Energy Conservation

TECHNICAL INFORMATION GUIDE

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Preface

This guide is one of a set of energy-conservation technical information guides (TIGs) designed to bring you up to date on conservation technologies and help you find additional information. It is written for several audiences, especially local utility managers and state energy office personnel, who have a major interest in seeing that the residential sector—a major contributor to total energy consumption and peak demand—becomes more energy efficient and better matches utility production capacity. However, utilities and energy offices can only influence, not control, the degree of energy efficiency and peak demand built into a new or remodeled home. The information in this guide is intended to help them influence both builders and buyers to select from currently available building techniques and equipment that are energy efficient and cost effective. This guide is neither a primer for beginners nor a how-to for builders. Rather, it assumes that the reader is familiar with basic building technology and wants to learn about the most up-to-date techniques and equipment available.

Most of this guide focuses on structural elements and mechanical items that conserve energy and lessen or shift peak demand in new and existing homes. Topics range from energy-efficient walls and windows to high-performance heating systems and energy-conserving appliances. Further, information is provided about indoor air quality as it relates to energy-efficient housing. The guide also provides explanations of energy design and diagnostic tools and how energy use is monitored in homes.

Advances in energy conservation have come about through the efforts of many individuals at all levels of government and in the nonprofit, private, and utility sectors. To the degree possible, this guide covers those sectors that have had or are having the greatest impact on current practice in the field. Much past and current research was started through specific Department of Energy programs; the contributions these programs have made and will continue to make are emphasized.

The references appearing throughout this guide do not represent all the material available on a specific topic. Our objective is to identify sources of information that will help you begin your search. The selection of references is based on several factors, including relevancy to the particular topic, the date of publication, and availability.

Acknowledgments

This set of technical information guides is the joint effort of the U.S. Department of Energy (DOE) Office of Buildings and Community Systems and the DOE Western Area Power Administration.

Contents

How to Use This Book

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Often, the best way to access data bases is also through libraries. Libraries that subscribe to a computer search service, such as DIALOG or BRS, can perform data-base searches for patrons. Commercial search services have standard charges for online search time and printed results.

This guide is not intended to be exhaustive but rather to list citations that deal significantly with energy conservation. By its very nature, energy conservation encompasses a wide variety of disciplines, such as architecture; building and construction; energy management; fenestration; heating; ventilating, and air conditioning; and power production. An attempt has been made to include citations referring to these disciplines that have placed an emphasis on energy-conservation issues.

Chapter 1

Introduction

Single-family homes account for about 15% of our total energy use [1]. All residential buildings account for over one-fifth of the total energy used in the United States today. Total residential energy use would be much higher if significant improvements had not been made in the energy efficiency of single-family homes over the last 10 years. However, the potential in new and existing homes for additional energy savings and greater control over the time of energy use still exists. Figure 1-1 shows how energy is currently used in residences.

Some energy-efficient homes have cut total energy use by 50% to 75% compared to conventional homes. Since the 1973 oil embargo, roughly 20 million new homes have been added to the U.S. housing stock. Of these homes, an estimated 250,000 are low-energy homes; some are custom, passive solar designs, and others are superinsulated homes put up by production builders.

The challenge is to refine and build on the excellent progress made to date by our most progressive builders. The concern is no longer whether builders can build cost-effective, energy-efficient homes but how to spread the word about our most workable and cost-effective technologies.

This information guide describes the many proven technologies used by those contractors who successfully build and sell energy-efficient and low-energy homes. Clearly, a wide range of energy-efficient options are now available to them. As a result of the diffuse nature of the U.S. housing industry, the wide variety of climates, and the strength of individual ingenuity, it is a virtual certainty that no one package will suit everyone's needs. Thus, where applicable, this guide makes recommendations about the best practices.

An Efficient Building Shell

Improvements in structural energy-conserving features have been slow but steady since the oil embargo. Just 15 years ago, little consideration was given to the air-infiltration rate and the amount of insulation in new or existing homes. Typically, attics had only 34 in. of insulation (approximately R-11), and slabs and basements were rarely insulated. Most homes, both new and existing, had single-pane windows and uninsulated walls. Uncomfortable wintertime draftiness was the norm.

Today's energy-conserving new home is built with greater attention to the amount of insulation as well as where and how it is installed. New energy-efficient homes in cold climates are likely to have R-20 insulation in the walls, R-40 insulation in the ceilings, and insulated basements. Insulation batts are still the most common approach, but sprayed insulations and rigid foam materials are becoming more accepted. Energy-conscious builders can choose among several techniques to reduce the air that flows in and out of a home, robbing it of expensive heated or cooled air. In hot climates, radiant barriers and windows with special coatings are readily available ways to cut heating and cooling requirements.

Many of these products and concepts also apply to the upgrading of existing structures. Chapter 2 describes some of the applications and

Hirst, Eric; Clinton, Jeanne; Geller, Howard; and Kroner, Walter. (1986). *Energy Efficiency in Buildings: Progress and Promise.* Edited by F. M. O'Hara, Jr. Washington, DC: American Council for an Energy Efficient Economy; 328 pp.

Reviews current knowledge on energy use and efficiency in residential and commercial buildings and suggests important research and program topics for future study. Overall patterns of energy use in residential and commercial buildings and the dramatic changes in energy trends after 1973, including government, utility, and private-sector efforts to make these changes, are reviewed. Reasons are discussed for continuing research and programs to improve energy efficiency in buildings and note the complexity and diversity among buildings in their design, construction, operation, maintenance, and use. How much has been accomplished and learned about inducing energy use in buildings since the 1973 oil embargo is examined. Finally, suggestions are offered for both the short and long terms. The book is aimed at two audiences: The first group includes officials responsible for research and development funding and conservation program decisions. The second group consists of energy professionals and others interested in the field of building energy conservation.

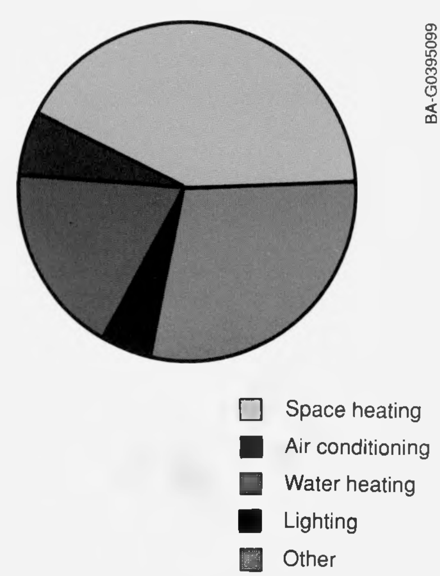

Figure 1-1. Energy use in residential buildings by end use, 1980

Source: Adapted from Eric Hirst, Jeanne Clinton, Howard Geller, Walter Kroner, and F. M. O'Hara, Jr., eds., Energy Efficiency in Buildings: Progress and Promise, *Washington, DC: American Council for an Energy Efficient Economy.*

techniques used by builders and energy retrofitters to optimize the energy efficiency and reduce the peak demand of new and existing building shells. With today's lower energy prices, many of these features are selected as much for the comfort advantage they offer as for the energy they save.

Efficient Heating, Ventilating, and Air Conditioning Equipment and Appliances

Once a building is well insulated, equipped with good glazing, and tightly built, some of the home's mechanical features must be reassessed. Lower-capacity heating and cooling equipment can be used. Major strides have been made in increasing the efficiency of furnaces, hot water heaters, and air conditioners. Other household appliances, such as refrigerators and clothes dryers, have also been redesigned for greater efficiency. Even the type of heating system selected can be different from the typical central, forced-air furnace.

The newest generation of heating, ventilating, and air conditioning (HVAC) equipment can perform several tasks. At least one manufacturer has introduced an integrated appliance that heats and cools air, heats water, and provides fresh air. This approach will ultimately reduce both the cost and energy consumption of HVAC systems. Many more such systems are being developed.

Today's energy-efficient builders tend to focus primarily on reducing heating and cooling bills and do not give equal consideration to appliance use. In energy-efficient homes with gas-heated water and space, electric bills for appliance use are typically higher than annual gas costs. In hot climates, extensive appliance use can significantly increase cooling costs. Most HVAC equipment and appliances come with improved controls that assist in reducing peak load as well.

With the passage of the 1987 Appliance Energy Conservation Act, both builders and buyers will find it easier to make choices in appliances that consistently conserve energy. Chapter 3 describes the range of energy-efficient HVAC equipment and appliances on the market today and discusses this act further.

Indoor Air Quality in Energy-Efficient Residential Buildings

Builders and buyers are concerned about potential problems with indoor air quality in today's tighter buildings. They have learned that the building shell itself can be the source of some indoor pollution (formaldehyde). Mechanical systems can also cause problems (unburned combustion gases). However, a widely publicized pollutant such as radon has less to do with how a home is built than with where a home is built.

In response to these pollution concerns, some builders and regulators seem to believe in the "leakier is safer" theory. A few individuals recommend leaving buildings loose to avoid air-quality problems, but pollution-monitoring studies indicate this theory is simply unfounded.

Informed builders are using building products that contain lower levels of formaldehyde. Because they are aware of problems with radon and combustion gases, they use products and techniques that keep these pollutants out of the home. These builders also realize that a tighter house affords better control of when and where fresh air is brought into the home. Chapter 4 examines the relationship between envelope tightness and air quality, describes four major pollutants in homes, and discusses ways to minimize indoor pollution problems.

Design, Analysis, and Diagnostic Tools for Energy Efficiency

Production builders tend to evaluate each energy feature in a home solely on the basis of its individual cost and energy savings. If the savings from upgrading R-11–insulated walls to R-19–insulated walls does not pay for the added cost within two to three years, most builders will not install the higher level. This piecemeal analysis often stops designers and builders from adopting economically sensible strategies for a building that will be used for at least 30 to 40 years.

Today's most energy-conscious designers and builders approach energy choices from a different, integrated perspective. They still evaluate the cost-effectiveness of various wall and ceiling insulation approaches, but they also consider the cumulative impact of individual measures. For example, instead of looking at the individual impact of increased insulation or high-efficiency windows, they evaluate how a combination of these features can reduce energy consumption. In addition, they analyze how such a combination might reduce the capacity and cost of heating and cooling equipment. Builders now also have access to computer design tools that determine what combination of features makes the best economic sense for both the builder and the buyer.

Energy-conscious builders are just as concerned about quality as quantity. Whenever energy efficiency is a key goal, good construction detailing and workmanship are essential. Gaps in insulation can reduce effectiveness dramatically. Two diagnostic tools—the blower door and the infrared camera—allow contractors to better control the quality of their energy upgrades. Chapter 5 describes the range of design and diagnostic tools now available for use with both new and existing homes.

Looking to the Future

The necessary building technologies for reducing energy consumption are well established, but they are not yet in significant demand. The reasons for lagging industry interest range from consumer attitudes and builder resistance to undervaluation of energy features by lending institutions. Most builders think in terms of two to three years for return of front-end cost and payback for any added energy-conservation features, and the payback for occupants of a home with envelope energy improvements is likely to be over a 10-year period. Unless local incentives or standards are established or gas and electric costs rise dramatically, typical building practices will probably not improve without a renewed appreciation within the marketplace for the benefits of energy-conserving features.

Our current understanding of the interaction between various energy options in buildings still qualifies more as an art than a science. Research is under way to develop a greater understanding of how various individual energy features affect the overall performance of whole buildings and how they contribute to time-of-day energy use. These ongoing research efforts are highlighted at the end of each chapter. These exciting new developments will direct us toward a more energy-efficient future in the housing industry.

Vieira, Robin K., and Sheinkoff, Kenneth G. (1988). *Energy-Efficient Florida Home Building.* Soloman, Milt, ed. Cape Canaveral, FL: Florida Solar Energy Center; 149 pp.

Provides energy-efficient building strategies that have proven effective in Florida homes. A major focus is marketing ideas to help the builder sell these concepts and techniques to clients. The chapters cover site planning, home design, foundations, walls, windows, roofs, equipment, appliances, and amenities. Each chapter provides the builder with a list of recommended strategies, associated costs, and estimated savings; a section on how to market the recommended strategies; and a section on how to carry through each recommendation. The latter section includes product selection, sizing, and installation information.

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Chapter 2

Energy-Conserving Envelope Features in Residences

Costs for space heating and cooling represent a significant drain on our pocketbooks. The average family in a single-family detached residence paid $1255 for heating, cooling, hot water, and appliance use during the 12 months preceding March 1985, of which space heating and cooling accounted for about half (this estimate is based on average fuel prices during this time of $.075/kWh for electricity, $.16 per hundred cubic feet for natural gas, $1.06/gal for fuel oil, and $.90/gal for liquefied petroleum gas [2]). Contributing greatly to this expense is excessive heat loss or cold-air entry into the house through cracks, walls, ceilings, floors, foundations, and windows. Figure 2-1 shows typical areas of energy loss for a conventional home.

Traditionally, change in the home-building field has been slow in the United States. Upgrading the shell has been modest in the average new American home. As recently as 1983, nearly 50% of all U.S. homes had walls containing R-11 insulation or less, 45% had R-13– or R-14–insulated walls, and only 7% had R-19 insulation or better. Of new U.S. homes, 38% had R-19 or less insulation in the ceiling, and 38% were built with single-glazed windows. Insulation features accounted for about 3% of the total cost of a house, about the same as for paint or roofing materials.

Studies being done by the national laboratories in the 1980s demonstrate the promise of new energy-conserving designs. The space-conditioning needs of these new designs, compared with those of the average home in 1983, were cut in half. With some reasonable additional effort, these savings could be increased by another 25% [3].

Because roughly five times more energy is used to heat than to cool a home—40.4% compared with 7.7% in 1983—this chapter principally deals with energy-conserving concepts in regions that require heating the home. However, some features that specifically apply to cooling designs are also included. The chapter discusses energy-conserving measures in new construction and in retrofits to existing homes and includes a section on factory-built buildings.

Residential Energy Consumption Survey: Consumption and Expenditures, April 1984 through March 1985; Part 1: National Data. (4 March 1987). DOE/EIA-0321/1(84). Washington, DC: U.S. Department of Energy; 189 pp. Available NTIS: Order No. DE87006842.

Presents data collected in the 1984 Residential Energy Consumption Survey (RECS) conducted by the Energy Information Administration (EIA). The 1984 RECS was the sixth national survey of U.S. households and their energy suppliers. The purpose of these surveys is to provide baseline information on how households use energy. Households in all types of housing units—single-family homes (including townhouses), apartments, and mobile homes—were chosen to participate. The report presents data on the U.S. consumption and expenditures for residential use of major fuels—natural gas, electricity, fuel oil, kerosene, and liquefied petroleum gas—from April 1984 through March 1985. The information in this report should be of use to public and private planners, housing construction companies, energy suppliers, and manufacturers and suppliers of home appliances. The sections describing RECS findings and the detailed statistics can also provide officials, businesses, and consumers with an overview of current patterns in U.S. home energy use.

The Influence of Sweden on Energy-Efficient Housing

In terms of improving the energy efficiency of building envelopes, the buildings industry in the United States would do well to follow the example set by Sweden. Sweden is the acknowledged international leader in designing and building energy-efficient housing; low energy use is featured in virtually all its new homes [4]. The level of care given to the thermal envelope of the average Swedish home would surprise most buyers and builders in the United States. Standard practice often includes R-33 wall insulation and R-43 ceiling insulation, with insulation accounting for about 9% to 12% of the total cost [5,6]. Special framing and insulation techniques help to reduce heat loss. Windows in Sweden are rated between R-3 and R-5. Tight construction is required by code in

Nisson, J. D. Ned, and Dutt, Gautam. (1985). *The Superinsulated Home Book.* New York: John Wiley & Sons; 316 pp.

Describes the design and construction of superinsulated homes. Superinsulated houses use airtight construction, controlled ventilation, and passive solar design elements to greatly improve their energy efficiency. The book includes scientifically accurate explanations and formulas for researchers and students as well as simple descriptions and explanations for laypersons and homeowners. Part 1, Principles, includes introductory material; history; and chapters on the fundamentals of insulation and airtightness, proper air quality, and ventilation. Part 2, Practice, presents details of

Sweden, and all new homes have some type of controlled ventilation system to supply fresh air.

Because of these envelope features, the Swedes typically use half as much energy as Americans for space heating, even though they actually set their thermostats higher. Their latest "optimized home" designs include insulation levels that are even higher. Most builders in the United States call this type of construction *superinsulation.*

The first so-called superinsulated houses were built in North America in the late 1970s. Builders of these homes paid a great deal of attention to the thermal shell during design and construction. The Saskatchewan Conservation house was built in 1977 with R-44 walls, an R-60 ceiling, virtually airtight construction, and a ventilation system to provide fresh air. Despite a severely cold climate (12,000 heating degree days [HDDs]), the above–average-sized house required only $35/year to heat. In 1979, builder Eugene Leger constructed a more modestly insulated home in eastern Massachusetts that cost $40/year to heat.

Despite the exceptional performance of homes such as these, the total number of superinsulated homes built in the United States is estimated to be only 20,000 to 40,000 [7]. Measured data compiled on over 350 new "low-energy" U.S. homes by Lawrence Berkeley Laboratory's (LBL) Buildings Energy Data Group for the Buildings Energy-Use Compilation and Analysis (BECA-A) data base showed that as a whole these homes require only 30% to 50% of the heating energy of homes built according to current practice. LBL also maintains a similar data base of 50,000 retrofit examples (BECA-B) [8].

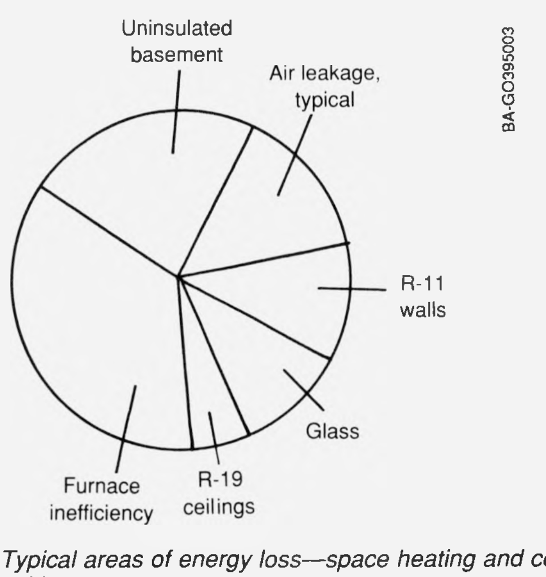


Figure 2-1. Typical areas of energy loss—space heating and cooling—for a conventional home

design and construction for walls, foundations, roofs, windows, and air-vapor barriers as well as discussions of ventilation systems, heating systems, appliances, and methods for evaluating them. The appendixes provide the following information: data on insulation materials; R-values of common building materials; useful weather data for selected U.S. and Canadian cities; lists of products and manufacturers; information resources; and SI units, conversion factors, and energy content of fuel.

Blue Book of Major Home-Builders: Major Research Report on Who's Who in Housing. (1985). Crofton, MD: LSI Systems, Inc.; 397 pp.

Contains information on 2598 building firms. The individual reports include company name, address, telephone number, names of key personnel, gross revenues, number and type of housing units produced for the last four years and planned for 1985, and the extent of nonresidential production. In addition, data are usually shown on the firm's involvement in property management, residential repair and remodeling, other related business activities, operation areas, prices and rents, construction methods, money, and land requirements for the coming year.

Schipper, Lee, and Meyers, Stephen. (1985). *Coming in from the Cold: Energy-Wise Housing in Sweden.* Cabin John, MD: Seven Locks Press; 85 pp.

Discusses the spectacular success of the Swedish housing system in providing a well-built, energy-efficient home for the average Swede. The main features of the total housing system are described. The system incorporates both advanced building technology and a complex set of policy measures—building codes, housing finance programs, research and information programs, and a tax law. The intent is to show how Swedish technology and policy dovetail to encourage world-class new houses and energy-saving improvements in existing buildings. Although many of the observations apply to all kinds of housing, the primary focus is on single-family houses, which today make up nearly two-thirds of all new residential construction.

Cairns, Elton J., and Rosenfeld, Arthur H. (July 1986). *Applied Science Division Annual Report: Energy Efficient Buildings Program, FY 1985.* LBL-20203. Berkeley, CA: Lawrence Berkeley Laboratory; 121 pp. Available NTIS: Order No. DE87000895.

Details the Energy Efficient Buildings Program at Lawrence Berkeley Laboratory (LBL), which conducts theoretical and experimental research on various aspects of building technology that will permit gains in energy efficiency without decreasing occupant comfort or adversely affecting indoor air quality. To accomplish this goal, LBL has developed six major research groups: Energy Performance of Buildings Group, Building Ventilation and Indoor Air Quality Group, Building Energy Simulation Group, Windows and Daylighting Group, Lighting Systems Group, and Buildings Energy Data Group. A chapter is devoted to each group. After summarizing the scope and objectives of the particular group, the chapter details its activities and accomplishments. The document concludes with a list of publications for the Energy Efficient Buildings Program covering the years 1982–1985.

Orientation—A First Step

For builders of new homes, the proper orientation of a home is a first step toward energy efficiency. In the past, solar access has not been a major concern to subdivision planners. Usually, the site plan reflects economics, aesthetics, and drainage but not the path of the sun. A subdivision that offers more solar access does not require sacrifice or increased costs. In fact, land planning for maximum solar access and acceptable land use has worked repeatedly throughout the country, so much so that solar easements are becoming as commonplace as utility easements.

In typical production housing, most of the windows face either the street or the backyard, regardless of the home's orientation to the sun. With only modest relocation of the windows, these homes could collect more solar energy during the winter. Homes with south- and north-facing windows are protected from the summer sun, which is most intense on east and west walls.

When a house faces within 20 deg of the south, the solar gain through an average number of windows (3% to 4% of floor area) can reduce the heating load in an energy-efficient home by 10% to 15% (Figure 2-2). By orienting roughly one-half a home's windows (5% to 6% of floor area) toward the south, a builder can reduce the heating load by as much as 15% to 25%. These savings can be achieved at virtually no extra cost for the building shell. No special interior masonry or other heat-storage materials are required.

Wintertime solar savings are usually associated with sunny southwestern cities, from Denver, Colorado, to Sacramento, California. Yet, proper orientation tends to be effective in most climates. From Phoenix, Arizona, to Miami, Florida, a house with most windows facing south and north has a significantly lower cooling load than one with windows facing east and west. In any climate, south-facing windows should have a properly sized overhang, awning, or other shading device (Figure 2-3).

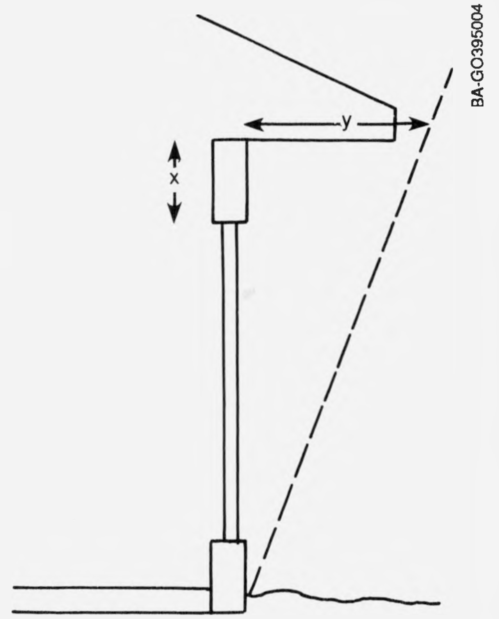


Figure 2-3. A well-designed overhang reflecting both "x" and "y," not just "y"

In most flat-lying areas, determining the east-to-west orientation of streets can be done at no increase in cost during the development design stage. Figure 2-4 shows the reorientation of streets in one small development based on a Nevada builder's existing subdivision. In this case, the site plan to allow for solar access actually increased the number of building sites by one. The second plan also allowed for 75% of the sites to have adequate solar orientation, an increase from 21% in the original plan.

Figure 2-2. An example of a home with equivalent of 6% of its floor area in south-facing glass. (Photograph by Steve Andrews)

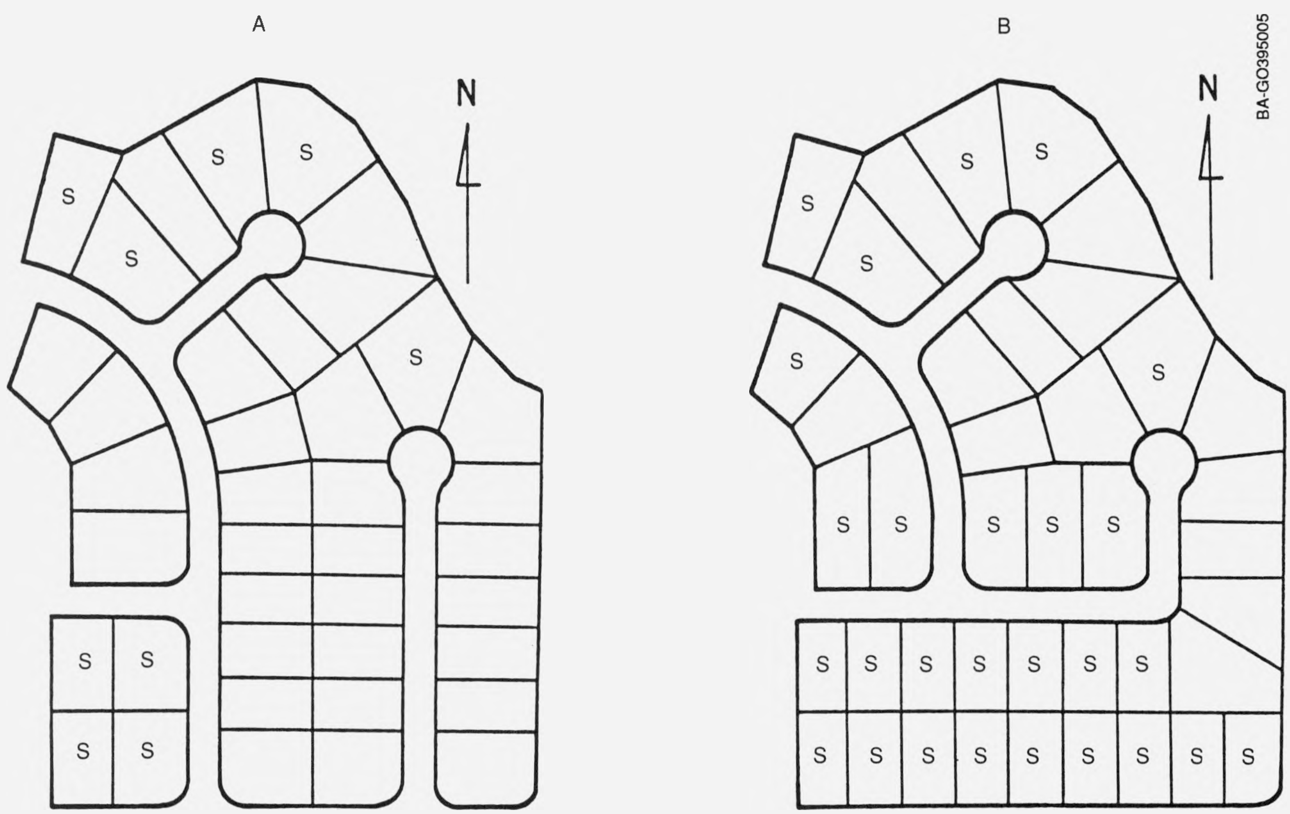
The Value of Retrofitting

Although the best time to take measures to curb energy costs is during the construction of new homes, the value of retrofitting existing homes should not be overlooked. According to data collected by the Energy Information Administration during the decade following the oil embargo of the 1970s, energy use in the average U.S. home was trimmed by nearly one-fourth. We can increase these savings through continued improvement of envelope features in existing buildings. By the year 2010, approximately two-thirds of the residences in this country will have been built before 1985 and without the benefit of advanced conservation techniques. Obviously, much opportunity exists for improvement through proper retrofitting techniques.

After more than a decade of retrofitting existing homes, results indicate that 75% to 80% of all retrofitting has been cost effective. Unfortunately, the data do not specify exactly how much energy can be saved from each of the many processes available. An analysis of 45,000 homes that were retrofit in the 1980s shows that the average package of energy upgrades cost about $1350. Some of the more popular retrofit applications included adding more insulation in the attic, walls, and floors; adding storm doors and storm windows; caulking and weatherstripping; and improving heating systems. Packages that included improvements to both a building's shell and the heating system appeared to be more cost-effective than a shell retrofit only.

Goldman, Charles A. (May 1985). "Measured Energy Savings from Residential Retrofits: Updated Results from the BECA-B Project." *Energy and Buildings* (8:2); pp. 137–155.

Summarizes measured data on energy savings from conservation retrofits in existing residential buildings. The data are organized into four general categories: utility-sponsored conservation programs, low-income weatherization programs, research studies, and multifamily buildings. Building performance was completed on approximately 115 retrofit projects. The sample size for each project varied widely, ranging from individual buildings to 33,000 homes. Retrofits to the building shell—principally, insulation of exterior surfaces, window treatments, and infiltration-reduction measures—were the most popular, although data on various heating system retrofits are now available. The average retrofit investment per unit in multifamily buildings was approximately $695, far lower than the average of $1350 spent in single-family residences. The median annual space heat savings in the four categories ranged from 15 to 38 gigajoules. The savings achieved were typically 20% to 30% of preretrofit space-heating energy use, although large variations were observed in both energy savings and cost per unit of energy saved. Even given the wide range in



Nine of 39 lots face within 30 deg of south (either the front or rear exposure)

Twenty-seven of 40 lots face within 30 deg of south (either the front or rear exposure)

Figure 2-4. Subdivision layout before (A) and after (B) improving lot orientation

Several utilities and government agencies sponsored retrofit programs during the late 1970s and early 1980s. Reduction in energy consumption for space heating averaged between 20% and 30%. A substantial difference existed in the reported energy savings achieved at any given investment level. Savings varied by a factor of four for an investment of $2500. Retrofits that cost more than $2500 per house were usually not cost effective [9].

Generally, though, actual savings have not matched the savings predicted by engineering estimates; these estimates can also also be wrong. Measured energy savings in utility-sponsored programs fell short of predictions in five of eight projects examined by LBL researchers. In other research and demonstration programs, however, savings have occasionally exceeded predictions. Lifestyle variables can have a major impact on the results of any conservation upgrade [10].

Today's stabilized energy prices have reduced the sense of urgency to increase insulation, or "tighten," older buildings. A key concern now is the resale value of the house. Do structural energy-conserving retrofits add value to a home being resold, or must they be justified solely on the basis of energy savings? Generally, realtors tend to point out that a home has storm windows or attic insulation, although, clearly, energy efficiency is only one feature of a good house. Few realtors or lenders are adept at helping a buyer compare one home's annual heating bills to another or understand the value of other less visible conservation measures. Currently, the data are insufficient to predict the resale value of energy-conserving retrofits.

Questions about the cost-effectiveness of some shell retrofits remain to be answered. Among the main concerns is the discrepancy between predicted and actual savings. How regional differences affect this discrepancy is uncertain. The region about which most questions remain is the hot and humid portion of the U.S. sunbelt.

Despite uncertainties, proper insulating and weatherizing retrofits still make sense over the long term. The potential exists to save as much as 40% of space-heating energy through comprehensive shell retrofits. Proper design and relatively new approaches to installation quality control can help make envelope retrofits live up to their intended performance.

savings, the data showed that most retrofit projects are cost effective. Approximately 75% to 80% of the retrofit projects had costs of conserved energy below their respective space-heating fuel or electricity prices.

Goldman, Charles A. (July 1985). *Measured Results of Energy Conservation Retrofits in Residential Buildings.* LBL-20950. Berkeley, CA: Lawrence Berkeley Laboratory; 25 pp. Available NTIS: Order No. DE86009394.

Summarizes measured data on energy savings from conservation retrofits in existing residential buildings. Retrofits to the building shell, principally insulation of exterior surfaces, window treatments, and infiltration-reduction measures, are the most popular, although data on various heating system retrofits are now available. The average retrofit investment per unit in multifamily buildings was approximately $700, far lower than the average of $1350 spent in single-family residences. Savings were typically 20% to 30% of preretrofit space-heating energy use, although large variations are observed in both energy savings and cost per unit of energy saved. Retrofit strategies that were particularly cost effective are identified based on measured energy-use data. Predicted versus actual savings are also compared for groups of homes in 24 retrofit projects.

Envelope Design Features for Residences

Insulating Foundations

Of all the design features, foundations have received the least attention with regard to energy efficiency. They can be a major drain on energy use and cause discomfort in the winter months. The large heat loss from this source can be reduced in new homes in several ways [11]. The common approach relies on either rigid foam insulation placed outside the foundation or batt insulation applied on the interior.

The majority of existing homes do not have insulated foundations. The two key concerns when retrofitting foundation insulation are cost-effectiveness and appropriate location for installation. Unless a homeowner can do the job or have it done for free, the excavation required for adding insulation on the outside is prohibitively expensive. Moreover, if patios, walks, porches, or driveways block access to the foundation, then insulating the interior is the only choice. Most of the items discussed here cover interior options.

Christian, Jeff. (June 1987). "Insulation Levels for Foundations." *Progressive Builder* (2:6); pp. 11–18.

Is a builder's guide to R-values for basements, crawlspaces, and slabs. The graphs show optimum R-values for concrete basement walls, slabs on grade, crawlspaces, and floors over unheated spaces. A methods and assumptions section describes the performance model and cost-estimating procedures used. A mock interview answers common questions asked about optimum foundation insulation levels.

Basements

In 1983, 32% of all new homes were built with full or partial basements. The trend now appears to be away from homes with basements, which held 42% of the housing market in 1979. According to researchers at Oak Ridge National Laboratory (ORNL), the economic benefit from insulating basements is based more on heating season requirements than cooling season. In areas with more than 3000 HDDs, the amount of heat saved by having basement insulation in the heating season is 8 to 15 times greater than the disadvantages incurred by having insulation in the cooling season.

More choices are available for insulating basements than slabs. The two most common are exterior foam and interior batt. Other systems used by energy-conscious builders include treated wood foundations and pre-formed foam products.

When selecting exterior insulation, builders assess three issues: climate, use, and utility costs. Local climate and the intended use of the basement help to determine the thickness of the insulation and how far below grade it should extend. In a climate similar to that of Chicago, Illinois, or Denver, Colorado, 2 in. of rigid foam insulation (approximately R-10) extending to at least the frost line are recommended. For a heated basement, the insulation should cover the full height of the basement wall (Figure 2-5).

