect that the building envelope, equipment, lighting, people and weather together have on the amount of energy that buildings are designed to use. The intent of the research is to optimize building performance by applying research findings that identify, analyze, and quantify the impact that the interaction of building subsystems, occupants and climate has on the energy performance of residential and commercial buildings. Figure 1.1 illustrates the concept of how materials, components, and subsystems are combined to form the building system.

The term "system" is used throughout this plan to refer to the building as a

whole. Major parts of the building such as the heating ventilating, and air conditioning (HVAC) elements, the lighting elements, and the envelope (roof, floor, and walls, including windows) elements are referred to as subsystems.

An effective energy-efficient building (or system) is more than just a collection of energy-conserving materials, components and subsystems. Rather, it is one in which each element has been selected, designed and constructed to interact effectively with other building elements, climate, and occupants as an energy-using system. For example, in a well-designed commercial building, window design and selection are not based solely on climate characteristics; the needs and operating patterns of the building's occupants and the window's impact on the building's lighting and HVAC subsystems are also considered. While there are many buildings in the U.S. whose design and operating history reflect the concept that an integrated energy design results in optimum energy use, reduced energy costs, increased thermal and lighting comfort, and better indoor air quality, they constitute a relatively small percentage of new buildings designed and constructed each year.

1.2 NEED FOR BUILDING SYSTEM INTEGRATION RESEARCH

The importance of a focussed research program to support development of improved building design and construction processes can be illustrated by a comparison with the design and manufacturing processes for an automobile. As in buildings, the energy performance of cars is a function of equipment (engine) performance, shell design, size, shape, weight, and user characteristics. Careful design of cars has more than doubled their fuel efficiencies in the last two decades. Building energy performance can be similarly increased through careful design and construction, but the process is different. Cars are mass-produced based on a prototypical design by only a few producers, but only after the prototype has been exhaustively tested on the bench, in wind tunnels, and on the track. During this testing, design errors can be corrected before significant capital investment is made, and the risk of design malfunction of cars sold to and used by people is lessened. The few large automobile manufacturers can afford the research and development necessary for

FIGURE 1.1. Building System Integration

design, testing, and prototyping of new automobiles.

Buildings, unlike automobiles, are generally unique products that have been designed and constructed by thousands of independent companies. They are generally not replicated from prototypes that have been thoroughly tested and optimized. From the design stage to final construction, buildings have little chance for laboratory testing and modification. Each building performs differently, and individual building performance is difficult to predict accurately. As a result, there are many buildings that are "energy-use" failures. This situation will not quickly reverse itself, as there are few building producers who have the resources to conduct research on the design and construction processes in order to improve the performance of their buildings.

Buildings and cars built today will have significantly different impact during the next generations. Buildings typically have a life expectancy of 50 or more years, and most of the buildings constructed today will still be in service for the next generations, using energy at nearly the same rates at which they do today. After construction is complete, the opportunities for major efficiency improvements occur only when and if the building is retrofitted or rehabilitated. The automobile population, however, is replaced on a much shorter time basis, and so the overall performance of the automobile in the next generation will be impacted only very little by the cars designed and built today.

Because buildings are constructed to be long-lasting, the consequences of their energy consumption patterns affect the economy for many years. Buildings that are not designed to promote optimum energy use are a drain on valuable natural and economic resources. For many decades energy use was not an issue, but during the last ten years there has been a major industry effort to save energy and cut costs. This consciousness has led to a lower growth rate in total building energy use, and reduced energy consumption on a per-square-foot-of-floor-space basis. Buildings constructed in 1986 will use an average of 5% to 10% less energy than comparable buildings built in 1976 (Flynn 1984); this is far less than the 30%-60% reduction that might be expected from well-designed buildings.

Aggregate new building performance does not meet conservation expectations for four primary reasons:

- There is only a superficial understanding of the interactive effects of energy conservation measures.
- Building energy standards are developed from inadequate data bases.
- The buildings industry is a highly fragmented sector composed chiefly of small firms.
- There is little direct market pressure for energy-efficient buildings.

These reasons are discussed in more detail in the following paragraphs.

Decreased energy consumption in buildings has resulted from a wide variety of energy conservation measures. The use of many of these measures, such as insulation and double pane windows, is not new, but only became fashionable as energy prices rose and conservation developed a high market visibility. However, the full potential of existing energy conservation measures has not been realized. These measures are usually added to a building or building design without much thought given to how they might interact with other elements of the building. As a result, these conservation measures sometimes counteract each other, using more energy than if they had not been implemented, and rarely do they provide the total cost/energy savings that had been predicted. These misapplications increase cost and in some cases lower the quality of the building. Energy conservation in buildings will never reach its full potential until building system interactions are understood and can be easily implemented by most designers and builders.

A second reason why building energy efficiency has not increased as expected is the lack of a knowledge base to improve current and future building energy design standards. Building energy standards are now based on numerous rules that simplistically assume steady-state operation of independent building components. Current standards do not give credit for positive interactive effects, and may even discourage or prohibit more energy-efficient designs that are based on interactions under dynamic conditions. Hence, there is little incentive and/or direction for developing buildings that utilize these positive interactive effects. Improvement of these design standards requires data and algorithms that can only be provided by BSI research.

The diversity of the buildings industry and its need for a focal point for BSI research is a third reason why building energy efficiency has not increased as expected. The buildings industry is a multifirm sector of the economy that includes product manufacturers, architects, engineers, builders, financiers, owners, operators, and building-code officials. A significant amount of industry-sponsored research has been conducted, but it has traditionally been conducted to improve product lines, rather than overall building performance. For example, heating and air-conditioning product manufacturers conduct research to develop energy-efficient HVAC equipment because of the economic incentives involved in new products. These same manufacturers do not generally attempt to determine how their product is most efficiently used in the context of the whole building. Such an effort would be costly and would not enhance their positions in the marketplace. Until recently, federally sponsored research has had the same focus, with very little funding devoted to examining the interactions of a building's components, ways to improve the design process, or ways to ensure construction quality. BSI research is intended to provide this type of integrative research.

The fourth reason that conservation technologies have not radically improved building performance is that the marketplace has not demanded greater energy efficiency. Energy prices have stabilized and fuel availability is not questioned. There are, however, indirect market drivers. New residential housing is becoming more expensive and many homeowners are unable to afford combined mortgage and utility bills. The cost of constructing and operating commercial buildings is rising quickly, resulting in higher rents and lower profits. Energy is being wasted unnecessarily, and imposing commensurate costs on today's building owners and on future generations. BSI research can provide a basis for improved building efficiency, thereby reducing the total cost of homeownership and improving profits within the commercial sector.

1.3 HISTORY OF BUILDING SYSTEM INTEGRATION RESEARCH

Figure 1.2 illustrates the present and future roles of the public and private sectors in pursuing building energy research, and the building industry's use of this research in designing and constructing buildings. The private sector has been more heavily involved in materials and equipment research and the federal government more heavily involved in subsystems and system integration research. The shaded areas

represent relative levels of research conducted to date. The empty boxes indicate that there is still much to learn about system integration.

Building system integration has a long history in the U.S., dating back to the colonial period when pre-engineered kit houses were shipped from Europe. More recently, in the late 1950s and 1960s, several major U.S. and Canadian projects produced significant innovation by addressing the system integration problems of schools. At that time, building quality and cost were the problems, not energy. The school project produced such products as return air lighting fixtures that demonstrated excellent performance. Those fixtures address current energy problems by returning conditioned air through the fixture, cooling the lamp for improved lighting performance, and reducing the heat from lights entering the space, thereby reducing cooling loads. However, those products were not originally intended as energy savers; energy was not singled out as a system integration issue until the 1970's.

Some of the first energy-related research on building system integration was conducted in developmental support of DOE's Program for Energy Conservation Standards for New Buildings (see Appendix B). This work documented that there is a tremendous potential for energy efficiency when buildings are designed in an integrated manner. In this work, energy consumption simulations were performed for 10 different commercial building categories across 8 climate zones. The 10 buildings were redesigned from an existing design standard (ANSI/ASHRAE/IES Standard 90-1975) to a more stringent standard based upon the results of system integration research. The redesigned buildings reduced total energy consumption by 10% to 15%, and reduced total energy consumption in some building categories by about 30%. Total operating costs were always substantially reduced; first cost sometimes increased by a small amount, and many times was reduced (PNL 1983). These savings were achieved not through the selection of high-risk, high-technology computerized machinery and components, but rather through codified procedure of (partially) integrating commonly used building components and subsystems. If building-specific system integration had been conducted, or if advanced design tools had been applied during the design process, energy and cost savings would have been substantially greater.

Another example of the relative energy savings available through system integration is documented in the Small Office Building Handbook: Design for Reducing First Costs

FIGURE 1.2. Energy Research Roles and Products

and Utility Costs (Burt Hill Kosar Rittelmann Associates 1985). The handbook demonstrates that significant amounts of energy can be saved in small office buildings by implementing simple, but judiciously-selected conservation strategies. One example cited in the text is a small office building designed for Washington, DC. This building configured to typical pre-1973 crisis standard would consume \$125,000 of energy per year; configured to current building standards, it would consume energy at a cost of \$60,000 per year; reconfigured to simple system integrating strategies reduces the total annual energy bill to \$35,000 per year.

The same relative savings can be captured on the residential scale, where the integration of energy-efficient appliances, efficient heating and cooling equipment, and building materials in optimal combinations can make residences more affordable. Using the "slide rule" incorporated in DOE's Affordable Housing and Manufactured Housing Through Energy Conservation Programs, manufacturers and builders can calculate energy and cost savings from a wide range of energy conservation measures. For example, in a single-section, 902 sq. ft. manufactured home located in Fredericksburg, VA, integrating 12 relatively low cost energy conservation measures can reduce energy costs by up to \$650 annually. If the buyer used the annual savings to buy extra, non-energy amenities, he could purchase an energy-efficient home costing \$27,000 for the same annual cost of home ownership as a standard, low-option \$25,000 home. This \$2000 difference means that more (5%) low-income families could afford the home (Manuf. Housing 1979).

Today, the energy benefits of conducting such research are widely acknowledged by both the DOE and the private sector. However, because the buildings industry is diverse and because there is little economic incentive for individual members to conduct energy-related system integration research, a single national entity must become the catalyst for research. The DOE is the federal agency that has the experience and resources to manage that responsibility.

1.4 PROGRAM SCOPE

As stated earlier, the BSI Research Program will develop an improved technical understanding of the energy-related interactions among the envelope, HVAC, lighting, hot water, appliances, equipment (e.g., office equipment), occupants, and climate components of buildings. The objective of the research will be to provide the buildings industry with the basis for developing improved building subsystems and design and

construction procedures, and ultimately, less costly and more energy-conserving residential and commercial buildings. The study of residential buildings includes site-built, manufactured and low-rise multifamily housing. Commercial buildings include all other buildings, with the exception of industrial buildings and commercial buildings with high-process loads. Within each area, building types have been targeted for priority research because they provide the greatest opportunities for saving energy.

The products of BSI research will be technical data and information, design and analysis tools, and architectural and engineering knowledge. The private and public sectors will use this information to base decisions on cost-effective energy-efficient design, construction, rehabilitation, and operation of buildings. The program will add to an established research base and to existing technologies.

BSI research will examine future issues surrounding 21st century buildings and inhabitants. Such issues include research into so-called "smart buildings," an area where the National Association of Homebuilders (NAHB) has been at the forefront of home electrical supply technologies. (A synopsis of the NAHB "smart house" is presented in Appendix C.)

The BSI Research Program will also address issues that crosscut the residential and commercial sectors. These issues include developing a better understanding of the effects of microclimate on a building, and the impacts of energy-using subsystems on indoor air quality.

The program is structured in much the same way that a building is designed and constructed. The research initially focuses on subsystem interactions: the interaction of the envelope, HVAC, lighting and interior subsystems, keying on energy and economic performance. Next, the program concentrates on the impact of climate on a building and an improved understanding of how building size, shape, orientation, location and site conditions create a building-specific microclimate and, in turn, affect energy consumption. The impact of occupant needs, occupant control of building environment, and building functional uses are also studied.

The technical data and information gathered in the interactions research will then be incorporated, with additional research, into the design and construction, maintenance and operation processes as design and construction tools. These tools will be used

to aid architects, engineers, builders, etc., to incorporate state-of-the-art knowledge in building design and construction. Because system integration is a large and complex issue, the research will be addressed in manageable projects and will be primarily applied to energy issues in the predominant building types.

Through its energy conservation research, the DOE will continue to play a significant role in improving building energy-efficiency through long-term, high-risk, high-payoff research. The DOE will incorporate the knowledge gained from other DOE and private sector research into this program. And, although the residential and commercial sectors are separated for research purposes, many elements of the research such as climate and indoor air quality are common to both and will be studied jointly. Research products identified in this plan are essential to a comprehensive research program that, after transfer to building industry users, can result in cost-effective energy-efficient design and construction as common practice. The products will require industry involvement in order for them to be incorporated into practice.

Not all building system integration research needs to be conducted by the DOE. The DOE will work jointly with the private sector, but funding will be provided for a research project only if the following criteria are met:

- The project provides national or regional benefits.
- The project has potential for significant long-term energy and economic savings.
- No significant private sector research is being conducted on the research topic.
- Federal support does not impair operation of the free market.
- The project is fully consistent with established legislative and organizational responsibilities.
- Research does not duplicate or conflict with actions of other DOE offices and federal agencies.
- The project is identified and reviewed in cooperation with the building industry.

1.5 PLAN DEVELOPMENT

To ensure development of a program that addresses actual problems and user needs, representatives of major residential and commercial building industry groups have been involved as an informal panel to help structure the research and to review the plan. The basic approach taken is outlined below:

1. Existing building system integration research was reviewed and areas of appropriate research were identified.
2. A preliminary BSI research agenda was prepared for residential and commercial buildings.
3. The preliminary assessment was reviewed by representatives of several segments of the building industry.
4. Based on the assessment and on building industry recommendations, a draft multiyear plan was prepared.
5. The draft plan was widely reviewed by representatives of the building industry, government laboratories and university researchers.
6. On the basis of the wide-scale review, recommendations for a detailed plan were prepared.

These recommendations have been delivered to the DOE for review and for use in developing a final plan for DOE implementation.

1.6 REPORT CONTENTS

This program plan comprises five chapters and three appendices. In Chapter 2.0 commercial and residential building energy consumption trends are discussed as a background for understanding the basis for the proposed research. Chapter 3.0 describes the technical plan for implementing the research. Section 3.1 is the residential BSI research plan and Section 3.2 is the commercial BSI research plan. In Chapter 4.0 the DOE's management responsibilities and strategy are described. The financial resources necessary to fund the research program are provided in Chapter 5.0.

Appendix A lists the participants involved in developing this plan. Appendix B presents information on system integration research conducted in support of the development of commercial building standards. Appendix C presents information on the "smart house" concept being developed by the National Association of Homebuilders.

1.5. PLAN DEVELOPMENT

To ensure development of a program that addresses actual problems and needs, representatives of major residential and commercial building industry groups have been involved as an informal panel to help structure the research and to review the plan. The basic approach taken is outlined below:

1. Existing building system integration research was reviewed and areas of appropriate research were identified.
 2. A preliminary BSI research agenda was prepared for residential and commercial buildings.
 3. The preliminary assessment was reviewed by representatives of several segments of the building industry.
 4. Based on the assessment and on building industry recommendations, a draft building plan was prepared.
 5. The draft plan was widely reviewed by representatives of the building industry, government laboratories and university researchers.
 6. On the basis of the wide-scale review, recommendations for a detailed plan were prepared.
- These recommendations have been delivered to the DOE for review and for use in developing a final plan for DOE implementation.

1.6. RESEARCH CONTENTS

The program plan comprises five chapters and three appendices. In Chapter 1.0, commercial and residential building energy conservation programs are discussed as a background for understanding the basis for the proposed research. Chapter 2.0 describes the technical plan for implementing the research. Section 2.1 is the residential BSI research plan and Section 2.2 is the commercial BSI research plan. In Chapter 3.0, the DOE management responsibilities and organizational resources are described. The financial resources necessary to fund the research program are provided in Chapter 4.0.