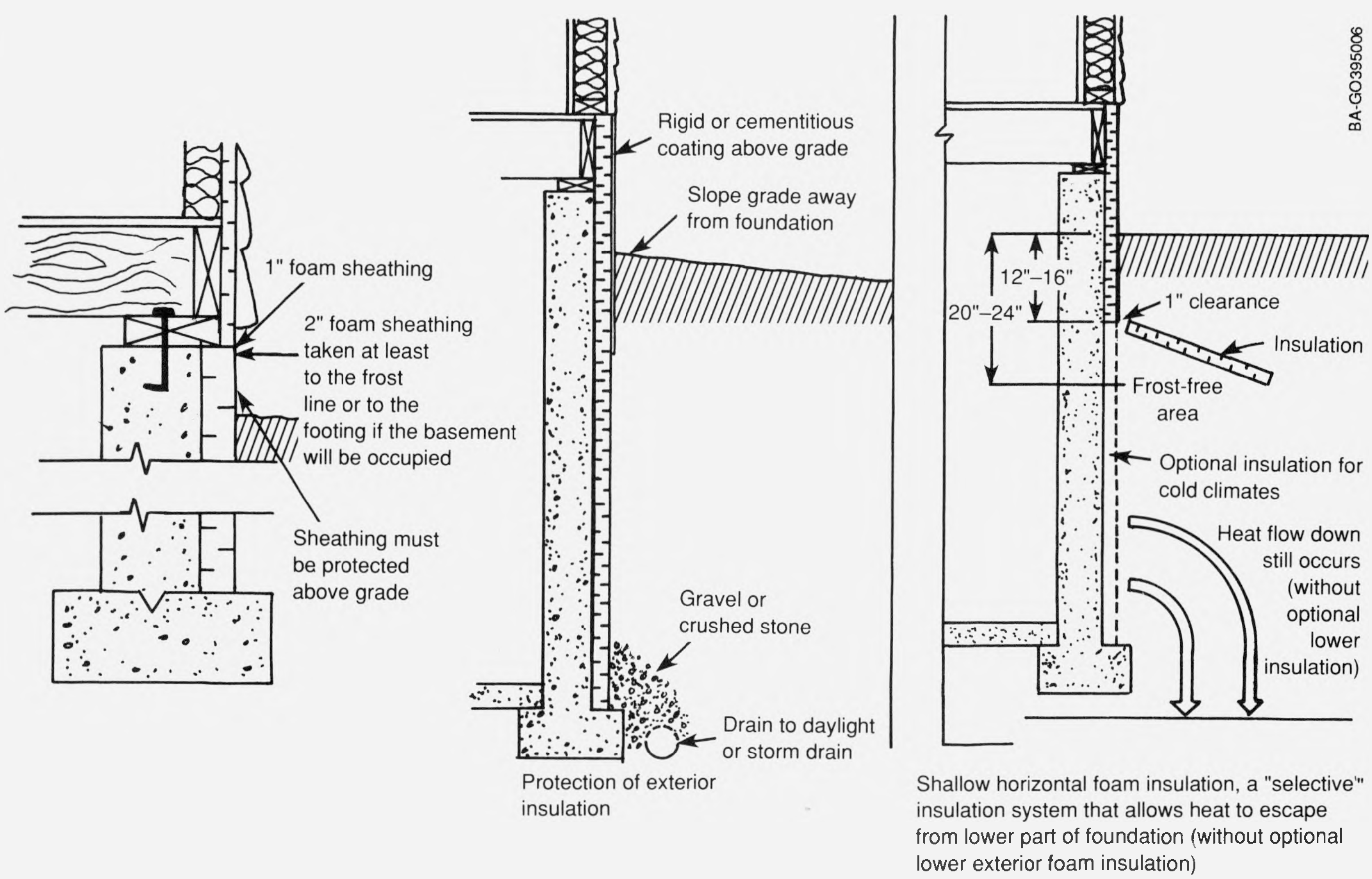


Figure 2-5. Protection of exterior foundation insulation. (Source: Adapted from Nisson, J. D. Ned, and Gautum Dutt, 1985, *The Superinsulated Home Book,* New York: Wiley)

If it extends above grade, exterior insulation must be protected from the sun. Coatings vary from troweled-on stuccolike products to rigid sheet material such as treated plywood or fiberglass skirting. Exterior insulation generally provides slightly better performance (for a particular R-value) and better foundation protection against freezing or expansive soil problems than interior insulation.

If, however, a particularly cold local climate requires more than the recommended R-10, then interior insulation is usually more cost effective. In any case, a basement should be insulated on the inside whenever a plan calls for a finished, heated basement.

With a block or poured concrete wall, the most common way to insulate the inside is to build a frame and install batt insulation (Figure 2-6). If more than R-13 is desired, then the frame can simply be held away from the foundation to accommodate a larger-sized batt. Some builders use

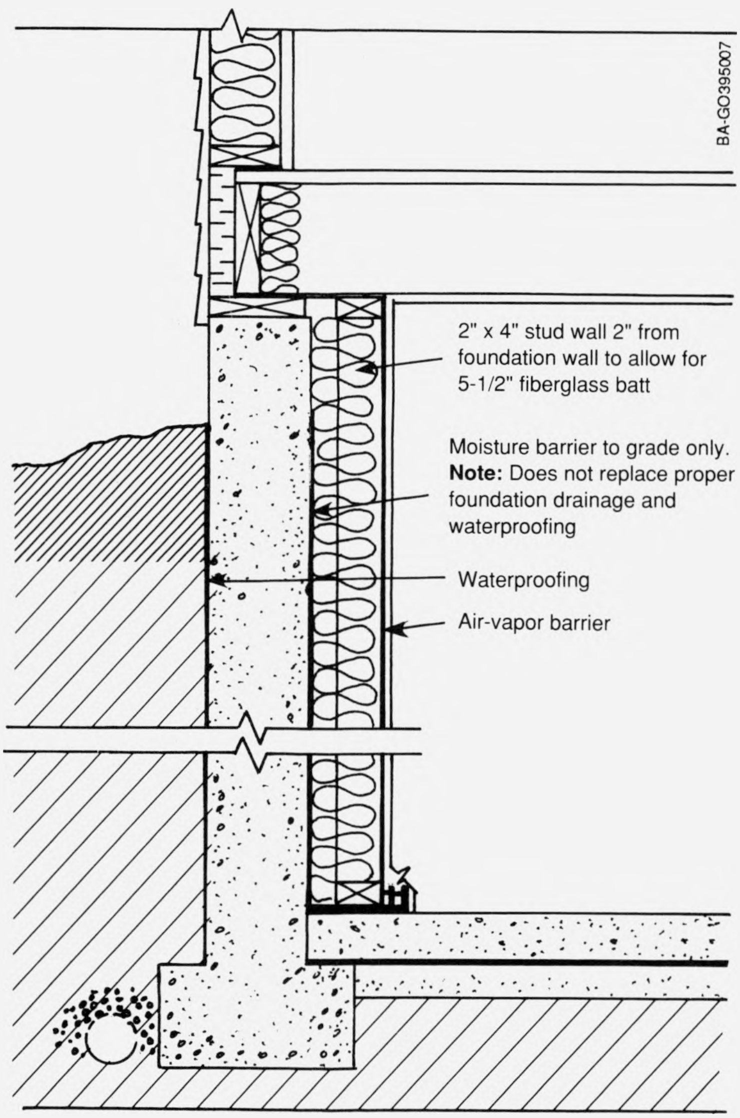


Figure 2-6. Interior foundation insulation showing concrete basement wall with 2 x 4 stud wall set off from foundation and insulated with fiberglass insulation; note the installation of air-vapor barrier and moisture barrier. (Source: Adapted from Nisson, J. D. Ned, and Gautum Dutt, 1985, *The Superinsulated Home Book*, New York: Wiley)

spray insulation rather than batting. Spray is usually economical only if it is being used in above-grade walls as well.

Any interior insulation scheme requires that the insulation cover the full height of a basement wall. The accumulation of moisture on the inside of the foundation is a potential problem for builders using the interior insulation approach. Condensation can run down the wall and cause the base of the wall to rot. To avoid this problem, a builder should waterproof the exterior of the wall and provide good drainage.

Treated wood foundations are a cost-effective option in a cold climate if basement bedrooms or other finished living spaces are part of the house plan. The wall foundation provides adequate space for various levels of batt insulation—from R-11 to R-30. Finishing requires no more than attaching drywall to the foundation framing members. Compared with a standard basement wall, this approach eliminates the redundancy of putting up a frame inside the structural wall (Figure 2-7).

The number of manufactured products available that provide both structural forms and insulation for foundations is increasing. One product made by several manufacturers uses preformed foam insulation that is placed on footings. The space inside the foam walls is then filled with concrete. This system can provide an insulation value as high as R-20 (Figure 2-8).

Existing Basements

Some different techniques are necessary for adding insulation to the basement of an existing home. If saving energy is the primary objective, then insulating between the main floor and the basement is the most cost-effective approach. If the goal is to heat the basement more efficiently, then wall insulation is required.

As with new construction, insulation that is added to a basement wall must extend down to the floor. Otherwise, heat in the lower uninsulated portion of the wall is conducted up and out the top. The least expensive technique is to attach horizontal nailers at the bottom, middle, and top of the wall and then staple 4-ft batts with a fire-rated foil facing. If the basement is to be finished, then insulating a new framed wall with batt material makes the most sense. Recommended insulation levels range from R-7 to R-19 [12].

The serious moisture problem inherent in many basements is actually compounded by adding an insulated frame inside the wall. Placing an air-barrier film made of spunbonded polyethylene, such as Tyvek, against the wall directs any water to the base of the wall. (This type of material is normally used on the exterior of framed walls. What makes this interior application useful is that it does not allow water that might penetrate a crack in the wall from soaking the frame, but it still allows water vapor that might penetrate the insulated wall from the interior to migrate up and out the interior wall.) As an added precaution, builders can use treated lumber for the bottom plates. An alternative strategy is to use rigid foam insulation, which does not degrade because of moisture. A few specially designed foam products are available that are either laminated to drywall or have imbedded 1-by-3-in. nailers for attaching drywall.

A high water table can cause a severe water problem in some areas. In this situation, excavating the exterior, correcting drainage problems, and applying waterproofing and rigid foam on the outside is probably the most effective approach. However, such an extensive project clearly has to be justified by more than just potential energy savings.

Figure 2-7. Permanent wood foundation that automatically includes space for insulation, eliminating some redundancy with conventional concrete foundations where interior insulation is desirable; walls for an average-sized home are placed in one morning. (Photograph by Steve Andrews)

Slabs

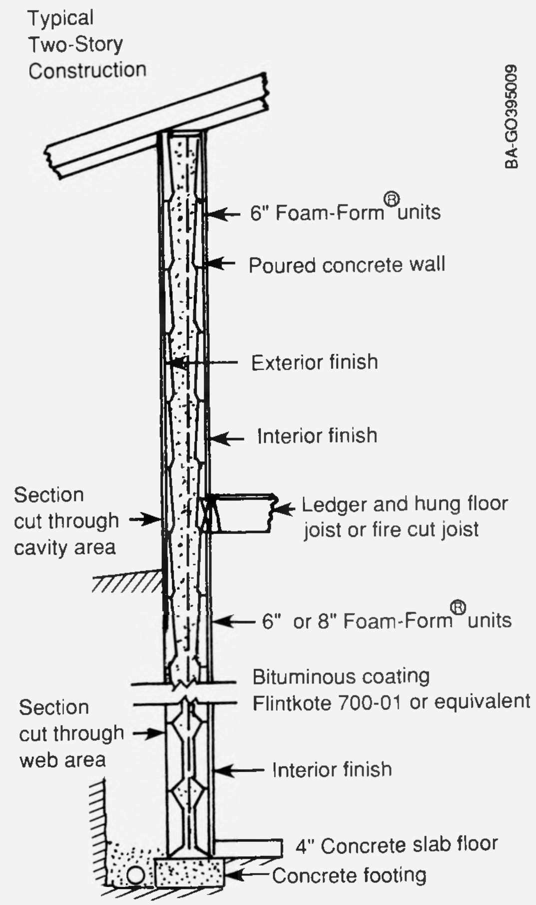
In 1983, fifty-six percent of new single-family homes were built on a slab. This percentage was up from 32% just five years earlier, reflecting the rapid growth of sunbelt housing starts where slab-on-grade foundations are common. Still, 70% of the builders currently do not insulate slabs or basements unless required to do so by code.

The need to insulate beneath and around the perimeter of slab floors depends primarily on local climate. Proximity to the area's water table and bedrock is also a factor. In a cold climate with a high water table or bedrock, builders insulate around the perimeter and beneath the slab. In a moderate climate, the most important insulation location is the edge of the slab—the highest area of heat loss.

Any slab that is heated directly by either hydronic or solar heat should have subslab insulation. A thin layer of subslab insulation is a good idea even if the floor is not heated, especially if it is not carpeted. In a climate such as in San Diego, California, with low heating and cooling requirements, perimeter insulation might not be justified. Surprisingly, research indicates that 1 in. of perimeter insulation would be useful in Miami; Phoenix; Dallas, Texas; and Houston, Texas.

The most common product used for perimeter or subslab insulation is extruded polystyrene (R-5.2/in.). In a cold climate, 2 to 3 in. of insulation around the perimeter is the standard, with 1 to 2 in. under all or a portion of the slab (Figure 2-9). Builders attach the foam vertically, either inside or outside the foundation wall, around the perimeter.

A



B

C

Figure 2-8. The Foam-Form® system: (A) Diagram of a Foam-Form block; (B) Cutting the foam-forming foundation; (C) Filling the block. (Source: Adapted from information supplied by Rocky Mountain Foam-Form.) (Photographs by Steve Andrews)

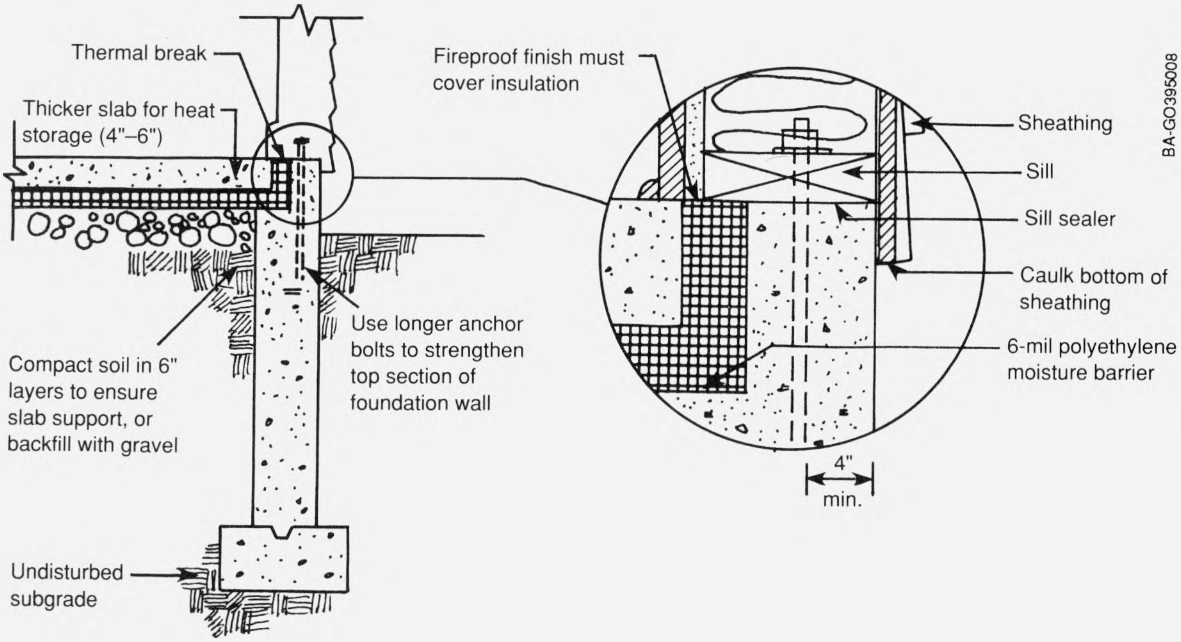


Figure 2-9. Insulation for slab. (Source: Adapted from Schwolsky, Rick, and James I. Williams, 1982, *The Builders Guide to Solar Construction*, New York: McGraw-Hill)

Exterior application is usually preferred (Figure 2-10). The interior approach involves intricate floor finishing details if more than a 1-in. thickness is applied.

As mentioned previously, when exterior insulation is used, it must be covered above grade to protect it from the damaging effects of ultraviolet solar radiation. Some building techniques, such as pouring the slab and footings at the same time, can only make use of the exterior placement method. In response to the need for less time-consuming construction techniques, at least one major foam insulation manufacturer markets a structural foam that insulates and forms the slab in a one-step process (Figure 2-11).

Existing Slabs

Adding insulation to the slab of an existing structure is obviously more difficult than incorporating insulation in the construction of a home. Contractor installations around existing slabs rarely make good economic sense (Figure 2-12). An exception is a cold-climate slab that contains heating ducts. If a homeowner is willing to dig down 1 to 2 ft, attaching rigid foam insulation around the perimeter of a slab can be cost effective. The recommended thickness, usually 1 to 2 in., varies with climate.

Crawlspaces

Selecting the most appropriate way to insulate a crawlspace is more complicated than any other flooring or foundation insulation detail. Issues such as freezing pipes, radon gas seepage, and moisture intrusion must be considered. (Radon gas and moisture problems are discussed further in Chapter 4.) A variety of materials and techniques are available, however, to help reduce heat loss in a crawlspace and deal with these other problems.

The typical solution for a vented or unheated crawlspace is to insulate the floor joists above the crawlspace with batt insulation (Figures 2-13, 2-14). Insulation values range from R-11 in a mild climate such as in Atlanta,

Lstiburek, Joseph. (December 1987). "How to Control Moisture in Houses." *Custom Builder* (2:12); pp. 9–14.

Discusses measures for controlling moisture in houses. Moisture is predominantly transported in building envelopes by vapor diffusion and bulk moisture leaking through the air. Each of these mechanisms can act independently. The article describes the following eight requirements for designing and constructing a more durable building envelope: (1) a mechanism to control bulk moisture, (2) a mechanism to control capillarity, (3) a ventilation system to control the air-pressure

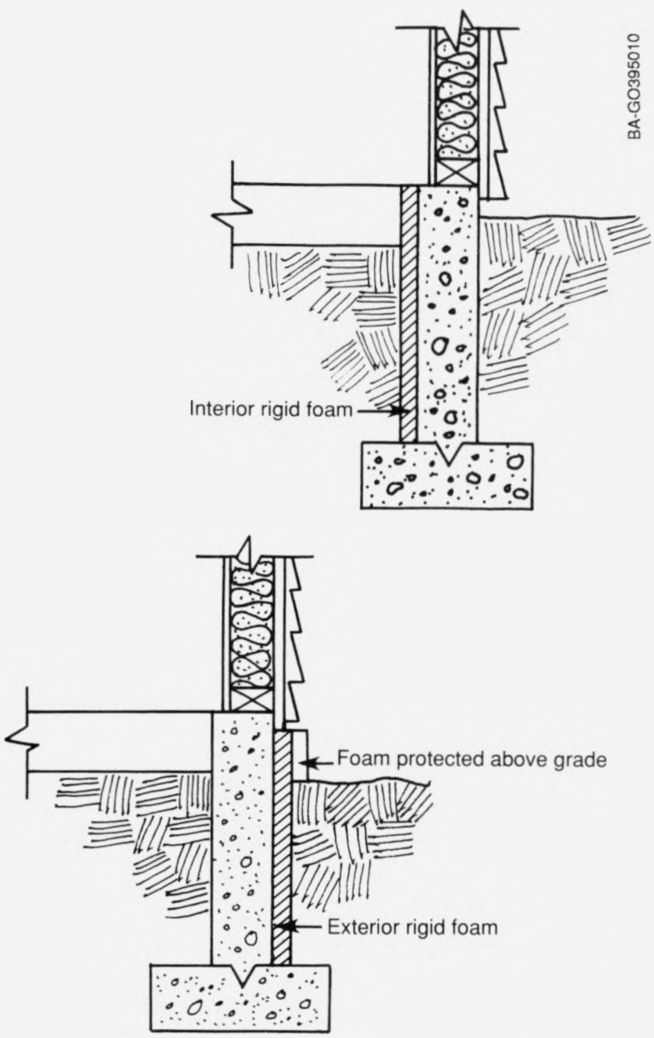


Figure 2-10. Options for perimeter insulation. (Source: Denver Home Builders Association Guidelines. Used with permission)

Georgia, to R-19 in Chicago and R-30 in Minneapolis, Minnesota [13]. Piping and ductwork must be carefully insulated in a cold climate.

Insulating a floor in a temperate humid climate poses special problems. During the air conditioning season, condensation from moist humid air can condense against the floor and cause dry rot. Recent experience suggests closing off a crawlspace in hot humid climates during the air conditioning season [14]. Another option is to staple continuous foil-faced, bubble-pack insulation (rather than batting) under the floor joists (Figure 2-15). When carefully sealed with aluminum tape, this product can provide a durable (though expensive) air barrier and vapor barrier to block out moisture [15]. Under the floor joists is also the best location for installing a radiant barrier (described later in this chapter) in a climate that requires heating because radiant heat is a major component of heat loss through the flooring [16].

Builders in cold climates often prefer an unvented crawlspace. By insulating side walls and rim joists, they include the crawlspace inside the thermal envelope. Interior batt insulation, R-11 to R-19, is cost effective for sidewall insulation. The batts should extend horizontally several feet from the foundation wall. Rigid foam is used when a builder prefers to insulate the outside of the crawlspace walls. Because rigid foam costs

differences across the building envelope and the moisture level in the indoor air, (4) an air barrier to limit infiltration and exfiltration, (5) a mechanism to control wind washing, (6) a mechanism to control air and moisture movement by convection, (7) a vapor diffusion retarder, and (8) a forgiving design in which more moisture can leave the building than enters it.

Moody, Thomas. (October 1985). "Foiling Crawlspace Heat Loss." *Solar Age* (10:10); pp. 59–62.

Discusses a new system to insulate crawlspaces. Tests showed the system solves the moisture problems, is more energy efficient, and costs less to install. The basic strategy involves three components: insulating the foundation walls rather than the floor, installing a poly ground cover, and getting rid of the foundation vents. The strategy leaves a small space for termite inspection if needed.

"Ventilation-induced Crawlspace Moisture Problems." (October 1987). *Energy Design Update* (6:10); pp. 8–10.

Discusses moisture problems in crawlspaces. Ventilating the crawlspace with warm, humid, outdoor air during the summer results in condensation on the cool surfaces inside the crawlspace, particularly in the floor insulation. Possible solutions to this problem are discussed. The use of unvented crawlspaces is emphasized; this discussion centers on how necessary crawlspace ventilation is, whether unvented crawlspaces solve the problem, and where the insulation should be installed.

more than batt material, builders generally limit the use of rigid foam to areas that require a value less than R-10.

The floor of an unvented crawlspace must be carefully covered with a moisture barrier. Typically, using 6-mil polyethylene dramatically reduces moisture wicking from the ground into the crawlspace, thus eliminating the need to ventilate a crawlspace (unless it contains a furnace;

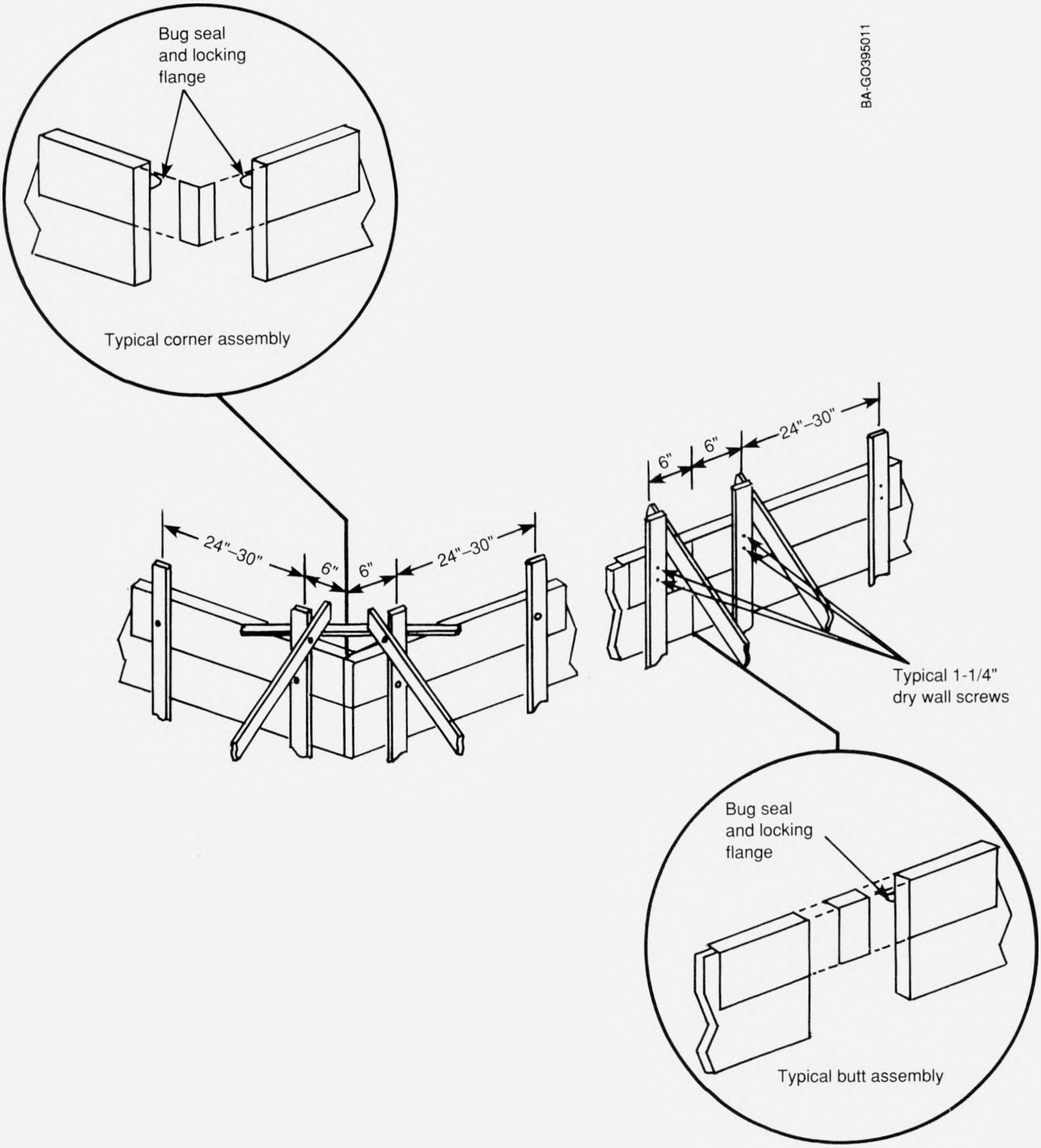


Figure 2-11. A structural form that insulates and forms the slab in a one-step process. (Source: Adapted from information supplied by Thermal Form™ Insulated Concrete Forms)

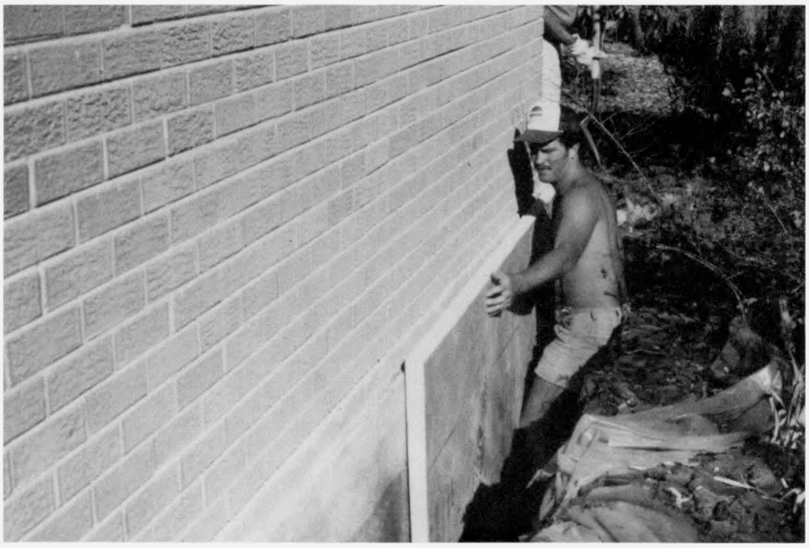


Figure 2-12. Retrofitting foam insulation outside foundation walls.
(Photograph by Steve Andrews)

see Chapter 3). If people occasionally need to enter the crawlspace to service a furnace or change a furnace filter, for example, then the area in use should have sand, foam sheeting, or roofing felt laid on the ground to prevent puncturing the moisture barrier. With sealed combustion units, it is possible to have a furnace in an unvented crawlspace because outside air is brought directly into the appliance (see Chapter 4).

Existing Crawlspaces

When adding insulation to an existing crawlspace, a builder must consider factors such as ease of access to foundation walls and subfloors; climate; prevalence of radon; ventilation in the crawlspace; and the presence or absence of heating, ventilating, and air conditioning (HVAC) equipment. If a combustion furnace is located in a vented crawlspace, the normal approach is to put batt insulation beneath the main floor. When radon gas is a potential threat, insulating the main floor is also the first choice (Figure 2-13). In some situations, however, insulated floors can lead to problems. In a cold climate, pipes and ducts should be insulated carefully to prevent freezing and heat loss. In a hot or humid climate, the air in a crawlspace can have a high rate of relative humidity. Air conditioning above the insulated wood floor can promote condensation between insulation and the floor; severe condensation can lead to structural rot. The solution then is to seal the crawlspace, at least during the air conditioning season.

Several distinct advantages exist to adding insulation when a crawlspace is not vented. It is easier and less costly to insulate foundation sidewalls and rim joists than to insulate beneath the floor. The concern about pipes freezing is eliminated. Furthermore, where outdoor humidity is high and air conditioning is required, an uninsulated floor above an unvented crawlspace is less susceptible to dry rot. In all cases, the ground in an unvented crawlspace should be covered with an effective vapor barrier.

Shallow Foundations

A fairly recent entry addressing the twin challenges of reducing construction costs and improving below-grade insulation is another Scandinavian import—shallow foundations. These foundations are particularly appropriate in areas that have high groundwater tables and freezing temperatures. In standard construction, it is recommended that the bottom of the

"Frost-Free Shallow Foundation Design Guidelines." (March 1988). *Energy Design Update* (7:3); pp. 4–10.

Presents principles and techniques of shallow foundation design as an alternative to conventional methods for protecting a foundation against frost heave. The design guidelines are based on

foundation footing be placed below the level of maximum frost penetration. Depending on the climate where the house is built, this distance could be as much as 7 ft. These recommendations, however, don't take into account that a heated building will be over this area and that its placement will affect the frost line.

Scandinavians and Canadians have discovered that enough heat is generated in a house to prevent frost under a shallow—12 to 28 in.—foundation if it is properly insulated. Such an approach would reduce construction costs by $500 to $2000 for most homes. Three types of insulation are used: subslab insulation of R-4.5 to R-10, depending on climate; foundation wall insulation of 1 5/8 to 4 in., depending on the climate and the height of the slab above grade; and horizontal ground insulation (2 by 20 in.) that extends away from the foundation wall by as much as 30 in. and is thicker at the corners. The largest current barrier to the wide use of shallow foundations is that none of the model building codes specifically allows their use; however, the National Association of Home Builders (NAHB) is promoting this approach [17].

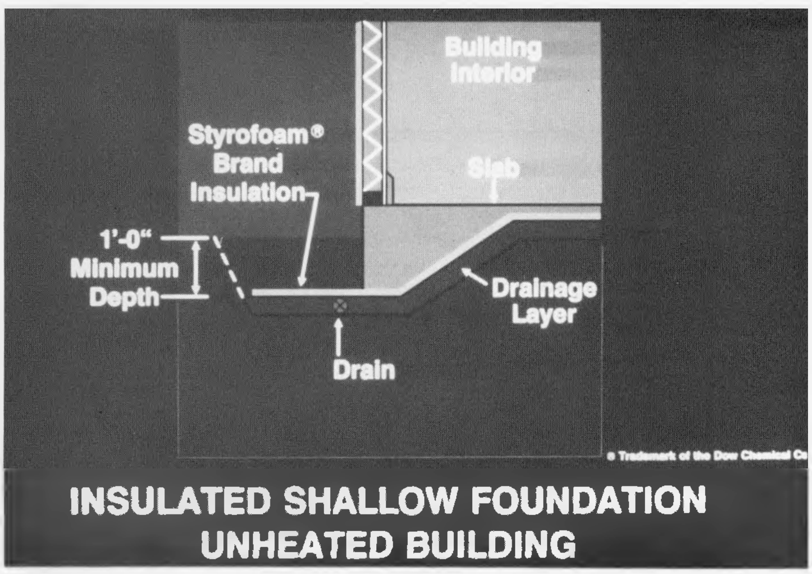


Figure 2-13. Insulation for vented or unheated crawlspace

Insulating Exterior Frame and Masonry Walls

Until about the 1970s, walls were typically hollow structures that supported the building and hid wiring and piping. Because they represent the greatest surface area in a home, walls are a major source of heat loss in a building's shell.

Frame Walls in New Construction

Contractors build exterior walls in various ways, ranging from double-stud construction to premanufactured foam panels. Most builders still frame and insulate their walls on site. The main reasons for the continued popularity of on-site framing are that materials are widely available, framing labor tends to favor this approach, and buyers and lenders are accustomed to the product. In addition, most builders believe that on-site framing is the least expensive way to build.

Energy-conscious builders generally use some variation of a 2-by-6-in. wall. Typically, they insulate with fiberglass and 1/2 to 1 in. of rigid foam insulation. Even standard 2-by-4-in. wall construction can be

Norwegian research and field experience and are derived partly from a National Association of Home Builders National Research Center booklet entitled *Frost-Protected Shallow Foundations for Houses and Other Heated Structures*. An alternative method for sizing shallow foundation insulation systems, developed by Eli Robinsky of the University of Toronto, is also presented.

Frost-Protected Shallow Foundations for Houses and Other Heated Structures: Design Details Developed by the Norwegian Building Research Institute. (1 January 1988). Upper Marlboro, MD: NAHB National Research Center; 43 pp. Available from NAHB National Research Center, 400 Prince Georges Center Boulevard, Upper Marlboro, MD.

Provides a translation of material produced and copyrighted by the Norwegian Building Research Institute in Oslo, Norway, on frost-protected, shallow foundations for heated buildings. It is the culmination of 35 years of research, experimentation, computer modeling and validation, and test house construction. The information has been fine tuned with empirical experience from the construction of more than a million frost-protected, shallow foundations. It is the result of a continual exchange of information among researchers from Finland, Sweden, Norway, and Canada.

Fisette, Paul. (November 1986). "Sprayed Insulation." *Progressive Builder* (11:10); pp. 23–27.

Discusses effective installation procedures for wet-spray cellulose. Its air-sealing and soundproofing qualities, as well as low installed cost, make wet-spray cellulose a desirable insulation option. However, more work needs to be done on standardizing ratings and application procedures. A sidebar in the article discusses using radiant barrier paint as a substitute for metallized foils and films hung in attics to reduce the downward flow of heat.

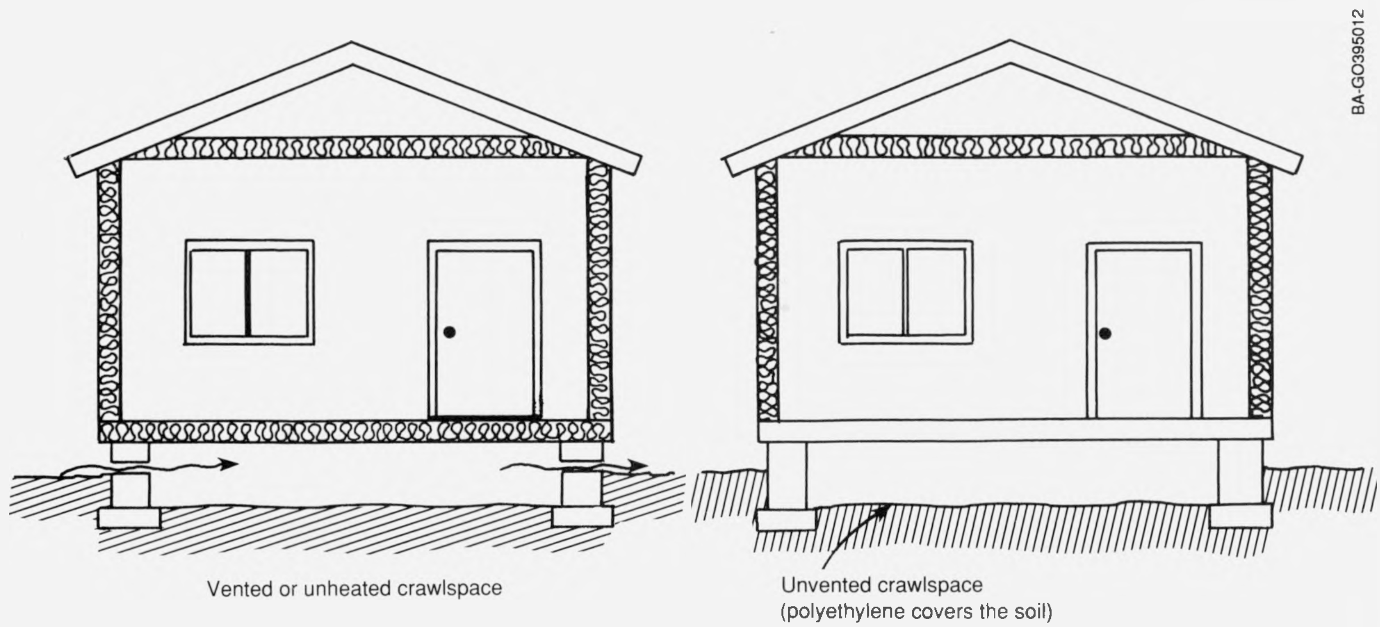


Figure 2-14. Schematic of vented or unheated crawlspace

upgraded to perform well. Combining R-13 batt with 5/8-in. rigid foam can provide an insulation level of R-17 that is cost effective in a moderate climate (Figure 2-16).

Appreciation is slowly growing for the potential benefits of loose-fill and sprayed insulation. A wall sprayed with wet cellulose costs more than a wall with batt insulation (Figure 2-17). However, a thermal scan with an infrared camera shows that wet-spray and blown-in insulation, when applied properly, can provide somewhat better coverage of wall areas than batt insulation (Figure 2-18). Field testing shows that properly applied dry blown-in material does not settle over time. No acknowledged standard currently exists, however, to indicate proper density [18,19].

One problem with any well-insulated wall is keeping heat from seeping out around the upgraded levels of insulation. Wood framing contributes the most to this problem. Framing usually reduces an R-11–insulated wall to less than R-9. To solve this problem, some small builders in cold climates use the double-stud wall system. Pioneered in Canada, this technique has been duplicated in several thousand homes in North America. The key advantages cited by the proponents of this method are increased levels of insulation, a decrease in heat loss through framing, and the protection of the polyethylene air barrier (Figure 2-19).

A variation of the double-stud wall, developed to provide the same advantages, is the strapped wall (Figure 2-20). A 2-by-4-in. or 2-by-6-in. wall is insulated to R-20 or R-25 and covered with polyethylene. Then, horizontal 2-by-2-in. furring strips are added to allow space for wiring and plumbing and for the installation of additional insulation without damaging the air-vapor retarder. The 2-by-4-in. or 2-by-6-in. walls described earlier adequately minimize heat loss in regions where insulation values higher than R-20 to R-25 are not necessary or cost effective.

An increasingly popular wall that shows great promise is the manufactured foam panel system. Preinsulated panels are installed as either the insulated skin for a post-and-beam skeleton or as a self-contained, loadbearing structure. Typically, the insulating skin panels come with drywall on one side and sheathing or finished siding on the other. The foam core (usually urethane) rates between R-24 and R-26 for a 4½-in. panel.

"Wet Spray Insulation for Houses." (September 1985). Energy Design Update (4:9); pp. 11–16.

Discusses wet-spray insulation, traditionally used only in commercial buildings, where it is commonly left exposed on ceilings and walls. However, it can also be used as cavity wall insulation in new residential construction. The article describes what wet-spray insulation is, its advantages for cavity walls, its disadvantages, and available products and manufacturers. The article concludes that although it has several advantages, the lack of consistent technical data and installation guidelines for wet-spray insulation products is a considerable drawback for their use in the residential market.

"Cellulose Insulation and Airtightness." (December 1986). Energy Design Update (5:12); pp. 4–7.

Presents evidence from research and case studies that cellulose fiber insulation suppresses air leakage to a much greater extent than other types of insulation. In fact, when analyzing the cost effectiveness of cellulose retroinsulation, researchers concluded one should probably factor in energy savings resulting from infiltration reduction. In new construction, cellulose has the advantage, common to most loose-fill–insulation materials, of completely filling cavities, avoiding gaps and spaces that can lead to convective degradation of thermal performance. However, it cannot be relied on to correct flaws in the house air barrier.

Andrews, Steve. (May 1986). "Selling Homeowners on Energy." Solar Age (11:5); pp. 28–30.

Presents an interview with Chicago builder Perry Bigelow about how he builds and markets houses with outstanding energy performance. The topics include his energy design strategies (including air-to-air heat exchangers, insulated wood foundations, heating system changes, and superinsulations) and marketing philosophy. A sidebar contains interviews with other builders who have successfully used incentives based on energy bills.

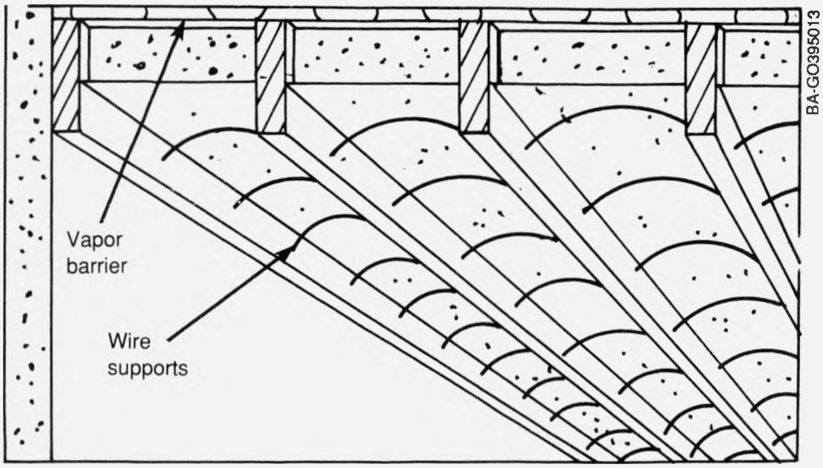


Figure 2-15. Reflective sheet insulating material for vented or unheated crawlspace. (Source: Adapted from information supplied by Public Service Company of Colorado)

One common type of structural foam panel comes with expanded polystyrene sandwiched between two layers of waferboard (Figures 2-21, 2-22). Once the walls are glued and nailed in place, any choice of exterior siding can be applied. Drywallers finish the interior in a standard manner. This procedure allows for consistent insulation values—usually R-15 for 2-by-4-in. walls to R-24 for 2-by-6-in. walls—with a minimum of gaps and thermal bridging across the wall. The procedure also lends itself to airtight construction.

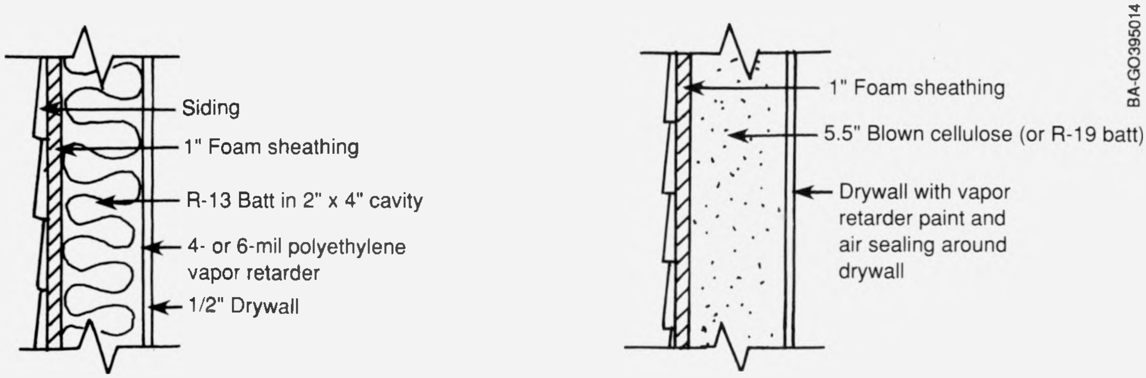
CASE STUDY

An example of energy efficiency with 2-by-6-in. construction is provided by Chicago builder Perry Bigelow, multiple winner of energy-efficient design awards. Bigelow's homes typically heat with natural gas for between $100 and $200 per year. Annual heating bills are guaranteed to be no more than $200 for the first three years.

Bigelow achieves a wall value of R-25 by backing 6-in. batts with 1-in. polyisocyanurate foam. Treated wood foundations are insulated with R-19 batt. By using optimized value engineering, a wall-framing approach that dramatically reduces the materials cost, Bigelow reports that his only extra cost is several hundred dollars for the foam sheathing (Figure 2-23) [20].

The high insulation levels justifiable at northern latitudes are of limited value in a climate characterized by cooling demands. In Miami, internal gain and solar radiation on and through the building shell are the biggest source of the July cooling load, not the conductive gain resulting from temperature differences between the indoors and the outside. Solar gain on unshaded east-facing and west-facing walls creates cooling problems. This load can be reduced by installing a properly designed radiant barrier in the walls.

A *radiant barrier* is a highly reflective foil that is bordered by at least a ½-in. airspace (Figure 2-24). Creating airspace in a wall is straightforward but adds to the cost. Builders attach siding to 1-by-3-in. vertical furring strips applied over the shiniest side of foil-faced sheathing. Installed in this way, a radiant barrier should significantly reduce the



R-20 wall for moderately cold climates (e.g., St. Louis) (2" x 4" construction)

R-28 wall for cold climates (e.g., Minneapolis) (2" x 6" construction)

Figure 2-16. Two examples of frame walls in energy-efficient construction

summertime gain through east-facing and west-facing exterior walls. Based on research conducted at the Florida Solar Energy Center (FSEC), wall radiant barriers should be cost effective in a climate with less than 1500 cooling degree days and more than 1500 HDDs. This range includes many homes from Miami to Los Angeles, California.

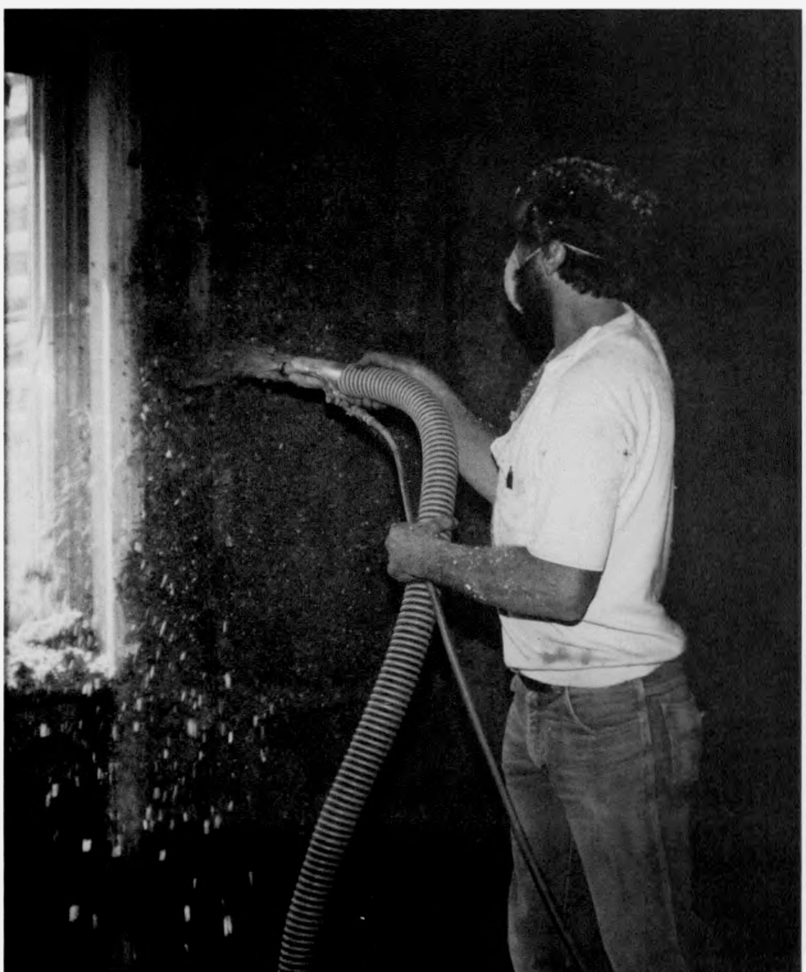


Figure 2-17. Sprayed cellulose insulation system used by Columbine Homes. (Photograph by Steve Andrews)

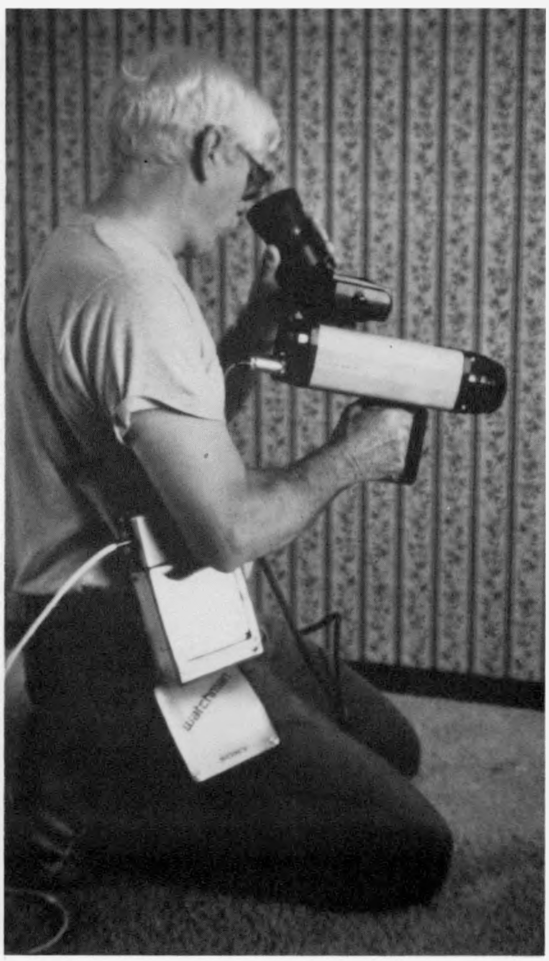


Figure 2-18. Infrared scanning device used to check for full filling of retrofit insulation. (Photograph by Steve Andrews)

Existing Frame Walls

Although insulating outside walls is a relatively expensive retrofit to a building's shell, properly installed wall insulation can save as much as 15% per year on heating bills.

The colder the climate and the higher the utility rates, the more cost effective wall insulation becomes. Blowing loose-fill insulation into the empty walls of a home in Maine or Minnesota makes good economic sense but only if the product is installed properly. A home in Los Angeles would not be a good candidate for an energy-saving retrofit.

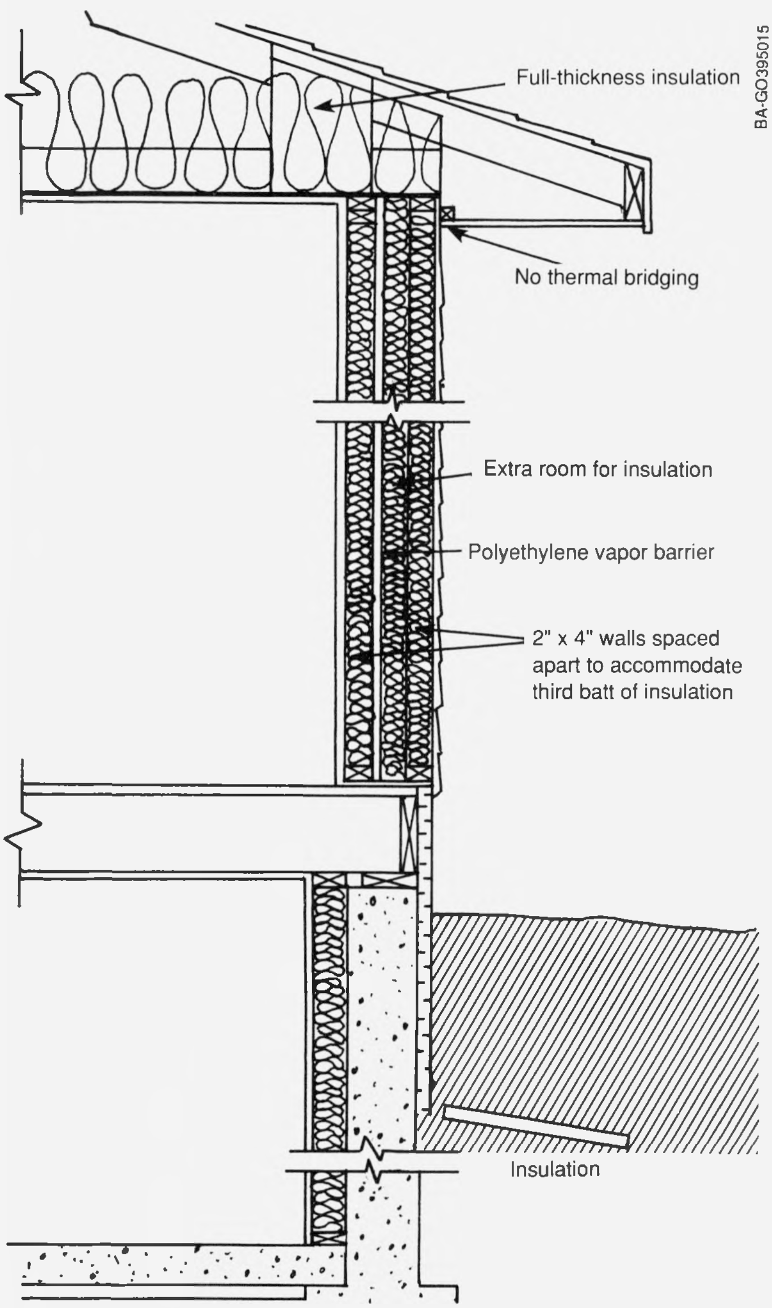


Figure 2-19. Double-wall construction. (Source: Adapted from Nisson, J. D. Ned, and Gautum Dutt, 1985, *The Superinsulated Home Book*, New York: Wiley)

Ward, Ronald J. (1983). *Thermographic Inspections and the Residential Conservation Service Program.* Providence, RI: Rhode Islanders Saving Energy; 4 pp. Available from Rhode Islanders Saving Energy (RISE), 280 Broadway, Providence, RI 02903.

Describes the results of thermographic inspections conducted by Rhode Islanders Saving Energy (RISE), a nonprofit corporation founded in 1977 to provide Rhode Island residents with a variety of energy-conservation services. Since January 1981, RISE has been performing energy audits in compliance with the U.S. Department of Energy Residential Conservation Service (RCS) Program. One aspect of the RCS program is the inspection of energy-conservation measures completed according to RCS installation guidelines. This paper describes both the use and results of thermographic inspections within the RISE program. The primary objective of these inspections has been to assure the quality of the building envelope after the completion of retrofit measures. Thermal anomalies have been detected that vary in size, location, and probable cause. Approximately 37% of all jobs performed through RISE in conjunction with the RCS program have required remedial work as a result of problems identified during the thermographic inspection. This percentage was much higher when infrared inspections were conducted on non-RCS retrofits. Statistics were planned that provide an interesting insight into the quality of retrofit work when performed in association with a constant inspection process.

Ward, Ron. (January-February 1986). "Using Infrared for Quality Control of Retrofits." *Energy Auditor and Retrofitter* (3:1); pp. 24–28.

Discusses the use of thermographic inspections by Rhode Islanders Saving Energy (RISE). They are used as a quality control tool to provide complete and proper insulation jobs and, in conjunction with the contractors, as an educational tool in an effort to reduce the occurrence of particular problems. This effort has resulted in higher-quality insulation jobs, and fewer problems are anticipated in the future.

"Retrofit Wall Insulation: Is There Really Quality in That Corner?" (September-October 1985). *Energy Auditor and Retrofitter*; pp. 6–10.

Examines the quality of retrofit wall insulation. Recent research sponsored by utility and state weatherization programs has shown that the performance and durability of certain wall insulation types are good when properly installed. Although mentioning foam insulation, the article focuses on the use of loose-fill insulation in walls. The study found that moisture damage and settling were not really problems for this type of insulation. However, voids resulting from improper installation were common. Several strategies for dealing with this problem are described, including the use of infrared thermography to inspect the installation and determine the performance of the insulation.

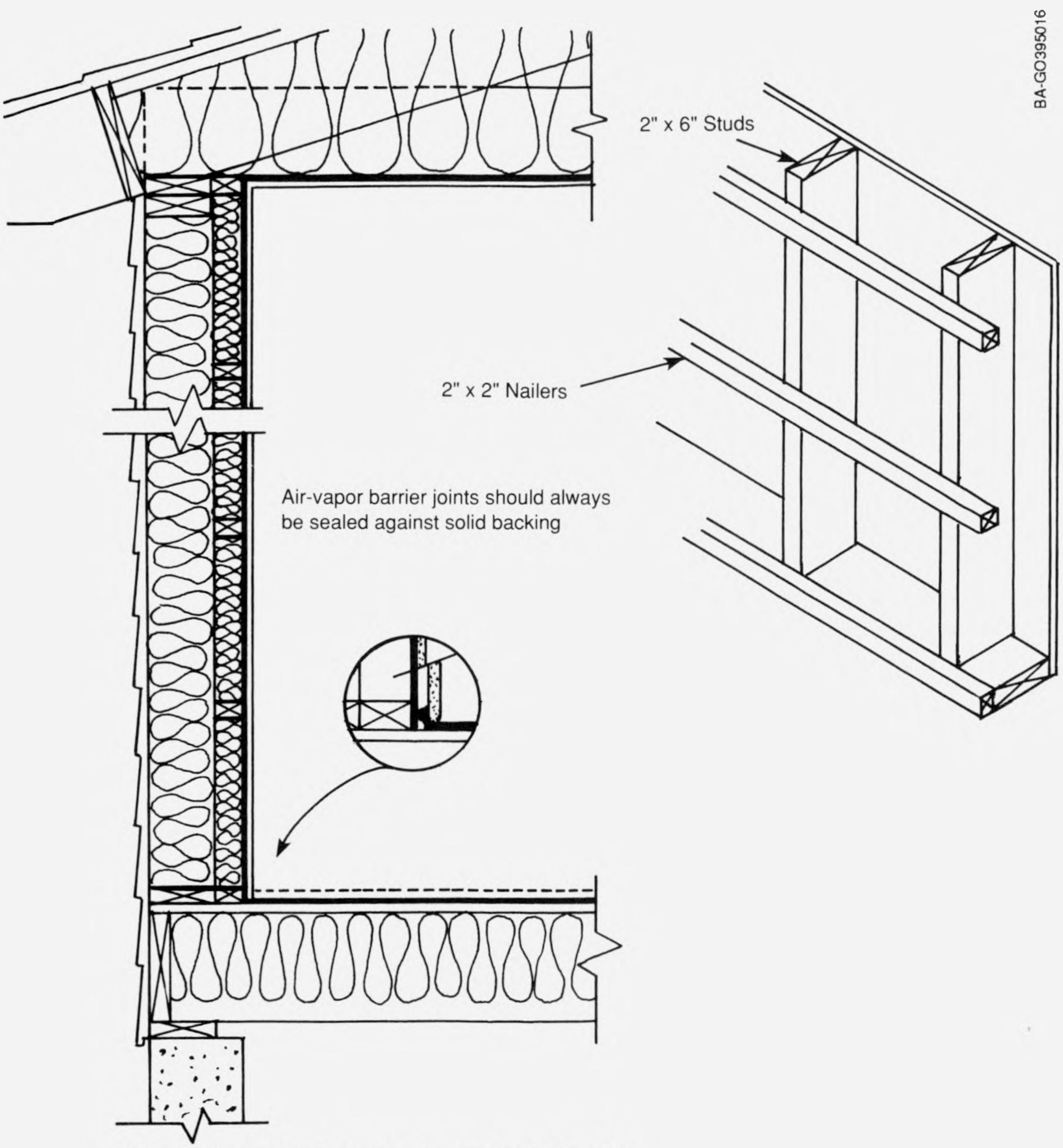


Figure 2-20. Strapped-wall construction. (Source: Adapted from Nisson, J. D. Ned, and Gautum Dutt, 1985, *The Superinsulated Home Book*, New York: Wiley)

A building's shape and style can determine whether retrofit insulation is necessary. The larger the wall area relative to the floor area, the more sense it makes to insulate the walls. Heat lost through an uninsulated two-story house will be proportionately greater than heat lost through walls in a ranch-style house with the same floor area. Another factor to consider, particularly if a house is occupied all day, is that a house with insulated exterior walls is more comfortable than a house with uninsulated walls and an equal or slightly lower thermostat setting. Filling the walls can also generally tighten a home and reduce drafts.

To insulate the cavities in an existing frame wall, most insulators drill holes and then blow them full of loose material. They use cellulose, rock wool, or

Tsongas, George A. (September 1985). *State-of-the-Art Review of Retrofitted Wall Insulation.* DOE/BP/30575-1. Portland, OR: Bonneville Power Administration; 88 pp. Available NTIS: Order No. DE86002562.

Reviews the state of the art of retrofitting wall insulation in residences and summarizes its status as an energy-conservation measure. The characteristics of the available insulating materials and approaches were summarized, including their thermal characteristics. The influence of a variety of factors on the thermal performance of wall insulation as well as on the overall building's energy use was assessed. Some of the factors considered include insulation density, mean temperature, and moisture

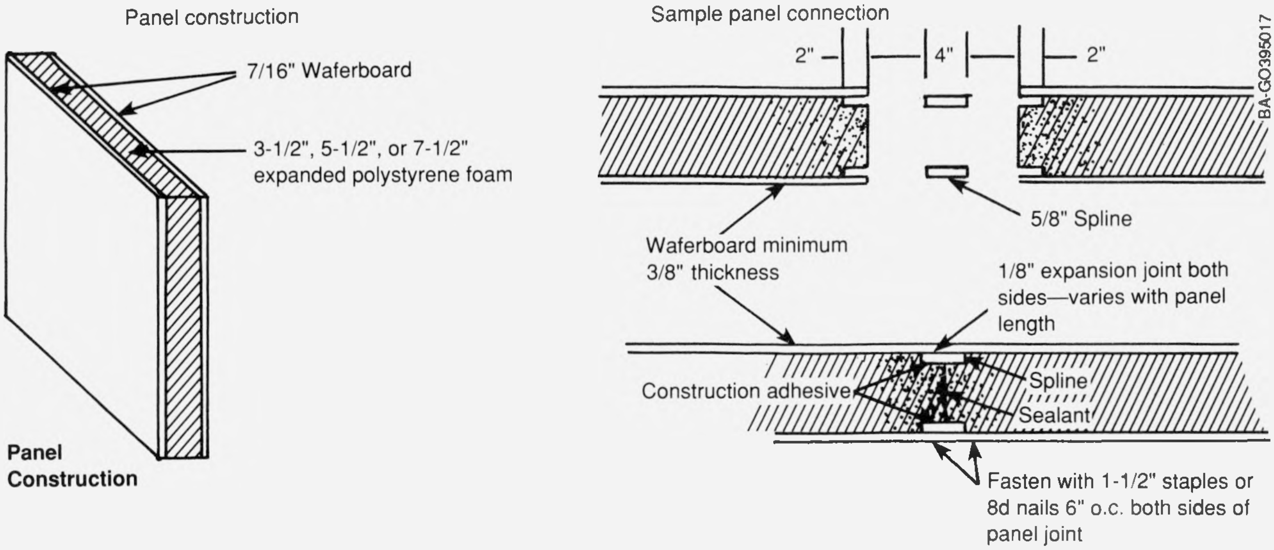


Figure 2-21. Sample of structurally self-supporting panel construction. (Source: Adapted from information supplied by Associated Foam Manufacturers)

fiberglass. With an insulating value of about R-12, cellulose is the most common product. Application techniques and installation costs are about \$.50 to \$1.50/ft^2, depending on the roof style and the exterior finish.

Typically, installers use one of three approaches: drilling holes through brick or wood siding, removing a course of wood or aluminum siding and drilling through sheathing, or drilling through top plates and filling cavities from the attic.

Moisture damage and insulation voids are two concerns with loose-fill wall retrofits. Studies conducted in the Pacific Northwest indicate that adding insulation to wall cavities does not increase the likelihood of moisture damage. Moisture levels did increase somewhat within the cellulose itself. Moisture damage found during the studies was mainly preexisting damage caused by rain, snow, or groundwater.

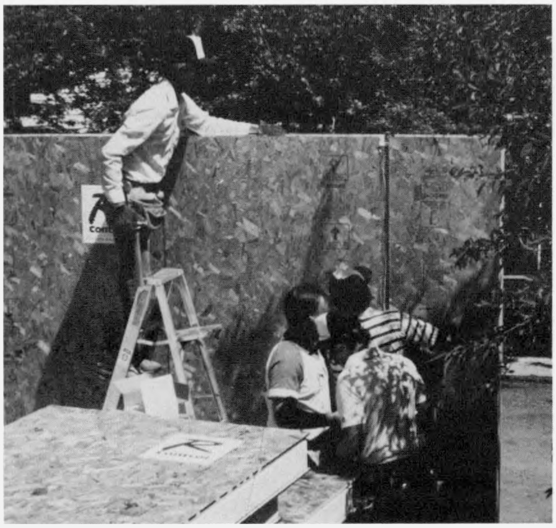


Figure 2-22. Foam-core panels (structural load bearing) being fit into place. (Photographs by Steve Andrews)

The second concern, voids left in wall insulation, can seriously reduce energy savings. Voids amounting to 10% of a wall area can lead to an estimated performance loss of as much as 40%. Most voids, above windows and at the top of wall cavities, are the result of incomplete filling rather than settling. Installers have developed several techniques to eliminate voids. One method is to drill two fill holes instead of one and then use a fill tube to reach all the way into the top and bottom corners of each cavity. When applied with the proper density, loose-fill insulation does not settle (Figure 2-25).

No way exists to ensure that proper coverage was achieved with blown-in insulation, although using an infrared camera can help. Much like a

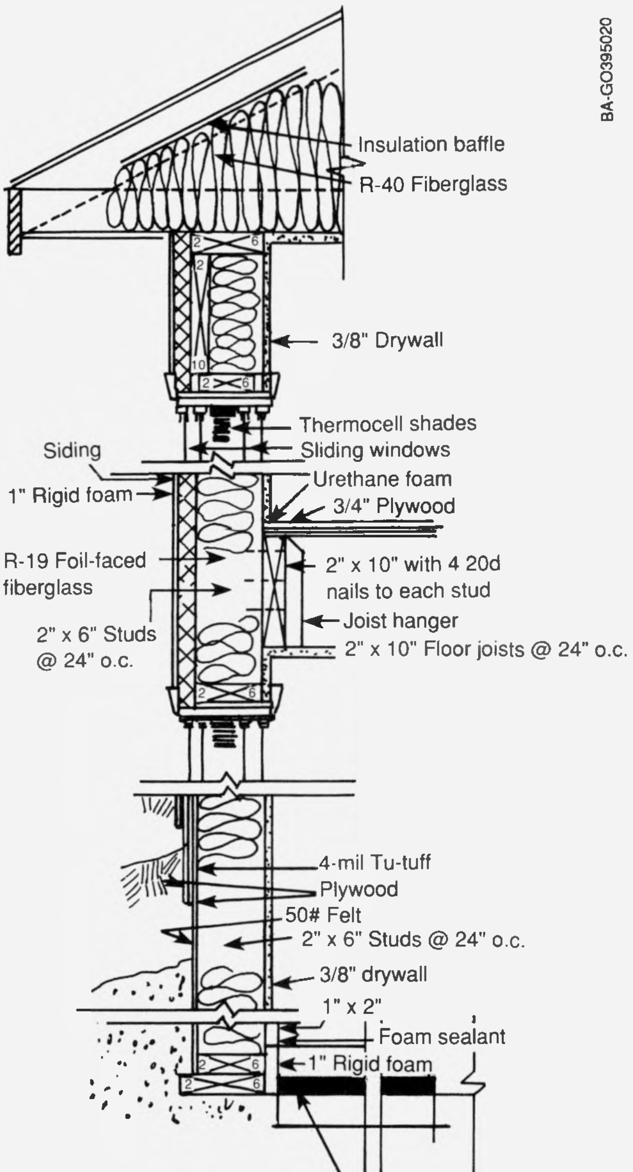


Figure 2-23. Continuous 2" x 6"s from footing to eave that make it easy to seal and insulate Bigelow's simple superinsulated wall; features to note: wood foundation, no headers on first floor, single 2" x 10" headers on upper floor, a hung bank-joist or ledger, and an airtight-drywall interior. (Source: Adapted from Andrews, Steven, 1986, "Selling Homeowners on Energy," *Solar Age* (11:5): 28–30)

content; setting and shrinkage; incomplete filling of wall cavities; air convection within the insulation; south-wall solar heating; as well as effects of added wall insulation on infiltration heat loss, use of lowered indoor temperatures, and decreased overall building energy use because of the reduction of the outdoor balance point temperature (i.e., length of the heating season). Numerous side effects that can result when retrofitting were also discussed, including moisture damage, fire hazards, corrosion, health hazards, and indoor air pollution. Other concerns were also addressed, such as quality control and consumer protection, including the need for infrared thermographic inspection programs and a possible derating of the R-value of insulations to account for the substantial influence of typical void areas. The fact that some insulation types seem preferable to others was noted. The potential market for retrofitting wall insulation was assessed, and the advisability of utility wall insulation retrofitting programs was discussed. Finally, recommendations for further study were presented.

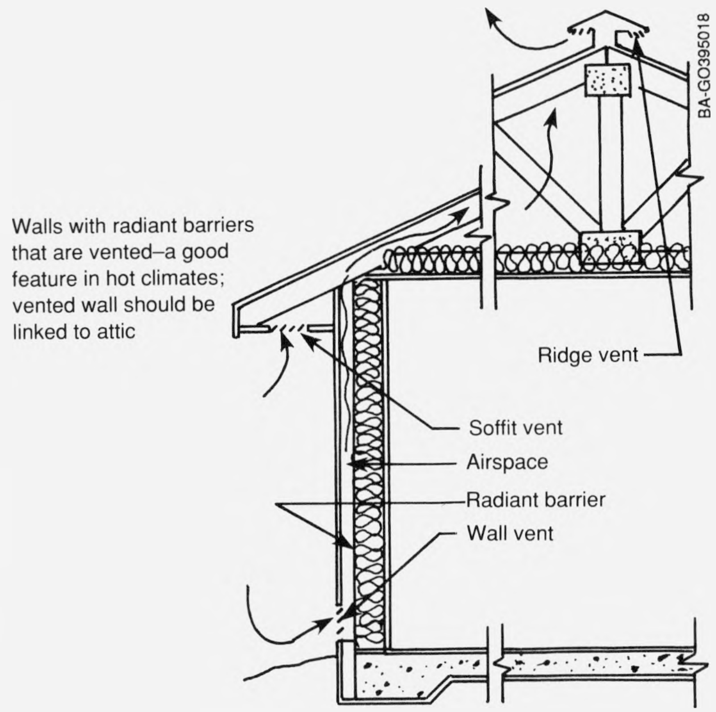


Figure 2-24. Walls with radiant barriers that are vented. (Source: Adapted from information supplied by the Florida Solar Energy Center)

video camera, an infrared scanner measures the rate of heat loss from a warm interior to the colder outside and then converts the data into a black-and-white picture. Gaps in wall insulation appear as a different color (Figure 2-26). A nonprofit energy group in Rhode Island found that insulation contractors who inspected their work with a scanner reduced their failure rate to less than one-third of that of other contractors [21].

Masonry Walls

Many new homes in the sunbelt states have walls built of brick, concrete, or other masonry material. Invariably, they are more difficult to insulate than frame walls, although insulation can be added to both the exterior and the interior. As a general rule, wherever heating costs outweigh cooling costs, insulation should be attached to the outside of masonry walls. The goal is to bring the tempering effect of the thermal mass indoors. On summer nights when the outdoor temperature drops below the indoor temperature, ventilation cools the massive walls. Then, the cool masonry absorbs heat from indoor air the next day (Figure 2-27).

Even if the night temperature is not cool enough for ventilation (such as in Phoenix in mid-July), the massive walls can be cooled during off-peak hours—10:00 p.m. to noon—using an air conditioner. This procedure should allow the occupants of the house to get through the peak hours (noon to 10:00 p.m.) with little or no need for air conditioning.