Appendix A lists the participants involved in developing this plan. Appendix B provides information on system integration research conducted in support of the development of commercial building standards. Appendix C provides information on the "Energy Conservation Program" developed by the National Association of Manufacturers.

As with architects, engineers, builders, etc., to incorporate state-of-the-art knowledge in building design and construction, building system integration is a large and complex task. The research will be organized in manageable projects and will be primarily applied to energy issues in the predominant building types.

Through its energy conservation research, the DOE will continue to play a significant role in improving building energy efficiency through long-term, high-risk, high-payoff research. The DOE will continue to coordinate the knowledge gained from other DOE and private sector research into this program. And, although the residential and commercial sectors are targeted for research, many elements of the research such as data and design will be common to both and will be studied jointly. The research projects identified in this plan are essential to a comprehensive research program that, after transfer to building industry, can result in cost-effective energy-efficient design and construction of commercial buildings. The products will require industry involvement in order for them to be incorporated into practice.

Not all building system integration research needs to be conducted by the DOE. The DOE will work jointly with the private sector, but funding will be provided for research projects only if the following criteria are met:

1. The project provides national or regional benefits.
2. The project has potential for significant long-term energy and economic savings.
3. No significant private sector research is being conducted on the research topic.
4. Federal support does not impair operation of the free market.
5. The project is fully consistent with established legislative and organizational responsibilities.
6. Research might not duplicate or conflict with actions of other DOE offices and Federal agencies.
7. The project is identified and reviewed in cooperation with the building industry.

2.0 THE BUILDINGS SECTOR

This chapter presents information on energy consumption and trends for residential and commercial buildings as a basis for understanding the value of the BSI Research Program and the types of research to be conducted. Section 2.1 provides an overview of building energy consumption to establish the role of buildings as an energy-using sector and to demonstrate the value of BSI. Section 2.2 provides more specific information on trends in residential construction and energy use as a basis for understanding the research priorities within the residential plan. Section 2.3 provides the same information on commercial building construction and energy use.

2.1 ENERGY USE IN THE BUILDINGS SECTOR

Building energy consumption is a major portion of the total U.S. energy consumption. Residential and commercial buildings consumed about 36% of total U.S. (source) energy in 1983, including natural gas, petroleum, electricity, and coal (EIA 1984a) (Figure 2.1). This is a significant growth in the overall energy share since 1960, when buildings consumed only about 30% of total U.S. energy use (Flynn 1984). This share growth reflects the difficulty in improving the performance of the long-lived building stock as compared to the relatively quick improvements possible in overall vehicle efficiency. The share growth also reflects the large relative reductions made in industrial energy use due to more efficient industrial processes and slowed industrial activity.

Today approximately 84 million residential housing units (comprising single-family detached, multifamily, and manufactured housing) account for 57% of total U.S. building energy use and 21% of total U.S. energy use. About 4 million commercial buildings account for the remaining 43% of building energy use, and about 15% of total U.S. energy consumption, as shown in Figure 2.1 (Flynn 1984).

Each year residential homeowners and renters pay approximately \$87 billion for energy, and commercial building owners and tenants pay about \$58 billion. Total building energy use and costs are projected to balloon during the next decade. By 1995, at present rates of growth, these costs are projected to rise to \$130 billion (103.8 million homes at \$1,256 per home) for residential buildings, and \$102 billion (65.7 billion sq ft at \$1.56/sq ft) for commercial buildings. (All costs are expressed in constant 1983 dollars.) During the same period,

energy use per household is forecast to decline at only an average annual rate of 1.4%, and commercial building energy use per square foot is expected to decline at an average annual rate of 1.2% (Flynn 1984).

FIGURE 2.1. Building Energy Consumption as a Fraction of National Energy Consumption (Flynn 1984)

An intensive research program into BSI research will exert an important downward force on these projections, but estimating those energy savings is extremely difficult. Most building energy researchers estimate that a well-integrated building will consume 30% to 60% less energy than conventionally designed buildings. If each of the 20 million residential units projected to be built between 1985 and 1995 were designed and built to reduce energy consumption by only 30%, those units' annual energy costs would be reduced from an average of \$1,256 to \$879 per home, allowing many more families to qualify for home ownership. Under the same scenario, with the expected increase of 17 billion square feet of commercial space, commercial building energy costs would drop from an average of \$1.56 to \$1.09 per square foot for new buildings (Flynn 1984), thus improving the profitability of those businesses. Of course, these efficient new additions would not significantly improve the performance of the total building stock immediately (due to the long life expectancy of today's relatively inefficient buildings). However, over the next decades the total building stock would slowly become more efficient, saving many quads of energy.

2.2 RESIDENTIAL BUILDING CONSTRUCTION AND ENERGY-USE TRENDS

In the following sections, data on residential building construction and energy-use trends are discussed. Building construction is discussed to provide a basis for understanding energy use and energy-use trends.

2.2.1 Residential Building Construction

Single-family detached units now supply housing for about 64% of U.S. families, apartment units for about 27%, and row/town houses and manufactured housing for about 5% each, as illustrated in Figure 2.2 (Flynn 1984). These figures represent total housing stock and do not accurately represent what is happening in new construction, where a very different picture is emerging.

FIGURE 2.2. Profile of U.S. Residential Housing by Building Type in 1983 (Flynn 1984)

The U.S. has, for the past decades, experienced a population shift from the more densely populated North to the less densely populated South and West. This shift is continuing, although recent U.S. Census data indicate a slowing in this trend (*The Washington Post* 1985). Population shifts are also occurring within these regions on a local basis, from rural and high-density urban settings to small towns and suburban regions. This shift is expected to continue, spurred by the lower tax rates, slower pace of life, and lower crime rates of those regions (Harvard-MIT 1980).

The effect of these regional and localized trends on construction of housing types

has been mixed. The single-family detached home is the building type of choice for people moving from major urban areas into small cities and suburban communities, but this preference in housing has been somewhat overridden by other socioeconomic factors. America's trend to smaller (and later) families has increased interest in multifamily housing and manufactured homes, and the tremendous rise in cost (in constant dollars) of single-family housing has proven a barrier to many families who would like to purchase their own homes.

The manufactured housing industry has grown appreciably in recent years, both in the sales of mobile homes and in component manufacture of site-erected single-family and multifamily structures. Almost half of all new housing units were at least partially manufactured in 1984 and over 400,000 new manufactured housing units are projected for 1985 (*Technology Review* 1985). Cost is a major reason for the move to mobile homes and factory-built components. Site-erected construction costs have been cut by 10% by using factory-built wall panels, including doors, windows, and electrical wiring (*Technology Review* 1985). Ryan Homes, one of the nation's largest builders, now builds 25% of its homes in this manner, and predicts the number will grow to 66% of their total construction (*Business Week* 1983).

The housing affordability gap, plus the growing proportion of small, childless households has also spurred the multifamily building industry to a 25% increase in new and rehabilitated building starts (*Building Design and Construction* 1984). These starts represent suburban new construction and the rehabilitation of older central-city and suburban neighborhoods.

2.2.2 Residential Energy Consumption

In 1980 55% of the purchased energy consumed in the residential sector was used for space conditioning; 48% of that total used for heating in the 99% of homes that were heated, and 7% of the total used for air conditioning in the 57% of homes that were air conditioned. Other energy was consumed for water heating (14%), refrigerators and freezers (13%), lighting (6%), cooking (5%), and miscellaneous (7%), as shown in Figure 2.3. Space heat was provided by gas fuels (60%), electricity (19%), and oil fuels (17%) (EIA 1982).

These total housing stock figures do not accurately reflect what is happening in the new housing market. Heating in new houses is chiefly electric (50%) and gas (43%), with only about 2% of new homes heated

by oil. Approximately 70% of the single-family residential buildings and nearly 90% of new multifamily residential buildings are electrically air conditioned (Lannus 1985). Since the BSI Research Program primarily targets new design and major rehabilitation, these latter attributes will determine the types of research to be conducted.

FIGURE 2.3. End-Use Disaggregation for Residential Building Energy Consumption in 1980 (EIA 1982)

2.3 COMMERCIAL BUILDING CONSTRUCTION AND ENERGY USE TRENDS

In the following sections, data on commercial building construction and energy use are discussed. As in Section 2.2, building construction is discussed to provide a basis for understanding energy use and energy-use trends.

2.3.1 Commercial Building Construction

The 4 million U.S. commercial buildings contain about 48 billion square feet. Most buildings (95%) contain less than 50,000 square feet, while the remaining 5% contain over 50% of total commercial floor space (EIA 1981). Much of the commercial space is dedicated to retail (including food sales), office, assembly, automotive, and multifamily buildings, as shown in Figure 2.4 (Flynn 1984).

As with residential buildings, much of the older stock is concentrated in the industrial North, and new construction is chiefly in the North Central and Sunbelt states, where commercial activity has followed the population shift (Figure 2.5) (Flynn 1984).

FIGURE 2.4. Commercial Building Space by Building Type in 1979 in (Flynn 1984)

About 21% of the total commercial floor space in existence in 1979 had been built after 1971, the latest date for which that information is available (Flynn 1984). Assuming a continuation of that construction trend, about 20% to 25% of all commercial buildings have been constructed since the impact of the 1973 energy crisis, which indicates that about 75% of the total commercial building stock has been designed and constructed without much thought given to energy conservation. These buildings are ready for rehabilitation, and considerable rehabilitation work is projected for the North and North Central regions.

Intra-regional trends for commercial buildings have tracked residential trends. The movement of retail, office, and multifamily residential centers away from the downtown to more localized shopping centers, office parks, and residential communities is expected to continue, fueling continued suburban construction.

The nature of new and existing office space is changing, becoming more technology oriented as computers become every-day tools for office workers. Space conditioning needs for these buildings are shifting from heating to cooling as the internal loads created by computers and related technologies increase. In addition, office-like space is increasing as America's heavy industry slowly gives way to service industries and light manufacturing --many specialized manufacturing facilities and warehouses are beginning to look like low- and mid-rise office buildings from energy and structural perspectives. Because

FIGURE 2.5. Commercial Building Floor Space by Year of Construction (Flynn 1984)

of the shift of business to the South and West, the rehabilitation and new construction boom in central cities, and the office-like approach being taken by industrial and warehouse buildings, the demand for new and rehabilitated office-type space will remain high.

A second building type that promises to capture much of the future commercial building market is multifamily housing. Many of the large multifamily apartment houses constructed over the last decades are now very energy intensive, and are liable for major rehabilitation projects. Between these rehabilitations and the new multifamily construction that will result from the rising cost of single-family detached housing, mid-rise and high-rise multifamily construction will be a major activity area in the next decades.

Finally, retail space is growing and will continue to grow over the next decades. The trend to the large suburban shopping center appears to have ended (Urban Land Institute 1982). The local strip shopping center is now the preferred retail configuration. Even though relatively few regional retail centers will be built over the next decades, the rehabilitation and expansion of existing centers will be extensive. In many cases, the expansion will transform single-use suburban retail centers into more urban

mixed-use developments through the addition of office, hotel, and other recreational space. Dining out will continue to be the prime recreational pastime for a large portion of the population, and restaurant space will correspondingly increase.

2.3.2 Commercial Building Energy Consumption

Functional use of energy in commercial buildings varies substantially from that in the residential sector. Based on 1980 data, the latest year for which disaggregated data are available, space conditioning accounted for 65% of the energy consumed in the commercial sector; as Figure 2.6 shows, about two-thirds of that energy was consumed for heating and one-third for air conditioning. Lighting also plays a major role in energy consumption, consuming more than 22% and providing as much as 25% to 40% of the peak demand. Hot water heating accounted for 10%, and miscellaneous uses, 3% (EIA 1982). However, within any one location of the country and within any particular building type, these end-use proportions and overall energy-consumption levels can change substantially.

End-use energy consumption for new commercial buildings varies dramatically from the total commercial building stock. For example, heating is the major end-use from a total-building-stock perspective. However,

in new buildings, heating is not the major energy user. With high lighting levels, office automation, improved building construction technologies, and the trend to new construction in the South and West, cooling and lighting are generally more important. The importance of air conditioning as an energy-using system is demonstrated by recent energy studies. Simulation of 10 commercial buildings configured to a proposed new federal commercial building standard shows a major shift from heating to cooling (Appendix B) (PNL 1983). A recent EPRI study (Lannus 1985) indicates that 25% to 40% of the summertime peak demand of utilities is from commercial customers. Moreover, only 4% of those customers--mostly large office and institutional buildings and retail stores--comprise almost half of the commercial cooling demand.

FIGURE 2.6. End-Use Disaggregation for Commercial Building Energy Consumption in 1980 (EIA 1982)

The second major area of concern, lighting, not only accounts for 22% of the total electricity use in the U.S. but also as much as 25% to 40% of the peak demand of commercial buildings (Lannus 1985).

2.4 IMPLICATIONS FOR BSI RESEARCH

These demographic and energy consumption trends have been used to establish research priorities for this plan. In the residential sector, the resurgence in multifamily housing

and the tremendous growth in the manufactured housing market clearly makes them major research targets along with single-family detached, with emphasis given to site-built erection of prefabricated housing components. The population shift to the Sunbelt states highlights the need for research on cooling in hot/dry and hot/humid climates in order to minimize growth in air conditioning energy consumption and to prevent an increase in peak-load problems in those summer-peaking utility districts. Technology-specific research needs to concentrate on reducing gas-fired and electrical energy-using systems because they constitute almost all residential energy consumption.

In the commercial sector, BSI research needs to concentrate on the building categories that will comprise most new floor space over the next decades. These categories are office (and office-like space), multifamily residential, and retail. The research needs to be oriented towards solving the problems that will be most pervasive in these building categories. These are generally lighting and cooling problems, with major emphasis placed on reducing a building's peak demand, which will provide benefits both to utilities and to their customers.

In both the residential and commercial sectors, much of the effort needs to be targeted at making new design technologies readily available to the typical designer. The proliferation of new technologies for equipment, components, materials, and special design features has made building design simultaneously simpler and more complex. Building design is simpler because almost all elements have improved energy efficiency compared with their predecessors. Building design is more complex because of the many options available to the designer, and because of the importance of understanding the interactions of these materials, components, and equipment in consuming energy. Being an energy conservation expert in today's rapidly changing technological world is a full-time occupation--a time commitment that few practicing design professionals can afford.

The true measure of success for this BSI research is not whether new energy-saving approaches can be developed for system integration, but rather whether these technologies, once developed, can be instilled within the mainstream of common design practice.

and the tremendous growth in the manufactured housing market clearly makes this sector research targets along with single-family detached with emphasis given to site-built fraction of prefabricated housing components. The population shift to the Sunbelt states highlights the need for research on cooling in hot-dry and hot-humid climates in order to minimize growth in air conditioning energy consumption and to prevent an increase in peak-load problems in those summer-peaking utility districts. Technology specific to energy needs to concentrate on reducing gas-fired and electrical energy-using systems because they constitute almost all residential energy consumption.

In the commercial sector, BSI research needs to concentrate on the building category that will comprise most new floor space over the next decades. These categories are office (and office-like space), multi-family residential, and retail. The research needs to be oriented towards solving the problems that will be most pervasive in these building categories. These are generally lighting and cooling problems, with major emphasis placed on reducing a building's peak demand which will provide benefits both to utilities and to their customers.

In domestic residential and commercial sectors, much of the effort needs to be directed at finding new design technologies and integrating the typical designer's (the practitioner of new technologies for equipment, components, materials, and control systems) design with more complex building design. Building design is similar because almost all elements have improved energy efficiency compared with their predecessors. Building design is more complex because of the many options available to the designer, and because of the large range of understanding the interactions of these materials, components, and equipment in demanding energy. Being an energy conservation expert in today's rapidly changing technological world is a full-time occupation. The commitment that the practicing design professionals can afford.

The true measure of success for this BSI research is not whether new energy-saving approaches can be employed for system integration, but rather whether these technologies, once developed, can be installed with-in the mainstream of common design practice.