In winter, the role of masonry walls with exterior insulation is reversed. Masonry walls absorb excess solar heat or internal gain from indoors during the day for release once the indoor air temperature cools at night.

Rigid or spray fcam insulation can be applied to all types of traditional masonry walls, including adobe. In the desert Southwest, 2 to 3 in. of urethane foam insulation (R-12 to R-18) are typically sprayed over at least the north, east, and west adobe walls, which are then finished with stucco. In cold or cloudy climates, any unglazed portion of the south wall should be insulated.

With block walls, the conventional approach is to insulate on the inside, not on the outside. Often, 1-in. furring strips are attached to the wall, and the 3/4-in. gap is the only space for insulation. The insulating value of such a wall ranges from R-4 to R-5. This insulation can be significantly improved at moderate cost. Using thicker furring strips allows for additional insulation. Combining foil-backed drywall with a small airspace adds a valuable radiant barrier (Figure 2-28).

In addition to these standard insulation techniques, builders have access to many new technologies that completely change the ways they can build and insulate masonry walls. One technique uses specially designed foam inserts within concrete blocks. Foam inserts in standard blocks can increase a wall's insulating value from about R-3 to about R-8. Combining the foam with a reduced webbing area leads to an R-10 to R-16 concrete block wall (Figure 2-29).

The insulating value of poured-in-place walls, either above or below grade, can be improved dramatically by using one of the new preassembled foam-forming products (see Basements in this chapter). Insulating values range as high as R-20 or better. Typically, the outside of the house is finished with a stucco coating, and the inside is finished with drywall. One disadvantage of this approach is that the mass is isolated and cannot contribute to any thermal buffering during the heating or cooling season.

Existing Masonry Walls

Retrofit insulation of brick, block, or adobe walls is an expensive undertaking. The economics of insulating masonry walls in a temperate or hot climate are particularly poor. Costs for exterior applications are typically about \$3.50 to \$5.00/ft^2 of wall area. Insulating the interior costs even more, including the finish work. This type of retrofit cannot be justified solely on the basis of energy savings. The improved appearance and comfort—no more cold masonry walls—must play a major role in either decision.

In cold climates, retrofit insulation can be cost effective. If brick or block walls provide an attractive facade, then insulating the interior is preferable to altering the outside by adding insulation, particularly when cracked interior surfaces need repair. Where space is limited, drywall can be applied over 2 to 3 in. of foam for R-8 to R-18 insulation, depending on the type of foam selected. Where space allows, holding the new 2-by-4-in. framed wall back from the masonry wall permits the installation of two layers of batt insulation—one horizontal and one vertical—for an

CASE STUDY

Projects in St. Louis, Missouri, and Philadelphia, Pennsylvania, that involved adding insulated frame walls inside the masonry demonstrated the cost-effectiveness of such an approach during a comprehensive retrofit. In the single-family St. Louis Rehab 2000 demonstration program, superinsulation retrofits resulted in an 83% energy savings. This savings more than paid for the increase in the mortgage costs to cover the added expense of using this approach. Savings of about 80% were realized in the Manchester Project multifamily dwellings in Philadelphia [22].

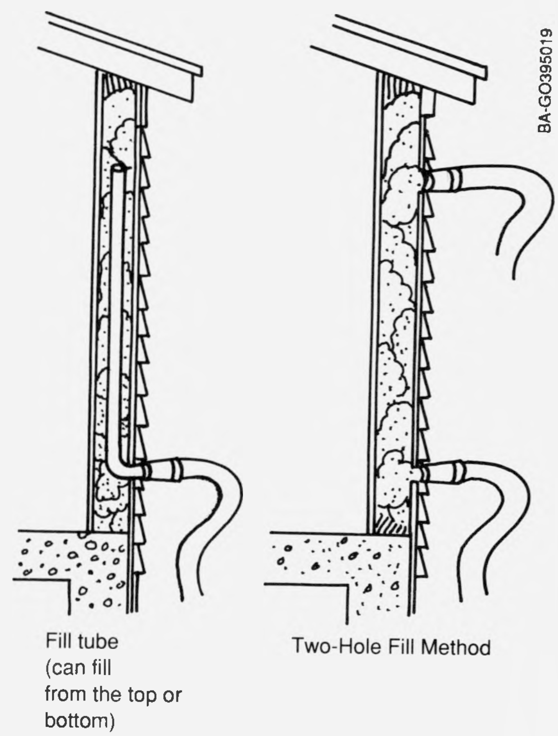


Figure 2-25. Methods of Applying Loose-Fill Insulation

Sackett, James G. (January 1985). *A Development Strategy for Superinsulated Homes.* Washington, DC: Energy Task Force of the Urban Consortium; 83 pp. Available from Publications and Distribution, Public Technology, Inc., 1301 Pennsylvania Ave. NW, Washington, DC 20004.

Discusses project that was undertaken to demonstrate that superinsulation is a highly effective means of residential energy conservation that could be employed in a cost-effective manner in the local climate. The basic approach was to implement a demonstration program that would produce a number of superinsulated housing units of a variety of types. These units would, in effect, be the test cases to adapt Canadian and European superinsulation standards to a midwestern U.S. climate. The actual energy use of the units was monitored to determine the reliability and cost effectiveness of the technology.

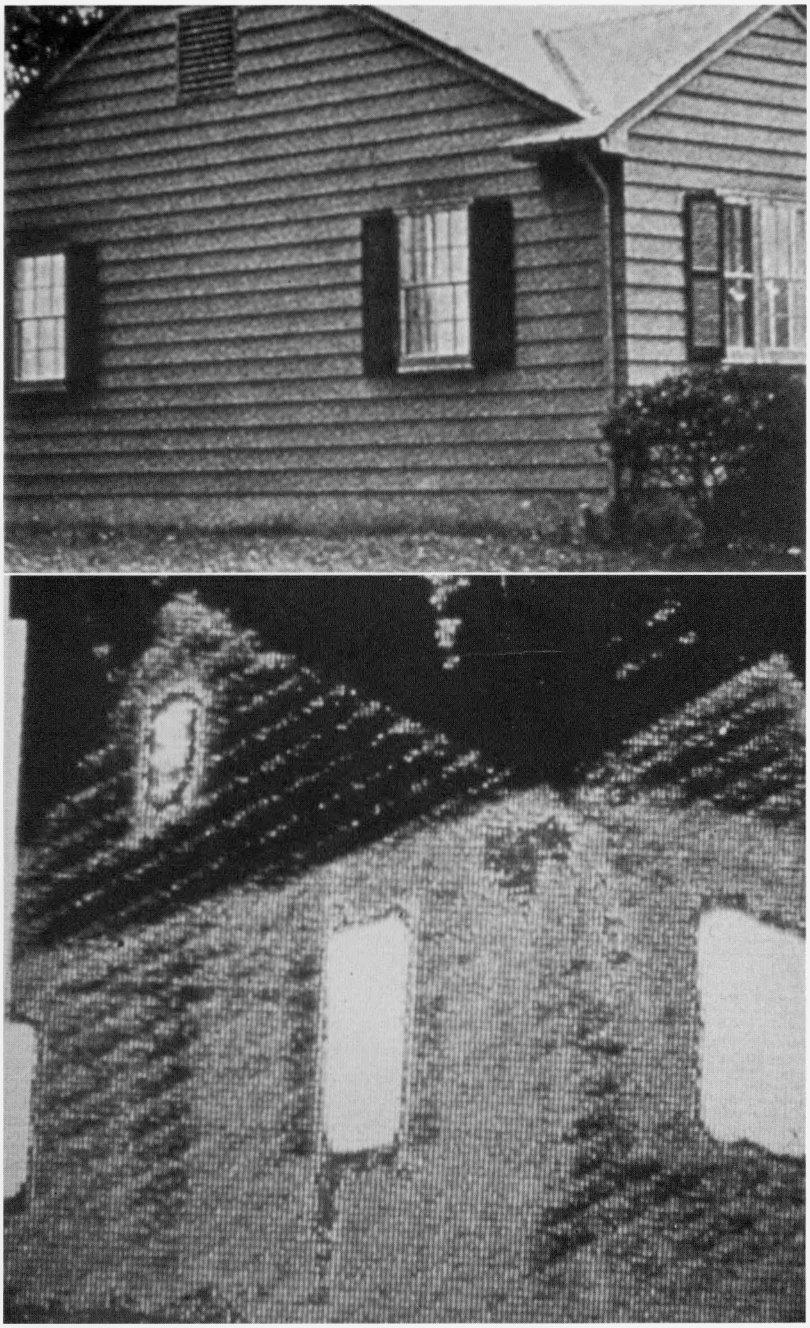


Figure 2-26. Thermogram showing areas of missing insulation

insulation total of R-22 to R-26. A third alternative is to apply a thick wet-spray insulation.

The exterior insulation alternative is a better option when brick has been painted and is ready for repair. The most common products include a flexible stucco finish applied over 1 to 4 in. of rigid foam attached to the masonry. The thicker layer of insulation is usually justified because the foam is the least expensive part of this labor-intensive technique.

Log Walls

Roughly 19,000 log homes were built during 1986. Most log home manufacturers sell log walls with thicknesses ranging from 4 to 10 in.

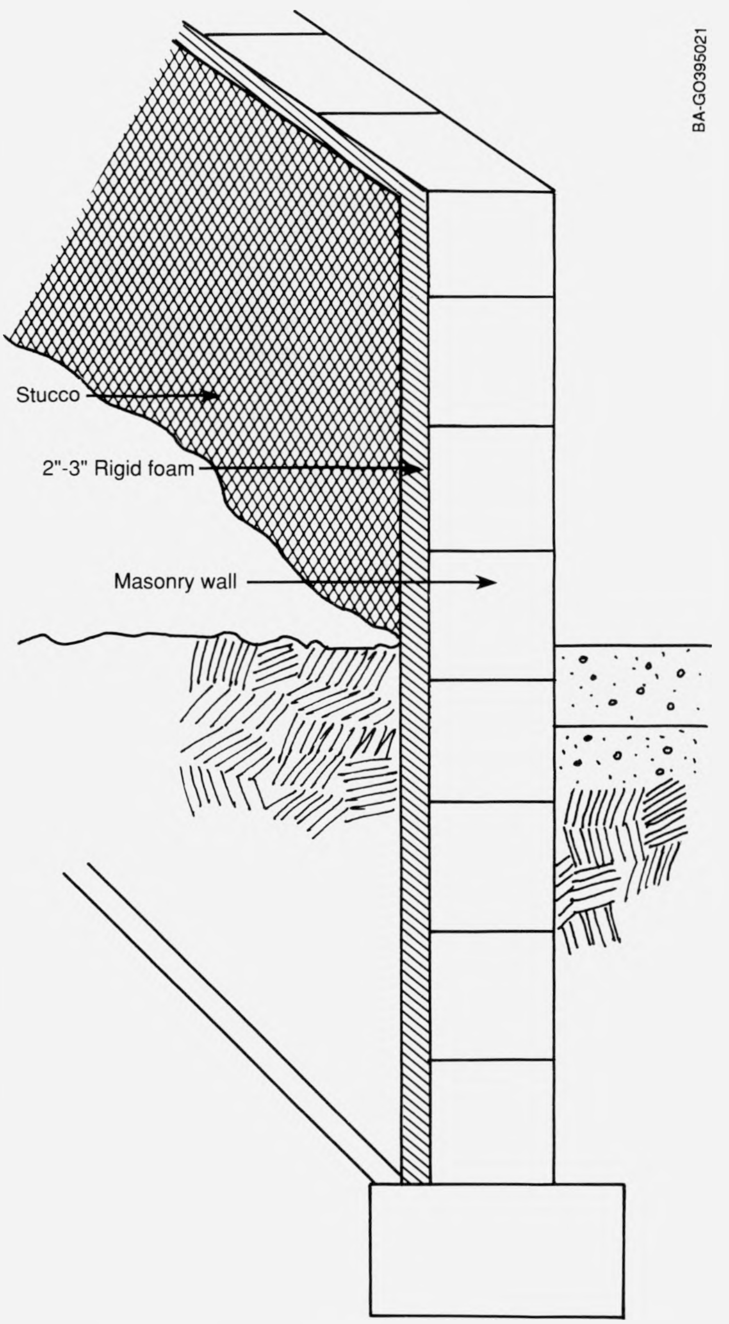


Figure 2-27. Foam outside masonry wall

Burah, D. M., and Licitra, B. A. (1987). "The Effect of Wall Mass on the Annual Space Heating and Cooling Loads of Residences." *Proceedings of the Third International Congress on Building Energy Management: ICBEM '87; Lausanne, Switzerland; September 28–October 2, 1987*; pp. 248–255.

Discusses field studies by the National Bureau of Standards investigating the effect of wall mass on space heating and cooling loads. The current computer study, using the Thermal Analysis Research Program (TARP), examines the effect of partition walls and interior furnishings in a house when direct solar gains contribute in a normal way to internal heat gains. Weekly space-heating loads were correlated with weekly average outdoor temperature. The presence of partition walls and interior furnishings caused the space-heating load correlations of the house to approach a linear relationship that coincided with steady-state theory. Under this condition, the presence of additional mass, such as wall mass, was found to have a small but beneficial effect on space-heating and space-cooling loads, except for climates where the house operated predominantly near to its balance-point temperature. Similarly, wall mass was found to have a small effect on space-cooling loads in the house with partition walls and interior furnishings.

Because softwood has an average insulating value of R-1.25 per inch, the insulating value of solid wood walls—R-5 to R-12—is not impressive by today's energy-efficiency standards.

The log home industry relies on a study conducted by the National Bureau of Standards for the U.S. Department of Housing and Urban Development (HUD) during 1981 and 1982. Results indicated that a small structure with 7-in. solid wood walls annually needed somewhat less energy for heating and cooling than a conventionally framed structure with 3.5-in. fiberglass batts. Structures with insulated masonry (2-in. polystyrene foam or 3.5-in. fiberglass) also outperformed the insulated, wood-framed structure. However, the results only apply in moderate climates such as in Washington, D.C., where the test was

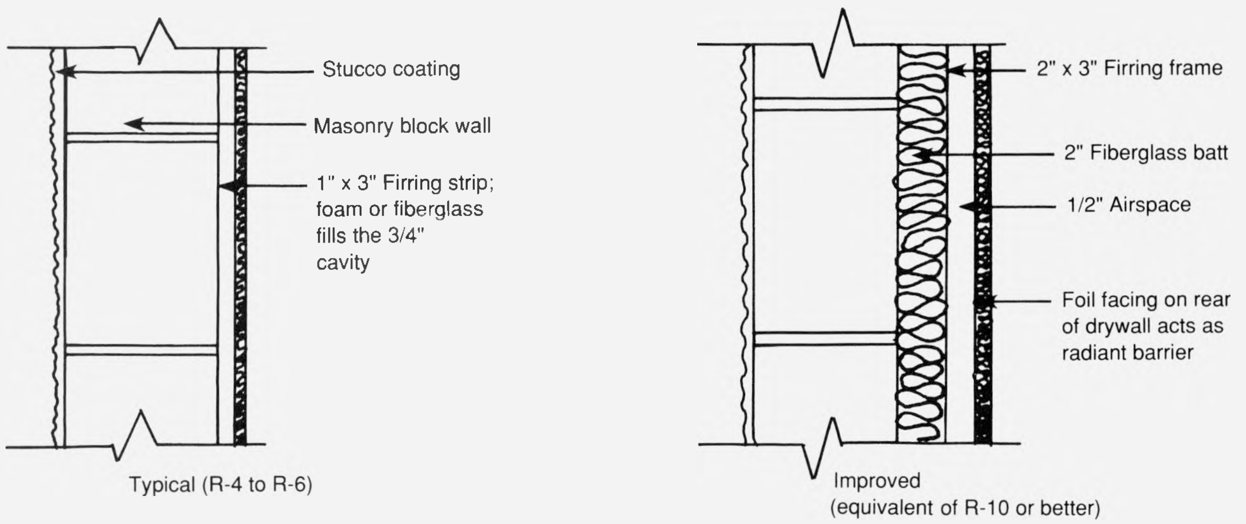
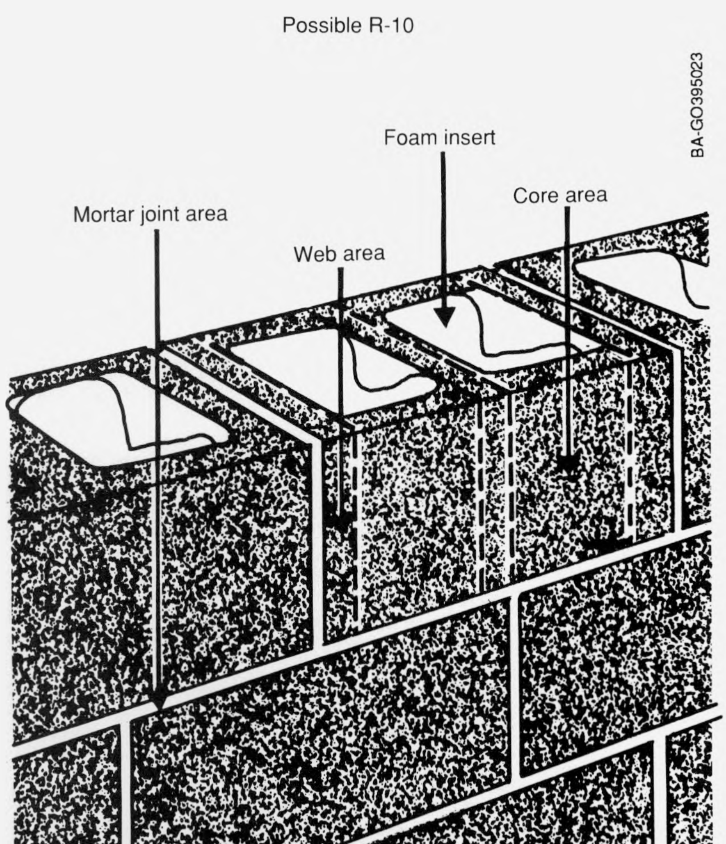


Figure 2-28. Radiant barrier formed by combining foil-back drywall with a small airspace

conducted. Furthermore, matching or exceeding the performance of a home with 3.5-in. fiberglass batts is not significant by today's standards of energy efficiency. Thus, homes with solid wood walls that are built in colder climates should consume considerably more energy for space heating than conventionally framed homes built with R-20 or better insulation.



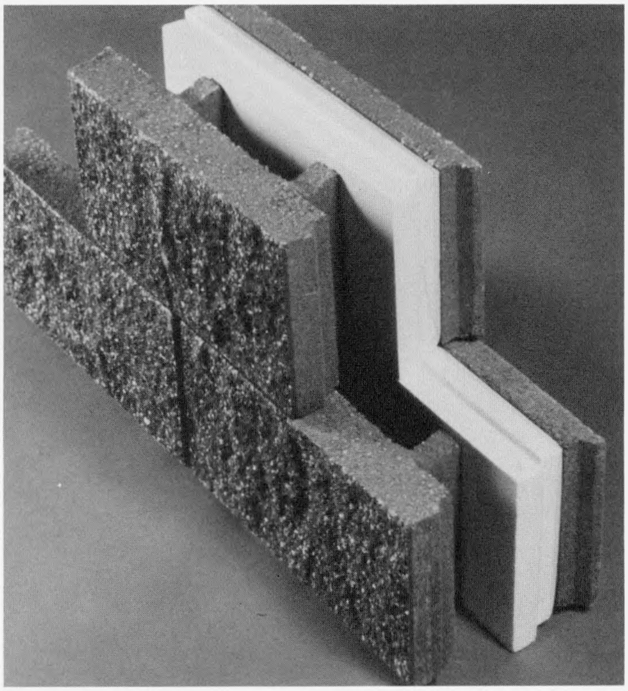


Figure 2-29. Foam inserts in standard blocks. (Source: Adapted from information supplied by Korfill Incorporated. Photograph courtesy of Korfill Incorporated*)*

Between 5% and 10% of the 300 log home manufacturers in the United States offer a product line with insulated walls. Cold-climate builders or buyers interested in log homes should seek out manufacturers who sell alternatives to walls filled with foam or fiberglass. Such alternatives include sheets of rigid foam attached on the inside of log walls and covered with tongue-and-groove wood paneling, foam on the outside of log walls covered by log veneer, log veneer applied to both sides of a relatively conventional frame wall, and laminated logs with a layer of foam sandwiched between layers of wood. These walls should provide an insulating value between R-15 and R-30.

Of the 15,000 to 20,000 log homes built annually during the 1980s, few were built with any wall insulation. Insulating the exterior of existing log walls is almost never cost effective. The lag effect of exterior mass walls is a benefit in a climate with moderate heating and cooling requirements [23]. The insulating value of such walls—R-6 to R-10—is far from optimal for a cold climate. However, not only is the high cost of increasing the insulation value prohibitive, but there is also an additional aesthetic penalty—the sacrifice of the log appearance.

Adding insulation to the outside of log walls in an existing home is rarely cost effective. The only case where it might be considered is in a very cold climate with relatively high fuel costs and thin log walls (4 to 5 in.).

Ceiling Insulation, Ventilation, and Radiant Barriers

Builders have gradually increased ceiling insulation levels to between R-19 and R-30 in conventional new homes. By contrast, levels installed in the most energy-efficient designs are usually 50% to 100% higher. Depending on the climate, the R-30 to R-45 value used by most energy-conscious builders is satisfactory. In most applications, these levels should be cost effective because, as previously mentioned, the ceiling is usually the least expensive location to add insulation.

Both flat ceilings and cathedral ceilings can be difficult to insulate thoroughly. One problem is ensuring that the full-height insulation extends to the edge of the outside walls. The raised-heel truss solves this problem of insulating hard-to-reach locations under low-pitched roofs (Figure 2-30). Raising the roof over the outside wall allows for full-height insulation coverage.

Ceiling trusses can cause gaps wherever high levels of batt insulation are used. Diagonal truss chords prevent batt insulation from being installed in two crosshatch layers; hence, the truss remains uncovered. One way to solve this problem in flat truss ceilings is to use loose-fill, blown-in insulation. When properly installed, the loose-fill insulation fully covers the trusses (Figure 2-31). However, loose-fill insulation is not foolproof. In 13 attics in Seattle, Washington, researchers discovered that the settled density of cellulose was higher, and therefore, its R-value was 20% lower than the manufacturer's specifications. Care must be taken to apply the product evenly and in sufficient quantity to ensure that the R-value meets design objectives, even after settling [24].

Cathedral ceilings are more difficult to insulate than flat ceilings. Results from 144 homes built through the Minnesota Energy Efficient Housing Demonstration Program highlighted some common flaws in insulating cathedral ceilings [25]. The homes were built in 1980 and carefully evaluated a few years later. Infrared cameras used to scan batt insulation revealed problems. In two cases, cold air was entering soffit vents and flowing up between the batts and the drywall ceiling. Cold air moving around or through batts reduces performance to well below the insulation's rated R-value. This situation occurs frequently in cathedral ceilings

"Density and Settling of Cellulose Insulation." (March 1987). *Energy Design Update* (6:3); pp. 9–13.

Discusses the problem of settling of cellulose insulation installed in walls and attics. It is possible to install cellulose in walls so that it won't settle, and the article describes how to determine the appropriate design density to prevent settling. Unlike wall applications, cellulose can't be compressed to a design density in attics, so some settling always occurs. The article discusses how settling affects R-value, how much settling occurs, and how to determine how much insulation to install by weight and by inches. Currently, in both types of installations, experience and skill are the only practical ways to ensure proper installation.

Nelson, B. D.; Robinson, D. A.; Nelson, G. D.; and Hutchinson, M. (September 1986). *Energy Efficient House Research Project.* ORNL/Sub/83-47980/1. Oak Ridge, TN: Oak Ridge National Laboratory; 206 pp. Available NTIS: Order No. DE86015941.

Presents the final report for the Energy Efficient House Research Project. Under this project, 144 detached and attached housing units were constructed throughout the state of Minnesota by 23 different builders. The 112 houses for which good-quality energy data existed performed well, but analysis of these data showed few significant correlations between energy performance and design features. One result that did prove to be consistently significant was the loss of space-heating energy as a result of below-slab, forced-air distribution systems. Detailed field investigation of 25 houses revealed many commonly practiced housing design and construction methods that degrade the energy performance of solar systems and other features of potentially energy-efficient houses. Indoor air quality was investigated in 12 energy-efficient houses and in an equal number of control houses. Air quality in the energy-efficient houses was found to be as good as in houses of conventional construction. Radon mitigation using subfloor ventilation was investigated if the flanges of kraft facing are stapled to the sides of trusses or rafters instead of the facing (Figure 2-32).

A good but expensive alternative for cathedral ceilings is to use a panelized foam product. When the rafter space does not allow room for R-30 or more insulation, foam can simply be nailed to the roof assembly, either above or below the batt-filled rafter space. Because ventilation cannot be provided, any wiring or plumbing penetrations must be carefully sealed to prevent water vapor from entering the roof cavity.

Another panelized roofing technique relies on structural laminated com ponents. Most commonly, waferboard is glued to both sides of a layer of expanded polystyrene foam 7- to 11-in. thick (R-30 to R-45+). Some products have long, clear-span capabilities for use with cathedral ceilings. Others, suitable for either flat or cathedral ceilings, need intermediate support. None of the foam panel systems can be ventilated in cathedral ceiling applications.

Existing Ceilings

Ceiling insulation has been the most widely used of any shell conservation measure since about 1973. Although a moderately insulated ceiling is not a major area of heat loss, it is usually easier and less expensive to add insulation to roofs than any other area.

If an existing home lacks ceiling insulation, adding R-30 insulation is cost effective in nearly all climates. Such a retrofit could save as much as 20% on heating costs and 10% to 15% on cooling costs. If some insulation is already present, such as 3 in. of cellulose or R-11 batt, then adding insulation is cost effective only in a cold climate or a region with high energy costs. Nearly all ceiling retrofit insulation is the loose-fill type. Batt insulation is awkward to install in tight ceiling spaces.

and found to be successful in reducing the concentration of this indoor air contaminant. Attempts to seal out radon in two control houses were not successful. An evaluation of the HOTCAN and CIRA computer programs for predicting space heat energy consumption showed these tools to be comparable. A computer model–based investigation of the cost effectiveness of various energy-efficient designs showed that tight and well-insulated houses of simple design are the most cost effective. Three general builder guidelines for designing and constructing energy-efficient houses are proposed.

Akeley, Jeff. (May-June 1987). "Bags, Bugs and Rulers: Preventing Insulation Fraud and Upgrading the Quality of Installation. *Energy Auditor and Retrofitter* (4:3); pp. 14–16.

Suggests bag counting as a simple way for the homeowner to ensure that the right amount of insulation has been installed. However, it should only be used in conjunction with some sort of independent inspection program that actually measures the depth and uniformity of insulation in certain percentage of sites. A method for calculating the number of bags is given.

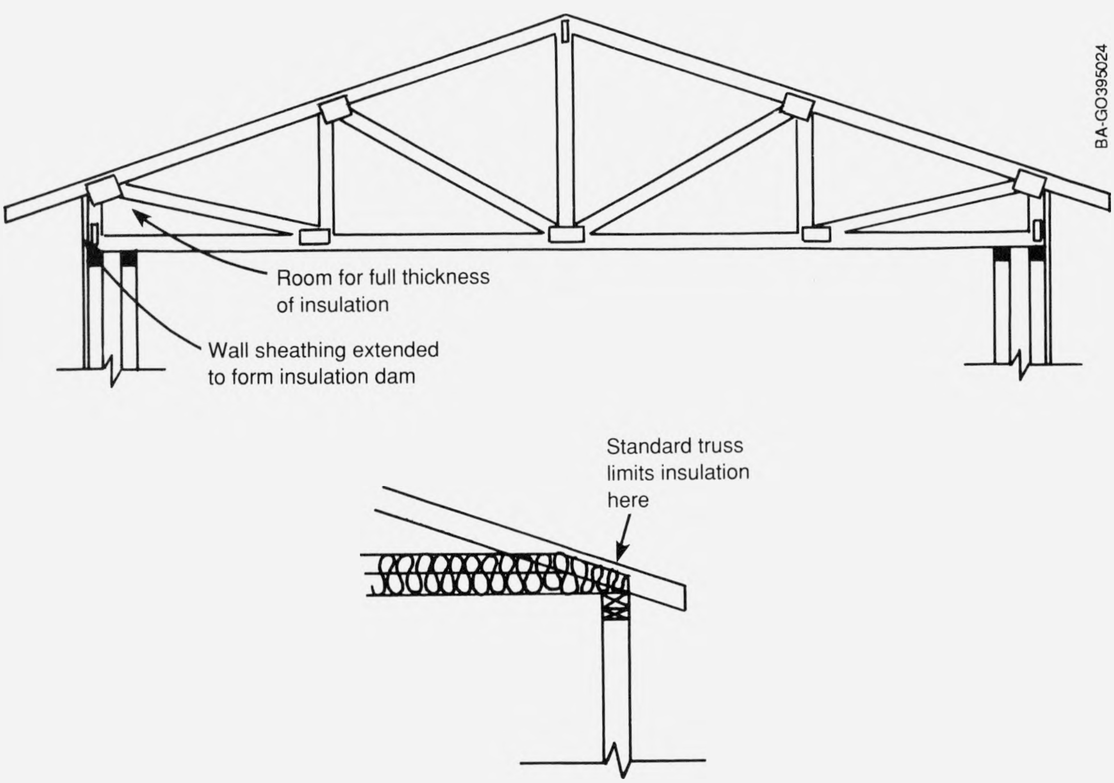
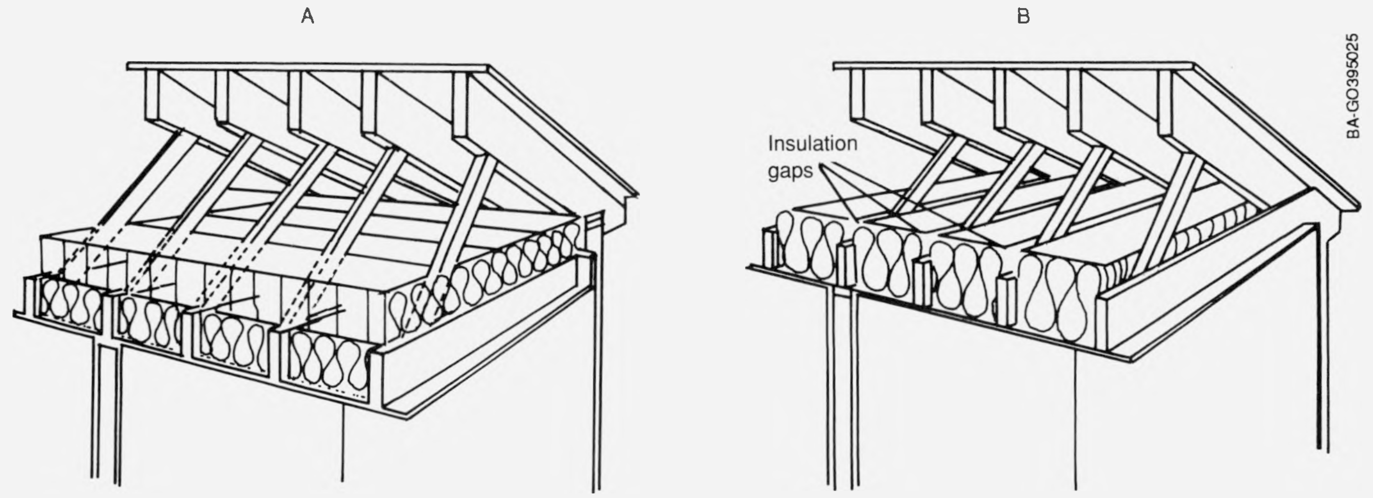


Figure 2-30. Raised hell ("Arkansas") truss, with extra height over wall plates to allow for full-thickness insulation over walls. (Source: Adapted from Nisson, J. D. Ned, and Gautum Dutt, 1985, *The Superinsulated Home Book*, New York: Wiley)



Double layer of fiberglass batts installed in attic at right angles to avoid any gaps

Single layer of fiberglass batts installed in attic between ceiling joists; notice gaps between batts

Figure 2-31. Fiberglass batts: With trusses, you can't crosshatch batts as shown in A, so loose-fill insulation helps prevent gaps if a single batt is used, as in B. (Source: Adapted from Nisson, J. D. Ned, and Gautum Dutt, 1985, *The Superinsulated Home Book*, New York: Wiley)

Four primary concerns should be considered when installing loose-fill insulation. First, installers must make sure that recessed lights are not covered, which could represent a fire hazard. Second, the insulation must be kept away from soffit vents to provide ventilation for cooling. Third, the attic must be evenly covered with the insulation. Insulation must cover top plates over outside walls. Installers might need extension tubes in order to insulate hard-to-reach locations under a low-pitched roof.

The fourth problem with insulation is the nontechnical issue of fraud. Several states (e.g., Georgia with its Office of Consumer Affairs) and utility districts (e.g., Florida Power Corporation) have reported numerous cases where homeowners paid for more insulation than they received. This problem could be eliminated through frequent auditing or third-party inspections during installation. If homeowners request that installers leave the empty insulation bags at the site after installation, then installers would be less likely to skimp on amounts of insulation.

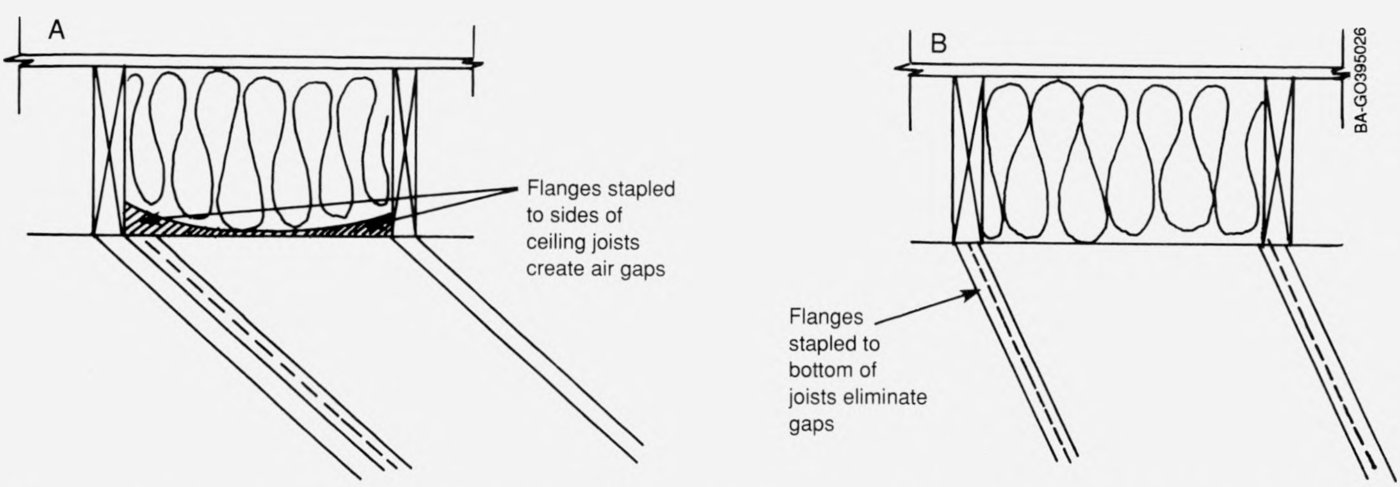


Figure 2-32. Flanges: Stapled to sides of ceiling joists to create air gaps (A); stapled to bottom of joists to eliminate gaps (B)

As a side note to the fraud problem, the settled density of the insulation material is probably higher than the manufacturers claim. A higher density insulation reduces projected performance even if installed in the specified amount [26]. Before adding more insulation, a homeowner should be sure that any existing insulation is adequately placed.

Attic Ventilation

Attic ventilation serves two purposes. In the winter, venting removes some of the water vapor that filters through the house. In the summer, vents exhaust hot air, which helps ceilings to stay cooler. In new energy-efficient designs, the latter function is the more important of the two [27].

Ventilation is a less effective way of minimizing condensation problems than simply blocking the flow of moisture-laden air from the home. In a cold climate, a well-insulated attic is several degrees cooler than an attic with average insulation. The cooler attic environment can lead to condensation on attic surfaces before water vapor can be vented. Blocking warm air movement into an attic requires attention to detail. Builders should apply weatherstripping to attic hatches, seal plumbing stacks and wiring penetrations, and use special recessed light boxes that can be sealed and insulated.

Lstiburek, Joseph. (April 1988). "Vented Roofs: Pros and Cons." *Custom Builder* (3:4); pp. 11–14.

Presents an analysis of vented roofs. Ventilating the space between the insulation and the underside of the roof deck is supposed to remove moisture. The most widely accepted ratio of free-vent area to insulated ceiling area is 1/300. However, the 1/300 rule was based on a reasonable theory for houses of the type built in the early 1950s, when the ratio first appeared. The author contends the present use of the 1/300 rule has led to serious problems because the materials and construction practices used to build houses in the 1980s are different. The effects of climate, level of insulation, rate of air change, air-pressure distribution, and type of heating system on attic ventilation are described. Strategies for correct attic insulation are recommended for various climates.

Radiant Barriers

During the summer, another way to cool an attic is to use a radiant barrier. Reflective materials stop about 90% of the heat in a roof from radiating downward, heating the insulation, and conducting the heat downward to the ceiling drywall. The installed cost of a radiant barrier is approximately \$0.10 to \$0.15/ft^2—about \$200 for an average-sized house.

A properly installed radiant barrier in a ventilated attic should reduce cooling costs by about 15% and heating costs by about 10% [28,29]. In a hot climate or an area where air conditioning costs are high, savings pay for the investment within three to seven years. The potential savings in a region with both heating and cooling demands are not well documented.

According to FSEC, the best installation strategy for new homes is to drape reinforced reflective foil material over the top of the roof trusses (Figure 2-33). A more difficult alternative is to staple the foil beneath the roof rafters. Researchers at ORNL have demonstrated that a radiant barrier placed on top of the ceiling insulation performs more effectively than when it is placed in one of the other two locations (17% savings compared to 9% in an identical home with the barrier stapled to the bottom of roof trusses) [30]. As a practical matter, however, a radiant barrier on top of ceiling insulation is susceptible to damage during any work in an attic (upgrading wiring or adding new circuits, adding or repairing ductwork, adding more insulation, adding a skylight or other remodeling work, etc.), and some question still exists about how the accumulation of dust on a radiant barrier rolled over ceiling insulation might affect its performance. There is also some concern about moisture effects on the fiberglass insulation below.

Regardless of how the radiant barrier is applied, an airspace next to the shiniest foil surface is essential. However, air movement above or below a radiant barrier does not affect the foil's ability to reflect radiant heat flow. A small gap or tear in the foil does not affect performance.

The combination of adequate attic ventilation and a radiant barrier is more effective than either measure by itself. In fact, without sufficient attic ventilation, the cooling load savings from a radiant barrier can be reduced by one-third. If some attic vents are already present, increasing

Fairey, Philip. (1986). *Radiant Energy Transfer and Radiant Barrier Systems in Buildings.* Design Note, FSEC-DN-6-86. Cape Canaveral, FL: Florida Solar Energy Center; 4 pp.

Examines the potential for reducing heat gain in buildings by controlling radiation transfer in walls and ceilings through the use of radiant barriers. This note attempts to provide an understanding of radiant energy transfer and how radiant barriers work in buildings. The systems described are particularly relevant to the Florida climate.

Fairey, Philip. (1984). *Designing and Installing Radiant Barrier Systems.* Design Note, FSEC-DN-7-84. Cape Canaveral, FL: Florida Solar Energy Center; 4 pp.

Discusses the radiant barrier system, a layer of foil facing an airspace that is installed in the envelope of a building. Such systems are effective in impeding radiant heat transfer and consequent heat gain, especially in southern residences. This note assumes the reader already understands radiant energy transfer and how radiant barriers work in buildings. This publication presents a series of construction alternatives; the details can be adjusted to suit the individual project.

Melody, Ingrid. (May-July 1987). "Radiant Barriers: A Question and Answer Primer." *Home Resource Magazine*; pp. 13–17.

Discusses the radiant barrier, a layer of aluminum foil placed in an airspace to stop heat transfer between a heat-radiating surface and a heat-absorbing surface. The benefits, costs, and energy savings are examined. How radiant barriers work, types of materials used, and installation techniques are described. A sidebar lists safety tips for installing an attic radiant barrier system.

the vent area is only cost effective if more area is required for the installation of a whole-house fan (see Chapter 3). Attic ventilation is primarily a strategy to eliminate unwanted accumulated moisture [31].

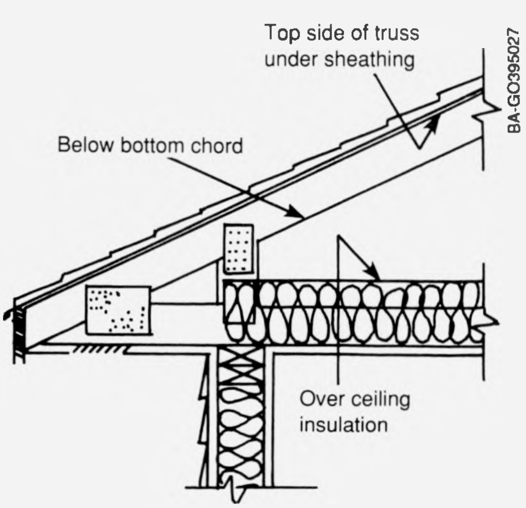


Figure 2-33. Radiant barrier sites in attics; location no. 1 is practical with products on the market today. (Source: Adapted from information supplied by the Florida Solar Energy Center)

"Radiant Barriers in Attics." (August 1987). *Energy Design Update* (6:8); pp. 7–10.

Describes two radiant barrier research projects, one at Oak Ridge National Laboratory and the other at Tennessee Valley Authority. The projects have demonstrated the effectiveness of attic radiant barriers in reducing winter heating and summer cooling consumption. However, the results for the winter data raise the question of whether it is the radiant barrier or, simply, the presence of an air barrier that results in the energy savings.

Levins, W. P., and Karnitz, M. A. (January 1987). *Heating Energy Measurements of Unoccupied Single-Family Houses with Attics Containing Radiant Barriers.* ORNL/CON-213. Oak Ridge, TN: Oak Ridge National Laboratory; 89 pp. Available NTIS: Order No. DE87007803.

Presents results of tests conducted by Oak Ridge National Laboratory (ORNL) to determine the magnitude of the heating energy savings achieved by installing attic radiant barriers. The radiant barriers used for the test consisted of a material with two reflective aluminum surfaces on a kraft paper base. The experiment was conducted in three unoccupied research houses operated by ORNL. Two variations in the installation of radiant barriers were studied. One house was used as the control house (no barrier was installed), and the other two were used to test the two methods for installing the radiant barriers. In one house, the radiant barrier was laid on top of the attic fiberglass batt insulation, and in the other house, the barrier was attached to the underside of the roof trusses. The attics of all three houses were insulated with a kraft paper–faced, R-19 fiberglass batt insulation. The winter test with the radiant barrier showed that the horizontal barrier was able to save space-heating electric energy in both the resistance and heat pump modes, amounting to 10.1% and 8.5%, respectively. The roof truss radiant barrier increased consumption by 2.6% in the resistance mode and 4.0% in the heat pump mode. The horizontal orientation of the radiant barrier is the more energy-effective method of installation.

Levins, W. P., and Karnitz, M. A. (July 1986). *Cooling-Energy Measurements of Unoccupied Single-Family Houses with Attics Containing Radiant Barriers.* ORNL/CON-200. Oak Ridge, TN: Oak Ridge National Laboratory; 53 pp. Available NTIS: Order No. DE86014343.

Presents results of tests conducted by Oak Ridge National Laboratory (ORNL) to determine the magnitude of the energy savings brought about by installing radiant barriers in the attics of single-family houses. The radiant barrier used for this test consisted of two reflective aluminum surfaces on a kraft paper base. The purpose of the radiant barrier is to reduce the radiant heat-transfer component impinging on the fiberglass attic insulation. The radiant barrier works as a system, in conjunction with an air space, and can theoretically block as much as 95% of far-infrared radiation heat transfer. The experiment was conducted in three unoccupied research houses operated by ORNL. Two variations on the installation of radiant barriers were studied. One house was used as the control house (no barrier was installed). The other two houses were used to test the two different methods for installing the radiant barriers. In one house, the barrier was laid on top of the attic fiberglass batt insulation, and in the other house, the barrier was attached to the underside of the roof trusses. The attics of all three houses were insulated with kraft paper–faced, R-19 fiberglass batt insulation.

The results showed a 21% savings in the cooling loads when the radiant barrier was laid on top of the attic fiberglass insulation and 13% with the radiant barrier attached to the underside of the roof trusses. The savings in electric consumption were 17% and 9%, respectively. The electric consumption data and the cooling-load data indicate that the most effective way to install the foil is to lay it on top of the fiberglass insulation. The radiant barriers reduced the measured peak ceiling heat fluxes by 39% for the case where the barrier was laid on top of the fiberglass insulation. The radiant barrier reduced the integrated heat flows from the attic to the house by approximately 30% to 35% over a seven-day time period.

Retrofit Radiant Barriers. Although the economics of installing a radiant barrier in a home in the sunbelt are appealing, retrofitting an existing home with a radiant barrier can be expensive. Because of the relatively new nature of this technology, contractor costs can get out of hand. Moreover, little information exists about the cost-effectiveness of contractor-installed radiant barrier retrofits. For a do-it-yourself homeowner, however, the material costs are easily justified by the savings.

Windows

Windows provide daylight and ventilation, offer views, collect solar energy, and serve as emergency exits. Windows are also the weakest energy feature in a residential structure in all climates. In hot climates, west-facing windows contribute to indoor discomfort and higher cooling bills. In cold climates, windows can account for 15% to 35% of the total heat loss in a home. A double-glazed metal window loses heat roughly 12 times faster than an R-20 wall.

Heat loss occurs through a combination of convection, conduction, and radiation. Various approaches to reducing heat loss include weatherizing, adding interior or exterior storm doors or windows, adding movable insulation, and installing upgraded replacement windows. When evaluated solely on the basis of saving energy, limited weatherizing is the only cost-effective method in most climates.

Builders should be encouraged to upgrade their windows. However, with the array of energy-conserving options available, making the most cost-effective choices can be difficult.

Movable Insulation

Windows lose heat primarily by air leaks through cracks, radiation through glass, and conduction through window frames. Movable insulation was originally thought to be a good solution to these sources of heat loss, particularly for new homes in cold, cloudy climates. The designs were simple, often consisting of decorative fabric over an insulating layer (R-3) with magnetic or track-edge seals to keep air from moving behind these “draperies.” A more expensive but higher R-value alternative is the rigid folding shutter that comes with foam insulation inside. Such shades and shutters were designed to reduce nighttime heat loss by 50% to 90%.

Despite the promise offered by movable insulation, performance results from two monitoring programs were disappointing, indicating that movable insulation was used properly only 70% of the time and made little difference in a building’s performance [32]. Based on information gathered through the Solar Energy Research Institute’s (SERI) Class B

Passive Solar Performance: Summary of 1982–1983 Class B Results. (December 1984). SERI/SP-271-2362. Golden, CO: Solar Energy Research Institute; 203 pp. Available NTIS: Order No. DE84013034.

Presents the results of the SERI Residential Class B Passive Solar Performance Monitoring Program, a low-cost program that evaluated the thermal performance of selected residential buildings throughout the country. The goal of the program was to provide a consistent measure of the thermal performance of different types of passive buildings in different climates. Measurements were taken beginning in 1981. The instrumentation was designed to measure the monthly building energy balance, separating the heating load into passive, auxiliary, and internal heating components. This report contains results obtained during the 1982–1983 heating and cooling seasons from 30 buildings, 16 of which had not been previously evaluation program, energy savings from movable insulation installed at night were negligible [33]. Although some homeowners saved a measurable amount, others who operated their shutters and shades improperly saved nothing and might even have done better without them. In Minnesota, several homes in the Energy Efficient Housing Demonstration Program developed problems with their windows. When movable insulation was kept closed on sunny days, a few glazing seals broke, and some weatherstripping melted.

These results notwithstanding, movable insulation can still be considered an option for some homeowners. Costs for materials range from \$0.50 to \$3.00/ft^2. The most cost-effective approach for a homeowner is to both make and install the product. Costs can be more than \$25/ft^2 for automated designs if installed by a contractor. These costs cannot be justified solely on the basis of energy savings, but nearly all designs provide privacy as well as decoration. One problem to consider: If the product's design or installation does not provide an airtight seal, then leakage can lead to severe condensation problems on the glazing.

Low-Emissivity Coatings

Radiation is responsible for more than 60% of the heat loss through conventional double glazing, which at best can be rated R-1 (Figure 2-34). Approaches to reducing this heat loss were originally developed at LBL in the mid-1970s, and many new glass coatings have surfaced during the 1980s. These low-emissivity (low-E) coatings reduce both winter heat loss and summer heat gain. Invisible to the eye, the atom-thin, low-E layers are usually sprayed on, or baked into, the outer surface of the inner pane of double glazing. The layers can also be added to a film suspended between panes of glass.

The key feature of a low-E coating is its ability to reduce radiant flow from warm interior surfaces and bodies to relatively cold glass. The performance improvement of windows has increased dramatically with the use of low-E glass. The insulating value increases from R-1.7 for typical double glazing to between R-2.5 and R-4 when low-E coatings are used.

Two application processes exist for low-E coating: soft and hard coating. *Soft coating* is a sputtering process that laminates layers of silver and metal oxides onto a film or finished glass. A glass surface with a low-E soft coat must be sealed in a double-glazed unit to prevent the deterioration of the coating. In the *hard-coating* process, the coating is deposited as the glass is being manufactured. When the glass cools, the baked-in coating is scratch resistant and can be exposed to air without deteriorating. Thus, it can be used as a single-pane storm window or a double-pane window. Most hard-coat low-E glass costs slightly less than glass with a soft coat, but soft-coat glass is rated as much as 25% better as an energy saver.

First-generation low-E coatings were most effective at preventing heat loss in a cold climate. Newer coatings allow a builder or designer in a mixed climate to adapt the windows for various orientations. For example, in a sunny climate, south-facing windows should remain uncoated to provide desirable solar heating in the winter. For east- and west-facing windows, a lower-transmittance coating blocks most of the unwanted solar gain in the summer.

In a hot climate, the low-E coating should be either on a suspended film or the outer pane rather than on the inner pane of glass. In some cases, these measures still might not save enough energy to justify the additional expense. Studies in Florida indicate that tinted windows are a more cost-effective option; however, aesthetic considerations with tinted windows can make them an unacceptable option [34].

monitored. Each of the 30 monitored buildings is summarized separately. Each summary includes a description of the building, its thermal characteristics, the measurements taken, and the building's thermal performance.

Holtz, Michael; Frey, Donald; Bishop, Robert; and Swisher, Joel. (October 1985). "The Future of Passive Solar Design." *Solar Age* (10:10); pp. 49–56.

Discusses the Class B Residential Passive Solar Performance Evaluation Program, which has monitored the performance of passive solar homes since 1978. The results of the program and the future of passive solar homes are assessed. The major conclusions and general tips for designing and building passive solar homes are listed. Specific results for sunspaces, window insulation, and auxiliary heating are described, along with some of the common problems.

Vieira, Robin. (November 1986). "Windows for Hot Climates." *Progressive Builder* (11:10); pp. 9–15.

Discusses various window options. The primary factors affecting window choices in hot climates are ventilation, air infiltration, and shading. Window options include double glazing, low-E glass, heat mirror film, tinted glass, and reflective films. Related options are window coverings, window frames, screens, blinds, and window hardware. In addition to discussing the window options, the article contains a number of tables and supplemental information, including a glossary of window terms, specifications on tinted glass, shading coefficients for window coverings, and the economics of various window types for several regions of the country.

Sullivan R., and Selkowitz, S. (November 1986). *Residential Heating and Cooling Energy Cost Implications Associated with Window Type.* LBL-21578. Berkeley, CA: Lawrence Berkeley Laboratory; 19 pp. Available NTIS: Order No. DE87007602.

Presents a comparative study in which residential heating and cooling energy costs are analyzed as a function of window glazing type, with a particular emphasis on the performance of windows having low-emittance coatings. The DOE-2.1B energy analysis simulation program was used to generate a data base of the heating and cooling energy requirements of a prototypical, single-family, ranch-style house. Algebraic expressions derived by multiple regression techniques permitted a direct comparison of those parameters that characterize window performance: orientation, size, conductance, and solar transmission properties. These equations are used to discuss the energy implications of conventional double- and triple-pane window designs and newer designs in which the number and type of substrate, the low-emittance coating type, and the location and gas fill are varied. Results are presented for the heating-dominated climate of Madison, Wisconsin, and cooling-dominated locations of Lake Charles, Louisiana, and Phoenix, Arizona. The analysis showed the potential for substantial savings but suggested that both heating and cooling energy should be examined when evaluating the performance of different fenestration systems. Costing and substrate properties and the location of the coating in the glazing system were

CASE STUDY

Modeling studies conducted by LBL in 1986 show the impact of different types of glazing, window sizes, and orientation and illustrate the dramatic difference in utility costs that low-E glass can achieve. In a heating dominated climate such as in Madison, Wisconsin, a 12-m^2 triple-pane, low-E window using argon and facing south contributed about $10/year to the energy bill, and a 24.5-m^2 standard double-pane unit facing northwest contributed $165/year. In the cooling dominated climate of Phoenix, a small-sized, bronze-tinted, double-pane window facing north or south contributed $50/year to the bill, and a large single-pane window facing southwest contributed almost $365/year [35].

shown to have moderate effects as a function of orientation and climate. In addition, with the low-conductance glazing units, the window frame becomes a contributor to overall residential energy efficiency.

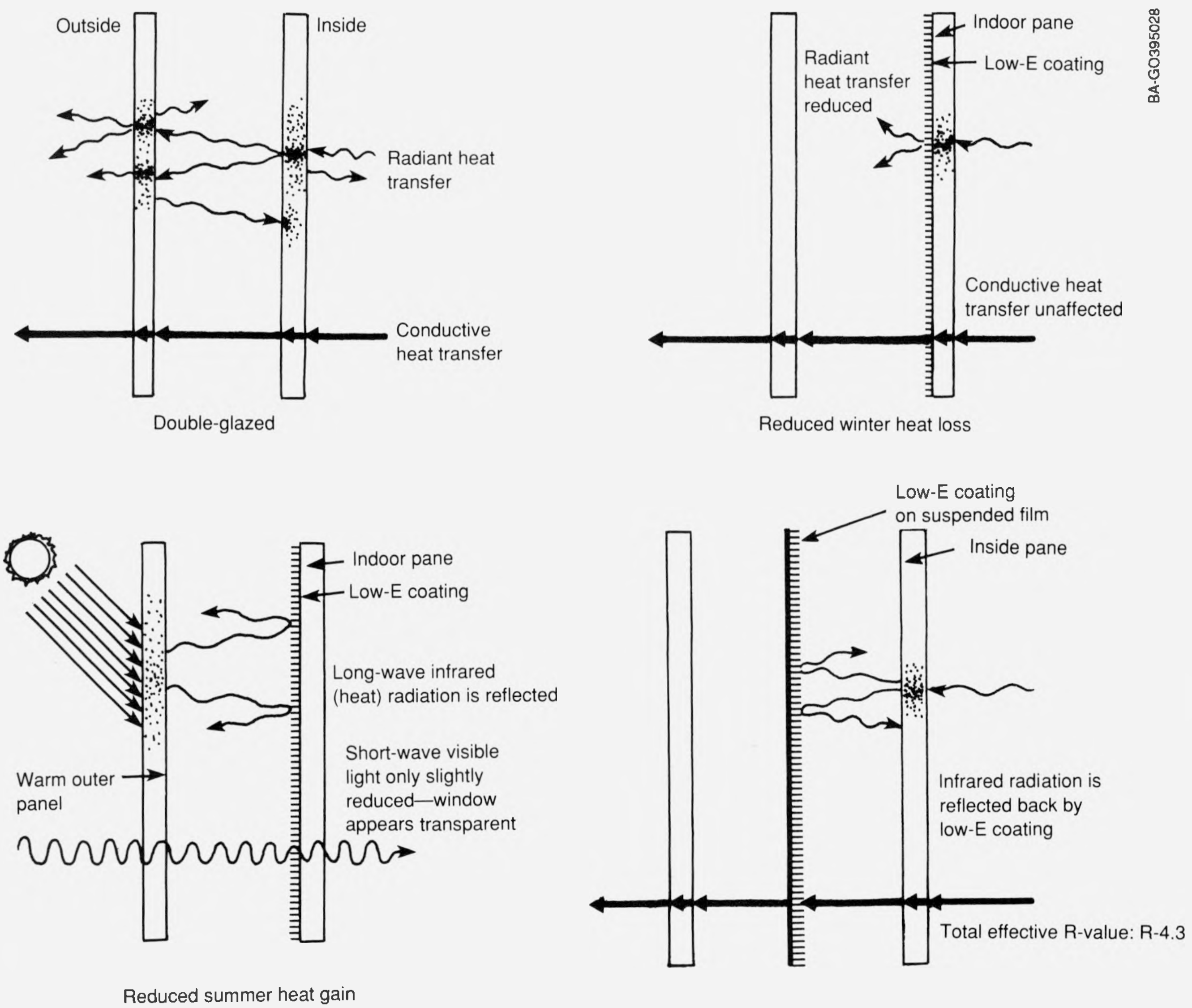


Figure 2-34. Coated low-E glass: Thermal resistance of the window increased by reducing radiation heat transfer. (Source: Adapted from Nisson, J. D. Ned, and Gautum Dutt, 1985, *The Superinsulated Home Book*, New York: Wiley)

Low-E coatings can add about 10% to the cost of a double-pane wood window. They increase the cost of aluminum windows by 25% to 30% over conventional models. In 1988, 20% of residential insulated glass units had a low-E coating. This figure was expected to increase to 30% by 1989 and to 50% by 1991 [36]. One of the largest manufacturers of wood windows reported that about 50% of its casement windows are being shipped with a low-E coating. These new glazings make window conservation the one area where the need for efficiency has coincided with market demand, producing airy environments and dramatically shaped windows [37].

A word of caution about low-E glass: One cannot assume that the listed R-value of low-E glass accurately represents the total performance of the window, particularly for metal-framed windows. Heat loss around frames and edge-spacing materials reduces the performance of low-E glass. Until improvements are made to the other thermally weak areas of a window, such as the frame and metal edge spacer, stated window performance should be viewed skeptically. Rating standards used by manufacturers lack uniformity.

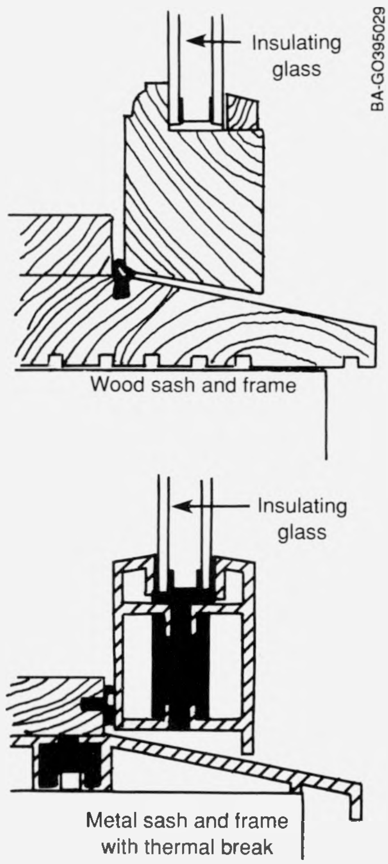


Figure 2-35. Windows that minimize conductive heat loss. (Source: Adapted from Schwolsky, Rick, and James I. Williams, 1982, *The Builders Guide to Solar Construction,* New York: McGraw-Hill)

Metal Frames Compared with Wood Frames

In cold climates, metal-framed windows without a thermal break draw heat out of a house and can leave puddles of condensation on the window sill. Switching to a quality metal-framed window makes good sense (Figure 2-35). However, switching from a quality metal window to a wood window is less economical, even though heat loss through the window is decreased by 10% to 15%. For a production builder, switching from metal windows with a thermal break ($1000 to $1200) to wood frames in an average-sized house more than doubles the cost of the window package. Unless you live in a cold climate or purchase your windows purely for aesthetic reasons, you might better spend the price difference between the two types of windows on upgraded insulation, air sealing, or HVAC equipment.

Given the many different types of window technologies on the market, it is not always easy to determine which approach to choose. LBL has developed a model to study the effects of gasses, coatings, and other design features on window heat transfer. The current model version, WINDOW 2, is used by over 600 glazing and window firms [38,39].

Weatherization

Weatherization options for windows in existing homes include installing pulley seals, caulking, and weatherstripping. Even when done by an experienced contractor, installing all three treatments can take as long as 45 minutes per window. Pulley seals are the quickest and most cost-effective feature to add [40]. Studies at Princeton University show that adding weatherstripping alone reduced whole-house air infiltration by 10% to 14%. The data also showed that the combination of storm windows and weatherstripping reduced air infiltration by 17% to 23%. In cases where weatherstripping can reduce as much as 50% of the air infiltration around windows, the addition of storm windows is probably not cost effective.

Anderson, Gary. (November-December 1985). "Sealing Double Hung Windows." *Energy Auditor and Retrofitter,* pp. 13–16.

Discusses the problem of window heat loss resulting from air leakage. The results of window infiltration field testing and a study of the available literature on the subject are presented. The author concludes that the most cost-effective retrofit is sealing the pulley openings, followed by caulking the fixed cracks. Weatherstripping should be the last priority.

Storm Windows

Storm windows are more durable than weatherstripping and reduce heat loss through glazing by about 50%. When the price of low-E coatings eventually drops, savings from adding low-E storm windows will increase. Storm windows also improve indoor comfort levels, reduce

CASE STUDY

In Snowmass, Colorado, Amory and Hunter Lovins built a large, superinsulated home that also houses the Rocky Mountain Institute (Figure 2-36). They were able to build their home-office without a furnace primarily because of the extensive use of low-E glazing.

The windows were constructed by suspending a film of soft low-E coating between layers of double glazing, then filling the glass unit with argon, an inert gas. The insulating value of the gas-filled, low-E windows is R-5. According to the Lovins, the few windows that do not have a low-E coating "grow ice" when the outside temperature drops below 0° F. Except for around the edges of the metal-glazing spacers, the low-E windows remain free of ice and condensation.

noise levels, and provide a sense of increased security to homeowners. If installed properly, they can also reduce wintertime condensation. (If the main window is leaky, the homeowner might choose to install a tight-fitting interior storm window; condensation results when an exterior storm window is installed behind a leaky main window.)

On the negative side, storm windows are expensive. Because of their expense, homeowners need to carefully consider the other advantages besides energy savings when deciding to install storm windows. Although adding storm windows might make sense in cold climates, it is almost never cost effective in hot climates.

Replacement Windows

If the homeowner's only objective is to save energy, then replacement windows are rarely cost effective. However, when an old or dysfunctional sash is being replaced during the remodeling or rehabilitation of a house, for example, then installing an upgraded window makes sound economic sense. Replacement windows tend to add between one-third and two-thirds of their cost (low end for contractor-installed windows, high end for homeowner-installed windows) to the equity in a home [41]. In any event, the appropriate type of glazing depends on the climate.

"Practical Homeowner's 1987 Remodeling Survey." (May-June 1987). *Rodale's Practical Homeowner* (2:5); pp. 43–63, 92.

Reviews 23 common home improvement projects in regard to how much each one adds to the market value of a sample house. Fourteen professional appraisers from 14 different metropolitan areas across the country were asked to evaluate each of the improvements. Each project description includes a cost estimate and the percent cost you can expect to get back in resale. Two recovery figures are given for most projects: One is the return on the cost of a professional job, the other is the return on the cost of materials alone.

Controlling Heat Gain

Windows contribute greatly to the cooling load of a building as a result of direct and reflected solar gain plus infiltration. Conduction gain through the glazing itself is a small contributor. In a climate that ranges from hot and humid to temperate, the primary strategy is to reduce solar gain through the east and west windows. The most effective approach is to use vegetation or operable shading devices to block solar gain on the outside. Interior reflective materials applied to the glass can also be cost effective [42]. If a homeowner objects to using reflective glass for aesthetic reasons, a far more expensive option is to use reflective material on roll-down shades.

Air Infiltration and Air Barriers

Air enters a home in many ways. It leaks past doors and windows, around plumbing and electric fixtures, and through gaps between the foundation and the frame of the house. The infiltration of either cold air or warm air contributes to the heating and cooling loads of a conventional home; for example, air infiltration accounts for 30% to 40% of the heating load for an average existing home. Reducing air infiltration not only reduces energy consumption but also improves occupant comfort and minimizes moisture damage caused by the exfiltration of water vapor in walls and ceilings.

A homeowner has no control over some sources of unavoidable or "natural" air infiltration in a house. A portion of cold air entering a home is brought in intentionally by furnace fans, kitchen and bathroom fans, fireplaces, and clothes dryers. The remainder enters unintentionally as a result of the natural effects such as wind, temperature, and the *stack effect.* (The stack effect develops when warm air rises, leaks out of holes high in a building, and is then replaced by cold air entering at floor level.)

Air-Infiltration Rates

Quantifying air infiltration has always been challenging. Measuring a home's leakage with a blower door is straightforward, but trying to

Figure 2-36. Lovins residence in Snowmass, Colorado. (Photograph by Steve Andrews)

equate this measurement with natural air-infiltration rates has proved to be difficult. Until recently, it was thought that existing homes leaked at about 1/2 to 2 air changes per hour (ACH). Building researchers contended a home that leaked at a rate of about 1/2 ACH allowed for an adequate inflow of fresh air; in a home with a rate less than 1/2 ACH, provision for additional fresh air was necessary.

Currently, professionals disagree about the average rate of air infiltration in both new and existing homes. Increasing evidence suggests that existing homes are more tightly constructed than was previously calculated. A report by the Bonneville Power Administration in 1986 added to this growing body of information [43,44]. If this report is true, the savings potential from extensive efforts to tighten homes is overestimated. Also, the leakage level at which mechanical ventilation is recommended, as well as the rate at which it should be supplied, might be overstated.

In light of this new information, Bonneville concluded that average homes were being built with a rate of 0.3 ACH. Further tightening did not seem to be cost effective. Therefore, Bonneville scaled back the tightness and mechanical ventilation requirements for its standards program. Follow-up analysis of the data led to a revision of the average home's tightness factor to 0.4 ACH. Bonneville is continuing its monitoring to resolve the still unanswered questions.

Clearly, aware builders, buyers, and homeowners are uncertain about the cost-effectiveness of tightening a house. Of particular concern is the potential health risk posed by indoor air pollution. Although the primary strategy is to keep pollutants out of a home, a secondary strategy is to provide controlled ventilation to dilute pollutants with fresh air. Ventilation is much easier to control in a tightly built home. Thus, in all likelihood, the trend toward tighter housing is likely to continue, with an increased emphasis on providing for controlled ventilation.

Parker, Danny S. (1987). "Thermal Performance Monitoring Results from the Residential Standards Demonstration Program." *Solar '87: Proceedings of the 12th National Passive Solar Conference, Portland, Oregon; July 11–16, 1987.* Andrejko, Dennis A., and Hayes, John, editors. Boulder, CO: American Solar Energy Society; pp. 104–109.

> Discusses the Residential Standards Demonstration Program that was sponsored by the Bonneville Power Administration in 1984, resulting in the construction of 400 energy-efficient, single-family homes in a four-state region. Typically, these buildings incorporated design features such as high levels of insulation for attic, walls and floors, triple-glazed windows, and airtight construction with heat-recovery ventilation. These energy-efficient buildings were compared with another group of 400 new but conventional houses in the Northwest to determine the actual savings of such efficiency standards for space heat. Each house was monitored for at least one year using a triple metering system that records energy use for space heat, domestic hot water, and appliances as well as average interior and exterior temperatures. In addition, a wealth of detail was collected on the construction of the homes and the heating system and occupancy characteristics. The project revealed average annual space-heat savings of 2 to 4 kWh/ft^2 of living area when comparing the energy-efficient homes with others currently built.

Air Barriers and Tightening Techniques

The basic element common to all tight homes is an air barrier. To be effective, an air barrier must have at least four features; it must be (1) continuous; (2) impermeable to air; (3) durable enough to withstand air-pressure differences from mechanical ventilation, stack, and wind load; and (4) maintainable [45]. The effectiveness of an air barrier should be verified by an appropriate testing device, such as a blower door or a tracer gas test.

It is important to distinguish between the function of an air barrier and that of a vapor barrier, more accurately called a vapor retarder. An *air barrier* is designed to save energy and improve occupant comfort by reducing the infiltration of outside air into a home. It also serves to prevent warm, moisture-laden air from leaking into walls and ceilings, which is important for preserving the structural integrity of a house. Some building experts say that air movement is responsible for 90% of the water vapor that moves from the home into the walls and ceilings (Figure 2-37).

By contrast, a *vapor barrier* is intended to minimize the passage of water vapor through solid building materials, such as drywall and wood trim. Compared with the amount of moisture that usually gets into a wall by air leakage, the diffusion of moisture through drywall is relatively minor. Some materials that can adequately retard the diffusion of vapor through drywall, walls, and ceilings include loosely installed polyethylene, foil-backed drywall, and so-called barrier paints.

Lischkoff, James K., and Lstiburek, Joseph. (1986). *The Airtight House: Using the Airtight Drywall Approach. A Construction Manual.* Ames, IA: Engineering Extension Service, Iowa State University; 84 pp.

> Clarifies the confusing issues surrounding airtightness. Section 1 explains the relationship between airtightness and controlled ventilation and their combined impact on energy efficiency, moisture control, air quality, and heat recovery. Section 2 deals with air barriers and presents an innovative airtightening technique (the airtight drywall approach) that does not use polyethylene. Section 3 discusses a variety of controlled ventilation strategies suitable for an airtight house. Finally, the appendix presents supporting evidence and a detailed discussion on the need for air barriers as opposed to vapor barriers.

An air barrier can be created using (1) an interior air-barrier film, (2) an exterior air-barrier film, (3) an interior rigid barrier, and (4) continuous foam insulation. A discussion of each follows.

Interior Air-Barrier Film. The use of an interior polyethylene film that doubles as a vapor barrier and an air barrier is based on the success of Swedish and Canadian airtight construction. A polyethylene (poly) air barrier consists of sheets of cross-laminated, durable films. To achieve a continuous barrier, the poly is overlapped at the joints and caulked or taped. Penetrations are minimized, and surrounding edges are sealed. Depending on the type of wall, the poly is installed behind drywall and over or between framing members. The objective of the installation is to achieve a continuous plastic bubble (Figure 2-38). Once the air barrier is installed, workers should be careful not to damage it.

In one type of application, 4-mil reinforced polyethylene is stapled to the inside of a 2-by-6-in. insulated wall. Then, 2-by-2-in. furring strips are added to provide space for wiring and plumbing runs (Figure 2-20). This procedure minimizes the need to penetrate the air barrier and provides enough room for some insulation. A strip of polyethylene is wrapped around the rim joist between floors to connect sheets covering the first- and second-story walls. All plumbing stacks, ventilation fans, doors, and windows need particular attention.

Some professionals are concerned about the long-term durability of any unsupported film that is used as an air barrier. Under certain conditions, wind loads on the film can be great and could cause some ripping or pulling apart of the seams. Tests conducted on some types of films not treated with ultraviolet (UV) protection indicate that their service life might be decreased after exposure to sunlight. Results of follow-up tests of Canadian homes built with polyethylene air barriers are generally positive; most homes have retained their tightness.