In new buildings, heating is not the major energy user. With high lighting levels, 50-60% of the energy is used for lighting. The first situation, improved building energy conservation technologies, and the trend to new construction in the South and West, cooling and heating are generally more important. The importance of air conditioning as an energy-using system is demonstrated by recent energy studies. Simulation of 10 commercial buildings configured as a proposed new federal commercial building standard shows a major shift from heating to cooling (Table 1). (EIA 1983). A recent EBSI study (Lanning 1983) indicates that 50% to 60% of the summer peak demand of utilities is from commercial customers. Moreover, only 41% of those customers—mostly large office and institutional buildings and retail stores—consume almost half of the commercial cooling demand.

FIGURE 1.1. End Use Classification for Commercial Building Energy Consumption in 1980 (EIA 1982)

The second major area of concern, lighting, not only accounts for 32% of the total electricity use in the U.S. but also as much as 75% to 80% of the peak demand of commercial buildings (Lanning 1983).

2.4. IMPLICATIONS FOR BSI RESEARCH

These demographic and energy consumption trends have been used to establish research priorities for this plan. In the residential sector, the response is multifamily housing

3.0 TECHNICAL PLAN

This chapter describes the technical plan for the Building Systems Integration (BSI) Research Program for the period FY 1987 through FY 1991. The plan is separated into residential and commercial parts to reflect the different research needs of the two building sectors. Commercial and residential buildings are (in general) designed and constructed by different members of the buildings community who are driven by different incentives and financial practices, and who use different construction methods. In addition, the buildings themselves are functionally different - they operate on different schedules, with different requirements for lighting, cooling, and equipment, and they have radically different occupancy conditions. The two building sectors present different research challenges that can best be met through separate research approaches that target specific research problems. However, where similar research needs exist, such as in indoor air quality, microclimate, and comfort research, joint research projects will be structured to meet the needs of both sectors.

The scope of the technical plan is as follows:

- For the five-year period, the research will focus on the residential and commercial building types that use the most energy. Residential buildings include site-built and manufactured single-family and low-rise multifamily housing. Commercial buildings include all other buildings, excluding industrial buildings and commercial buildings with a high degree of process loads, but including mid-rise and high-rise residences.
- New design and major rehabilitation of buildings are the major targets of the research. Rehabilitation occurs when a building is gutted except for structural members; many of the design alternatives available during the design of a new building are also available during rehabilitation.

- The research will be conducted to benefit the entire buildings community. It will address the problems inherent in specific climates across the nation, and will address the needs of major owner/tenant economic scenarios.
- The research is restricted to issues of system integration - issues concerned with interactions among building sub-systems, occupants, and climate.
- The research is long-term, focusing on better use of current and/or future technologies. Near-term research projects are included to meet immediate needs or to link past and future research.

The results of the program will be structured and formatted for immediate use by public and private sector users so that they can be applied to standard practice. Technologies developed under the program will be actively transferred to end users, both through mechanisms generated within the program and through existing DOE (and other) technology transfer channels.

The two parts of the plan are identical in structure. Each begins with a general description of the research methodology, followed by a detailed explanation of each research element. The explanation of the research elements includes the following:

- a definition of the problem(s) to be addressed by the research element
- a brief statement of the objectives of that research element
- an explanation of the research strategy to be followed for the element
- a description of technical activities to be undertaken, including summaries of individual research projects.

Each plan concludes with a diagram that depicts sequencing and the relationship among the activities/projects.

3.1 THE RESIDENTIAL RESEARCH PLAN

The residential Building System Integration Research Program comprises five major elements, shown in Figure 3.1.

Subsystem Interaction Research - This research will develop a better understanding of how materials, components, and subsystems interact from an energy standpoint, and will develop techniques and strategies for more efficient use of these subsystems. The emphasis of this research will be on single-family residences in southern (cooling) climates, since there has already been considerable research on strategies for the colder northern climates. The research will concentrate on the integration of cooling strategies within other building subsystems, on the problem of deterioration of efficient equipment systems in southern climates, and on the use of alternative design strategies (such as "low-E" coatings on windows).

Regional/Site Research - This research will concentrate on understanding system issues related to hot/humid and hot/dry climates, and will develop design guidance for use by builders in southern-tier states. This research will lead to a better understanding of the parameters and the techniques used in achieving cooling comfort. The products of the research will be a determination of the magnitude of the cooling problem and an identification of the most appropriate opportunities for reducing cooling energy consumption. The U.S. population shift to the south and west has increased the demand for air conditioning, creating a high priority need for research on such issues as natural and mechanical ventilation and alternative cooling strategies. This information will be useful for assisting both single-family

and multifamily homebuilders to provide less-costly and more efficient ways to cool southern-tier homes without air conditioning.

Design Process Research - This research will develop more effective approaches to home design. This research will characterize the homebuilding industry, its financial and design constraints, and regional design customs. Benefits gained from this research will be integrated with research results from the previous two elements to provide innovative approaches to residential building design. Single-family site-built, pre-cut, and modular and panelized housing will be emphasized because they are projected to be the predominant housing types of the 1980s and 1990s. Low-rise multifamily housing will also receive some emphasis since it is replacing single family homes for low-income families. The research will concentrate on developing guidance for the small and medium-size builder because they have less access to design assistance than does the large builder. The products of the research will combine innovative techniques with sound fundamental energy design strategies and will be in a form useful to even the smallest builder.

Construction Practice Research - This research will investigate interactions that are significant during the construction of residential buildings and will identify the potential for energy conservation through improved construction practices. The research will identify the significant performance degradations that occur when subsystems are combined during construction and will develop solutions for changing these conventional practices. Foreign construction practices will be reviewed to capture advanced approaches (if they exist) for use by U.S.

FIGURE 3.1. Residential Building System Integration Research Structure

homebuilders. Finally, since manufactured housing (including manufactured components) is becoming a large part of the total housing market, the potential for improved manufacturing processes will be explored.

The emphasis of this element will be placed on single-family site-built and manufactured housing in the northern-tier states since many of the major subsystem interaction issues, such as infiltration, relative to construction practice are more prevalent in the North.

Housing Innovation Research - This research will delineate how the positive characteristics of the interactions discussed above can provide a basis for creating a new generation of housing. The focus of this research will be the design and construction of homes 10 to 15 years from now. It will include speculation on building form, the availability of new and more efficient subsystems, alternative design strategies as related to the availability and price of energy. The research will build on current technologies to develop innovative technologies. The product of this research will be the construction of a house that typifies the "house of the future". This new structure will be built in the South or West (to complement the "Brookhaven House, a northern demonstration of innovative housing in a cold climate). Like the Brookhaven House it will be a show-case for new ideas and technologies and a learning laboratory for the future.

The technical activities associated with each program element will be conducted in three phases:

Phase I: identify/quantify

Phase II: test/assess

Phase III: outreach.

The activities in these phases consist of several components, including background information gathering, basic research, applied research, concept development, and testing. The schedule for these research activities is presented in Figure 3.2.

3.1.1 Residential Research Element #1: Subsystems Interaction Research

Problem Statement

When energy benefits are estimated, improving the effectiveness of one subsystem often is assumed to have a positive impact on building energy use and on the overall performance of other housing subsystems.

However, the character and extent of the interactive effect from an energy standpoint are rarely known.

A change in one subsystem can degrade the energy benefits associated with a change in another subsystem. For example, improved envelope performance can result in reduced heating loads, thereby reducing the benefits of improved heating equipment efficiencies. As houses incorporate more energy-saving features, interactive effects become more pronounced, influencing the economics of improved subsystem performance. Also, as the level of conservation increases, the profile of energy use changes, potentially affecting the appropriate specification and selection of mechanical subsystems, controls, and appliances such as hot-water heaters. Most existing energy calculation procedures, particularly those based either on steady-state principles or correlations to detailed hourly simulation data bases, do not adequately account for such interactions.

Objectives

The objectives of the subsystems interaction research are as follows:

- Identify and analyze the physical interactions of subsystems with other subsystems, components or materials.
- Quantify the extent of the interactions and develop procedures for static and dynamic testing.
- Develop units of measure for assessing whole-building performance.
- Prepare design guidance that may be used by the buildings industry.

Research Strategy

The DOE and other organizations have developed analysis and design tools for use by researchers, homebuilders, and home manufacturers. These tools have been used as aids in analyzing research, in developing building codes and standards, and in designing buildings. The information developed in this program will provide useful data for further refining those energy (and economic) design and analytical tools.

The effects of various energy conservation measures on the building system are just beginning to be understood. Further knowledge of subsystems interactions, especially between the envelope and mechanical systems, is required before the evolution is complete. To accomplish this end, test procedures will be developed for quantifying

FIGURE 3.2. Schedule for Residential Building System Integration Research

subsystem interactive effects. Correlations will be developed between levels of conservation for such areas as envelope and other load-related subsystems, the selection and specification of the mechanical equipment, the amount of thermal mass within the home, and the level of airborne moisture. Characteristics of system combinations, such as peak-load profiles, will also be generated and examined.

Those subsystems expected to have the highest degree of energy-use interaction will be identified for each of the three major residential categories. At a minimum, the research will investigate the interaction of temperature, humidity, infiltration, solar gain, ventilation, thermal mass, envelope,

HVAC equipment, distribution systems, domestic hot water, and control strategies. Climate variation and its impact on patterns of subsystem interactions also will be considered. The magnitude of the interactive effects will be measured and archived in a numerical data base. Also included in the data base will be information useful for developing and refining analytical and design tools.

Technical Activities

Figure 3.3 shows the three phases and the activities to be conducted in residential subsystems research. Phase I identifies the subsystems that have positive and negative interaction with each other,

Phase 1: Identify/Quantify

Phase II: Test/Assess

Phase III: Outreach

FIGURE 3.3. Residential Subsystems Research

establishes the nature of the interactions, and quantifies the energy effect. Positive interactions are the benefits that will accrue by successfully matching subsystems. Negative interactions are either the negligible or negative effects from the combination of the subsystems. Phase II involves testing and assessing significant positive interactions and developing procedures to mitigate negative interactions. Laboratory and/or field tests will be conducted to verify estimates of improved or enhanced subsystem interactions. Phase III involves the development of standard test procedures for evaluating interactions in cooperation with industry evaluation of consensus standards organizations, such as ASHRAE and ASTM (American Society of Testing and Materials). Guidelines for builders and manufacturers will also be developed under Phase III.

3.1.2 Residential Research Element #2: Regional/Site Research (Cooling)

Problem Statement

The amount of energy used for space conditioning in residential buildings depends primarily on climate-related heating and cooling loads. The building's microclimate, as created by regional climate but also topography, trees, and other buildings, is the important factor. However, detailed information regarding the impact of local microconditions on building energy use is lacking. This lack of information presents a major barrier to accurately quantifying climatic effects on buildings and to effectively integrating energy conservation measures.

Previous research efforts have provided a substantial knowledge base concerning a home's performance when exposed to various combinations of solar radiation, temperature ranges, wind speed and, to a limited degree, moisture content of the air, especially in colder climates. This work has resulted in the development of several energy-use simulation tools that are useful for design and research purposes. However, a home's actual performance on a specific site varies from its predicted energy performance, especially in hot/humid and hot/dry climates. Relatively little research has been conducted in these areas as compared with the colder North. With the population shift to the South and West and the increase in the use of air conditioning, it is important to determine ways to minimize the energy and economic effects of cooling requirements.

Objectives

The objectives of the regional/site research are as follows:

- Determine parameters of cooling comfort.
- Develop techniques for achieving cooling comfort (low energy/low cost).
- Determine the magnitude of the energy savings and where they are most effective (location).
- Determine the magnitude of the cooling problem and the most appropriate opportunities for reducing the cooling load.
- Identify, analyze and quantify building characteristics that are effective in minimizing cooling energy use.

Research Strategy

This program will identify innovative cooling concepts for hot/humid and hot/dry climates. The primary variables to be studied include the major variations in regional climatic conditions and the building subsystems. Innovative cooling concepts, such as vented walls, reflective barriers and other natural and mechanical ventilation schemes, and moisture's effects on increasing cooling loads will be studied. The products of this research will be strategies to reduce cooling costs without sacrificing comfort.

Because the cooling energy requirements and indoor humidity levels of buildings in humid climates are difficult to predict, data collected in this element will be used to refine analytical tools that simulate cooling performance. At present no public-domain computer program for analyzing building energy accounts for the interaction among phenomena such as moisture absorption/desorption by materials, air-conditioner transient and dynamic performance, and the interrelated effects of thermostat control. In-situ field testing and monitoring will also be an integral element in identifying building, equipment and in occupant interactions and in obtaining baseline cooling energy use and cost data.

The products of this research will be a comprehensive engineering data base that can be used for developing algorithms and modifying existing computer simulation programs. Design and construction guidelines will also be prepared to benefit builders in the southern climates. Finally, a demonstration home will be constructed to provide a full-scale laboratory for testing multiroom air movements, zoning of mechanical systems, integration of concepts such as structural ventilative cooling or the use of dry agents, and for examining the effects of localized venting. The full-scale model will provide the

program with the necessary credibility for builders to accept new or underused concepts.

Technical Activities

Figure 3.4 defines the three-phase program for regional/site research. In Phase I, possible strategies to reduce cooling use will be identified and quantified. These strategies will be screened and several of the most promising will be selected for further study and assessment. The results of this phase will have ancillary benefits, in that positive data and information will be made available to product manufacturers to use as the basis of new product development.

In Phase II, the selected strategies will be tested further using analytical models and in-situ testing. The information gained from this analysis will be used to upgrade the analytical models and to provide design guidance. Phase III includes outreach activities and the construction of a full-scale demonstration home that incorporates many of the design concepts developed in this research element. The demonstration home will be used for further testing.

3.1.3 Residential Research Element #3: Design Process Research

Problem Statement

Only in recent years has energy become a major factor in the design of housing in the U.S. Energy-related features have tended to be overlaid on existing building subsystems rather than integrated in a wholistic manner. Houses are rarely treated as a single integrated system where energy use is a prime consideration in the basic design and building process. Rather, initial cost and amenities often play a much larger role in the decision process. However, homeowners are expressing increased concern over rising monthly energy bills.

As homes are designed to be more energy-conserving, the conflicts associated with overlaying energy-savings techniques on conventional building practices are increased. From the start, the design process needs to contain procedures for integrating the major energy subsystems (envelope, mechanical systems and domestic hot water systems) of the home in a way that capitalizes on their potential energy-saving synergy.

A primary barrier to integrating energy issues in the design process is the way in which design information reaches decision makers and the primary forces in the marketplace. Unlike commercial buildings, where

an architect and/or engineer is generally employed to design the structure, residential buildings are most often designed by the builder, who uses a set of stock plans or models of successful (selling) homes within the community on product literature. Further, about 70% of new homebuilders build 25 homes or less each year, and only 10% of all homebuilders employ architects. Most builders are unlikely to expend significant effort improving the energy-efficiency of their houses. Thus, an important research task is to develop ways to transfer these new design approaches to the homebuilder at a low cost to him.

Objectives

The objectives of the design process research are as follows:

- Characterize the current design process.
- Identify the key design parameters that affect energy use.
- Develop techniques for improving the existing design process to incorporate key design concepts.
- Develop an approach for integrating the improved design techniques as part of common design practice.

Research Strategy

This research element will create design procedures that result in more efficient and less costly housing than current practice. The research will also identify the advantages and disadvantages of modifying current housing design and construction processes and will quantify the potential energy savings of such modifications. It is particularly important that the residential building industry be involved in the research. Research review panels that include members from the residential building industry will be formed as needed to ensure that the research products are widely applicable.

The potential for modifying common residential design procedures to better integrate the various elements of energy use will be assessed. Specifically, an attempt will be made to identify the potential for modifying the current residential design process with information that will allow designers with varying capabilities to better incorporate the full range of energy-related systems into the design. The benefits of a more effective design process will be quantified and the barriers to industry adoption defined.