Reported costs of polyethylene air barriers vary from one test program to the next. Costs were low for poly air barriers in 300 Canadian homes built under the R-2000 program. In the Pacific Northwest, costs claimed by builders were so high that the cost-effectiveness of the air barriers could be questioned.

Builders have mixed feelings about polyethylene air barriers. Some are convinced of their effectiveness, pointing to blower door test results as proof. Others decry the messy and time-consuming sealing process. Because of the complexity of installing poly air barriers and the need for careful quality control, it is highly unlikely that production site builders in the United States will ever embrace this measure.

Exterior Air-Barrier Film. Some builders wrap continuous air barriers outside the sheathing (Figure 2-39). The material they use differs from the polyethylene used for interior applications in that it is designed to prevent air movement in or out as well as allow any vapor that enters wall cavities from indoors to escape through the permeable sheeting. Some builders use both types of film together. The aim is to prevent moisture migration from the inside and wind "washing" of insulation from the outside.

Unrolling and stapling a typical spun-bonded polyethylene film over outside walls is a quick, easy process. To be effective, the material must be taped and sealed around doors, windows, and penetrations for plumbing or electric wiring. Taping the material at the top and bottom is both essential and straightforward. To be truly continuous, the material must be linked with standard polyethylene that covers the ceiling, an occasionally awkward step.

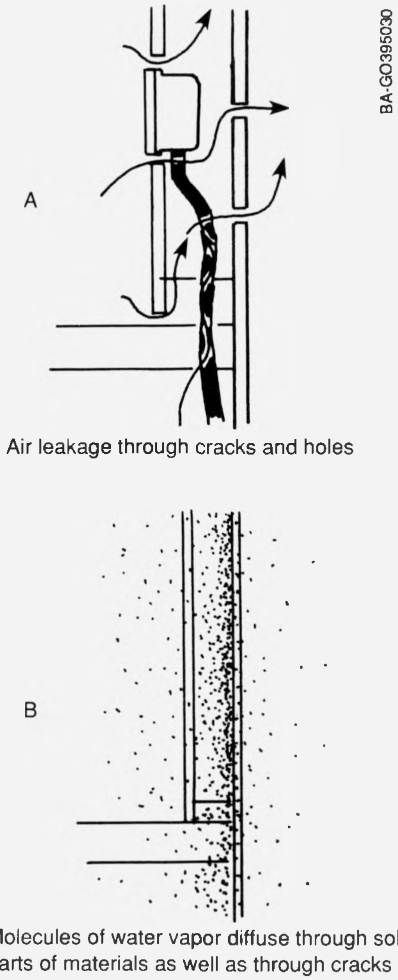


Figure 2-37. Water vapor escaping; most occurs by air moving rather than by diffusing through drywall: (A) air leakage through cracks and holes; (B) molecules of water vapor diffusing through solid parts of materials. (Source: Adapted from information supplied by Florida Solar Energy Center)

CASE STUDY

In 1985 to 1986, the state of South Dakota allowed builders to use either exterior or interior films to meet their (then) stringent air-barrier standard. Results of tests conducted on 17 homes using the interior approach and 20 using the exterior approach indicated that both methods worked equally well.

Interior Rigid Barrier. Most builders use some modification of this approach—either by design or default. The most common variation is called the airtight drywall approach (ADA) [46]. The originator of the ADA system claims that a continuous drywall box is easier to build and maintain than the system using the continuous plastic bubble with polyethylene. Wherever the drywall ends—at windows, floors, and doors—special gasketing, caulk, or foam is used to seal against air movement. As with the other systems, it is difficult, yet important, to maintain the air barrier's continuity between floors, at foundations, and in ceilings (Figure 2-40).

The ADA concept was first publicized in the early 1980s. Since then, several builders and air-sealing specialists have developed modifications that reduce the labor and materials required during construction. Some energy-conscious builders who have tried both the ADA technique and the polyethylene film technique now favor ADA, claiming it is a simpler and more cost-effective approach.

Continuous Foam Insulation. Although not the most common, this method is perhaps the simplest. Typically, a builder relies on prefabricated structural foam panels to make a continuous foam shell around the house (Figure 2-41). When properly installed, each foam panel is glued to floor decking, adjacent panels, and a roof system. As is standard with most air-tightening methods, all gaps between windows and doors are foam sealed. The few potential weak spots—between the foundation and the top of the floor decking as well as wiring and plumbing penetrations—also pose problems in most other approaches. However, unlike a home that is insulated with batt or loose-fill insulation, a home with continuous foam insulation actually has a shell that is impervious to air infiltration. This air-barrier approach appears to be the most durable of today's available technologies.

Currently, a variety of other foam-shell techniques with prefabricated components are being used. One manufacturer laminates a layer of foam to concrete, then uses cranes to lift the wall panels into place, where they are foam sealed to each other. Another approach relies on a double row of 1-by-4-ft concrete panels (1.5-in. thick) that are held apart by adjust able spacers; the resulting cavity is then filled with foam. Numerous products combine preformed foam and poured-in-place concrete. All these approaches create an airtight wall with a minimum of thermal breaks.

A drastically different—and potentially expensive—approach is *spray-foam insulation.* Spray-foam contractors fill the 2-by-4-in. or 2-by-6-in. framed cavities with solid foam. New foam-on-site products are now being developed that reduce the material and labor costs of filling wall cavities by close to 50%.

Detecting Leaks with Blower Door Tests

Sites of leaks often defy intuition. Leaks are commonly caused by wiring penetrations from interior partition walls to the attic. Detecting and fixing the sources of air infiltration are best done by a professional corps of

Offermann, F. J.; Dickinson, J. B.; Fisk, N. J.; Grimsrud, D. J.; Hollowell, C. D.; Krinkel, D. L.; Rosene, G. D.; Desmond, R. M.; DeFrees, J. A.; and Lints, M. C. (June 1982). *Residential Air-Leakage and Indoor Air Quality in Rochester, New York.* LBL-13100. Berkeley, CA: Lawrence Berkeley Laboratory; 106 pp. Available NTIS: Order No. DE82020640.

Presents results of a study of 58 occupied homes in Rochester, New York, most of which incorporated special builder-designed weatherization components, to assess (1) the effectiveness of construction techniques designed to reduce air leakage, (2) the indoor air quality and air-exchange rates in selected tight houses, and (3) the impact on indoor air quality of mechanical ventilation systems employing air-to-air heat exchangers. The specific leakage area was measured in each house using the fan pressurization technique. Houses built with polyethylene vapor barriers and joint sealing were as a group 50% tighter and had a 30% lower overall average heat-loss coefficient (W/°C-m^2) than a similar group of houses without such components. Mechanical ventilation systems with air-to-air heat exchangers were installed in nine relatively tight houses, some of which had gas stoves or tobacco-smoking occupants. Air-exchange rates and indoor concentrations of radon (Rn), formaldehyde (HCHO), nitrogen dioxide (NO_2), and humidity were measured in each house for one-week periods with and without mechanical ventilation. Detailed measurements, including concentrations of carbon monoxide and inhalable particulates, were made in two of these houses by a mobile laboratory. In all nine houses, air-exchange rates were relatively low without mechanical ventilation, 0.2–0.5 ACH, but indoor concentrations of Rn, HCHO, and NO_2 were below existing guidelines. Mechanical ventilation systems were effective in increasing air-exchange rates and further reducing indoor contaminant concentrations. The average sensible effectiveness of the heat exchangers was 0.65 ± 0.16. The authors concluded that when contaminant source strengths are low, acceptable indoor air quality can be compatible with low air-exchange rates.

air-sealing specialists called "house doctors." House doctors can dramatically reduce the natural air-infiltration rate by 30% to 50% using weatherization techniques. Moving about the house with a *blower door*—a large portable fan and adjustable door that exhausts several thousand cubic feet of air per minute—a technician uses a smoke stick around trim, outlet covers, doors, and windows to detect leaks (Figure 2-42). House doctors also use infrared cameras to spot previously overlooked leaks. Once they have determined the leaks, these specialists seal them with caulking and foam-sealing materials. Using this procedure, house doctors can help reduce total heating bills by 15%.

Although any number of construction approaches can effectively minimize air infiltration, only blower door testing can prove that a builder achieved the desired degree of tightness. Using before-and-after comparison, the house doctor is able to gauge the effectiveness of a particular sealing measure. Extensive testing of identical models built in Syracuse, New York, shows that air-infiltration rates in adjacent homes can vary by a factor of four. Similar results from other parts of the country reinforce the conclusion drawn by New York's Energy Research and Development Agency: You get what you inspect, not what you expect [47].

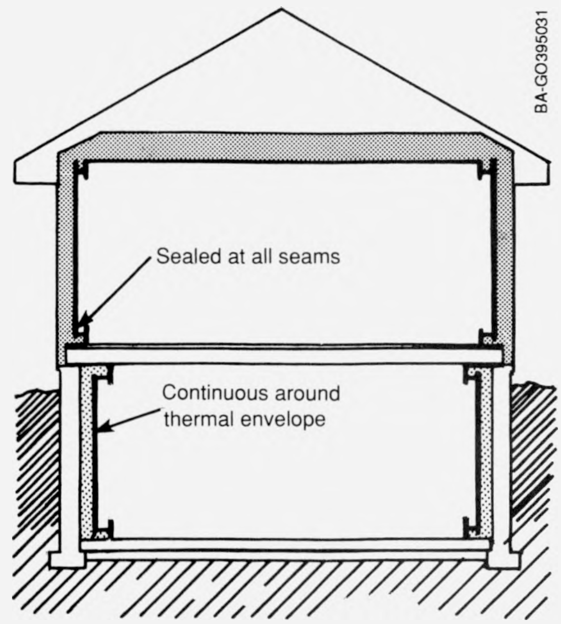


Figure 2-38. The interior air barrier film. (Source: Adapted from Nisson, J. D. Ned, and Gautum Dutt, 1985, *The Superinsulated Home Book*, New York: Wiley)

Figure 2-39. Air barrier installed over the exterior sheathing of a house

CASE STUDY

Columbine Homes, a production builder in Denver, sealed leaks and conducted a blower door test on each of the 270 homes they sold during 1986. Results of the tests showed that their sealing program reduced air-leakage rates by two-thirds compared with the infiltration rates measured in other Denver-area subdivisions. The favorable results were accomplished using the drywall as the primary air barrier. Air-sealing specialists used foam caulk to block air infiltration at the foundation and floor and wall joints. They also sealed wiring and electric penetrations in partition walls to minimize warm air movement into the attic. Annual heating bills averaged $135, or about one-third that of an average home. The cost of sealing varied with the size of the home but typically was between $300 and $400 for a home valued at $85,000. Besides providing quality control and saving energy, the sealing and testing program also helped to sell homes.

Older Homes. Experience has shown that the most effective place to begin sealing leaks in older homes is in the attic. The next most likely site is the floor above the basement or crawlspace and the foundation junction on a slab. Together, these sites typically account for more than 60% of the leaks in a home.

It is possible to seal several leaks without actually reducing the rate of air leakage in a home. For example, consider three adjacent holes in drywall, all leaking warm air through one hole in the siding. If all four holes are the same size, then sealing two of the drywall holes does not reduce the home's rate of air leakage; it simply transfers it to the remaining unsealed holes.

Safety Testing after Tightening

The blower door testing method can also be used to determine how susceptible a home is to backdrafting of combustion gases. Technicians have developed a backdraft test to determine how much exhaust air it takes to reverse the flow of unburned flue gases back down a flue. If this level is reached by simultaneously turning on several fans (kitchen and bath), contractors can take steps to supply additional air for combustion appliances. For further discussion, see Chapter 4.

Disadvantages of Blower Doors

Although a blower door can successfully detect leaks, using it to accurately and consistently calculate the rate of natural air infiltration is another matter. Testing methods vary from one region of the country to another. The discrepancy of methods has led to incompatible standards of measurement and calculation. Many of the more than 1000 blower doors used in the United States are never recalibrated in a testing chamber after being purchased. Another problem involves the adequate training and certification of technicians. In untrained hands, the blower door is a relatively useless tool; in the wrong hands, it presents an opportunity for outright fraud.

Another drawback to a blower door is its expense. The fan, adjustable door, pressure gauges, and computer typically cost between $1300 and $6000. At a cost of $0.30 or more per square foot, testing and sealing a typical 1500-ft^2 home often costs about $400 to $500.

When used in a utility-sponsored or low-income weatherization program, the cost for a door is acceptable. For example, in a conservation program

Meier, Alan. (September-October 1986). "Using the Blower Door: Part I." *Energy Auditor and Retrofitter* (3:5); pp. 12–18.

Meier, Alan. (November-December 1986). "Using the Blower Door: Part 2." *Energy Auditor and Retrofitter* (3:6); pp. 30–35.

Includes interviews from blower door contractors from New Jersey, California, and Washington about using the blower door to control air leakage. In Part 1, the contractors discuss their start in the business, their training, equipment and materials, and communications with the customer. In Part 2, the contractors discuss blower door accuracy and their experiences marketing an air-leakage service.

run by the city of Austin, Texas, 8500 blower door tests were conducted in 1984 alone as part of the audit and weatherization program.

The cost-effectiveness of reducing air infiltration after a blower door test is not well established. Some house-doctor retrofits in New Jersey that cost $400 per air-sealing job in the early 1980s showed an excellent return on the homeowners' investment. Partly because of New Jersey's cold climate and high utility rates, energy savings paid for the cost of air sealing within seven years. However, similar studies conducted by Bonneville showed the return to be poor. In a milder climate or an area with low utility rates, air sealing through the blower door technique is cost effective only when a home has a high air-infiltration rate [48].

Envelope Design Features for Factory-Built Buildings

The shell energy-conserving features already discussed in this chapter apply primarily to site-built homes and retrofit strategies. Although these features are just as important in factory-built housing, manufacturers face some special structural constraints that a builder on site can avoid. However, constructing a building within a controlled environment does provide the manufacturer with several potential energy-conserving advantages.

Manufacturers have improved the energy efficiency of their homes since the mid-1970s. Doors and windows are now more efficient, more insulation is used in ceilings, and heating system efficiencies are higher. A survey in 1984 showed that total utility bills averaged only $64 per month in new manufactured housing that met the HUD energy code [49].

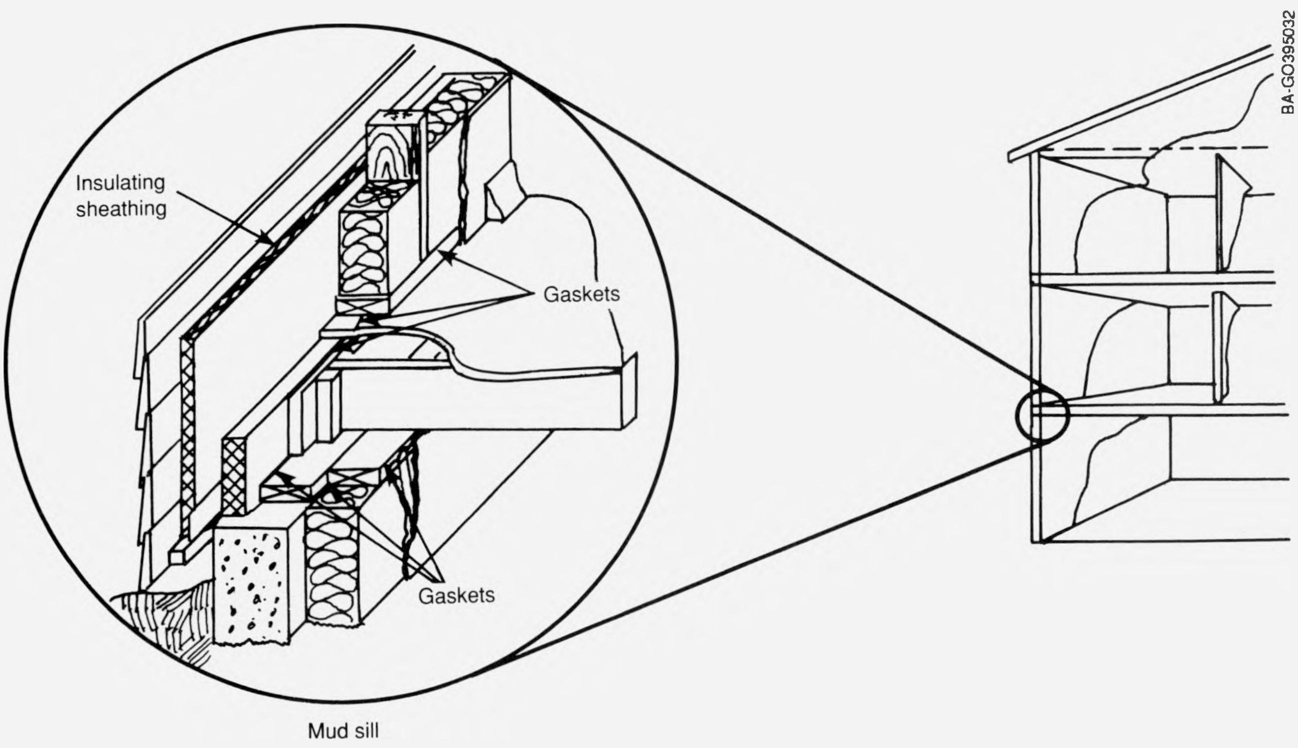


Figure 2-40. Airtight drywall gasketing—one of four key detail areas. (Source: Adapted from Lischkoff, James, and Joseph Lstiburek, January 1985, "Beyond the Poly Vapor Barrier," *Solar Age* 10(1): PB20)

Today, a manufacturer can choose from a variety of energy-efficient structural features. As with a site-built home, the efficiency of the average factory-built home is still far below that of the energy-conserving design.

The Factory-Built Home Market in the United States

In 1986, close to half of all new housing starts in the United States were either partially or fully built in a factory. The panelized home sector accounts for the largest and fastest-growing segment of factory-built housing. Other prefabricated approaches such as mobile, modular, and precut buildings have a sizable share of the market. Table 2-1 shows the market share for various types of factory-built housing.

Energy-Conserving Features and the Manufacturing Process

The manufacturing process imposes some constraints that limit some of the energy-conserving features that can be used. For example, a modular home must be structurally strong. A normal site-built home could never withstand being transported by truck at 50 mph and then placed on a foundation with a crane. To tolerate these conditions, a modular home has more framing in the walls and floors, which reduces the insulation value. Some energy-conscious modular builders have compensated for this lower insulating value by switching to a double-wall or a strapped-wall design. This design allows them to fit in extra insulation and still meet the stringent structural requirements.

Manufacturers do have some advantages over builders of on-site homes, particularly in preventing air leaks. Installing an air barrier within a controlled factory environment can be a cleaner and more thorough process than doing so on site. In the factory, the air-barrier and insulating processes are well understood and respected by electricians and plumbers working on modules only a few steps down the production line.

Table 2-1. Market Share of Various Segments of Factory-Built Housing

Market by Construction Type	No. of Units	% of Market
Mobile (HUD code)	285,000	14
Panelized	635,000	32
Modular	92,000	5
Stick-built	959,000	49
Total	1,971,000	100

Source: *Automation in Housing and Manufactured Home Dealer*, 1986, "Manufactured Housing 1986."

Manufacturers who use panel construction have an easier task of installing a tight air barrier because panel construction reduces the number of joints that need to be gasketed or caulked during installation. The foam-panel system is probably the most straightforward approach. Each panel is caulked on all four sides before being placed. This technique provides a durable air barrier that is not vulnerable to damage by other tradespeople.

The volume of buildings produced by a manufacturer makes it easier to buy and use blower doors. After a modular building is placed on site, blower door testing checks quality control, which can be used as a selling point.

Retrofitting Mobile Homes

Although newer mobile homes have substantially upgraded energy-efficiency packages, many mobile homes built before the implementation of the HUD standards in 1976 are still in use today. Recent research by SERI indicates that the challenge of retrofitting these units is substantially different than retrofitting a typical older, site-built house. SERI found it was almost impossible to find and correct the source of leaks without using a blower door. In testing 20 mobile homes, researchers found that the primary problems were to be found in water heater and furnace closets, shell penetrations for plumbing and appliances, distribution ducts, and swamp cooler chases. Infiltration was reduced by 40% when homes were weatherized with the assistance of a blower door, leading to a 15% reduction in utility bills [50].

Many housing manufacturers have demonstrated that it is possible to have low heating bills in a factory-built home. Methods of achieving a low heating bill vary dramatically. The following five case studies indicate the range of options.

Judkoff, R.; Hancock, E.; Franconi, E.; Hanger, R.; and Weiger, J. (December 1988). *Mobile Home Weatherization Measures: A Study of Their Effectiveness.* SERI/TR-254-3440. Golden, CO: Solar Energy Research Institute; 68 pp. Available NTIS: Order No. DE89000824.

Presents an investigation of cost-effective ways to weatherize mobile homes constructed prior to the enactment of the U.S. Department of Housing and Urban Development Thermal Standards in 1976. The effectiveness of a variety of infiltration-reducing retrofits was studied in FY 1987 by monitoring 20 units in the field before, during, and after application of air-tightening measures. In FY 1988, researchers began studying measures intended to reduce envelope conduction losses. These measures included storm windows; insulated skirting; and well, roof, and floor insulation. This part of the project resulted in the development of a short-term testing method for measuring the thermal impact of individual conduction-reducing retrofits.

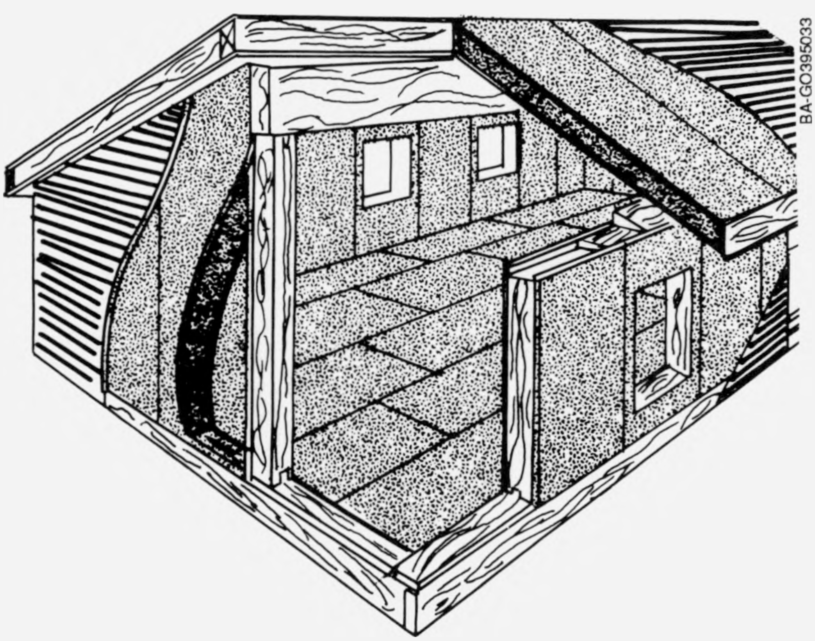


Figure 2-41. A continuous foam shell made by prefabricated structural foam panels as a durable rigid barrier against air infiltration. (Source: Adapted from information supplied by Foam Products Corp.)

CASE STUDIES

Acorn Structures, Inc., in Concord, Massachusetts, builds energy-efficient panelized homes for the upper-end market. It builds primarily in the Northeast but ships its homes all over the country. Many of its homes include both active and passive solar features. Much of its success with passive solar design stems from its involvement in SERI's Passive Solar Manufactured Buildings Program in the early 1980s [51]. Acorn's pilot design home, installed in Boulder, reduced energy consumption by 75% over a conventional home. Despite effective solar features, most of the savings in the Acorn home were attributable to conservation measures.

Pan Adobe Cedar Homes also participated in the SERI program. It is one of about 300 manufacturers that sell precut log homes. The insulating value of most log walls ranges from about R-5 to R-10. Pan Adobe developed options that help solve the problem of limited insulation of logs. In one approach, two rows of 3-in.-thick cedar logs are spaced as much as 4 in. apart; rigid foam is then inserted between the logs. Another option offers 1 to 2 in. of rigid foam on the outside of a single log wall. Cedar siding is used for the exterior finish. Either system could be adopted by log manufacturers to reduce air infiltration and boost the R-value of walls.

Buffalo Homes in Butte, Montana, builds about 20 superinsulated homes each year. Typical insulation values are high: R-45 batt material in a double-stud wall and R-60 in ceilings. It uses low-E double glazing and relies on carefully sealed polyethylene for an air barrier. Each home has a heat-recovery ventilator and is tested with the blower door technique on site to ensure airtight construction. One electrically heated 1400-ft^2 home with a garden-level basement was submetered by the local utility. During a relatively mild winter in a climate characterized by 8500 HDDs, the annual heating cost was $30.

Heritage Homes of Nebraska is another modular builder that ships homes within an eight-state region from Minnesota to Oklahoma. Heritage builds most of its homes with R-30 walls, R-50 ceilings, and tight construction. It guarantees a maximum annual heating bill when it sells a superinsulated home. The guarantee is based on a computer projection that was developed using such data as climate, orientation, home size, and utility rates. Guarantees range from $57 for a 1400-$ft^2$ gas-heated home in Colorado to about $300 for an all-electric model in Minnesota where it is colder.

Associated Foam Manufacturers (AFM) builds both structural and nonstructural foam-core panels for energy-efficient builders. A network of 36 distributors sells to independent builders throughout the country. A conservation program sponsored by the Western Area Power Administration in 1986 to 1987 in Brigham City, Utah, featured a well-publicized "energy diet" house built by energy specialists using AFM panels. The objective was to build a 1260-ft^2 house that would cost only $100/year to heat with electricity (about one-fourth the annual cost of heating a comparably sized home with natural gas). Initial energy bills indicated that the objective would be met. The airtightness and high insulating value of the panels—R-30 walls, R-50 ceilings—contributed more than any other element to the excellent performance of this house.

Figure 2-42. Blower door installed for testing a house. (Photograph by Steve Andrews)

The Emerging Influence of Scandinavian Technology on the Factory-Built Home Market

U.S. housing manufacturers face a different marketplace than their counterparts in Scandinavia; factories there have cornered as much as 90% of the housing market [52]. The Scandinavian reputation for quality and craftsmanship in factory-built housing is internationally known. The energy efficiency of each home's structure is a top priority with Scandinavian factory builders. The government tests 1 out of every 20 homes leaving a factory with the blower door.

The technology of factory-crafted housing in Scandinavia is slowly spreading throughout the United States in three ways:

1. Developers have built several imported upper-end housing projects, mostly concentrated along the East Coast. These projects demonstrate the quality and energy-efficient advantages of Swedish housing to American buyers and builders. High exchange rates and shipping fees, however, are diminishing the flow of Scandinavian homes into the United States.

2. Some American builders purchase Swedish-made energy-related products, such as gas-filled, low-E windows; UV-stabilized vapor barriers that come with a 50-year guarantee; and special gasketing material for use in airtight construction.

3. Some U.S. builders who have toured Scandinavian housing factories borrow some building details, ranging from new ways to gasket modules together for a tighter fit to the use of money-saving, precast foundation systems.

Lass, W.; Jones, R.; and Cerniglia, P. (August 1986). *The Danish House at the Brookhaven International Housing Village: First Year's Preliminary Results.* BNL-38790. Upton, NY: Brookhaven National Laboratory; 76 pp. Available NTIS: Order No. DE87007154.

Discusses the International Housing Village at Brookhaven National Laboratory, which has assembled affordable, prefabricated quality homes demonstrating what other countries have done to overcome many of the building industry's problems. The primary goals of the project are the demonstration of energy performance, affordability, efficient production techniques, and time-saving assembly. The Danish House at Brookhaven is described, and the experimental results for the first year are given.

Efforts such as these will continue to expose U.S. builders to more energy-conserving factory-built homes. Differences between the U.S. and Scandinavian housing industries, however, hinder the applicability of their building systems here. In Scandinavia, the industry tends toward heavily automated production of homes that are known for their craftsmanlike quality. U.S. housing factories have a reputation for using mediocre workmanship. Americans are still attached to the site-built home, which they consider superior to a factory-built home.

In Sweden, one national building code and a relatively uniform climate make it much simpler for manufacturers to meet code requirements; in contrast, most local jurisdictions in the United States have the authority to establish their own codes. Most adopt codes suggested by national code-development organizations such as the Council of American Building Officials but frequently add or delete requirements to suit their own climatic and political situations. Finally, in Sweden, the lending community actively supports energy conservation in buildings; in the United States, appraisers and lenders have been slow to acknowledge the value of energy efficiency in both site-built and factory-built homes and have been even slower to actively demand such efficiency.

CASE STUDY

One effort to better understand the implications of different approaches to factory-built housing is taking place at Brookhaven National Laboratory (BNL). BNL has established an International Housing Village that consists of examples of factory-built houses from several different countries. BNL is attempting to look at such elements as energy performance and cost, construction quality, "curb appeal," and livability. One of the earliest homes installed was from Denmark; it consisted of R-30 ceiling, R-21 walls, modular electric heating panels, a passive solar greenhouse, and a heat pump supplying space and water heating. Its performance was monitored on 30 different data points, and an energy balance was calculated showing that it uses 2.1 Btu per degree day per ft^2, significantly lower than the most energy-efficient, superinsulated buildings monitored in North America [53].

Ongoing Research Efforts

This section describes research in a variety of fields that will increase the efficiency of structural components and techniques, mechanical equipment, and appliances. Although it is not comprehensive, the section provides an indication of the directions being pursued by the U.S. Department of Energy (DOE), the various national laboratories, industry associations, and manufacturers.

Structural Elements for New Homes

Various national laboratories and agencies are measuring, quantifying, and comparing air-infiltration rates. The agencies studying this problem include the NAHB National Research Center, LBL, BNL, ORNL, and Bonneville.

Another topic being studied by numerous agencies is the thermal performance of insulating materials in different configurations. For instance, FSEC is focusing on windows and radiant barriers in hot climates; ORNL on foundations and roof and wall assemblies; SERI on windows;

the National Bureau of Standards on materials and window standards; and LBL on walls and windows. Special problems presented by hot-dry and hot-humid climates are receiving increased focus.

An upcoming federal program that could greatly affect existing practices is DOE's performance standards for new buildings. These Federal Residential Standards will be mandatory for all federal agencies and voluntary for the nonfederal sector. Federal agencies will have the option of adopting the mandatory standards or developing their own guidelines that meet or exceed those specified by the DOE program. The first demonstration of the standard—still in the development stage—will be in the Northwest, with assistance provided by Pacific Northwest Laboratories.

Structural Elements for Existing Homes

Research is under way that includes virtually all retrofit measures. The following list describes several projects:

- Foundations: The New Jersey Institute of Technology is developing improved guidelines for crawlspace insulation and ventilation as a function of geographic location. Work analyzing basement insulation at ORNL will prove useful in retrofitting existing homes as well as in constructing new homes.
- Ceilings: The Massachusetts Institute of Technology is studying the problem of moisture condensation in ceiling insulation. FSEC, the University of Mississippi, and ORNL are all continuing their research on the benefits of radiant barrier systems.
- Infiltration: Several studies at BNL focus on assessing data gathered with the air-infiltration measurement system tracer-gas technique and using it to determine natural air-infiltration rates in buildings. LBL is also working on refining infiltration measurement techniques. SERI is investigating infiltration-reducing weatherization measures in older mobile homes to determine the cost-effectiveness of retrofit measures.
- Overall Effectiveness: Data continue to be generated through Bonneville's multiyear Hood River Conservation Project, in which electricity use monitored in 320 Oregon homes allows accurate estimates of energy savings. Over 90% of the homes in a single community have been retrofitted with superinsulation-type energy features: R-49 ceilings, R-38 floors, triple glazing, and air sealing.

Factory-Built Housing

Bonneville has assisted in the development of energy-efficient manufactured housing in the Pacific Northwest. One of its early efforts involved the retrofitting and subsequent monitoring of 420 manufactured homes in Hood River, Oregon. Data are currently being gathered on 39 new homes; this information should be available in late 1988. Bonneville has assisted in the development of an additional 150 new factory-built homes under the Residential Construction Demonstration Program (RCDP), which were monitored during the winter of 1988 to 1989. RCDP homes include features that exceed the standards set for Bonneville's Super Good Cents Program.

SERI is investigating infiltration-reduction weatherization measures in 20 older mobile homes. The objective is to determine the thermal effectiveness and cost-effectiveness of retrofit measures.

Windows

Glass manufacturers are working on technologies that will produce windows with ratings of R-6 to R-10. LBL operates a Mobile Window Thermal Test Facility, which allows it to test many different types of glazing at different orientations.

In late 1988, a new version of LBL's window software program became available. WINDOW 3.1 goes a long way toward standardizing heat-transfer calculations and designing new insulating window systems [54].

SERI is developing a unique vacuum laser welding approach for edge welding of sealed and evacuated glazing [55].

Reilly, Susan, and Arasteh, Dariush. (May 1988). *Window 3.1: A Computer Tool for Analyzing Window Thermal Performance*. LBL-25148. Berkeley, CA: Lawrence Berkeley Laboratory; 7 pp. Available NTIS: Order No. DE88013708.

Provides an overview of WINDOW 3.1, a public-domain computer program developed by the Windows and Daylighting Group at Lawrence Berkeley Laboratory for analyzing best transfer through window systems. The program uses an iterative technique to calculate the one-dimensional temperature profile across a user-defined window system. From these data, window system performance indexes (e.g., U-value, shading coefficient) are calculated. WINDOW 3.1, a major update to WINDOW 2.0, incorporates several technical additions and many new user-friendly features and provides a consistent and versatile means for best transfer analysis, as did WINDOW 2.0. WINDOW 3.1 can vary environmental conditions, window tilt, number of glazing layers, layer properties (thermal infrared, solar and visible optical properties, and thermal conductance), gap widths, composition of gap gas fill, and spacer and frame materials. This paper presents the computational methodology, describes the capabilities of the program, and discusses the applications of WINDOW 3.1 for standardizing window heat-transfer calculations and designing new insulating window systems.

Office of Buildings and Community Systems: FY 1986 Research in Progress. (July 1986). DOE/TIC-11628. Washington, DC: U.S. Department of Energy; 38 pp. Available NTIS: Order No. DE87006788.

Describes the 1986 research activities of the U.S. Department of Energy Office of Buildings and Community Systems (OBCS). Activities undertaken by OBCS are grouped into six major subprograms: Buildings Systems, Technology and Consumer Products, Appliance Standards, Community Systems, and Analysis and Technology Transfer. The report is organized into corresponding sections. Three indexes help the reader find the entries based on the research and development subject, principal investigator, and organizational affiliation.

Chapter 3
Energy-Conserving Mechanical Features

All the energy delivered by utilities to new and existing homes is used by the mechanical equipment within the home; this equipment heats or cools the space, heats water, lights the home, and allows for the many other appliance functions that ease modern living. The efficiency of this equipment has a major impact on the energy consumed in a house. No comprehensive plan to conserve energy can focus exclusively on a home's shell energy features. It must also include efforts to maximize the efficiency of the mechanical equipment used every day.

Prior to the 1980s, mechanical equipment, like home-building techniques, was not designed with energy efficiency in mind; cost and ease of installation and maintenance were the primary considerations. During the 1980s, however, manufacturers have taken a quantum leap forward in improving the efficiency of residential lighting, water heating, and space-conditioning equipment. Extensive ongoing research and development (R&D) efforts will bring many more improvements in the efficiency of new equipment. Better space heaters, advanced heat pumps, and more energy-efficient clothes dryers will soon be available. Integrated appliances that heat water as well as heat, cool, and ventilate the home are also being tested, and early models are already on the market.

In March 1987, the U.S. Congress passed the first National Appliance Energy Conservation Act. The act establishes minimum efficiency standards (or maximum energy consumption) for residential appliances and heating, ventilating, and air conditioning (HVAC) equipment. To be implemented in stages between 1988 and 1992, the law will make efficient mechanical appliances the norm rather than the exception. Table 3-1 illustrates some of the changes that will take place as a result of this law.

The American Council for an Energy Efficient Economy (ACEEE) has tracked appliance efficiency for several years. It reports that these new standards are stringent enough that 70% to 90% of most products offered in 1986 do not qualify. The council estimates the standards will save consumers at least $26 billion over the lifetime of appliances sold through the year 2000. This figure amounts to about $300 per household. In addition, the council calculates that the new appliance standards will reduce peak electricity demand by the equivalent of 25 large power plants [56].

Heating and Cooling Systems

Nearly 80% of the heating equipment installed in homes is selected by the builder, the heating contractor, or the building designer [57]. The remaining 20% is specified by the homeowner. The builder tends to select equipment with a low front-end cost, most of which has bottom-of-the-line efficiency. By 1992, the National Appliance Energy Conservation Act will reduce the scope of this problem, but until this time, buyers need to be aware of the economic benefits of installing HVAC equipment with at least midrange efficiency.

A breakdown of space heating by equipment and fuel type is given in Table 3-2. The following subsections discuss these pieces of heating equipment.

Geller, Howard S. (April 1987). *National Appliance Efficiency Standards: Utility and Consumer Impacts.* Washington, DC: American Council for an Energy Efficient Economy; 13 pp. Paper prepared for the Third National Conference on Utility DSM Programs; 16–18 June 1987; Houston, TX.

> Summarizes the energy and economic impacts that can be expected from the National Appliance and Efficiency Standards from both the utility and the consumer perspectives. These standards contain minimum efficiency standards for residential appliances and heating, ventilating, and air conditioning equipment that apply at the point of manufacture. The appliance standards are relatively stringent. For most products, 70% to 90% of the models offered or produced in 1986 won't qualify when the standards take effect. Consequently, the standards will have a significant impact on residential energy consumption in the future. The energy savings resulting from the standards will need to be considered as utilities forecast load growth and plan supply-side investments and demand-side management (DSM) efforts. The effect the standards could have on other utility DSM efforts is also discussed.

Geller, Howard S. (April 1987). *Energy and Economic Savings from National Appliance Efficiency Standards.* Washington, DC: American Council for an Energy Efficient Economy; 13 pp.

> Examines the energy and economic savings that can be expected from the national minimum efficiency standards for appliances signed into law by President Reagan in March 1987. These standards represent a compromise agreed to by appliance manufacturers and conservation advocates. The proposed standards levels are listed in Appendix A. The savings are calculated on a product-by-product basis using a consistent methodology.

Table 3-1. National Appliance Efficiency Standards

Product	1985 Average Efficiency[a]	Standard Level[b]	Year Standard Takes Effect
Refrigerators	1100 kWh	976 kWh	1990
Freezers	790 kWh	671 kWh	1990
Electric water heater	0.836 EF	0.884 EF	1990
Room air conditioner	7.7 EER	8.6 EER	1990
Central air conditioner[c]	8.6 SEER	10.0 SEER	1992
Gas furnace	0.74 AFUE	0.78 AFUE[d]	1992
Gas water heater	0.494 EF	0.544 EF	1990
Gas range[e]	—	—	1990

AFUE = Annual fuel utilization efficiency.
EER = Energy efficiency ratio.
EF = Energy factor.
SEER = Seasonal energy-efficiency ratio.

[a] The 1985 shipment-weighted efficiency is expressed in terms of annual electricity use for refrigerators and freezers. For other products, the conventional unit of efficiency is used.

[b] The standard level is the average for all product classes. It is given in terms of the maximum electricity use for refrigerators and freezers and minimum efficiency for the other products.

[c] The central air conditioner standard applies to split systems; the minimum standard for package units is 9.7 SEER, effective in 1993.

[d] The gas furnace standard is based on the isolated combustion air test, which is equivalent to about an 0.80 AFUE rating with the test procedure currently used by the Furnace Industry Association.

[e] The gas range standard bans the use of pilot lights in ranges and ovens having an electrical supply cord.

Source: Geller, Howard, 1987, "National Appliance Efficiency Standards: Utility and Consumer Impacts," Paper presented to the Third National Conference on Utility DSM Programs, 16–18 June 1987.

Furnaces

Each type of furnace equipment has its own particular advantages, efficiencies, and problems. This section describes the current state of the technology for each fuel and equipment type.

Prior to the 1973 oil embargo, the average new natural gas furnace had a steady-state efficiency of about 65%. By 1986, the average had improved to 74%. However, this efficiency is still below the performance level of furnaces in today's energy-efficient homes, where 80% efficient furnaces are considered to be the most cost effective if the shell meets leading energy-efficiency standards.

In 1982, the first condensing furnace with a 90+% efficiency was introduced. By 1987, nearly all gas heating equipment manufacturers offered

"High-Efficiency Gas Furnaces—A Survey of Problems." (April 1987). *Energy Design Update* (6:4); pp. 9–13.

Presents results of a survey conducted by Howell-Mayhew Engineering for Alberta Energy, soliciting almost 600 complaint reports from equipment distributors, heating contractors, gas inspectors, municipal inspectors, utility supervisors, builders, educators, government officials, and homeowners. The list of complaints, which also had information on causes and solutions, included system shutdown, component failure, premature activation of temperature-pressure safety switches, improper installation, furnace noise, condensation in the existing flue, icing at the flue terminal and on the an array of medium- (80%) or high-efficiency units. According to the American Gas Association, one-third of all residential gas furnaces sold from 1984 through 1986 were 80% efficient or higher. Oil-fired furnaces have recently begun to catch up; several oil furnaces on the market offer 90% efficiency.

Table 3-2. Heating and Cooling Equipment in Single-Family Homes, 1979–1983 (% of houses)

Heating Equipment	1979	1980	1981	1982	1983
Gas forced air	41	45	41	48	45
Electric forced air	19	15	13	12	17
Oil forced air	2	2	1	1	1
Gas hot water	2	2	2	2	2
Oil hot water	1	—	1	1	1
Heat pump	25	24	25	25	25
Electric baseboard	7	10	9	8	7
Other	3	2	8	3	3
Total	100	100	100	100	100
Heating Fuel					
Gas	43	47	45	51	48
Electric	52	51	53	47	50
Oil	5	2	2	2	2
Total	100	100	100	100	100

Source: *Blue Book of Major Homebuilders: Major Research Report on Who's Who in Housing*, 1985. Crofton, MD: LSI Systems, Inc.

Typically, furnaces with a 90+% efficiency are condensing furnaces. Their higher efficiency comes from the ability to extract the heat from condensation from the water vapor in the exhaust gases.

In addition to offering lower heating bills, condensing furnaces can also save on space and installation costs. Because exhaust gas temperatures from condensing furnaces are 100 deg or lower, builders can exhaust these gases through side-venting 2-in. polyvinyl chloride pipe, thus eliminating the need for large flues and chimney chases. Also, many of these units use sealed combustion, with outside air piped directly to the combustion chamber so that unburned combustion gases cannot be backdrafted into a home.

The new condensing furnace technology has not emerged without its problems, however. A number of builders have complained about the complexity and reliability of the new models. HVAC contractors have cited problems with components, ranging from finicky exhaust fans to faulty pressure differential switches and corroded heat exchangers [58]. In general, though, manufacturers have responded quickly to these problems.

The move toward efficient homes during the last 10 years has increased concerns about possible inefficiency from oversizing. As late as the early 1970s, furnaces were typically sized to meet more than twice a home's expected heat-loss rate. High-efficiency furnaces can minimize these concerns about oversizing, but new data indicate that oversizing might have little impact on overall energy consumption [59]. However, because oversizing can lead to uncomfortable temperature swings, significant downsizing for today's energy-efficient home is still a necessary step. The new units that offer longer cycles with gradual heating are likely to provide more equal heating.

The highest-efficiency furnaces are rarely cost-effective investments in today's energy-efficient homes: The added cost outweighs any reasonable expectations of energy savings. The best furnace usually costs an additional $800, yet the annual savings in an energy-efficient home is in the $30 to $60 range. A possible exception to this guideline is a large custom home that might have a large heating load ($300 or higher) despite excellent energy-conserving features.

side of the house, corrosion, homeowner discomfort, and condensation in the house. The article also provides a summary of problems noted for specific furnace brands that existed at the time of the Alberta study.

"Options for Residential Forced-Air Heating." (January 1987). *Energy Design Update* (6:1); pp. 9–13.

Presents the SP43 computer model as a better way to look at residential heating systems. The model was developed as part of Special Project 43 sponsored by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) and cofunded by the Gas Research Institute and the U.S. Department of Energy. The purpose of this tool is to provide the heating, ventilating, and air conditioning industry with a way to assess options of system components and control modes to account for the dynamics and thermal interactions of equipment and loads. A tabulation of the results of SP43 simulations is planned for the *ASHRAE Equipment Handbook*.

CASE STUDY

Professional Builder has recognized Columbine Homes, Denver, Colorado, and Bigelow Homes, Chicago, Illinois, as among the most energy-conscious production builders in the country. They have built 1200 to 1700 ft^2 homes that heat for less than $150 during an entire winter by using R-20 or better wall insulation, R-45 ceilings, R-11 to R-20 basements, and tight sealing (Figure 3-1). If these homes had 95% efficient furnaces, rather than 80%, the savings would be under $30/year. It would take over 20 years—beyond the furnace's life expectancy—for the savings to offset the added cost.

Space Heating with Water Heaters

A clear trend for the future is the development of a single energy-efficient heating appliance that performs several mechanical functions. In the early 1980s, the Swedes pioneered the use of integrated mechanical equipment that heats homes, heats water, and provides fresh air. By 1987, only one U.S. company had a similar appliance on the market. The Gas Research Institute (GRI) is testing an integrated HVAC prototype. To date, the only multifunction HVAC approach that has been installed on a widespread basis is combined space and water heating.

In today's typical new, gas-heated home, a 60,000 to 100,000 Btu/hour gas furnace for space heating alone is the norm. However, it is not unusual for a state-of-the-art, energy-efficient home of average size to require only 15,000 to 25,000 Btu/hour under peak winter conditions. Such a small heating load is typical for the two production builders mentioned in the previous case study. Both builders are able to meet this entire load with hot water heaters rated at 40,000 Btu/hour.

Figure 3-2 illustrates this hot water heater. The heater has a separate line running to a water-to-air fan-coil unit inside an air handler. When the home needs heat, hot water is pumped from the hot water heater to the air handler, which supplies warm air. Because the air handler is less expensive than a furnace, it allows the builder to upgrade to a high-efficiency hot water heater.

Figure 3-1. Columbine Homes model in Denver, Colorado. (Photograph by Steve Andrews)

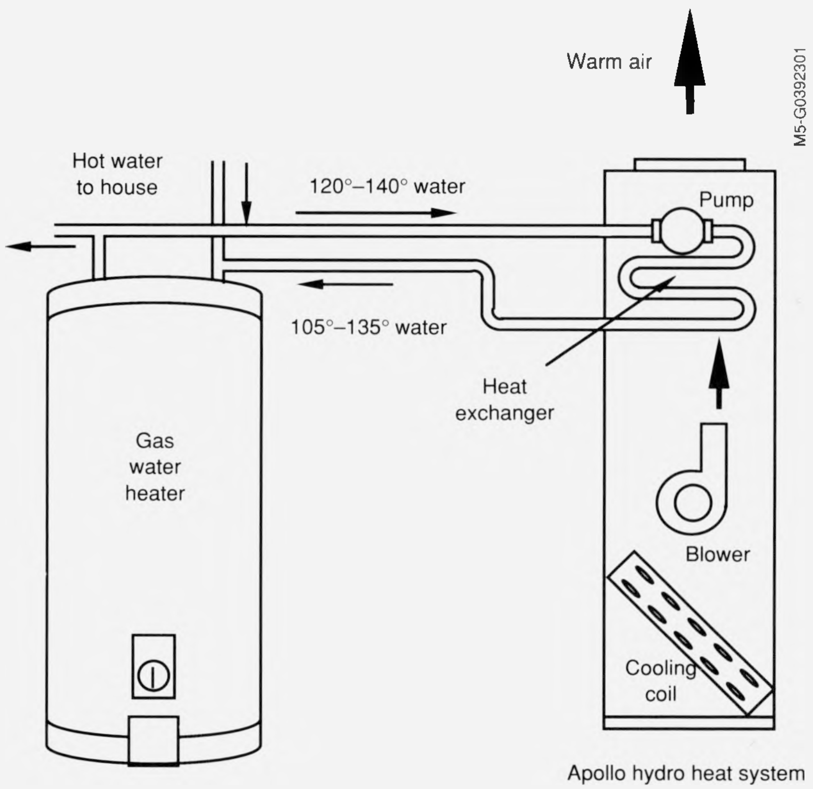


Figure 3-2. Space heating with a water heater and an air handler.
(Source: Adapted from information supplied by Apollo Comfort Systems.)

Using a water heater to heat efficient homes in the sunbelt is quite simple. Standard water heaters must simply be checked to ensure they offer enough capacity to handle a home's heating load. Even in severe climates such as in Canada, one state-of-the-art home near Saskatchewan (which has 12,000 heating degree days) is heated with a typical 36,000-Btu water heater.

Boilers

Gas-fired hydronic heating systems for baseboard heating or radiant floor slabs circulate water instead of air and offer the advantages of zone-controlled, comfortable heat delivery without noise. The best units on the market have improved their efficiencies through the use of such design features as low-mass copper heat exchangers. However, those units with top operating efficiencies, about 87%, are typically 5% to 10% less efficient than the best gas forced-air systems.

GRI has teamed up with a manufacturer to develop a condensing boiler that can achieve 90+% efficiency. Compared to other high-efficiency boilers on the market today, its primary advantage is cost. GRI estimates the boiler will provide immediate positive cash flow compared to every other boiler on the market.

Hydronic boiler manufacturers continue to improve their products. They have increased the number of models on the market that provide both space and water heating. Such equipment eliminates both the water heater's separate burner and its heat-draining center flue so that water-heating efficiency is significantly improved (Figure 3-3). Even so, in recent years because of the high initial cost, the number of hydronic heating installations has declined to 2% to 3% of the market. This trend is expected to continue, especially with the increasing number of other multifunction systems being developed.

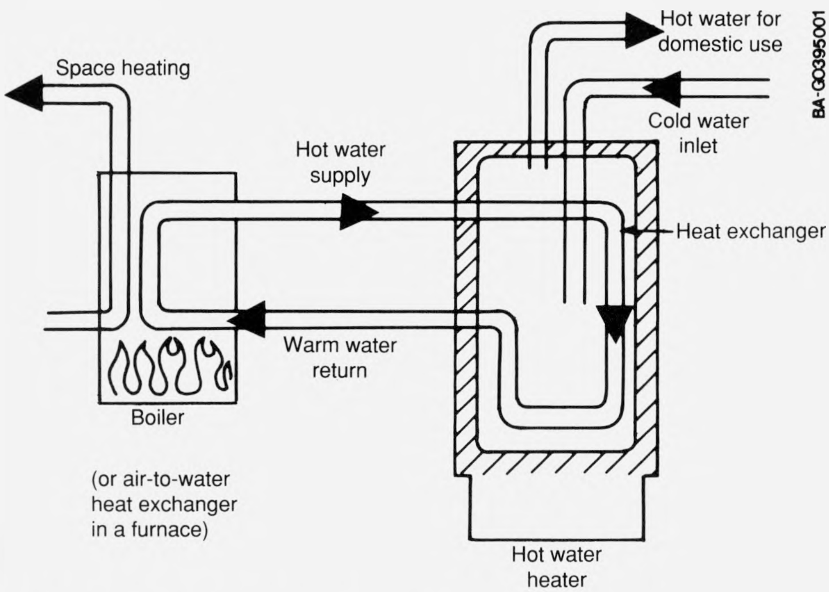


Figure 3-3. Heating water with a boiler

Electricity

In 1986, forty-six percent of all new homes were heated with electricity, and 47% were heated with gas. In most regions of the country, natural gas is on the average the least expensive fuel per Btu of delivered heat on average. Gas used in a 70% efficient furnace costs less than $9.00/million Btu ($0.57 per hundred cubic feet), but 100% efficient electric heating costs over $23.00/million Btu ($0.08 per kWh). Only when heating loads or electricity costs are extremely low, such as in the Pacific Northwest, can electricity costs come close to those for natural gas. Even then, electricity competes only when the initial cost of electric heating equipment is lower than the installed costs for gas equipment.

Electric heating comes in several forms: zoned heaters, electric storage furnaces, and heat pumps.

Zoned Electric Heating

There are three basic types of zoned electric heaters: baseboard, forced-air fan, and radiant. Baseboard heating is the least expensive option to install. Fan-forced electric wall heaters provide zoned heating at a marginally higher cost. The one advantage they offer is the elimination of baseboards, which gives homeowners increased flexibility with furniture placement.

Electric radiant heating, a more expensive choice, is slowly gaining ground among energy-conscious builders. It provides zone control with materials in the ceiling that are mounted on or behind the drywall. Manufacturers claim that radiant heat provides a comfort and performance advantage because of the "radiant effect." They point out that radiant heat flows to objects and people first before it warms the air (Figure 3-4). These efficiency advantages might have value in a drafty house but are nearly eliminated in energy-efficient homes. The California Energy Commission gives radiant systems a 4% credit for the radiant effect. Additional testing of radiant heating systems is under way to accurately establish whatever savings advantage they might offer [60,61].

Andrews, Steve. (January 1987). "Electric Radiant Heat." *Progressive Builder* (12:1); pp. 29–32.

Discusses whether electric radiant heating actually saves energy. Three studies conducted in Massachusetts found that using radiant heating did not significantly save energy. In addition, problems were noted in occupant comfort and even heat distribution. Manufacturers cited other studies showing radiant heating did save energy. One manufacturer suggested several reasons for the Massachusetts test results and recommended several solutions to common application problems. Studies conducted in other states suggested that radiant heating has advantages when used for zoned heating and when factors such as maintenance and appearance are considered. The article concludes with descriptions of basic types of radiant heating products and information on future tests to be conducted by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers and Portland General Electric.

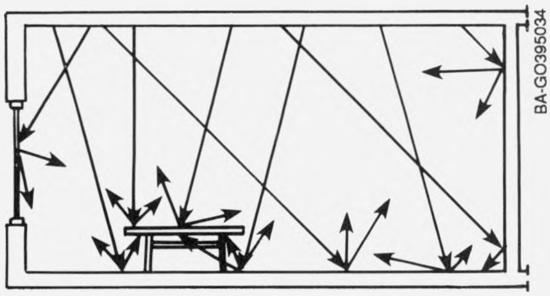


Figure 3-4. A warm ceiling radiating infrared radiation to other surfaces and objects in the room without warming the air in between; eventually, objects heat the air, and in an energy-efficient home, the air and surrounding surfaces reach equilibrium. (Source: Adapted from "Special Report: Electric Radiant Ceiling Heat," October 1986, *Energy Design Update* (5:10): 11)

"Special Report: Electric Radiant Ceiling Heat." (October 1986). *Energy Design Update* (5:10); pp. 10–19.

Examines whether using radiant ceiling heat really does result in energy savings (Part 1). The basic finding was that energy savings result when radiant ceiling heat is used for zoning but that by allowing people to operate their houses at a cooler temperature, its use generally does not help to reduce energy consumption. The second part consists of an electric radiant ceiling buyer's guide. Descriptions, products, and manufacturers are listed for flexible element heaters, gypsum board with embedded heater wires, modular heating panels, and cable systems.

Electric Storage Furnaces

Electric storage furnaces store heat for later use. To date, they haven't offered efficiency advantages for energy-efficient homes. However, a new product might soon change this situation. Under the sponsorship of the Electric Power Research Institute (EPRI), a new furnace has been designed that can store energy when electricity rates are low and provide heat, as needed, during higher-cost periods. Heat purchased during the off-peak period is stored in a ton of crushed rock (Figure 3-5). This heat-storage furnace went on the market in 1988.

Heat Pumps

The heat pump is the clear-cut leader in electric heating installations. EPRI reports that over 1 million new heat pumps were installed during 1985. Just over one-fourth of all new homes come with heat pumps.

The heat pump is designed to extract "free" heat from outside air (40° F or higher) or the soil or groundwater and raise the indoor temperature to the desired level. A pump that gets its heat from the outside air is called an *air-coupled heat pump* (simply called a heat pump here), and that which extracts its heat from the soil or groundwater is called a *ground-coupled heat pump*. By using the free heat, the heat pump can attain the desired indoor temperature at half the cost of standard electric heating. When a home also requires some mechanical cooling to provide dehumidification, the heat pump is usually the first choice for the HVAC system, especially in regions where winter temperatures rarely drop below freezing. In freezing climates, the electric resistance unit in a heat pump must occasionally defrost the outdoor air coil, thus decreasing performance; heat pumps can't extract much heat energy from air that is below freezing, which also decreases cold-climate performance.

The efficiency of electric heat pumps is steadily improving. Manufacturers have developed more efficient motors and compressors. Larger condenser coils provide more effective dehumidification. Controls have also improved.

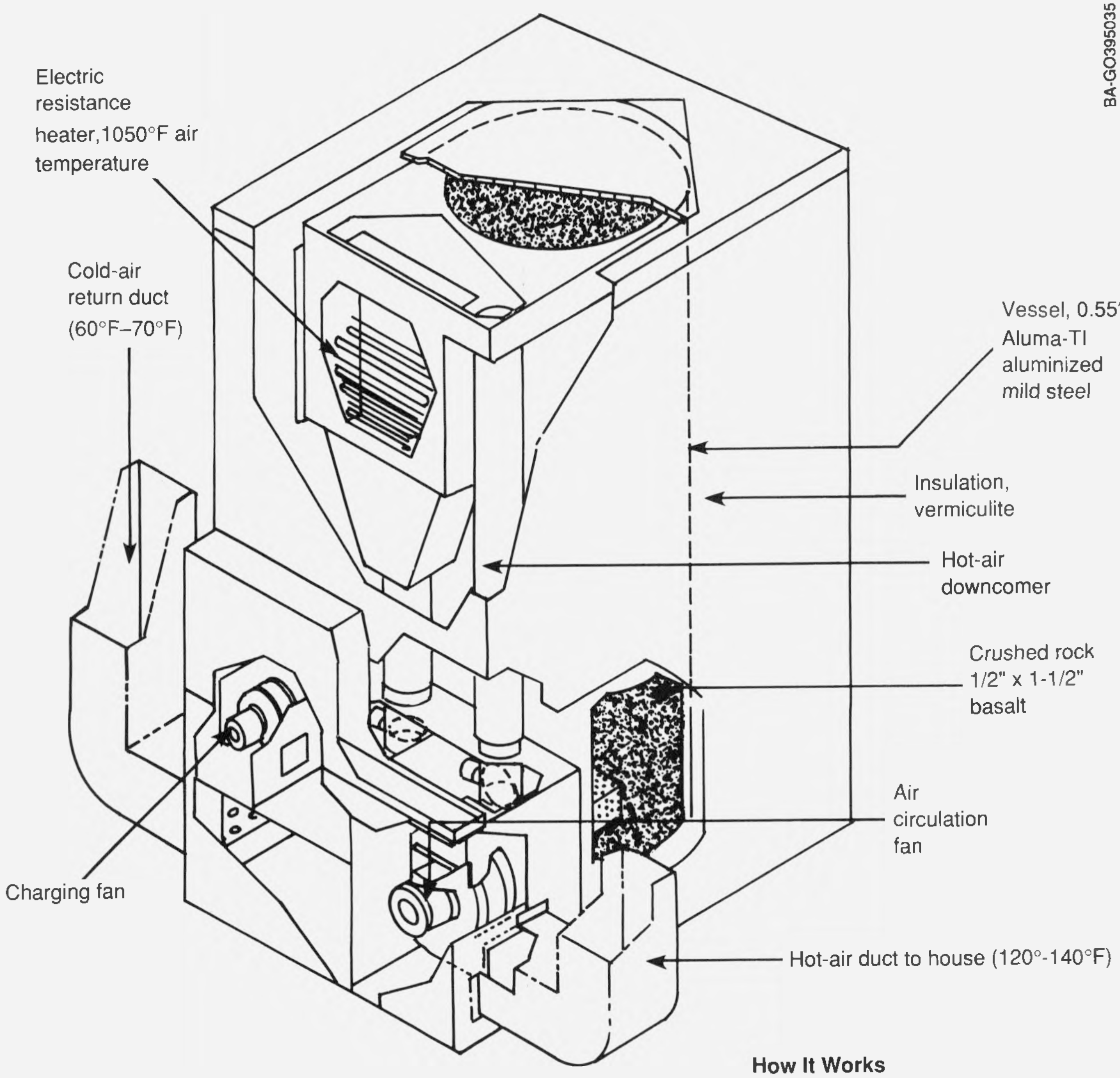
According to ACEEE, the average heat pump sold in 1986 had a cooling seasonal energy-efficiency ratio (SEER) of 8.6 and a heating season performance factor (HSPF) between 6 and 7. However, the 1987 Appliance Energy Conservation Act requires minimum SEERs of 10 and HSPFs of 6.8. Gas forced-air heating systems have nearly achieved their theoretical

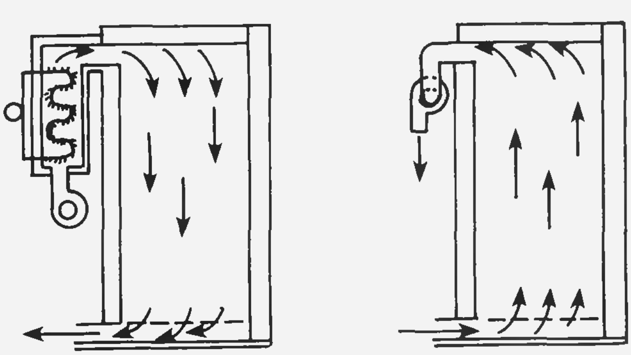
"Electric Heating Can Compete Economically with Gas, Study Shows." (July 1987). *Energy Design Update* (6:7); p. 63.

Reports on the findings of a study performed by Dr. George Tsongas of Portland State University in Oregon. Although the study's observations are specific to the Northwest region, they might also be of interest to the heating industry in general. The study revealed that annual heating costs with noncondensing power-vented gas furnaces are about the same as annual heating costs with conventional heat pumps. High-efficiency heat pumps, however, have the lowest annual energy costs. Zonal electric heating systems cost approximately the same to operate as most commonly installed conventional gas furnaces. Finally, the annual heating costs of most electric and gas space-heating systems are fairly comparable in the Portland area.

Heat Pump Reliability. (1986). Palo Alto, CA: Electric Power Research Institute; 4 pp.

Summarizes results of studies begun in 1984 to assess the reliability of heat pumps installed in the mid-1960s by analyzing equipment service life and maintenance characteristics. Three EPRI-sponsored research projects have been completed to date to determine both heat pump service life and compressor life: two surveys of heat pump owners and one study of heat pump maintenance records. Information is provided on how to obtain these and other reports on heat pump reliability.





How It Works

Charging
A charging fan blows air through a resistance heater, where it is heated to 1050°F. The air is then forced through the bed of crushed rock, heating the rocks to near 1050°F. The air is exhausted from the bottom of the bed into the plenum at about 170°F.

Discharging
The circulating fan sucks the returning house air through the heated crushed rock bed, initially heating it to near 1050°F. The air then flows down the hot-air downcomer and is released into the fan plenum through a modulating damper. The hot air is diluted to 120°–140°F by return air passing through the bypass orifice.

Figure 3-5. The Electric Power Research Institute heat storage furnace. (Source: Adapted from information supplied by the Electric Power Research Institute)

CASE STUDY

High-efficiency heat pumps compared favorably with other heating options in a recent study of monthly bills in Portland, Oregon, where electricity costs—$0.05/kWh—are well below the national average of $0.082. The study showed that heating bills for homes with conventional heat pumps had the same annual heating costs as medium-efficiency (80%) gas furnaces. Standard zoned electric heaters cost more, or about the same as conventional (65% efficient) gas furnaces. The lowest annual heating costs were for high-efficiency heat pumps [63].

optimum performance, but heat pump efficiencies should continue to improve [62].

According to studies by EPRI, the reliability of heat pumps has improved since the first installations in the early 1950s. Surveys by Alabama Power Company and Commonwealth Edison Company, Chicago, indicate that heat pumps installed in the late 1960s generally lasted more than 15 to 20 years (Figure 3-6). In Alabama, 75% of the units were still operating after 15 years, and more than 50% were still operating after 20 years. In Chicago, the 15-year figure was 53%. Some units lasted 26 years. About one-half the heat pumps were still operational when they were replaced [64].

EPRI data also indicate that most owners will replace their compressor only once during the heat pump's lifetime. However, some studies by Bonneville are less encouraging. In some cases, they show a compressor lifetime of under three years.

EPRI reports that in 1985, the average installed cost for a 3-ton heat pump was $3500, excluding duct work. However, initial heat pump costs should be lower for energy-efficient homes because of the smaller output required. When sizing a heat pump for a tightly built well-insulated

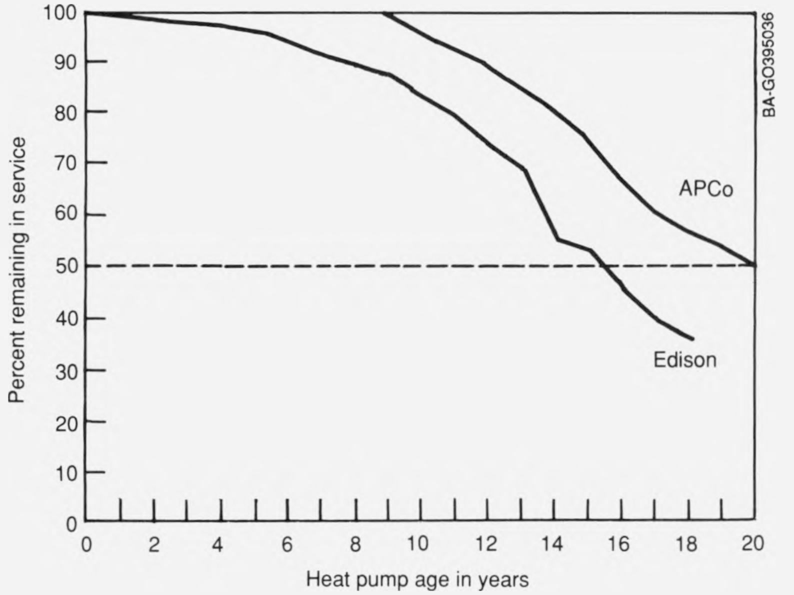


Figure 3-6. Heat pump service life possibly greater than 20 years, according to surveys conducted by Alabama Power Company and Commonwealth Edison Company

Ground-Coupled Heat Pump. (1987). Technical Brief. Palo Alto, CA: Electric Power Research Institute; 2 pp.

Provides basic information on ground-coupled heat pumps for the residential sectors. The separating principles and efficiencies are described and compared to air source units. The general specifications, availability, costs, and reliability of residential units are given. Customer and utility benefits and acceptance are discussed.

"Ground-Coupled Heat Pumps: ORNL Research Aims at Lowering Costs." (1987). *Oak Ridge National Laboratory Review* (3); pp. 23–24.

Discusses research at Oak Ridge National Laboratory (ORNL) on closed-loop, ground-coupled heat pump (GCHP) systems. Several GCHP systems tested in Knoxville, Tenn., by ORNL and the University of Tennessee have achieved higher efficiencies than a high-efficiency air-to-air heat pump (AAHP). However, because of the high cost of a ground-core heat exchanger, the GCHP is more expensive than the AAHP. Reducing the cost of the ground-coil heat exchanger has been the goal of ORNL research. Activities have focused on the development of more realistic design models of the ground-coil heat exchanger and the optimization of the GCHP system design. The optimization project has shown that increasing the efficiency of the water-source heat pump (WSHP) reduces the ground-coil length and, thus, the system's cost. Two high-efficiency WSHP prototypes have been built, and field testing has shown promising results.

home with low-E windows, care must be taken to accurately calculate the reduced heating and cooling loads.

The ground-coupled heat pump is the newer technology [65]. It circulates water or antifreeze to capture heat from water or soil. Because ground temperatures rarely fall below 40 or 45 deg, the earth provides a stable source of heat relative to the widely varying air temperatures (Figure 3-7). The advantage of the ground-coupled heat pump has the advantage over the air-coupled heat pump because the ground makes a better heat source than outdoor air; it is warmer in the winter and cooler in the summer than air. As a result, the energy consumption is less in a ground-coupled heat pump than in a standard one.

EPRI conducted monitored tests of ground-coupled heat pumps in Oklahoma from 1981 to 1983. Tests showed that these heat pumps reduced both demand and energy consumption by 29% compared to standard heat pumps. During cold winter weather, the electric resistance units never came on at the Oklahoma test homes. Because the electric resistance unit was not needed to defrost the outdoor air coil during freezing weather, the ground-coupled heat pump performed better. In addition, the entire unit could be set indoors.

EPRI studies indicate that the ground-coupled heat pump costs more to install than the other type ($5000 versus $4000 for a 3-ton system). However, the ground-coupled system uses less total electricity during operation. Thus, the ground-coupled type is appropriate wherever

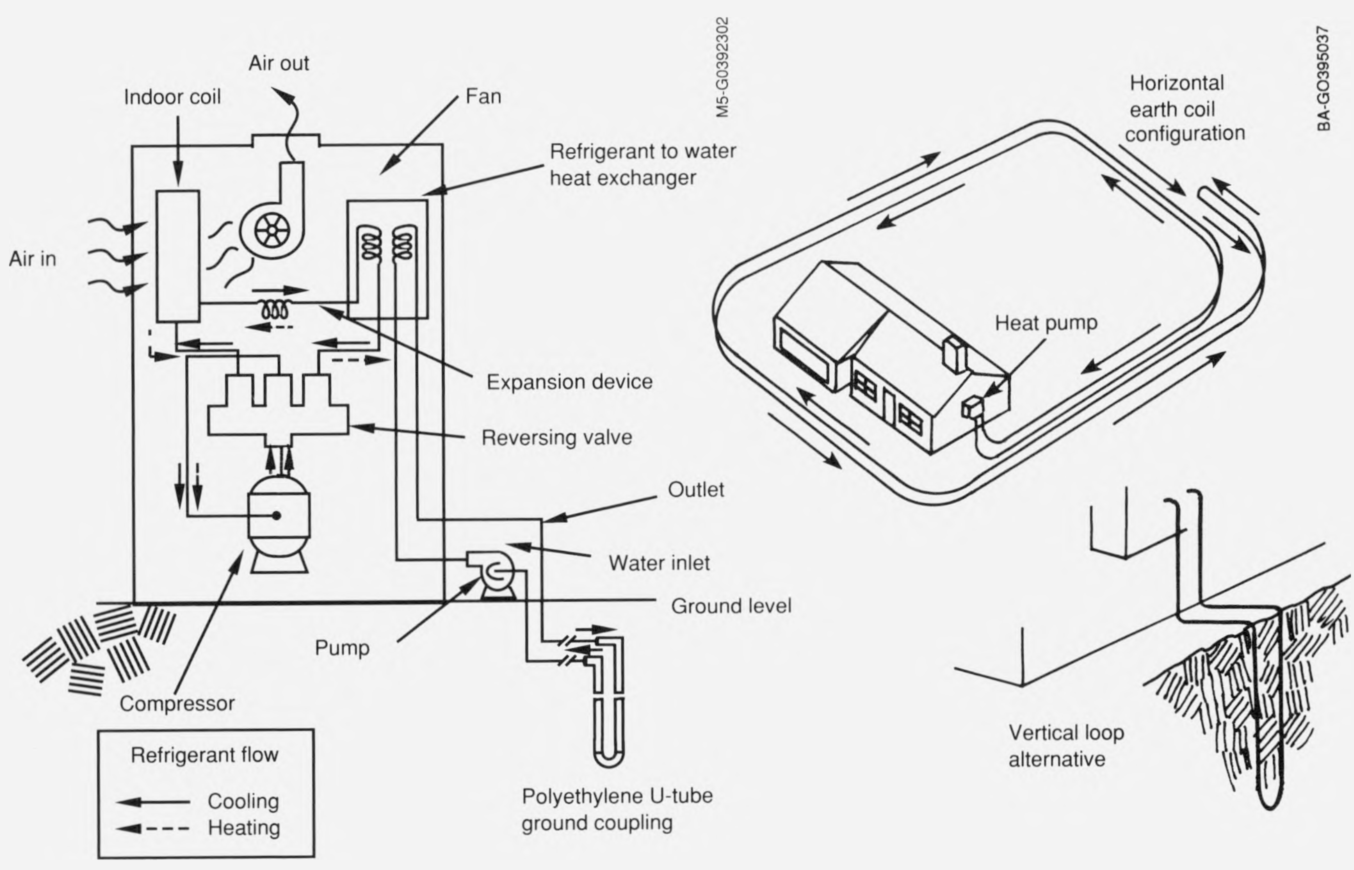


Figure 3-7. Ground-coupled heat pump

minimum ground temperatures remain above 40°F. Coefficients of performance for heating range as high as 4, and SEERs go as high as 14.