Phase I: Identify/Quantify

Phase II: Test/Assess

Phase III: Outreach

FIGURE 3.4. Residential Regional/Site Research

Design approaches for both a modification of existing construction procedures and new and innovative integrated building practices will be developed. The approaches will be compared with each other and with conventional practice, and their technical, economic, and procedural weaknesses and strengths described.

The design concepts will be tested and refined. Industry will participate in testing the concepts in actual residential buildings under construction. The test results will be compared with conventional design and will serve as a basis for refining both the design concepts and their estimated potential savings.

Technical Activities

During the last four years, the DOE has undertaken a program to develop design tools for homebuilders and home manufacturers. These tools are part of an Affordable Housing Through Energy Conservation Program and are commonly referred to as the "Slide Rules" tools and the "PEAR" (Program for Energy Analysis of Residences) program. They are, respectively, manual and computerized design aids that were developed to give homebuilders and home manufacturers more accurate information on the effect of several common energy conservation measures incorporated in new homes in any U.S. climate. Each tool was developed from a data base derived from several thousand computer simulations of prototypical houses in many different climates. This data base has subsequently been used as the basis for federal and private sector residential standards.

This project element will upgrade and extend the data base by reviewing the assumptions used in its development, by incorporating information derived from the subsystems interactions and regional research described earlier, and by adding innovative energy conservation technologies. In the past, research has concentrated on single-family site-built and manufactured housing. Low-rise multifamily apartment buildings are being added to the data base to include the third largest sector of the residential industry. The data bases derived from this project will be used by researchers to improve mainframe computer simulation models, to upgrade residential building codes and standards, and to develop design process aids.

This research element will continue the refinement of the manually used "Slide Rules" and the computerized "PEAR" program, or some derivations thereof, to include the upgraded

data base and more specific economic methodologies, and to develop other applied design tools as appropriate. Both small and large homebuilders and home manufacturers will be considered as the tools are prepared.

Figure 3.5 defines the design process research. Phase I, the existing design process and tools used in homebuilding and home manufacturing will be characterized. Models of effective design and construction practices will be developed for the several levels of the homebuilding industry. Existing energy analysis and expert system tools will be reviewed to determine the most effective method for building and using a composite tool.

Phase II will consist of evaluating and validating the models and then field testing them for accuracy. In Phase III, the models and composite expert system will be used to prepare design process tools that will serve both the large and small builder and manufacturer for the three major building types - single-family site-built, manufactured, and low-rise multifamily housing.

3.1.4 Residential Research Element #4: Construction Practice Research

Problem Statement

Current construction practice research is focusing primarily on component optimization, such as building a more thermally effective wall or designing a more efficient mechanical system. The selection of these energy conservation features for residential buildings is typically based on calculative analysis of individual building subsystems. However, a difference often exists between calculated and actual energy performance, and the design-calculated energy savings frequently are not realized. The actual energy performance of residential buildings is often weakened because of the way subsystems are combined in the construction process. For example, the compression of wall insulation by electrical wiring degrades the thermal performance of the wall.

Objectives

The objectives of construction practice research are as follows:

- Identify the significant performance degradations that occur when subsystems are combined during construction.
- Identify possible solutions and procedures for changing conventional practices.

Phase I: Identify/Quantify

FIGURE 3.5. Residential Design Process Research

- Identify opportunities for adapting foreign construction practices.
- Construct prototypes, monitor, and evaluate.

Research Strategy

Construction practice research will identify and examine areas for improving

construction practices either by alleviating problems in subsystem interface or by developing new and innovative construction technologies for use in standard practice in U.S. housing construction.

This research element will address the physical and functional interactions of the individual building subsystems in order to improve the potential synergies and to avoid

performance degradation. Information from retrofit and infiltration research on known energy-related construction impacts will establish priority issues by area and construction type. This activity will be designed to take maximum advantage of expertise developed in the U.S. and abroad in the areas of integrating building envelope subsystems, combustion space conditioning subsystems, and related technologies. Manufacturing of housing and housing components will be examined to determine the advantages and disadvantages of factory construction and site assembly.

Technical Activities

This research element is designed to emphasize a collaborative relationship between the research community and industry. Industry will be an active partner in all phases of the work, expediting the adoption of products of the construction technology research.

Figure 3.6 defines the three-phase program for construction practice research. Phase I is primarily a documentary study, whereas subsequent phases will require developmental and evaluational testing. Phase I will include a detailed characterization of the most promising advances in construction technology. Its primary objective is to identify the significant performance degradations resulting from a range of subsystem interactions. These interactions range from positive (e.g., free cooling provided by a hot water heat pump), to interference effects (e.g., tighter insulation reducing the benefit on which the purchase of highly efficient equipment may be based), to mutually destructive interactions (e.g., deterioration of air quality occasionally experienced when building envelopes are tightened).

The research in Phase I will include an examination of the conditions associated with performance degradation, including the interactions of subsystems and construction materials, how and when degradation occurs, and the housing types and locations affected. This research will be conducted with input from housing industry representatives, including builders, manufacturers and researchers. A panel will be convened periodically to identify and discuss the problem areas.

Many precedents exist for changing conventional construction practice to improve system integration. Many of these can be found in foreign housing construction, most notably in Scandinavia, Western Europe, and Japan. Also, much U.S. research on innovative construction practices research may

have the potential for being adopted by the conventional housing market. To identify improved construction techniques, Phase I of this research element will examine both foreign construction technology and innovative construction procedures in this country. Construction techniques that demonstrate a potential for improving the energy performance of U.S. construction will be identified, and adapted for each building type.

Also in Phase I, data and information will be collected to quantify the potential savings from implementing the identified techniques. This research is expected to require a close collaboration with the foreign and U.S. research and construction communities. The cumulative list of problem solutions/opportunities will be screened and evaluated. For each solution/opportunity, the potential for energy-use reduction will be gauged and the criteria for industry acceptance outlined. A detailed scenario will specify the types of research and development work required to incorporate the problem solutions/opportunities into standard industry practice. Quantifying potential energy savings and characterizing the adaptation process are intended to provide the background for identifying research priorities among the solution and opportunity areas. The subsequent developmental phases of the program will concentrate on those areas with the highest priority.

In Phase I, the process to convert the high-priority areas into a form useful to the homebuilding industry will be specified. These applications will be divided into four categories. The first includes concepts that can be translated by industry into a new material or product. These concepts will be immediately disseminated to industry for possible development and implementation. Concepts requiring significant technological innovation to be adopted will be characterized in the second category, but addressed in detail under the next research element, housing innovation research.

The third category includes those concepts related to the design and construction of potentially effective and adaptable integrated systems. These concepts relate to the physical features of the home. For example, the Danish housing industry uses an effective method for integrating the ventilation system into the envelope system. A scenario will be created outlining the changes needed to convert this foreign technology into an applicable form for U.S. homebuilders. In this example, a variation of conventional wall framing and a modified installation of existing ventilating systems may be required.

Phase I: Identify/Quantify

FIGURE 3.6. Residential Construction Practice Research

The fourth group of concepts will provide procedures or models for changing the method for assembling the construction materials or systems. The order of material or system assemblage may inherently degrade energy performance. Procedures exist for modifying the order of construction without changing the material features of the home. Concepts in this category, therefore, relate to the process of construction.

In Phase II, the concepts identified in the process of converting high-priority areas into a form useful to the homebuilding industry will be tested and refined. Prototypes of the proposed physical modifications also will be constructed and tested in the field or laboratory. The purpose of this testing

is to prove that the concepts are suitable for conventional U.S. construction materials and procedures and are effective at reducing energy use.

The concepts related to proposed changes to construction process also will be tested in Phase II. This testing will include the active participation of U.S. homebuilders and home manufacturers. The purpose of this test will be to demonstrate that the new process(es) can be employed economically and that they are effective in reducing energy use.

In Phase III, appropriate outreach vehicles will be created for transferring the proven technologies to industry. For example, standardized testing procedures may

be created for rating the new integrated systems. These testing standards would be developed in association with industry testing agencies (e.g., ASTM, ASHRAE). Additionally, guidelines will be created documenting the results and findings of the research. This documentation will serve as a catalyst for rapid dissemination of the effective construction practices and processes to industry.

3.1.5 Residential Research Element #5: Housing Innovation Research

Problem Statement

The residential research program discussed in the first four elements and the vast majority of research work conducted to date are designed to address problems relevant to contemporary construction. However, this type of problem-oriented approach, while necessary and valuable, does not provide a vehicle for addressing future energy-related housing needs. Specifically, the focus of the housing sector and the design of homes in 10 to 15 years should be researched without the constraints of today's technologies.

Future energy-related needs should be addressed now for two reasons. First, by anticipating these needs, the research community has sufficient lead time to create and disseminate practical and well-conceived solutions to problems as they arise. Conversely, new design concepts and approaches can be developed that might not be generated by problem-oriented research. Second, addressing these issues will generate ideas and concepts that provide new insights and solutions to contemporary problems.

Objectives

The objectives of housing innovation research are as follows:

- Characterize future housing in terms of well-integrated system performance in the future.
- Identify the interaction of future building form, subsystems, and energy use.
- Develop design guidelines that reflect the above research for optimizing performance in each region of the country.

Research Strategy

This research element will use the results of other housing-related research as a basis for creating scenarios of housing designed to meet future energy needs. Both physical and theoretical models will be con-

structed of new housing concepts that reflect anticipated trends and developments in design techniques and material and construction technology.

The issues that will be addressed include the following:

- The future energy environment and design of homes to take advantage of this environment.
- Optimum combinations of subsystems to obtain the maximum energy efficiency.
- Use of trends in other technologies (e.g. controls and microprocessors) in designing and constructing new housing for the next generation.
- Improvements in housing design, construction and marketing to better account for energy-related considerations.

The development of innovative housing concepts will involve representatives of the major sectors of the housing industry in a consortium to direct and advise the research.

Technical Activities

Figure 3.7 outlines the activities to be conducted in the three phases of this research. In Phase I, a consortium of representatives will be convened as an advisory body to the research in this element. The consortium will help set criteria for the research, review and critique results, suggest and participate in appropriate related industry-sponsored research, and lead industry adoption of the research products.

Phase I will also include the conceptual development of new approaches to integrating new and existing technologies. Criteria will be defined for developing those integrated designs; those criteria include economic and technical market viability. Where feasible, the conceptual models will be refined and built as physical models, in cooperation with industry. For example, one scenario may combine existing housing construction technology with sophisticated and advanced controls and new equipment design.

In Phase II prototypes of the new and innovative designs will be constructed and tested. The test will define the conditions under which the designs will be effective both from a technical and a production standpoint. Several physical models typical of a range of regional climate conditions will be developed in Phase III. Also in Phase III, products and information, such as designs and process descriptions, will be developed for the building industry's use.

Phase I: Identify/Quantify

FIGURE 3.7. Residential Housing Innovation Research

3.2 THE COMMERCIAL RESEARCH PLAN

The commercial Building System Integration Research Program comprises four major elements, shown in Figure 3.8.

FIGURE 3.8. Commercial Building System Integration Research

Subsystem Interaction Research - This research will develop an understanding of how various materials, components, equipment, and subsystems interact and how these interactions affect energy consumption. This research will provide a basis for developing 1) guidance for optimizing the design of commercial buildings, and 2) recommendations for equipment-specific or component-specific research based upon opportunities and constraints identified from this "whole-building" perspective.

Building/Occupant Interaction Research - This research will examine building/human interactions with two primary focuses: 1) understanding the effect of a building's energy-using subsystems on human comfort and productivity, and 2) designing interfaces for human control of building subsystems, with an emphasis on energy-saving approaches to controls.

Design Process Research - Under this element, research will be conducted to develop more effective approaches to building design, taking into account knowledge and financial constraints of typical designers. These approaches will be integrated with research results from the former two elements in order to provide a system integration approach to building design.

Construction, Operation, and Maintenance Research - This research will help ensure that energy-efficient designs are implemented and maintained. Building construction problems often occur where there is subsystem interaction, that is where the work of different trades interact. Building operating problems often occur when maintenance has been inadequate, or when the operating principles of buildings have not been considered

in their operation. This research is intended to identify these problem areas and to propose solutions for resolving them. This element will provide input to design process research, since one of the best ways to eliminate construction, operation, and maintenance problems is to design buildings so that these problems cannot occur.

The relationship of the four research elements is shown in Figure 3.8. Subsystem interaction and building occupant interaction research are intense investigations into the way buildings operate and the way they should operate. These elements produce a technical knowledge base that must be injected into the design process research element. Finally, the best methods of ensuring that energy-efficient designs are implemented on the job site are researched in the construction, operation, and maintenance research element. This research structure is not unlike the actual design process for a real building, where a basic understanding of the building and its clients needs to precede actual design, construction, and operation. These four research elements are described in the next sections, and the technical approach for each is illustrated in research process flow charts within those sections.

The commercial building research proposed here is not entirely new. Certain projects have been identified in earlier DOE research prioritizations and are now under way or completed. This includes an ongoing effort of subsystems characterization, planning for whole-building energy performance targets and design tool development, technical input to the development of commercial building design standards, and building-specific research for office and multifamily residential buildings. The research program described here has been designed to include and extend these earlier projects within a highly integrated and complete research program of building system integration research.

Each of the four major research elements will be conducted on a building-type by building-type basis. Prior standards-related research has demonstrated that different types of commercial buildings have very different energy problems, energy-using subsystems, and building design constraints. Thus, commercial building types need to be addressed separately, in research projects tailored to their specific energy issues. This program will develop a good understanding of system integration in one building type before progressing to a second building type. This approach will ensure continuous flow of information to the design profession.

The first building category, office buildings, will be studied in detail in each of the four research elements. (Some of this work is already complete, other is under way.) Work on the second building type, multifamily mid-rise and high-rise residential buildings, has just been initiated. As this work becomes established, work on the third major building category, retail stores, will begin. Together, these three building categories account for much of commercial building energy consumption and a high percentage of projected commercial building construction. Other building categories will be candidates for system integration research, but only after work on the major

three categories is complete, and only as resources allow. A schedule for these research activities is presented in Figure 3.9.

The research activities conducted for each building type will start with research on current energy-use conditions and opportunities, progress to development of innovative concepts, and finish with the design and construction (in cooperation with industry) of a prototype of an advanced (office) commercial building. This prototype will provide information on performance of advanced concepts and information for developing advanced design tools. It will also serve as a real example of these advanced

FIGURE 3.9. Schedule for Commercial Building System Integration Research

technologies for review and evaluation by the buildings industry.

The relationship of research activities for a single building type is presented in Figure 3.10, using office buildings as an example.

3.2.1 Commercial Research Element #1: Subsystem Interaction Research

Problem Statement

To date, public and private buildings-related research and development has focussed on products that more effectively prevent heat loss and/or gain, and on more efficient HVAC and lighting equipment. This focus has been reflected in the tendency of building designers to use more energy-conserving components and equipment as their primary approach to dealing with the energy issue.

This approach has also been successfully used in most national and regional building codes and standards, with the result that buildings today are generally more energy-efficient than they were a decade ago. The component-improvement approach has been used primarily because it is simple and widely applicable; selection of more efficient materials, components, and equipment requires little knowledge of the interactions of building subsystems and little knowledge of specific applications.

The next generation of energy savings will not derive solely from the use of more efficient components. Much of the "easy" energy savings have been captured, and to save further significant amounts of energy, designers need to understand how building subsystems interact. Once this understanding exists, then true system integration will follow by optimizing the way that different

FIGURE 3.10. Example of Building-Specific Approach to Commercial Building System Integration Research

subsystems naturally work together, by electronic control of interacting subsystems, and by combining subsystems into more efficient, multipurpose elements.

Automated controls appear to be an extremely cost-effective technology for reducing energy consumption in commercial buildings. However, to make controls work effectively requires a detailed understanding of how a building works, so that they can monitor important variables, recognize trends, anticipate near-term conditions, diagnose equipment abnormalities, and respond to the needs of occupants, thereby optimizing building operation. With the recent availability of powerful microcomputers, the lack of a detailed understanding of how buildings work is the only obstacle to developing a new class of automated building controls.

Preliminary examination of subsystem interactions has revealed substantial potential for subsystem combinations as a promising area for increased energy conservation and cost reduction. For example, existing "extract-air" window subsystems incorporate an HVAC return-air duct within an exterior window. This is an effective combination of two distinct building subsystems that reduce the energy needed to heat the building's perimeter. This occurs because it raises the radiant temperature of the window (lowering the air temperature needed for comfort), and it increases the efficiency of the HVAC subsystem by concentrating the heating load. This is only one existing example of many possible beneficial subsystem combinations that could be developed with a better understanding of desirable interactions.

Another promising research area for subsystem integration lies in the integration of energy storage and generating technologies with commercial building subsystems. These new technologies are showing potential for alleviating one of the major concerns of building owners and operators, and utility managers as well--control of the building's peak demand. These technologies will best prove effective if they are integrated with other subsystems during the building's design rather than from an add-on perspective.

Objectives

The objectives of the subsystem interaction research activities are as follows:

- Identify, characterize, and quantify the effects of subsystem interactions.
- Verify these data through field measurements.

- Develop new approaches for optimizing these interactions.
- Make the data widely available to industry.

These objectives will allow the building industry to develop improved design strategies, products, and controls that significantly contribute to energy conservation in commercial buildings.

Research Strategy

The basic strategy of this research element is to provide an extensive reliable data base on building subsystem interactions. The data base will be developed through computerized analysis of existing and future building systems that will provide extensive information on subsystem interactions. It will serve as a resource for building design and product development, and as a basis for further developing subsystem integration research and design tools.

When this data base has been developed, a three-step approach will be used to develop advanced system integration. In the first step, technology integration issues will be examined. The issues include identifying the interaction of building components, the important interaction parameters, and the best method for designing, selecting and integrating materials for the structural, mechanical, lighting, and envelope subsystems of the building. Much of this information is presently available from specialized research programs, such as the daylighting program at Lawrence Berkeley Laboratory, the HVAC research conducted at the National Bureau of Standards, and from research in other public and private laboratories. This ongoing research provides information on performance of individual subsystems, but it generally fails to consider the whole building as a system.

The second step will consist of advanced subsystems research that can build on this data base to investigate innovative subsystem options. This research will provide guidance to designers on identifying the innovative approaches that appear to be beneficial, including opportunities for specialized subsystem combination, problems of managing electrical demand, specifications for energy-generation and storage in buildings. This research will be conducted through computerized analysis of existing and future building subsystems that will provide extensive data sets on subsystem interactions.

The third step in the process will be the development of prototypical buildings that demonstrate the technologies developed in steps 1 and 2. These buildings will be designed and constructed in cooperation with private industry, and will serve as an effective means of transferring these technologies to the private sector.

Technical Activities

Three types of activities will be conducted under the subsystem interaction research element: subsystems characterization, advanced subsystems research, and demonstration of advanced design concepts. The program structure for subsystem interaction research is presented in Figure 3.11.

Subsystem characterization will consist of characterizing energy flows within commercial buildings. This research will result in a cause-and-effect understanding of a building's energy consumption that is keyed to energy transport over time and space. This will provide equipment and building designers with information on the most effective methods for integrating existing equipment within commercial buildings. The research will be conducted through end-use metering of existing commercial buildings, the analysis of existing end-use data, review and retrieval of relevant existing research results, and simulation analysis. This research will result in an extensive, reliable data base on subsystem interaction.

In advanced subsystems research, innovative approaches to subsystem combinations will be evaluated. Combining subsystem functions in single components has potential energy and first-cost advantages. One example that will be evaluated is the use of building structural members as HVAC distribution subsystems. The benefits of this integration include eliminating parts of, or all of, HVAC ducting, and using the mass of structural subsystems for thermal storage and load leveling within the building. Other promising subsystem combinations that are developed during the subsystems characterization research will be evaluated, as appropriate. This work will be extensively based upon the subsystem interaction data base. This research will result in a series of publications that explain the concept, estimate the energy and cost savings, and provide specific design guidance on subsystem combination for energy conservation.

The benefits of centralized versus localized subsystems will also be evaluated under advanced subsystems research. HVAC

and lighting subsystems in commercial building are generally large centralized subsystems with single controls covering large areas. Localized control of lighting (task lighting) has recently been successfully used to save energy in office buildings. This research will evaluate whether this localized-control-and-delivery approach can be applied to subsystem integration in other building types and for other subsystems such as heating and cooling, and ventilation (separately) as well as for envelope factors (insulation and window control). This work will be extensively based upon the subsystem interaction data base. This research will result in a series of publications that examine local versus centralized control, make recommendations for a general approach to control, and provide design guidance on centralized versus localized subsystems.

Advanced subsystems research will also evaluate the future of building-related energy generation for demand control, with an emphasis upon photovoltaics and other innovative technologies. Research will not be conducted on photovoltaics (or other generation technologies) themselves, but rather on designing buildings and building subsystems to best take advantage of these promising generation technologies. This work will be extensively based upon the subsystem interaction data base and technology-specific information from other sources. It will provide two sets of benefits: 1) it will prepare building designers to investigate incorporating these generation technologies in their designs, and 2) it will provide energy-generation researchers with specifications on the nature of technologies most likely to succeed as functional elements within commercial buildings. A series of publications will be written to disseminate the results of this research.

Another element to be investigated under advanced subsystems research will be energy-storage alternatives that can be used by building owners to reduce peak energy consumption. Again, the focus will not be to develop new storage technologies, but rather to identify the most appropriate storage technologies for commercial buildings and to determine the optimal designs for incorporating those technologies. This work will be extensively based upon the subsystem interaction data base and technology-specific information from other sources. A series of publications will be written to disseminate the results of this research.

The final activity that will be conducted in commercial subsystem interaction

Research targeted at understanding current energy consumption in commercial building.

FIGURE 3.11. Commercial Subsystems Interaction Research

research is the design and construction of demonstration prototypes. These prototypes will be developed and monitored by members of the buildings community with DOE technical assistance. The objectives of these demonstrations will be to prove innovative design concepts and to provide technology transfer to the public and private sectors.

3.2.2 Commercial Research Element #2: Building/Occupant Interaction Research

Problem Statement

Commercial buildings exist solely to meet the needs of their owners and occupants, and they need to provide an environment that is comfortable, healthy, and encourages productivity. Generally people are comfortable in modern buildings, but often at high energy costs. Alternative approaches that require significantly less energy for maintaining comfort and productivity are available.

Building designers generally incorporate stock measures of human comfort in terms of air temperature, humidity, and footcandles of light that are related to specific building functions. When building designers apply energy conservation strategies, they generally focus on reducing lighting levels and air ventilation and infiltration, and on providing wider temperature excursions within the buildings--all effective ways to save energy. Often occupants are not comfortable under these conditions, however, and comfort is quickly improved by overriding control systems, and/or retrofitting specific building subsystems. These changes often increase energy consumption, thereby defeating the original designer's approach to energy conservation. In other buildings where the designer's energy-saving approach is "high-tech" the control subsystem may be too complex for operators. This may result in the building being run inefficiently, despite the good intentions of the owner/occupant/operator.

This trial-and-error approach for achieving both human comfort and energy efficiency can be significantly improved. Air temperature is not the only cause of thermal comfort (or discomfort); the perceived level of occupant control, the radiant temperature of building surfaces, the amount and quality of light, and the air flow velocity also have a major effects. Only limited information is available on how to trade off these building characteristics to provide an optimum combination of human comfort and energy conservation across a range of climatic conditions. It is difficult to quantify the comfort effect of a very cold or very warm

window, or the change in internal air temperature that is required to compensate for extreme window temperatures. The lack of clear, quantitative measures of human comfort limits the extent of building subsystem tradeoffs available to the building designer.

Health and productivity are also system integration issues. Indoor air quality is affected by both building materials and the ventilation subsystems. Lighting, temperature, (HVAC-system) noise, and other building subsystem characteristics (even "view" out the window) all contribute to building environments that affect physical and psychological health and ultimately occupant productivity. Substantial information exists on how most single subsystems affect health and/or productivity, but little information exists on how the building environment, as created by all of these subsystems, affects health and productivity.

Finally, little solid evidence exists on the optimal design of controls to ensure appropriate and energy-saving building operation. It is not clear when local control is more beneficial than centralized control, or when automatic controls are better than manual controls. We do not know how complex controls need to be to achieve their purposes, nor the limits of acceptable control complexity, nor what qualifications building operators should have and the best way to train them.

Objectives

The objective of the building/occupant research is to determine ways that building components, equipment, and control subsystems can be combined to create a total environment that meets human comfort, health, and productivity needs while minimizing energy consumption and cost.

Research Strategy

Environmental parameters will be researched to determine combinations of thermal, lighting, (HVAC-related) noise, and other characteristics that provide acceptable levels of human comfort, health, and productivity at minimum energy cost for specific building functions. Generally, this information-gathering will rely on the analyses of "human-factor" laboratories that regularly conduct such work. Health-related research will focus upon developing design solutions to health-related problems, relying on existing knowledge relating health to environmental parameters. If necessary to fill important information gaps, however, primary research will be conducted in these areas.

The information obtained in this research will then be developed into algorithms for use in the design and analysis processes. Innovative approaches for control of subsystem parameters to provide desirable environments will be investigated. Much of the research will be building-specific, to obtain appropriate solutions to meet the needs of office, retail and other specialized building occupants. These solutions will also be approached from a life-cycle perspective, to determine how environments can best be created and controlled in buildings, including buildings whose functions vary across the building and over time.

Technical Activities

Two types of activities will be conducted in the research of building/occupant interaction: 1) collection/development of information on comfort, health, productivity, and energy consumption, and 2) development of innovative design strategies. The program structure for building/occupant interaction research is presented in Figure 3.12.

An important first step in any energy-related research on building/occupant interaction is the collection/development of information on comfort, health, productivity, and energy consumption. This information is needed to characterize the combinations of environmental conditions that are suitable for building occupancy. Information will be collected on temperature, air flow, room surface temperatures, humidity, and lighting to determine the combinations that provide acceptable levels of comfort and productivity while minimizing energy consumption. Primary research will be conducted if inadequate data are available on important and/or common building situations.

When these conditions have been adequately characterized, they will be used to develop innovative building/occupant interface design strategies. The development of innovative design strategies will involve three efforts. First, certain building situations that negatively impact occupant health, such as building materials that emit chemical fumes, video display screens, and

FIGURE 3.12. Commercial Building/Occupant Interaction Research

window glare, will be identified. Specific problems will be characterized, and designs will be developed to resolve or lessen those problems.

In a second effort, the building life-cycle will be investigated to determine how occupant comfort, health, and productivity knowledge can be applied by designers to meet today's needs for flexible buildings - buildings that are generally multi-use, and whose use patterns and functions change over time. Considerations will include centralized versus local control, the need for emergency control, and first and operating cost tradeoffs. This work will be extensively based upon the subsystem interaction data base.

In another effort, a project team will examine innovative concepts that provide basic human requirements without the constraints of existing building technologies. The objective is to develop and evaluate entirely new approaches to building design that may result in very significant energy savings.

3.2.3 Commercial Research Element #3: Design Process Research

Problem Statement

The design of commercial buildings is a complex process. The major objective is to design a structure that is suitable to its function, that provides a productive atmosphere for its occupants, and that is designed and built within budget. In the 1970s and early 1980s, energy conservation became more of a consideration in building design, but its impact has lessened over the last few years as oil prices have fallen.

Design of an energy-efficient building need not result in additional cost, or lost amenity. Architects and engineers knowledgeable about energy-conscious design can design buildings that have reduced first costs and that are both pleasant and productive. Unfortunately, most building designers are not yet familiar with energy conservation design, nor are their fee structures sufficient to warrant the additional time required for considering energy issues. As a result, most building designs do not take advantage of available energy conservation technologies or design techniques. Owners who want efficient buildings must employ energy consultants and assume the added design costs.

Objectives

The objective of the building design process research is to integrate energy con-

servation into the commonplace design process by developing improved design processes, computerized tools, and energy consumption targets. These will enable current and future designers to design energy-efficient buildings within the limits of their knowledge and fee structure.

Research Strategy

The basic approach of building design process research will be to 1) develop an understanding of the design process currently used by most building designers, 2) compile and integrate energy conservation knowledge (focusing on research products from subsystem integration and building/occupant interaction research), and 3) integrate these two products in the form of design guidance, computerized design tools, energy consumption targets, and scientific bases for developing codes and standards.

This approach addresses both general and building-specific design strategies. This work will be done in close cooperation with representatives of the commercial building design community, as well as with vendors of building design tools and equipment.

Technical Activities

Figure 3.13 presents the program structure for commercial building design process research. Four research activities will be conducted within this element: 1) design tool development, 2) building-specific research, 3) supporting research for standards and guidelines, and 3) development and dissemination of whole-building energy performance targets.

The first research activity, design tool development, is needed because few tools are suitable for use in the design process, and none are true design tools. Currently, many analytical tools are available for designers to evaluate the energy performance of building designs, but only after a design or portions of the design have been completed. This research effort will focus on developing a design tool 1) that incorporates energy-efficient design into a design process, 2) that is least disruptive to commonplace design practice, and 3) that does not require intensive training for the building designer. The method under consideration is knowledge-based computer tools that could eventually be integrated with CADD (computer-aided design and drafting) systems being developed in the private sector. The ultimate goal of this research is to develop an interactive design tool that automatically

FIGURE 3.13. Commercial Design Process Research

considers the energy impact of design decisions without requiring the designer to perform specialized analyses.

The second research activity will focus on developing design guidance for specific building types. The work will focus on improving the integration of existing subsystems, not on developing advanced subsystems.

The research will consider the specific building functions, economic concerns, and client constraints that are common to each building type. The projects will include the major commercial building categories, including offices, multifamily mid-rise and high-rise residences, retail stores, medical and educational facilities, warehouses, hotels and motels, and assembly

buildings. This work will contribute to and will be based on the subsystem interaction data base. This research will result in design manuals, computer-based calculation tools, and other design aids.

The purpose of the third research effort will be to develop whole-building energy performance targets that can be used as a basis for designing new buildings and for evaluating the energy performance of existing buildings. This research will be conducted in cooperation with representatives of major building design, owner, and tenant organizations. The ultimate goal for the building energy targets research is to provide an industry consensus on appropriate levels of cost-effective energy conservation in commercial buildings. This work will be extensively based upon the subsystem interaction data base and will result in a set of internally consistent whole-building energy consumption levels that can be used as design targets.

Finally, developing supporting research for standards will be an ongoing effort under design process research. The DOE is responsible for developing and promulgating building energy standards for new buildings. These standards are mandatory for the federal sector and will serve as voluntary guidelines for the private sector. The purpose of this research area is to prepare reliable information and data bases that can be used in developing these standards. Included with that activity will be the preparation of manuals of acceptable building practice. These manuals will be the product of a joint effort with the design profession and will receive widespread industry review.

3.2.4 Commercial Research Element #4: Construction, Operation, and Maintenance Research

Problem Statement

Good design practice is only part of the solution for reducing energy consumption in commercial buildings. Quality construction and attention to operation and maintenance procedures are equally important. Building energy performance often does not meet design expectations because design specifications are altered during construction, or because building maintenance and operating recommendations are not implemented. A major reason for these failures is that the importance of following correct procedures and the implications of ignoring procedures are not well understood by owners and operators. Some examples of the effects of inferior construction quality and maintenance on energy performance are the improper balancing

of air-handling subsystems, substitution of inferior material or equipment, and the incorrect setting of control devices such as thermostats.

Many problems associated with construction, operation, and maintenance quality are not building system integration issues, but rather subsystem-specific problems. These are being addressed by others. The research under this element will focus on problem areas of subsystem interactions, such as an HVAC shaft penetration through a wall or roof section where air leaks could be caused by improper sealing.

Objectives

The objective of this research is to identify, characterize, and develop design solutions for construction, operation and maintenance problems in commercial buildings.

Research Strategy

This research will concentrate on identifying areas of a building where poor construction, maintenance, and operation techniques might adversely affect subsystem interactions and increase energy use. The energy impact of these areas of concern will be characterized and quantified. For the significant problem areas, technical and procedural solutions will be identified and disseminated in appropriate vehicles.

This research should increase awareness of the importance of proper construction, maintenance, and operation among commercial building owners and operators. With this increased awareness of potential energy and cost savings, building owners and operators will become more demanding in their interactions with the design and construction industry, thus improving the quality of construction, operation, and maintenance of their buildings, and reducing energy consumption.

In the past, one solution to poor construction quality has been a pass/fail building acceptance test before the owner/operator fully accepted the building from the designer/constructor. These tests will be reviewed to develop sets of acceptance specifications that will help ensure that buildings are energy-efficient.

Technical Activities

The program structure for research on construction, operation, and maintenance in commercial buildings is presented in Figure 3.14. The first effort will characterize the impact of poor construction, operation,

FIGURE 3.14. Commercial Construction, Operation and Maintenance Research

and maintenance. Energy losses will be assessed through computerized analyses and inspection of existing buildings. When this information has been developed, solutions to the shortcomings will be developed and widely distributed to the buildings community.

Under the second project, both technical and procedural recommendations for improving commercial building acceptance tests will be developed.

4.0 MANAGEMENT PLAN

In this chapter, the management responsibilities for the Building System Integration Program are described. Coordination of DOE research with the building industry is also discussed.

4.1 MANAGEMENT RESPONSIBILITIES, STRATEGY, AND CONTROL

The Building Systems Division (BSD), Office of Buildings and Community Systems (BCS), under the Assistant Secretary for Conservation and Renewable Energy, is responsible for managing the Building System Integration Research Program, as well as energy conservation research on building materials, components, and subsystems. The BSD is responsible for establishing the program goals and objectives, implementation policies, and funding levels. The BSD is also responsible for determining overall program schedules, and for assuring that projects are managed and executed in a manner that meets the program goals, schedules and budgets. Efforts also include coordinating this research with other relevant government and private-sector research.

In accordance with the DOE policy of decentralizing project management to field organizations with established capabilities, the Office of Buildings and Community Systems has assigned responsibility for day-to-day management of segments of this program to several of the national laboratories, as shown in Figure 4.1. Management of technical activities in the commercial building segment of the program has been assigned to Pacific Northwest Laboratory (PNL). Management of the residential building segment of the program has been jointly assigned to Lawrence Berkeley Laboratory and Brookhaven National Laboratory.

As a matter of policy, the BCS has sought to encourage a public/private partnership in many of its research initiatives and has sought industry input in developing this plan. Clearly, it is in the national interest for BCS and the national laboratories to coordinate with, communicate with, and encourage the participation of private sector researchers.

Technical activities in this program are executed in accordance with an annual operating plan that is developed in consultation with the national laboratories and major private-sector contractors. The annual operating plan specifies a detailed organizational structure and work breakdown structure, along with milestones, schedules, and

budgets for all program elements. Formal program and budget guidance is issued by the BCS in accordance with the operating plan.

Program management is provided through several activities. Periodic program and administrative reviews provide direct communications between the BSD and its subcontractors, and among subcontractors. Detailed monthly technical and financial reports are prepared for and reviewed by the BSD. These monthly reports provide technical highlights, and details of financial and milestone status, and identify technical and administrative issues requiring resolution.

4.2 BUILDING INDUSTRY COORDINATION

Although private sector efforts exist in building energy research, such efforts generally focus on product development. Building system integration research is not generally found in the private sector, yet the buildings industry is profoundly interested in the possible benefits of such research. Thus, coordination of DOE research with the buildings industry is a high priority in the BSD.

Coordination of DOE research with the building industry is accomplished through several mechanisms. A primary mechanism is the direct use of private-sector researchers. Initial research in this program has included a substantial subcontracted component to universities and architectural and engineering firms. For example, 54% of the FY 1985 program expenditures at PNL were for private-sector subcontractors. The BSD policy is to continue the use of private-sector researchers in a balanced program with in-house laboratory efforts.

A second mechanism for industry coordination is the use of Technical Review Committees. In program elements or projects that investigate a particularly complex technical issue or that have little benefit of previous work, the BCS convenes a Technical Review Committee (TRC). The committee consists of leading experts in that particular (or related) area representing many of the major organizations having an interest in the subject. The TRC provides ongoing technical advice on relevant research (public or private), on the most promising technical directions, and on the structuring of results to realize the maximum ultimate benefit to building industry practitioners. The private sector receives the research results directly through the TRC member, through publications recommended by TRC members, and through DOE technology transfer efforts.

FIGURE 4.1. Program Management

Membership in key industry committees by BSD and laboratory personnel is considered a priority activity by the BSD. For example, the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) produces several energy conservation standards for buildings that are recognized by the American National Standards Institute; many DOE/BSD and laboratory researchers are ASHRAE members who serve on a number of ASHRAE Committees. Personnel also serve on the Masonry Research Foundation Advisory Committee and are active members of the American Solar Energy Society.

The BSD also conducts many activities designed to transfer results of particular research projects to the building community. Research products on system integration in residences and on small office buildings

were separately compiled as design tools, and they received the prestigious Progressive Architecture Research Awards in 1984 and 1985, respectively. A major technical publisher was selected through a competitive procurement to publish and distribute the Small Office Building Handbook (Burt Hill Kosar Rittelmann 1985), now in its second printing. Workshops were held with design professionals across the U.S. to discuss and display the residential design tool, a slide rule for energy decisions. The BCS also sponsors annual institutes for the faculties of architectural and engineering schools that present recent DOE-supported research results and new approaches to teaching energy conservation. Finally, DOE research results are routinely published in building industry journals.

5.0 RESOURCE PLAN

The resources required to implement the Building System Integration Program are outlined in this chapter. These requirements are for funding research projects as well as for facilities and equipment acquisition for the period FY 1987 through FY 1991.

5.1 RESEARCH COSTS AND FUNDING

The technical activities described in Chapter 4.0 require a coordinated effort between research performed in the commercial and residential categories. As in past years, these activities will proceed simultaneously because the research areas are equally important. However, the programs will be coordinated in order that information and data common to both areas can be jointly developed and used.

The projects to be funded vary widely in (dollar) size and complexity. They will require not only small-scale laboratory experiments and computer simulations, but also larger-scale testing and performance monitoring. The latter will require an addition to present levels of capital expenditure.

To complete the technical tasks itemized in Section 4.0, an estimated average of 35 to 40 person-years per year (PY/Y) of research and technical support personnel are required for the five-year program period. At the current average cost of \$120,000/PY for research labor, overhead, and administrative costs, this Building Systems Integration Research Program will require an average of \$4.5 million per year. The five-year research costs by year are shown below.

Estimated Funding (millions \$)				
Fiscal Year				
1987	1988	1989	1990	1991
3.0	4.0	5.0	5.5	4.9

This funding level provides adequate support for critical activities that are necessary to accomplish major sections of the research program in the five-year time frame, while laying the foundation for completing the remaining portions of the research program in future years. This funding estimate does not consider either unexpected technical breakthroughs nor funding limitations that might result in a slower-paced or faster-paced program. These re-

source estimates are for planning only. Future DOE funding requests will depend on the availability of government funding, the priority of this effort compared with other national needs, the time phasing of activities, and unexpected funding received by other government agencies or industry.

Although building energy research is already being conducted by the DOE and the buildings industry, it is oriented to materials, components, subsystems, or (in the case of the DOE Renewable Energy programs), to the use of a particular energy source. These research programs produce results that are important inputs to a building systems integration research program, and they comprise a valuable financial and technical resource. This plan, however, represents the first cohesive attempt at identifying, examining, and solving system integration research problems.

Surveys in preparation for this plan did not discover research programs of this type in the private sector. Private-sector organizations have always demonstrated enthusiasm for this type of research (and for this plan, specifically), but these organizations are typically not positioned to engage in this integrative kind of research - either because of extremely limited resources (in the case of architectural and engineering firms), or because it would provide little direct benefit to the sponsoring firms (equipment manufacturers, for example).

5.2 FACILITIES AND EQUIPMENT

Building systems integration research is a two-step process: developing scientific theory using computer facilities, and verifying the theories using laboratory facilities. Computational facilities are available to some extent within the national laboratories. Laboratory facilities applicable to this program also exist at the National Bureau of Standards, and outside the federal sector at the National Association of Homebuilders Research Foundation, the Florida Solar Energy Center, and Owens-Corning Fiberglas Corporation. These facilities will be used to reduce costs and to develop private-sector capabilities; however, these organizations, personnel and equipment will continue to be focused on other areas of research.

Source estimates are for planning only. The DOE funding requests will depend on the availability of government funding. The priority of this effort compared with other activities needs, the time phasing of activities, and anticipated funding received by other government agencies on industry.

Although building energy research is already being conducted by the DOE and the building industry, it is oriented towards basic research, subjects on the cost of the DOE Research Energy Program, to the use of a "practical" source. These research programs include research on building energy for building systems, building energy research, and energy conservation research program, and they are being conducted in the building industry. The plan, however, represents the first concerted attempt at building energy research and system integration research program.

Surveys in preparation for this plan will not only assess progress of the DOE and the private sector, but also identify areas where government and private organizations have already demonstrated an interest for this type of research (and for the DOE and industry). But these organizations are currently not positioned to undertake this type of research. The reason is that the DOE and industry are not positioned to undertake this type of research. The reason is that the DOE and industry are not positioned to undertake this type of research. The reason is that the DOE and industry are not positioned to undertake this type of research.

2.1 FACILITIES AND EQUIPMENT

Building system integration research is a two-pronged effort. On the one hand, it is a research effort to develop theory and computer facilities and on the other hand, it is a research effort to develop the theory and computer facilities. The DOE and industry are not positioned to undertake this type of research. The reason is that the DOE and industry are not positioned to undertake this type of research. The reason is that the DOE and industry are not positioned to undertake this type of research.

The resources required to implement the building system integration program are outlined in this chapter. These resources include funding, research facilities, and equipment acquisition for the period 1985 through 1995.

2.2 RESEARCH COSTS AND FUNDING

The technical activities described in Chapter 2.0 require a coordinated effort between research performed in the commercial and residential categories. As in past years, these activities will involve substantial research and development costs. However, the program will be conducted in a manner that is consistent with the DOE's research and development goals.

The projects to be funded vary widely in technical size and complexity. They will include not only small-scale research projects and computer simulations, but also large-scale testing and development work. The latter will require an additional amount of capital expenditure.

To conduct the technical tasks outlined in Section 2.0, an estimated average of 35 to 40 person-years per year (PY) are required for the five-year period. At the current average cost of \$120,000 per person-year, overhead, and administrative costs, the total estimated cost of the research program will be approximately \$4.5 million per year. The five-year total research costs by year are shown below.

Estimated Research Salaries (\$)				
Fiscal Year				
1985	1986	1987	1988	1989
3.0	4.0	5.0	5.5	6.0

This funding level provides adequate support for critical activities that are necessary to accomplish the research program in the five-year time frame while leaving the foundation for continuing the research program of the research program in future years. This funding estimate does not cover other work related to the program, such as building research facilities, equipment, and other research costs that might be required in future years.

REFERENCES

- American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Inc. 1985. ASHRAE Standard - Proposed American National Standard. Energy Efficient Design of New Non-Residential Buildings and New High-Rise Residential Buildings. ASHRAE, Atlanta, Georgia.
- Building Design and Construction. December 1984. "Building Design and Construction." p. 89.
- Burt Hill Kosar Rittelmann Associates. 1985. Small Office Building Handbook: Design for Reducing First Costs and Utility Costs. Van Nostrand Reinhold, New York, New York.
- Business Week. November 7, 1983. "Homebuilding's New Look." p. 92.
- Energy Information Administration. 1981. Nonresidential Buildings Energy Consumption Survey: Building Characteristics. DOE/EIA-0246, Energy Information Administration, U.S. Department of Energy, Washington, D.C.
- Energy Information Administration. 1982. 1981 Annual Report to Congress, Volume 3, Supplement 3. DOE/EIA-0173(81)-3, Energy Information Administration, U.S. Department of Energy, Washington, D.C.
- Energy Information Administration. March 1984a. Monthly Energy Review. DOE/EIA-0035, Energy Information Administration, U.S. Department of Energy, Washington, D.C.
- Energy Information Administration. April 1984b. 1983 Annual Energy Outlook. DOE/EIA-0383(83), Energy Information Administration, U.S. Department of Energy, Washington, D.C.
- Flynn, W. T. 1984. Residential and Commercial Buildings Data Book. Pacific Northwest Laboratory, Richland, Washington.
- Harvard-MIT Joint Center for Urban Studies. 1980. Projections of Housing Consumption in the U.S., 1980 to 2000 by a Cohort Method. Harvard-MIT Joint Center for Urban Studies, Cambridge, Massachusetts.
- Harvard-MIT Joint Center for Urban Studies. 1983a. Housing in the 1980s: Review of Alternative Forecasts. Harvard-MIT Joint Center for Urban Studies, Cambridge, Massachusetts.
- Harvard-MIT Joint Center for Urban Studies. 1983b. The Changing Utilization of the Housing Inventory: Past Trends and Future Prospects. Harvard-MIT Joint Center for Urban Studies, Cambridge, Massachusetts.
- Lannus, A. 1985. EPRI Research on Building Systems. Electric Power Research Institute, Palo Alto, California.
- Manufactured Housing Quarterly. Fall 1983. Manufactured Housing Institute, Arlington, Virginia.
- Manufactured Housing Quarterly. Fall 1985. "DOE Guide Identifies Best Energy Options for Manufactured Homes." Manufactured Housing Institute, Arlington, Virginia.
- National Association of Homebuilders. 1979. Profile of the Builder. National Association of Homebuilders, Washington, D.C.
- Pacific Northwest Laboratory. 1983. Recommendations for Energy Conservation Standards and Guidelines for New Commercial Buildings. PNL-4870, Vols. I-IV (40 documents), Pacific Northwest Laboratory, Richland, Washington.
- Pacific Northwest Laboratory. 1984. Residential and Commercial Buildings Data Book. Pacific Northwest Laboratory, Richland, Washington.
- Technology Review. November/December 1985. "The House That Machines Built."

The Washington Post. November 21, 1985. "Nonurban Population Is No Longer Surging."

Urban Land Institute. 1982. Demographic Changes and Their Effects on Real Estate Markets in the 1980s. Urban Land Institute, Washington, D.C.

U.S. House of Representatives. 1985. House of Representatives Report #99-54 Accompanies the DOE Civilian R&D Authorization Act for FY86, FY87 and FY88. U.S. House of Representatives, Washington, D.C.

APPENDIX A

DEVELOPMENT TEAM FOR BSI MULTIYEAR RESEARCH PLAN

APPENDIX A

DEVELOPMENT TEAM FOR BSI MULTIYEAR RESEARCH PLAN

This multiyear plan was developed by the following people:

General

John Rivera
D&R International

Jean Boulin
Building Systems Division, DOE

Mary Ann Eichenberger
ECON, Inc.

Raymond Reilly
Pacific Northwest Laboratory

Residential Research Plan

Marvin Gorelick
Building Systems Division, DOE

Ron Ritschard
Lawrence Berkeley Laboratory

Jean Boulin
Building Systems Division, DOE

Steve Byrne
Lawrence Berkeley Laboratory

John Rivera
D&R International

Ralph Jones
Brookhaven National Laboratory

Emanuel Levy
The Levy Partnership

John Andrews
Brookhaven National Laboratory

Commercial Research Plan

Ted Kurkowski
Building Systems Division, DOE

Jean Boulin
Building Systems Division, DOE

John Holton
Burt Hill Kosar Rittelmann Associates

Raymond Reilly
Pacific Northwest Laboratory

The following industry representatives attended planning meetings to structure the research agendas for the residential and commercial plans and to provide feedback on drafts of the plan.

Dan Meacham
Miles Bolton Associates

Earle Kennett
AIA Foundation

John Sims
Champion Homebuilder Company

Walter Kroner
Rensselaer Polytechnic Institute

Frank Walter
National Manufactured Housing Institute

John Kaufman
Illuminating Engineering Society

Merle McBride
Owens Corning Fiberglas

Roland Downing
Building Owners & Managers Association

James Morgan
ASHRAE

Tom King
Mueller Associates

James Brodrick
Gas Research Institute

George Barney
Masonry Research Foundation

Mike McGrath
Edison Electric Institute

Jack Warner
ACEC R&D Foundation

Richard Hibbert
U.S. Naval Facilities Engineering Command

Joe Vandenberg
Edison Electric Institute

Victor Goldschmidt
Ray W. Herrick Lab

Jerry Harper
Electric Power Research Institute

Mike Bell
National Association of Homebuilders

James West
Tennessee Valley Authority

Barbara Harwood
BBH Enterprise, Inc.

James Griffith
National Fenestration Council

Mike Dicks
Mueller Associates

Jose Reig III
ASHRAE

John Spears
National Association of Homebuilders

Greg Franta
ENSAR Group

Numerous other government and industry representatives reviewed draft plans. These people are included in the distribution list for this document.

APPENDIX B

A CASE STUDY ON SYSTEM INTEGRATION RESEARCH -
DEVELOPMENT OF A DESIGN STANDARD FOR NEW COMMERCIAL BUILDINGS

APPENDIX B

A CASE STUDY ON SYSTEM INTEGRATION RESEARCH - DEVELOPMENT OF A DESIGN STANDARD FOR NEW COMMERCIAL BUILDINGS

The following information is included in the program plan as an indication of the benefits that are possible from a system integration approach to building design. The energy savings presented here result from system integration as defined by a standard that would be applied to all building types in all locations. If a system integration approach were tailored to the design of a specific building, the energy savings would be far greater.

Congress has required the U.S. Department of Energy (DOE) to develop, test, and issue an energy conservation standard for the design of new commercial buildings. The standard will be mandatory only for the design of new federal government buildings and will be issued as a voluntary guideline for use within the private sector. The proposed standard that has been developed differs significantly from ANSI/ASHRAE/IES 90A-1980, which it was designed to replace. The major difference between the two standards is in their approach: the proposed standard attempts to design the building from a system integration perspective, whereas under 90A-1980, building subsystems are designed in isolation from one another. For example, under the proposed standard, wall design takes into account lighting, people, other internal loads, orientation, and climate, whereas under 90A-1980, climate is the only determinant in wall design. The new standard could not extract maximum benefit from a system integration approach however, because of the current shallow understanding of building system integration, ways to effect that integration, and its benefits. Determining that information is the intent of this program plan.

The project to develop the standard was conducted cooperatively by the DOE and the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) in 1982 and 1983. For the DOE, the intent of the project was to develop recommendations for DOE's Congressionally mandated federal design standards. For ASHRAE, the project was to serve as a technical basis for its continuing effort to improve and maintain building energy conservation standards. ASHRAE's standard (ANSI/ASHRAE/IES Standard 90A-1980, "Energy Conservation in New Building Design") now serves as a basis for building energy codes in more than 40 states. ASHRAE is now conducting its own independent development, review, and consensus acceptance process based upon the DOE recommendations before it issues a revised commercial standard.

The project comprised four major elements performed sequentially, but with considerable overlap: 1) evaluation of the existing standard and identification of problem areas, 2) basic research to develop a scientific and engineering basis for developing improvements and problem solutions, 3) formulation of recommendations for a revised standard, and 4) testing of recommendations for conservation and economic effectiveness.

The newly developed conservation standard (90E) was tested for conservation and economic effectiveness in a comprehensive application of the standard to 10 "real" test buildings. In the test, the plans for 10 existing buildings were selected from a larger set based upon their ability to 1) serve as a suite of more-or-less typical buildings (being rigorously "typical" or "representative" was not essential for this project because the buildings were not being used to derive a standard, but only to test one), and 2) as a whole, test each of the important aspects of the recommendations. Each of these buildings was reconfigured with 2 to 4 "typical" HVAC systems, and then these 27 test variations (2 to 4 x 10) were tested across 5 climates, 3 levels of the standard (ANSI/ASHRAE/IES Standard 90-1975, 90-1980A, and the proposed 90E), and 3 economic perspectives, for a total of 1215 primary case studies. Additional analyses were conducted for daylighting on 4 test buildings, and each of those buildings was tested for two levels of standard (90-1975 and 90E) at 3 additional locations. Thus, approximately 2205 cases were tested. In addition, approximately 810 additional test runs were conducted to isolate the systems and lighting (a preliminary version of the final recommendations for lighting) sections of the recommendations.

CASE STUDY - MEDIUM OFFICE BUILDING

For the economic analysis, four ownership perspectives were considered: 1) owner-occupied, 2) state and local government, 3) federal, and 4) speculative. Life-cycle cost analyses were performed for the first three perspectives, using present value as the metric of life-cycle cost.

The project test results indicate that if the proposed standard is applied during design of buildings, significant cost-effective energy savings will result across a wide range of commercial building categories. When the ten test buildings were upgraded from ANSI/ASHRAE/IES Standard 90A-1980 to comply with the proposed federal standard, energy conservation improved substantially. Offices averaged about 19% total savings (with 27% savings using daylighting strategies were employed); retail averaged 17%; and residential 10%. Other building categories experienced 10% to 15% savings. (All energy estimates are presented in site-energy units.) In general, the life-cycle cost of constructing and operating each building was lowered or remained constant with the redesigns.

The largest energy savings (in most cases) resulted from reduced lighting energy consumption (20% to 25%) and corresponding reductions in space cooling loads and fan energy. Other major factors included a tightening of the envelope, and a reduction in the solar loads on windows through reduced shading coefficient and/or external shading. These changes to the envelope and lighting designs usually resulted in significantly reduced cooling peaks that allowed reduction of HVAC system size and economic savings. Heating loads were generally reduced by about 20%, reflecting several factors, including the reduction of the interior design temperature from 72°F to 70°F and a tightened envelope.

One important outcome of the testing process was to highlight the overriding influence of lighting design on the performance of air-conditioned buildings. The interdependence of artificial lighting, natural lighting, and peak and annual cooling loads proved to be of dominant importance in determining energy use in every climate for several major building categories, and must be the prime consideration in design of these buildings.

Another clear outcome of the test results is a better understanding of the declining impact that efficiency improvements for heating and cooling equipment has on total energy use. This indicates that the point of diminishing returns is being reached in this area, and that future advances will depend on the invention of new systems that are inherently more efficient than present devices, and that can be better integrated with the evolving envelope and lighting technologies.

The following section presents the energy and economic impacts of applying ANSI/ASHRAE/IES 90-1975, 90-1980A and the proposed 90E to a medium office building. The building and its systems are first described. Next, the lighting and envelope changes that resulted from redesigning the building for compliance with the various levels of standard are outlined. Finally, the results of the energy and economic analyses are presented and discussed.

Building Description

The medium office building selected for testing was built in Farmington, Connecticut, in 1973. It contains 49,500 gross square feet on 3 floors, with a steel-frame superstructure and exterior walls of 4" precast concrete panels. Floor-to-floor height is 12 feet. There is one hydraulic passenger elevator and 2 internal stairways. The first floor is partially bermed. (The building was recently expanded laterally on all three floors by almost 60%.)

About 36% of the wall area is glass, with fairly constant proportions on all sides and floors. The first floor windows slope into the building at 57° (like a greenhouse), and the second floor windows are shaded by the 5 foot overhang of the top floor. The first floor also receives some shading benefit from the top floor. Aside from this unusual glazing, it is a typical medium-sized office structure, with above average construction quality. It is occupied by 330 people, all involved in office activities, on a basic 5-day work week schedule (some occupancy on weekday

evenings; 30% of daily occupancy on Saturdays - daytime only; and go occupancy on Sundays and holidays). Thermostats are set at 78°F cooling and 72°F heating (70°F for 90E), with a night and weekend heating setback to 55°F.

Major Compliance Trends

The connected lighting load in the building was reduced from 2.5 w/ft² for 90-75/90A compliance to 1.9 w/ft² for 90E compliance, or 24% (Table B.1)(a). Glazing was typically single in the warm climates and double in the colder climates for 90-75/90A, and generally remained the same for 90E (although Milwaukee went to triple glazing, and El Paso to double). All glass was either tinted or reflective, except for 90E Milwaukee, which was clear. Horizontal shading was provided on the third floor windows in Houston and Los Angeles for 90E to assist them in meeting the cooling criteria, but it was removed for the daylighting runs to enable compliance with the heating criterion. Roof changes are mixed, while wall U₀ values typically decreased with increasing levels of standards.

Discussion of the Energy Analyses

Under Standards 90-75 and 90A the medium office building consumed roughly 60 to 80 KBtu/ft²/yr. Under 90E the building consumed 40 to 64 KBtu/ft²/yr and was slightly lower under the 90E daylighting configuration (Figure B.1)(a).

From Standard 90-75 to 90A, there were total energy savings of approximately 5% more in the hot climates than the cooler ones. The savings were generally due to increases in equipment efficiency (10-30%, depending upon system type). There are no significant differences in the lighting energy.

From Standard 90A to 90E energy savings average about 16%, due chiefly to reductions in lighting (25%) and associated cooling loads. Heating energy is reduced at all test sites except Houston (despite less heat being available from lighting) because of tightening of the envelope.

From Standard 90A to 90E/daylighting the average energy savings was 23%, due in large part to savings in lighting energy (37%) and cooling energy (25%). Heating energy remained largely unchanged as compared to 90E despite the reduced light-generated heat available because of a further-tightened envelope and (in the case of Houston) the removal of the external shading on the third floor.

Discussion of the Economic Results

From Standard 90-75 to 90A, total life-cycle costs (TLCC) were slightly lower in all cities but Seattle. Energy savings ranged from 2.3 to 11%, while capital costs rose slightly in response to the increased cost of more efficient HVAC equipment (Figure B.2)(a).

From Standard 90A to 90E, TLCCs were reduced by up to 5% except for Seattle, where TLCCs were essentially unchanged. With such low-cost energy, Seattle energy savings could not overcome the higher capital costs. The capital cost increases due to envelope and equipment improvements were partially counterbalanced through substantial downsizing of HVAC systems and equipment.

From Standard 90A to 90E/daylighting, TLCCs were reduced by 3%. (The only increases that occurred were for some cases in Seattle.) In general, energy savings were considerable, but electrical layout and controls requirements consumed most of the operational savings. The energy costs were approximately 23% below the 90A levels, and approximately 10% below 90E levels. Capital costs rose by 1% above 90A.

A speculative owner's analysis shows that Standard 90A resulted in paybacks of less than 2 years. Seattle had a payback of more than 5 years for alternative #3 when 90E is compared to 90A, and was the only location in which daylighting did not consistently payback within 2 years.

(a) Key to figures and tables: A=ANSI/ASHRAE/IES Standard 90-1975; B=ANSI/ASHRAE/IES Standard 90A-1980; F=Proposed Standard; G=Proposed Standard with Daylighting.

TABLE B.1. Compliance Summary for Medium Office Building

STANDARD LEVEL	90-75	90A-80	90E	90E DAYLIGHTING
ROOF Uo				
El Paso	0.038	0.031	0.080	0.080
Houston	0.050	0.050	0.080	0.080
Seattle	0.106	0.106	0.060	0.060
Wash DC	0.150	0.150	0.073	0.073
Milwaukee	0.038	0.038	0.038	0.038
Los Angeles	0.031		0.087	
Boston	0.073		0.060	
Omaha	0.073		0.050	
WALL Uo				
El Paso	0.437	0.420	0.332	0.318
Houston	0.437	0.420	0.478	0.442
Seattle	0.271	0.262	0.265	0.252
Wash DC	0.258	0.262	0.265	0.252
Milwaukee	0.436	0.248	0.182	0.172
Los Angeles	0.271		0.465	
Boston	0.271		0.231	
Omaha	0.271		0.219	
FENESTRATION				
	number of panes / type / shading coeff / x = external shading			
El Paso	1/refl/.45	1/refl/.45	2/refl/.36	2/refl/.36
Houston	1/refl/.45	1/refl/.45	1/refl/.45/x	1/tint/.38
Seattle	2/tint/.55	2/tint/.55	2/tint/.55	2/tint/.62
Wash DC	2/tint/.55	2/tint/.55	2/tint/.55	2/tint/.55
Milwaukee	2/tint/.55	2/tint/.55	3/clr/.72	3/clr/.72
Los Angeles	1/tint/.69		1/refl/.36/x	
Boston	2/tint/.55		2/tint/.55	
Omaha	2/tint/.55		2/tint/.55	
LIGHTING (w/sf)				
Bldg Average	2.5	2.5	1.9	1.9

FIGURE B.1. A Comparison of Annual Energy Consumption for a Medium Office Building Configured to ANSI/ASHRAE/IES Standards 90-1975(A), 90A-1980(B), and the Proposed Standard 90E(F) and 90E with Daylighting(G)

FIGURE B.1. (contd)

FIGURE B.2. A Comparison of Life-Cycle Costs for a Medium Office Building Configured to ANSI/ASHRAE/IES Standards 90-1975(A), 90A-1980(B), and the Proposed Standard 90E(F) and 90E with Daylighting(G)

FIGURE B.2. (contd)

Legend
 [Hatched Box] FUEL COSTS
 [Black Box] O&M COSTS
 [White Box] CAPITAL COSTS

APPENDIX C

THE NAHB "SMART HOUSE"

APPENDIX C

THE NAHB "SMART HOUSE"

The National Association of Home Builders Research Foundation, Inc., (NAHB/RF) has initiated a project of system integration for electric/electronic subsystems integration within residential buildings. The multifirm project will produce a household wiring system that combines power, control, data, and communications capabilities in a single physical system. NAHB's intent is to develop the system and then to use the influence of the NAHB constituency (tens of thousands of independent home builders) to promote acceptance of the concept.

This project is rather unique among private sector organizations. The conditions that have led to the project are listed below:

- Conventional home electrical systems are redundant and therefore costly. Separate wiring is laid for power, communications, and various ancillary functions. Each major appliance and utility subsystem has its own separate timing and control devices.
- While electronic technology has evolved substantially, home wiring has not kept pace. The reasons include building codes, industry interface problems, vested interests, and other issues.
- A growing number of home electrical devices are capable of complex control and diagnostic routines. Consumers have shown themselves to be increasingly interested in these capabilities.
- Such devices cannot be used to their full potential because they cannot communicate with one another or the outside world for lack of a standard communications protocol.
- For the few devices with communications capabilities, separate signal cable must be laid to provide the necessary links.
- With a combination of proven technologies, it is possible to integrate the power and signal cabling of a house and to coordinate and control all devices from a single processor. Such a system could have a lower installed cost and be safer and more reliable than conventional arrangements while making possible numerous new functions through exploitation of the communications capability.
- The interdependence of the components in an integrated home electrical and communications system has made it impossible for any one firm to develop and promote the complete package.
- Recent changes in regulation and Justice Department policy allow greater interfirm cooperation in joint development projects, and new methods of accounting for such projects permit favorable tax treatment.

DISTRIBUTION

No. of
Copies

No. of
Copies

OFFSITE

5 Ted Kurkowski
U.S. Department of Energy
Building Systems Division
Forrestal Building
Washington, DC 20585

40 Jean Boulin
U.S. Department of Energy
Building Systems Division
Forrestal Building, GH-068
Washington, DC 20585

5 John Rivera
D&R International
9915 Connecticut Avenue
Kensington, MD 20895

5 Marvin Gorelick
U.S. Department of Energy
Building Systems Division
1000 Independence Avenue, SW
Washington, DC 20585

30 Technical Information Center

Mary Ann Eichenberger
2227 20th Street, NW
Washington, DC 20009

George Barney
Masonry Research Foundation
4203 North Kennicott Avenue
Arlington Heights, IL 60004

Daniel H. Nall, AIA, P.E.
Jones, Nall & Davis
Flatiron Building, Suite 900
84 Peachtree Street, N.W.
Atlanta, GA 30303

Craig McDonald
Synergic Resources Corporation
555 City Line Avenue
Suite 1050
Bala Cynwyd, PA 19004-1105

Gene Brewer
National Institute of Building Sciences
1015 15th Street, NW
Suite 700
Washington, DC 20005

Bruce Hunn
University of Texas at Austin
10100 Burnet Road
Austin, TX 78758

Art Rosenfeld
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Steve Selkowitz
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Ron Ritschard
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

John Andrews
Brookhaven National Laboratory
Upton, NY 11973

Walter Loess
Brookhaven National Laboratory
Upton, NY 11973

Jim Hill
National Bureau of Standards
National Engineering Lab
Gaithersburg, MD 20899

Ron Kammerud
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Robert Shibley
SUNY-Buffalo
School of Architecture,
Rm. 114, Hayes Hall
3435 Main Street
Buffalo, NY 14214

George Courville
Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, TN 37830

Tamami Kusuda
National Bureau of Standards
National Engineering Lab
Gaithersburg, MD 20899

Joseph Deringer
The Deringer Group
335 Cove Road
Riva, MD 21140

Malcolm Lewis
Malcolm Lewis Associates
15500 Rockfield Blvd.
Suite 7c
Irvine, CA 92718

No. of
Copies

Ron Judkoff
Solar Energy Research Institute
1617 Cole Blvd.
Golden, CO 80401

Charles Achilles
Institute of Real Estate Management
430 N. Michigan Ave.
6th Floor
Chicago, IL 60611

James Binkley
U.S. Postal Service
Washington, DC 22060

Jim Barron
NYS ERDA
2 Empire Plaza
Albany, NY 12223

Jordan Heiman
110 Stoneyside
St. Louis, MO 63132

Gifford H. Albright
Directorate of Engineering
National Science Foundation
1800 G Street, N.W.
Washington, DC 20550

Thomas R. Schneider, Ph.D.
Energy Utilization and Conservation
Technology
3412 Hillview Avenue
P.O. Box 10412
Palo Alto, CA 94303

Thomas Vonier
Thomas Vonier Associates
3741 W Street, N.W.
Washington, DC 20007

John L. Weidt
John L. Weidt Associates
401 Lake Village Center
Chaska, MN 55318

Marilyn A. Brown
Oak Ridge National Laboratory
Building 4500 N - P.O. Box X
Oak Ridge, TN 37831

Maxine Savitz
The Garrett Corporation
9851 Sepulveda Blvd.
Los Angeles, CA 90009

Tom Foley
Northwest Power Planning Council
850 SW Broadway, Suite 1100
Portland, OR 97205

No. of
Copies

Allen C. Weidman
Manager, Codes and Standards
American Gas Association
1515 Wilson Blvd.
Arlington, VA 22209

Gear Day Ding, AIA
Small Homes Council
1 East St. Mary's Road
Champaign, IL 61820

Charles Eley
Charles Eley Associates
142 Minna Street
San Francisco, CA 94105

Allen S. Kennedy
Energy and Environmental System
Division
Argonne National Laboratory
Argonne, IL 60439

J. Thomas Black
The Urban Land Institute
1090 Vermont Avenue, N.W.
Washington, DC 20005

William Seaton
ASHRAE
1791 Tullie Circle, N.E.
Atlanta, GA 30329

Bruce Wilcox
The Berkeley Solar Group
3140 Martin Luther King Way
Berkeley, CA 94703

Murray Milne
UCLA
Graduate School of Architecture
and Urban Planning
405 Hilgrad Avenue
Los Angeles, CA 90024

Subrato Chandra
Florida Solar Energy Center
300 State Road 401
Cape Canaveral, FL 32920

Andrew Euston
Energy Division
U.S. HUD
Washington, DC 20410

Jim Brodrick
Gas Research Institute
8600 West Bryn Mawr Avenue
Chicago, IL 60631

No. of
Copies

Mike Bell
National Association of Homebuilders
15th & M Streets, NW
Washington, DC 20005

Ralph Johnson
National Association of Homebuilders
Research Foundation
527 S Lawn Lane
Rockville, MD 20870

Greg Franta
ENSAR Group
12819 W. Ellsworth Place
Lakewood, CO 80228

Ralph Jones
Brookhaven National Laboratory
Building 475
Upton, NY 11973

Steve Byrne
Lawrence Berkeley Laboratory
1 Cyclotron Road, Bldg. 90
Berkeley, CA 94720

Merle McBride
Owens Corning Fiberglas
Technical Center
Granville, OH 43023

Mike McGrath
Edison Electric Institute
1111 9th Street, NW
Washington, DC 20036

Joe Vandenberg
Edison Electric Institute
1111 9th Street, NW
Washington, DC 20036

Earle Kennett
AIA Foundation
1735 New York Avenue, NW
Washington, DC 20006

Victor Goldschmidt
Ray W. Herrick Lab
School of Mechanical Engineering
Purdue University
West Lafayette, IN 47907

John Sims
Champion Homebuilder Company
5573 East North Street
Dryden, MI 48428

Richard Hibbert
U.S. Naval Facilities
Engineering Command
200 Stovall Street, Rm. 10N-41
Alexandria, VA 22332

No. of
Copies

5 M. Emanuel Levy
The Levy Partnership
40 East 19th Street
Seventh Floor
New York, NY 10003

Dan Meacham
Miles Bolton Associate
3166 Mathison Drive N.E.
Atlanta, GA 30305

Frank Walter
National Manufactured Housing
Institute
1745 Jefferson Davis Highway
Arlington, VA 22202

Rich Davis
Farmers Home Administration
14th & Independence Avenue, SW
Washington, DC 20250

Walter Kroner
Center for Architectural Research
Rensselaer Polytechnic Institute
Troy, NY 12180

John Kaufman
Illuminating Engineering Society
345 East 47th Street
New York, NY 10017

Jerry Harper
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, CA 94304

Tom King
Mueller Associates
1401 Edgewood Street
Baltimore, MD 21227

Jose Reig III
10816 Horde Street
Wheaton, MD 20902

Barbara Harwood
BBH Enterprise, Inc.
2655 Villa Creek
Suite 150
Dallas, TX 75234

John Holton
Burt, Hill, Kosar, Rittelmann
Associates
44D First Street, NW
Suite 500
Washington, DC 20001

No. of
Copies

Harry Gordon
Burt, Hill, Kosar, Rittelmann
Associates
440 First Street, NW
Suite 500
Washington, DC 20001

Fred Creswick
Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, TN 37830

Claude Robbins
Solar Energy Research Institute
1617 Cole Blvd.
Golden, CO 80401

Douglas Balcomb
Los Alamos National Laboratory
Los Alamos, NM 87545

Chairman, Energy Committee
American Institute of Architects
1735 New York Avenue, NW
Washington, DC 20006

Harrison Fraker
School of Architecture
University of Minnesota
89 Church Street, SE
Minneapolis, MN 55455

Don Watson
Yale University
730 Main Street
Branford, CT 06405

Harvey Bryan
Massachusetts Institute of Technology
Rm. 3-435
77 Massachusetts Avenue
Cambridge, MA 02139

Jerold Jones
University of Texas at Austin
Dept. of Mechanical Engineering
Engineering Teaching Center, 7.140
Austin, TX 78712

William K. Tao
William K. Tao & Associates
2357 - 59th Street
St. Louis, MO 63110

G. Kimball Hart
Box 125B
102 W. Washington St.
Middleburg, VA 22117

No. of
Copies

Jack Warner
ACEC R&D Foundation
1015 15th St., NW
Suite 802
Washington, DC 20005

John Spears
NAHB Research Foundation
P.O. Box 1627
627 Southlawn Avenue
Rockville, MD 20850

Gary Purcell
EPRI
3412 Hillview Avenue
P.O. Box 10412
Palo Alto, CA 94303

Richard Wright
ASHRAE
1791 Tullie Circle
Atlanta, GA 30329

Andrew Parker
Mueller Associates
1401 S. Edgewood Street
Baltimore, MD 21227

Martin Mintz
NAHB
15th & M Streets, NW
Washington, DC 20005

Ronald Thomas
Meridian Corporation
5113 Leesburg Pike
Falls Church, VA 22041

Chairman, Energy Management Committee
IES-NA
345 E. 47th Street
New York, NY 10017

Noel Leary
BOMA International
Suite 200
1250 Eye Street, NW
Washington, DC 20005

National Fenestration Council
3310 Harrison
White Lakes Professional Bldg.
Topeka, KS 66611

Tennessee Valley Authority
Division of Conservation and
Energy Management
Commercial & Industrial Branch
Chattanooga, TN 37401

No. of
Copies

Ervin Bales
School of Architecture
New Jersey Institute of
Technology
Newark, NJ 07102

Bruce Maeda
California Energy Commission
1516 Ninth Street, MS 25
Sacramento, CA 95814

David Conover
NCSBCS
481 Carlisle Drive
Herndon, VA 22070

James McCollum
Energy Division
U.S. HUD
Washington, DC 20410

Steve Hickock
Bonneville Power Administration
P.O. Box 3621
Portland, OR 97208

Robert Biener
Masonry Research Institute
815 15th Street, NW
Washington, DC 20005

Bion Howard
National Concrete Masonry Assoc.
Box 781
2302 Horse Pen Road
Herndon, VA 22070

Allen Yorkdale
Brick Institute of America
1750 Old Meadow Road
McLean, VA 22102

Roland Downing
First National Bank of Atlanta
1430 First Atlanta Tower
2 Peachtree Street, NW
Atlanta, GA 30383

William Griffith
National Fenestration Council
3921 Caruth Boulevard
Dallas, TX 75225

James West
Tennessee Valley Authority
375-401 Building
Chattanooga, TN 37401

No. of
Copies

Holt Blomgren
National Manufactured Housing
Federation
Suite 1240
1015 15th Street N.W.
Washington, DC 20005

James Morgan
ASHRAE
1791 Tullie Circle, N.E.
Atlanta, GA 30329

Sizemore/Floyd
1 Piedmont Center
Suite 200
Atlanta, GA 30505

Michael Holtz
Architectural Energy Corp.
8753 Yates Drive
Suite 105
Westminster, CO 80038

AREA, Inc.
2403 San Mateo, NE
Suite S-16
Albuquerque, NM 87110

Donald Ross
Ross & Baruzzini, Inc.
7912 Bonhomme Avenue
St. Louis, MO 63105

William Whiddon
6727 Curran Street
Third Floor
McLean, VA 22101

Jack Duffie
University of Wisconsin
1500 Johnson Drive
Madison, WI 53706

Alfred Guntermann
The Austin Co.
3560 Mayfield Rd.
Cleveland, OH 44121

Harry Misuriello
WS Fleming & Associates
536 Seventh Street, SE
Washington, DC 20003

Huber Buehrer
Buehrer & Stough
Architects & Engineers
4246 Sylvania Avenue
Toledo, OH 43623

No. of
Copies

Ray Lackey
Masonry Research Foundation
815 Fifteenth Street, NW
Washington, DC 20005

Gerald Pine
Gas Research Institute
8600 W. Bryn Mawr Avenue
Chicago, IL 60631

Building Thermal Envelope
Coordinating Council
RCC on the Thermal
Performance of Whole Bldgs
1015 15th Street, NW
Suite 700
Washington, DC 20005

Passive Solar Industries Council
125 S. Royal Street
Alexandria, VA 22314

Lighting Research Institute
345 East 47th Street
New York, NY 10017

Ron Lutha
DOE-Chicago Operations
9800 S Cass Avenue
Argonne, IL 60439

Janet Neville
DOE-San Francisco
1333 Broadway
Oakland, CA 94612

Ho Fu Wu
College of Architecture
Arizona State University
Tempe, AZ 85281

Robert Strenght
Monsanto Plastic & Resins
800 N Lyndberg Blvd.
St. Louis, MI 63166

National Rural Electric Corp Assoc
1800 Massachusetts Avenue NW
Washington, DC 20036

David Harrje
Center of Energy Environment
Studies
Princeton University
Princeton, NJ 08544

Fredrick Rohles
Institute for Environmental
Studies
Kansas State University
Manhattan, KS 66506

No. of
Copies

Leon Glicksman
Institute for Joint Studies
MIT
77 Massachusetts Avenue
Cambridge, MA 02139

Ken Mentzer
Mineral Insulation Manufacturers
Association
382 Springfield
Summit, NJ 07901

Faye C. McQuiston
School of Mechanical Engineering
Oklahoma State University
Stillwater, OK 74078

Gary Willems
Headquarters USAF/LEEHF
Pentagon Room 5D 431
Washington, DC 20330

Jeff Christian
Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, TN 37830

Joe McCarty
Corps of Engineers
HQUSACE
DAEM-ECE-E
20 Massachusetts Avenue, NW
Washington, DC 20314

Edward J. Lisee
ACEC
1015-15th NW
Suite 802
Washington, DC 20005

Phil Windell
Bonneville Power Administration
P.O. Box 3621
Portland, OR 97208

Mike Warwick
Bonneville Power Administration
P.O. Box 3621
Portland, OR 97208

Dennis Oster
Bonneville Power Administration
P.O. Box 3621
Portland, OR 97208

Kirk Hall
Bonneville Power Administration
P.O. Box 3621
Portland, OR 97208

No. of
Copies

Mike Santoro
Tyndall AFB, Bldg. 1120
HQ AFESC/DEB
Panama City, FL 32403

Captain Timothy Goodman
Tyndall AFB, Bldg. 1120
HQ AFESC/DEB
Panama City, FL 32403

Lt. Col. Rich Cardinale
Tyndall AFB, Bldg. 1120
HQ AFESC/DEB
Panama City, FL 32403

- 5 Sue Balistocky
938 N. Croft
Beverly Hills, CA 90069

Clyde Arnold
Facility Systems Division
Naval Civil Engineering Laboratory
Port Hueneme, CA 93043

Mary Lingua
Facility Systems Division
Naval Civil Engineering Laboratory
Port Hueneme, CA 93043

David Holmes
Facility Systems Division
Naval Civil Engineering Laboratory
Port Hueneme, CA 93043

John Millhone
Office of Buildings and Community Systems
U.S. Department of Energy
Forrestal Building, CE-11
Washington, DC 20585

Richard Jones
Office of Buildings and Community Systems
U.S. Department of Energy
Forrestal Building, CE-11
Washington, DC 20585

Fred Abel
Office of Buildings and Community Systems
U.S. Department of Energy
Forrestal Building, CE-11
Washington, DC 20585

John Ryan
Building Equipment Division
U.S. Department of Energy
Forrestal Building, CE-112
Washington, DC 20585

No. of
Copies

Mark Friedrichs
Building Services Division
U.S. Department of Energy
Forrestal Building, CE-115
Washington, DC 20585

Ted Kapus
Building Equipment Division
U.S. Department of Energy
Forrestal Building, CE-112
Washington, DC 20585

Jim Smith
Building Systems Division
U.S. Department of Energy
Forrestal Building, CE-111
Washington, DC 20585

Joseph Holmes
Building Services Division
U.S. Department of Energy
Forrestal Building, CE-115
Washington, DC 20585

Bill Bethea, Director
Federal Energy Management
U.S. Department of Energy
Forrestal Building, CE-116
Washington, DC 20585

Joe Cooper
Building Services Division
U.S. Department of Energy
Forrestal Building, CE-115
Washington, DC 20585

Bob Oliver
Building Systems Division
U.S. Department of Energy
Forrestal Building, CE-111
Washington, DC 20585

Mike McCabe
Building Equipment Division
U.S. Department of Energy
Forrestal Building, CE-112
Washington, DC 20585

Ron Fiskum
Building Equipment Division
U.S. Department of Energy
Forrestal Building, CE-112
Washington, DC 20585

Tina Van Sickle
U.S. Department of Energy
Federal Energy Management Programs
Forrestal Building, CE-116
Washington, DC 20585

ONSITE

DOE Richland Operations Office

J.J. Sutey/D.R. Segna

17 Pacific Northwest Laboratory

R.W. Reilly (5)

D.B. Crawley

R.C. Adams

J.W. Currie

W.B. Ashton (5)

T.J. Secrest (5)

C.A. Geffen

R.G. Rivera (5)

Publishing Coordination (2)

Technical Information (5)