The primary barrier to broad use of ground-coupled heat pumps is the installed cost. Prices range from $1200 to $1500 per ton (12,000 Btu of cooling). As homes become more energy efficient, the installed costs drop. However, this price is not cost effective for energy-efficient homes with low annual heating and cooling loads (under $300 combined). The best application in the late 1980s for ground-coupled heat pumps is likely to be in large homes built in low-density developments and located where electric costs are high, and heating and cooling loads are significant. Oak Ridge National Laboratory (ORNL) is studying the closed-loop heat pump system, which uses a vertically or horizontally oriented buried-pipe heat exchanger and a circulation pump rather than a well as in an open-loop system [66]. The following case study describes the closed-loop system in more detail.

CASE STUDY

The closed-loop ground-coupled system is best suited for northern climates where heating consumes most of the energy. The major obstacle to its use is the high cost of the ground-coil heat exchanger. The goal of ORNL research has been to reduce this cost by developing more realistic design models of the heat exchanger so that system design can be optimized. Models that more realistically predict performance were validated with monitored field data from sites in New York and Tennessee. A system optimization project led to an advanced design that uses 30% less ground coil than current standard design. With these improvements, ORNL expects that the overall cost of the ground-coupled heat pump can be reduced by 10%. This reduction lowers the simple payback of this type of heat pump to only 3.5 years compared with an air-to-air heat pump for installations in New York State.

Refrigeration Air Conditioning

Refrigeration air conditioning serves two purposes: It drops the indoor air temperature to a comfortable range of 77 to 78 deg and reduces the humidity generated by cooking, bathing, and respiration to less than 50%. It is also the most costly HVAC equipment to operate in warm climates.

The improvement in air conditioner efficiency matches the improvement in heat pumps. According to ACEEE, the average central air system installed in 1986 had a SEER of 9. The 1987 Appliance Energy Conservation Act required that all new air conditioning units have a minimum SEER of 10 by 1992. Today's best models have SEERs of 12 to 15 or higher, but the initial price of the most efficient units limits their cost-effectiveness. In today's energy-efficient homes, high-performance air conditioners only make sense in hot and humid climates.

Cooling in hot climates is needed to offset heat penetrating through windows, walls, and ceilings (sensible heat gains). An air conditioner must also dehumidify the effects of indoor activities, such as cooking and bathing (latent heat gains). According to the Florida Solar Energy Center, an air conditioner in a typical Florida home must solve a cooling problem that is 75% sensible (air temperature) and 25% latent

"The Vagaries of Cooling Load Calculations." (December 1986). *Energy Design Update* (5:12); pp. 11–13.

Examines the uncertainties in basic cooling load calculations used to predict cooling energy consumption. As a result of these weaknesses, conventional calculation techniques overpredict cooling energy loads in dry climates and underpredict in humid climates. A study by the Florida Solar Energy Center shows that moisture absorption and desorption must be considered when estimating ventilation energy savings.

"DINH Z-Coil—Cooling with Comfort." (July 1987). *Energy Design Update* (6:7); pp. 13–15.

Discusses the DINH Z-Coil as an innovative solution to the problem of providing proper cooling and dehumidification in warm, humid climates without sacrificing energy efficiency. The DINH Z-Coil uses heat pipe technology to increase the latent cooling potential of any residential air conditioner.

(dehumidification). However, energy-efficient homes in hot, humid climates typically face loads that are 60% sensible cooling and 40% latent [67].

Most cooling equipment does a better job of eliminating sensible, rather than latent, heat gains. Few units can handle the 40% latent load, resulting in unacceptably high indoor humidity levels at otherwise acceptable air temperature settings. For example, in New Orleans, Louisiana, during the summer, the indoor temperature in an energy-efficient home can be a tolerable 78 deg, and the humidity can be uncomfortably over 60%.

However, solutions do exist to this ratio problem of sensible versus latent cooling [68]. Proper sizing of an air conditioner is the first step. Oversizing leads to frequent cycling, which decreases the dehumidifying capacity. Second, an air conditioner that varies the air handler speed and condenser functions can meet varying temperature and humidity problems. Third, thermostats are available with a humidity-measuring function that keeps the air conditioner operating until comfort—a combination of humidity and temperature—is achieved. Finally, air conditioning units exist with improved dehumidification functions. One manufacturer's unit has an automatic sensor that slows the fan speed when additional dehumidification is required. Another system uses heat pipes for two-stage cooling; the second stage supercools the air, which provides extra dehumidification.

In general, less work has been done to model and understand the tradeoffs for different approaches to cooling and dehumidification than to understand heating issues. One simplified computer program that was developed under the sponsorship of the U.S. Department of Energy (DOE) at Lawrence Berkeley Laboratory is the Program for Energy Analysis of Residences (PEAR 2.1). This simulation program is best used for new homes and has the ability to model the impact of a variety of heating and cooling conservation measures for over 800 locations around the United States. It contains files that allow both the British thermal units and the dollar savings to be calculated as well as equipment and installations costs so that the most cost-effective solutions can be found [69].

"Comfort-Stat from Trane." (March 1987). *Energy Design Update* (6:3); pp. 14–15.

Presents the Trane XT 400 thermostat, which attempts to address the problem of proper humidity control in energy-efficient houses in humid climates. The problem arises when the sensible heat ratio of the cooling equipment is not matched to that for the house. The XT 400 is presented as an easy, off-the-shelf solution that uses a combination of measured air temperature and humidity to maintain a preset comfort index.

PEAR 2.1 (Program for Energy Analysis of Residences): User's Manual. (March 1987). LBL-PUB-610. Berkeley, CA: Lawrence Berkeley Laboratory; 72 pp.

Provides user information for the Program for Energy Analysis of Residences (PEAR), an interactive program for residential building energy analysis using a comprehensive DOE-2.1 data base for residential buildings. This data base was compiled by Lawrence Berkeley Laboratory with over 10,000 computer simulations covering five residential buildings in 45 geographic locations. This document provides descriptions of the data screens that make up PEAR, together with step-by-step instructions for using the microcomputer program diskette. PEAR is on a single 5-1/4-inch diskette that can be used by IBM-compatible personal computers with at least 128K memory.

Evaporative Coolers and Whole-House Fans

An *evaporative cooler* produces cool air by combining the natural process of water evaporation with a simple air-moving system. Fresh outside air is filtered through a water-saturated pad, cooled by evaporation, and circulated by a blower. They are most effective in hot, arid regions.

Evaporative coolers continue to be underutilized. The evaporative cooler costs less to install than an air conditioner. In addition, it only uses 10% to 20% of the energy consumed by an air conditioner for equivalent cooling in a hot, arid region.

In western regions, the increased humidity provided by evaporative cooling usually does not present a problem and can provide welcome relief. The one notable exception is Phoenix, Arizona, during the midsummer monsoon season, where air conditioning is considered essential to beat the humidity problem. Relatively recent developments in evaporative coolers now make some versions appropriate for humid situations. An indirect two-stage version that can provide dehumidified cool air is now being marketed.

A less expensive cooling strategy is the *whole-house fan*. Many regions have moderate cooling requirements. In these locations, whole-house

Wu, Hofu (January 1988). Identification and Evaluation of Cooling Strategies in Residences of Hot, Arid Climates. Task 1: Performance Monitoring of a Two-Stage Evaporative Cooler. Phoenix, AZ: Arizona State University; 39 pp.

Discusses the performance of a two-stage evaporative cooling system that was monitored in a residence in Scottsdale, Arizona, in the summer of 1987. Two separate periods were monitored. In the first period, the unit was operated as a single-stage, direct evaporative cooler, yielding a performance of an average 74% wet-bulb depression. During the second period, the unit's full capacity as a two-stage evaporative cooler was tested. The first-stage, indirect evaporative cooling process reached an average 54% wet-bulb depression. The second stage of direct evaporative cooling yielded an average 88% wet-bulb depression. In general, the supply dry-bulb air temperature was below the wet-bulb temperature of the outside air. The maximum indoor temperature recorded was only 85.7°F, with an average temperature of 79.5°F. Regression models predicting supply air temperatures were derived by using outdoor day- and wet-bulb temperatures as independent variables.

CASE STUDY

At Arizona State University (ASU), a commercially available two-stage evaporative cooler was monitored for five years to determine its performance capabilities. The cooler consists of a direct evaporative cooling unit with an indirect evaporative-cooled heat exchanger that supplies cooler and drier air than conventional evaporative coolers. The capability of each unit was tested separately and in tandem. When operated in the single-stage direct evaporative mode best suited to low humidity, it showed an average SEER of 5.7. When operated in the two-stage mode (where it would compete with the performance of a normal air conditioner in a humid climate), it showed an average SEER of 28.5. ASU developed a regression model that will predict the efficiency and cost of using this system in many different climate zones [70].

fans can eliminate or reduce the need for refrigeration air conditioning or evaporative cooling. Air movement from the whole-house fan provides comfort whenever outdoor temperatures are under the low 80s. Features that reduce the energy used by whole-house fans include timers and exhaust thermostats, which shut the fan off once a home is cooled.

Even in climates with high humidity, whole-house fans can be used during the milder spring and fall cooling seasons. However, using a whole-house fan at night during peak summer months can be counterproductive. Studies by FSEC indicate that night ventilation can significantly increase the moisture content of indoor objects. Carpeting, furniture, and other objects can generate a latent load that is ten times that of the indoor air by itself. Once a home has been vented at night, dehumidification by air conditioning the next day can be a lengthy process [71].

Thermal Distribution

In addition to the heating or cooling equipment, each home needs a method of distributing the conditioned air through the living space. Usually, a series of ducts are installed in the furnace and connected to each room in the house. In the average home, this delivery system does a better job in some rooms than in others.

An energy-efficient home is less likely to have heat-distribution problems than a home built to conventional standards. The well-insulated building shell prevents one room from cooling down much faster than another, although duct losses from poorly connected or uninsulated ducts can still undermine the conservation efforts. The most efficient way to distribute heat is to keep the distribution network completely inside the conditioned space. Builders and designers of energy-efficient homes should pick carefully among the existing distribution ideas; some traditional approaches might be inappropriate.

In most homes, heat is delivered along the perimeter, i.e., under windows and along outside walls—the areas of highest heat loss. However, in tight, well-insulated homes with low-E glazing (see Chapter 2), heat loss is dramatically reduced. Regardless of where heat is delivered in a room, ideally temperatures should be quite even from floor to ceiling and room to room. In fact, heat losses should be so low that perimeter heating might not be needed. Eliminating perimeter heating reduces distribution costs. For example, a single point-source heater that is centrally located might be able to provide adequate comfort in energy-efficient homes. A *point-source heater* releases heat where the heating unit is located; the heat circulates between rooms by natural convection. Two common types of point-source heaters are gas wall furnaces and wood stoves.

CASE STUDY

Three 1174-ft^2 Denver townhomes built in 1984 with superinsulated shells (R-26 walls, R-40 ceilings, well-insulated floors, tight construction, and an air-to-air heat exchanger) were each heated with a single point-source heater installed at a cost of $635 (Figure 3-8). The 30,000-Btu through-the-wall gas furnace simply released heat in the living room on the north wall of the lower floor, and the heat mixed by natural convection within the open floor plan. Occupants reported they were pleased with the comfort level and with their heating bills, which averaged between $120 and $150 during the first winter.

Figure 3-8. Denver townhouses that use point-source gas heaters. (Photograph by Steve Andrews)

CASE STUDY

Results from a carefully monitored home in Saskatoon, Canada, demonstrate the possibilities for different distribution concepts. A 2000-ft^2 superinsulated demonstration home was built in 1980. Insulation measures included an R-60 ceiling, R-44 wall insulation, R-28 basement insulation, triple glazing, and tight construction.

The National Research Council of Canada tested heat distribution possibilities by limiting all heat input to two 1500-W heaters at one corner of the rectangular home, with another 2000-W heater in the basement. These heaters temporarily served as point-source heaters: All the heat was released at one location, with no active distribution to the rest of the home.

Temperatures were continuously recorded in multiple locations (Figure 3-9). With the interior doors open and the heaters off, the maximum temperature difference between the warmest and coldest spots was 4° F. With the doors open and the heaters on, the greatest difference was 5 deg. With the doors closed at night and the heaters on, the difference jumped to 13 deg—a level unacceptable to many homeowners. However, in a similar study, the temperature difference was reduced to 2 deg—even with the doors closed—when an air-to-air heat exchanger was operating. Even though it moves only a small volume of air, the heat exchanger was able to even out the temperatures between rooms through simple redistribution of the home's warm air; this redistribution is only possible in a home with a slow rate of heat loss. These results indicate that in today's best homes, traditional distribution might be unnecessary.

The efficiency of gas–fuel-fired point-source heaters is improving. One unit developed by GRI has achieved 90+% efficiency. Sizes range from 20,000 down to 4500 Btu/hour output. In addition, the unburned combustion gases are fan forced outside, preventing the flue gases from backdrafting into the home.

The wood stove is a point-source heater that appeals to some buyers of energy-efficient homes. Prices for the best high-efficiency, low-polluting stoves range from $700 to $1200, excluding chimney and installation costs. Efficiencies range from 50% to 75% under optimum conditions. The wood stove operates most efficiently when it is burned "wide open." However, in an energy-efficient home, a hot burn can rapidly overheat the area where the stove is located; therefore, a wood stove is not recommended for use in an energy-efficient home.

Although a wood stove can cause problems, e.g., air pollution and overheating, it is safer and more efficient than a fireplace. In a tight home, the potential for backdrafting of carbon monoxide into the living space makes the fireplace a distinct health hazard. Where a fireplace is included, it should be equipped with outside air for combustion and the tightest-fitting glass doors available.

Heating and Cooling Systems in Existing Homes

A decade ago, turning down the thermostat was still the best way to cut heating bills. Although the savings from turning down the thermostat can still be quite significant, these savings might not be permanent and can be lost with a drop in energy prices, when people tend to turn their thermostats back up. Only a permanent change in heating system efficiency can guarantee savings.

Upgrading existing HVAC systems or replacing old systems with high-efficiency units can potentially save more than any other single conservation step for existing homes. Gradual replacement of existing gas and oil units with higher-efficiency models should save about one-third of the energy previously used to heat these homes. Replacing electric baseboard units and conventional air conditioners or replacing older heat pumps with high-efficiency heat pumps could achieve similar savings on a per-house basis. It might take 20 years to accomplish these changes, however, because much of the older equipment will last another 15 to 20 years [72].

Several major stumbling blocks need to be overcome when upgrading or replacing HVAC equipment. First, the initial investment can be quite high, especially for high-efficiency replacement units. For this reason, homeowners usually delay the replacement until old equipment has broken down. Then, they have an immediate need to replace lost service, which precludes the opportunity to shop for the most cost-effective equipment. A homeowner whose furnace or heat pump fails in the middle of winter often selects whatever the service person recommends and has in stock. By 1992, the 1987 Appliance Energy Conservation Act will have partially solved this problem, eliminating the least efficient choices.

Contractors and homeowners must carefully weigh the cost-effectiveness of improving existing HVAC equipment. By itself, the most cost-effective conservation measure for a poorly insulated, leaky home with an old, inefficient furnace might be to replace the furnace with a new, 90+% efficient unit. However, once this same home is insulated and well weatherized, a medium-efficiency furnace is typically much more cost effective.

Single-Family Building Retrofit Research Multi-Year Plan: FY 1986–FY 1991. (May 1986). ORNL/CON-207. Oak Ridge, TN: Oak Ridge National Laboratory; 140 pp. Available NTIS: Order No. DE86013580.

Describes a research and development (R&D) agenda that will support private- and public-sector efforts to improve the energy efficiency of existing single-family buildings. The plan provides an overview of the characteristics of the single-family sector and summarizes private and government activities that have been directed at energy-conservation retrofits in single-family buildings. The single-family Retrofit Research Program focuses primarily on space heating, air conditioning, and domestic hot water. The research and information needs for the program were classified into five areas: (1) program planning and support, (2) research on the application of retrofit measures and approaches, (3) basic applied research on new and improved retrofit measures, (4) technology adoption R&D, and (5) technology transfer. Within these program areas, several project areas were recommended for research. The project area that had the highest priority was performance monitoring of retrofits in occupied buildings.

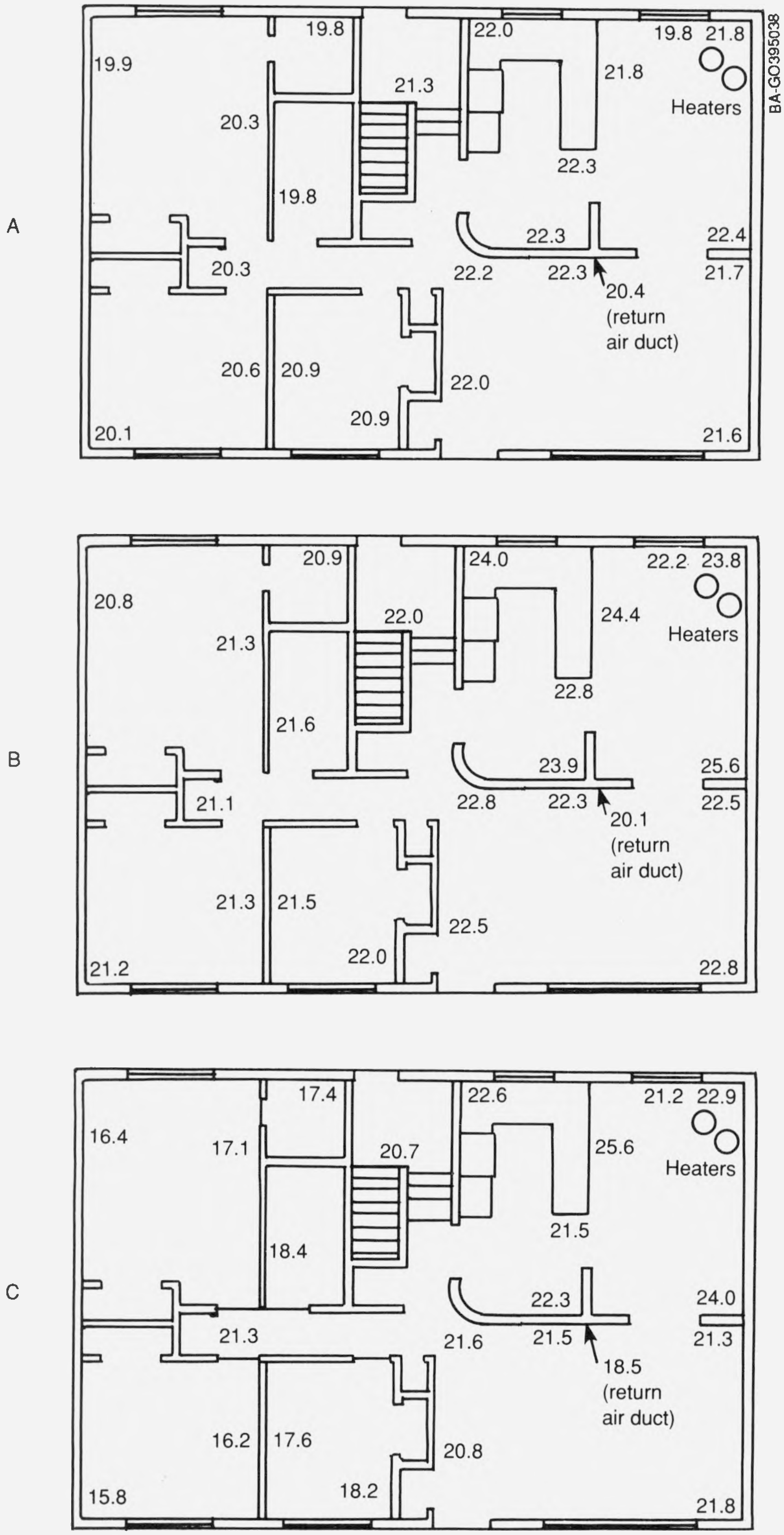


Figure 3-9. Monitored home in Saskatoon, Canada, March 2, 1981, point-source electric heat: (A) interior doors open, heaters off; (B) interior doors open, heaters on; (C) interior doors closed, heaters on

Upgrading Heating Systems

In theory, retrofits to improve the efficiency of fossil fuel heating systems can save 25% on heating bills. In practice, however, a 15% savings is a more reasonable expectation. Measured reductions typically have been less than the anticipated savings, ranging from 5% to 15%. Unfortunately, data are limited on the savings attributable to upgrading only the heating systems; most programs combine weatherization and heating system improvements and report the savings from both.

Heating system upgrades typically involve three generic categories: repairs, hardware retrofits, and efficiency adjustments. The most cost-effective measures seem to be efficiency adjustments, which include tune-ups, duct work repairs, and other simple maintenance measures.

CASE STUDY

A Colorado furnace program focused on delivering furnace efficiency tuneups at a cost of $150 or less. The savings averaged 12% of the yearly heating costs—a two-year payback on thousands of furnaces [73]. The program concentrated on the following adjustments:

- The fan on-off switch was adjusted downward to 90 deg.
- The blower speed was increased.
- The duct work was repaired.
- The blowers were cleaned.
- The filters were changed.
- Other minor repairs were conducted.

The minimum efficiency measures described in this case study make sense for almost every type of furnace. In homes that have already been insulated and tightened, this retrofit measure might be the only adjustment that makes good economic sense.

The wisdom of various hardware retrofits varies dramatically with individual houses and furnaces. DOE has sponsored programs that attempted to identify the savings available from such activities as replacing burners, adding flue dampers, changing filters frequently, and adding electronic ignitions. According to an analysis by ACEEE, replacing burners on oil furnaces saved the most energy, roughly 14%, of several DOE-sponsored furnace retrofit programs. In fact, the results indicated that this measure was the most cost effective of any of the many DOE conservation research projects [74].

Other results from research programs indicate that electrically operated flue dampers, an expensive measure, saved roughly 6%; thermally activated dampers saved only half this amount. The age and location of a furnace should be assessed before adding a flue damper or an electronic ignition device. Adding a flue damper on a small flue in a cold basement does not make good economic sense, nor does it pay to add an electronic ignition to a 20-year-old furnace.

Not many homeowners are inclined to change their furnace filter or make nightly adjustments to their thermostat setting. For these homeowners, a clock thermostat or a furnace filter device that whistles when the filter is dirty can be sensible hardware investments.

Proctor, J., and Foster, B. (1986). "Low-Cost Furnace Efficiency Program—10,000 Furnaces Later." *Proceedings from the ACEEE 1986 Summer Study on Energy Efficiency in Buildings: Appliances and Equipment, Volume 1; Santa Cruz, California; August 17, 1986.* Washington, DC: American Council for an Energy Efficient Economy.

Presents results from three new studies of this program. Over 10,000 furnaces have been treated by agencies under the Colorado low-cost furnace-efficiency program. One study showed a potential savings of 11.3%. Another study done by the state of Colorado showed a savings of about 12%. This new information makes possible a method of screening that guarantees the program works on the highest-priority furnaces. The paper contains a detailed analysis of the individual items contributing to the savings and of areas requiring additional research.

FY 1988 Energy Conservation Multi-Year Plan. (July 1986). Washington, DC: U.S. Department of Energy.

Is a planning document that represents a continuing process by the U.S. Department of Energy Office of Conservation to analyze and evaluate programs and plan for the future. Chapter 1 discusses the program's mission and its objectives and strategy. Chapter 2 outlines the methodology and assumptions used in the technical assessment of research needs and program priorities and describes the technical content of the program and its benefits to the nation and planned areas of emphasis. Chapters 3 through 6 present technical assessments of various program sectors: residential and commercial buildings, transportation, industry, and energy utilization. Each of these chapters includes a statement of the objectives and strategy, an assessment of research needs, and a presentation of rank-ordered candidates for federal research and other activities. Finally, Chapter 7 presents a technical plan for the Federal Energy Management Program.

Proctor, John. (1986). *Low Cost Boiler Efficiency Improvements.* Denver, CO: Sun Power Consumer Association; 9 pp.

Studies boiler efficiency work in 46 households. Most of the work was done as part of the Colorado Office of Energy Conservation Weatherization Program funded by the Low-income Energy Assistance Program. The units in this study were single-family residences with natural gas–fired boilers. The procedures and treatments described can also be applied to propane and oil-fired units. The paper consists of two sections; the first deals with the technical details of the program, including boiler controls; combustion and distribution efficiency improvements; and the essential administrative components of feedback, training, and control. The second section deals with the evaluation method, results, and conclusions. The boiler program savings exceed the low-cost furnace efficiency program results. The average annual gas heating bill for this group of homes was $786. The boiler program alone saves approximately 13.7% of this amount, or $107/year. The average per unit cost of the efficiency work (parts, labor, and administration) is $198. This cost results in a payback on the efficiency items of 1.85 years.

CASE STUDY

Another Colorado program dealt with low-cost boiler tuneups. In an efficiency program, a boiler adjustment cost $198; $107 was saved in the first year, reducing energy consumption by about 14%. The principal upgrade was a control system change—adding a time-delay device to the boiler—that varies boiler water temperature with total system demand. At a cost of $25 in materials and a half hour of labor, between 8% and 18% was saved over the cost of a single-control thermostat. Other improvements included insulating distribution pipes and improving steady-state efficiency [75].

Add-on heat pumps are placed beside an existing forced-air fossil fuel furnace. In the heating mode, the heat pump runs only when outdoor temperatures (above 40 deg) offer high efficiency. EPRI has evaluated the effects of installing an add-on heat pump. Heating costs averaged about 30% less for a small sampling of homes.

The initial cost for the heat pump is high—$2000 to $3500—which makes it difficult to justify for homes that have had their overall energy efficiencies significantly improved.

This dual-fuel approach makes sense in some energy-efficient homes, for example, if (1) electric costs are low; (2) the utility offers off-peak electric rates; (3) fossil fuel costs are high; (4) the old furnace is inefficient; or (5) a significant air conditioning load exists, and the current air conditioner is inefficient and needs replacing.

Replacing Heating Systems

In the long run, replacing a heating system can contribute more to overall efficiency than upgrading an existing unit. Careful analysis is required in each energy-efficient home in order to make the most cost-effective purchase.

Three factors must be considered when replacing a heating system: (1) the price of heating fuel, (2) the rate of fuel cost increases compared to average inflation, and (3) the total size of the annual heating load. In some cases, the cost of a 90+% efficient furnace or a high-efficiency heat pump makes sound economic sense. In others, the increased cost of the heating system might be high enough that savings during the life of the appliance would not pay for the additional cost.

A reasonable way to assess the merits of two competing heating systems is to do a simple life-cycle cost analysis. Such calculations are generally not used because of their complexity. ACEEE, however, provides a worksheet in its annual publication, *The Most Energy-Efficient Appliances*, that simplifies this calculation [76].

In some homes, putting in a replacement furnace leads to problems with high humidity. The humidity problem is usually worse if the home has also been weatherized and insulated. Because older, more inefficient furnaces operate more frequently than their replacements, they exhaust the humid indoor air and regularly bring in drier outside air. Even when the furnace is not operating, the open flue allows a steady venting of inside air. With house "sealing" and new high-efficiency furnaces, a furnace's ventilation structure is eliminated, and less natural air exchange can occur through openings in the shell. In this situation, the top priority is to control indoor sources of humidity.

The Most Energy-Efficient Appliances. (1987). Washington, DC: American Council for an Energy Efficient Economy; 18 pp. Available from American Council for an Energy Efficient Economy, 1001 Connecticut Ave. NW, Suite 535, Washington, DC 20036.

Lists the top-rated models for all major types of appliances and heating and air conditioning systems. It also includes a convenient form for comparing the cost savings of different models.

Intermittently increasing the rate of exhaust air also warrants attention. This increase can often be achieved by simply adding a humidistat or an intermittent timer control function to an existing kitchen or bath exhaust fan. Additional strategies for addressing this indoor air pollution problem and others are discussed in Chapter 4.

Air Conditioning and Cooling Systems

Although the value of replacing old furnaces with top-of-the-line equipment in energy-efficient homes can be debated, monitored data indicate that purchasing a high-efficiency heat pump makes good sense in homes with moderate heating and cooling requirements.

Several utilities offer homeowners financial incentives to replace their older air conditioners with medium-efficiency models. The older units, with a typical SEER of 6.5, are being replaced by units with a SEER of 9. Savings for customers in Houston, Texas, averaged 18%.

In dry climates, cooling costs can be saved by replacing the air conditioner with an evaporative cooler. Several western and southwestern utilities encourage this strategy. Cooling costs should be reduced by 80% or more.

Thermal Distribution

Many homeowners have problems with their heating and cooling distribution system. Complaints range from a radiator that lags behind to a room that never warms up. If the cold areas are used frequently, homeowners often raise their central thermostat to compensate; however, this solution unnecessarily overheats the rest of the home. The solutions to thermal distribution problems should lead to better comfort and energy savings.

Some simple ways to improve the distribution systems of gas forced-air furnaces include hooking up disconnected ducts in attics or vented crawlspaces, adding insulation to ducts (this practice can raise delivered temperatures by 5 deg or more), unblocking registers by rearranging furniture, and opening dampers that were inadvertently closed in the basement or at the point of delivery.

In some cases, replacing a short section of poorly designed duct work or installing an inline duct booster can solve the problem (particularly with cold bathrooms), although boosters often cost more than other solutions. A less expensive solution is simply to cut an inch off the bottom of the bathroom door, which relieves any back pressure that might be preventing warm air from flowing into the room. A final option is to install a small supplemental heater, such as a wall- or ceiling-mounted radiant heater.

Sometimes, one entire floor runs colder than another. A relatively new retrofit zoning concept for central forced-air systems can solve this problem. Automated in-line dampers and a second thermostat can be installed, dividing the home into two separate zones. When one thermostat calls for heat, the system opens dampers to this zone and closes others. This same strategy can also be implemented in homes that have no distribution problems, simply as a money-saving device. In either case, only the bedrooms are heated at night and only the living space during the day, leading to as much as a 20% savings.

When a new addition is made to a home that has already been upgraded for energy efficiency, heat can often be supplied by tapping into the existing heating system. If this procedure is too complicated, another option is to purchase an efficient small space heater. One draft-induced, spark-ignition, 90% efficient model operates on as little as 4500 Btu/hour and costs about $300.

Old steam or water heating systems can be hard to control. They frequently overshoot the comfort range in a room, prompting homeowners to open windows. Improving the circulation of these systems to cold rooms can eliminate this costly form of temperature control.

Typically, the last room on a hot water–heating loop runs colder than the others. Dampering air registers, increasing the water flow, and cleaning air exchange fins in baseboard convectors can help rebalance the system. Slow or erratic steam radiators might need a different air vent at the radiator or elsewhere in the system. A drastic step is to switch to high-output convectors in the coldest room. Another effective but costly step is to add a bypass valve and another thermostat in the warmest room; this step creates a zone within a zone, allowing the heat to be shut down in the warmest room if the colder area is still calling for heat. The key problem with homes that still have steam systems and have been energy updated is simply finding a repair person qualified to work on the system.

Solving electric heat distribution problems can also save some energy. As with other systems, reconnecting or sealing duct work and insulating duct runs in attics and crawlspaces is highly cost effective. Thermostats for electric baseboard heaters are notoriously inaccurate. The same setting in different rooms does not produce the same results and leads to overheated rooms for unwary homeowners. One solution is to install a thermostat that lists comfort levels, not degrees Fahrenheit.

Electric radiant panels that are installed beneath the ceiling can occasionally cause a problem. Some electric radiant panels with high heating output (high density) can give people warm hands and cold feet. Simply replacing the panels with lower-wattage models should solve the problem, although it might not save any energy.

A frequent complaint about heat pumps is the "cold-blow" problem, which can be solved by replacing or redirecting air diffusers. Alternatively, a small in-line electric resistance booster can push the air temperature into a comfortable range.

Water Heaters

In 1983, DOE figures indicated that energy used to heat water accounted for over 16% of nationwide residential energy consumption, making the water heater the second largest energy user in a home. In a new or existing energy-efficient home, the heating load is reduced so significantly that even in moderately cold climates, the water heating bill can be higher than the space heating bill. The annual energy consumption for a water heater in an all-electric home can run $460 or more (60 gal/day; $0.082/kWh). Efficient new water heaters typically cut energy consumption by 20%. Clearly, buyers and builders should be encouraged to install efficient units or upgrade existing ones.

New Systems

According to ACEEE, the typical gas hot water heater sold in 1986 had an energy factor (EF) of approximately 0.5. This figure means that half the energy delivered to the water heater is wasted. Better insulation, smaller pilot lights, and more effective heat exchangers have increased the efficiency of the best units by as much as one-third; the most efficient conventional gas water heaters in 1987 had EFs of 0.65, making these systems a cost-effective purchase for builders and homeowners. These units will easily meet the top standard of 0.56 set by the 1987 Appliance Energy Conservation Act.

Harris, James E., and Greenberg, Joseph. (May 1987). *Performance of Instantaneous Gas-Fired Water Heaters.* NBSIR-87/3537. Gaithersburg, MD: National Bureau of Standards; 60 pp. Available NTIS: Order No. PB87-200390.

Presents an analysis of various instantaneous, gas-fired water heaters. Four different units were tested to develop a test method to determine *recovery efficiency and energy factor.* All four water heaters were from foreign countries (West Germany, the United Kingdom, France, and Japan). Various flow rates and water draws were used during the

Approximately 53% of all single-family homes are equipped with natural gas water heaters. The main problems associated with gas heaters have been combustion inefficiency and heat losses from the tanks into the home or up the flue.

Two new high-efficiency gas hot water heaters are now available. The first unit is a *condensing water heater*. It was specifically designed to heat water for both domestic use and space heating. Hot water is pumped from the tank to fan-coil units in an air handler. Fan-forced air movement across the coils heats the home in a manner similar to a forced-air furnace. However, this product is quite expensive and is only justified where it doubles as the furnace (Figure 3-2).

The second system uses a heat exchanger tied to the boiler or furnace. Water in a heat exchanger is first heated in the boiler. The water is then pumped to the heat exchanger in the storage tank, where it heats water for domestic use (Figure 3-3). These tanks are often made of long-lasting materials such as stainless steel. Because they are not directly exposed to a burner element, they should be more durable than conventional gas water heaters. Flue losses are eliminated. With this technique, water heating EFs of 0.83 or better are possible.

Sealed combustion and draft-induced gas water heaters were introduced during the 1980s. They eliminate the possibility of backdrafting combustion gases into the home by isolating or fan forcing the combustion process.

Heat pump water heaters (HPWHs) were first introduced in the United States in the early 1980s. They pull heat from the surrounding air and use it to heat water. Efficiencies run two or more times higher than electric resistance water heaters. The best units available have EF ratings of 3.0 or better. Although their installed costs range from $800 to $1200, HPWHs can be cost effective wherever electric rates are high.

Climate can be a factor in the cost-effectiveness of HPWHs. Because they take heat from the surrounding air, these heat pumps act as small air conditioners. This feature allows them to serve double duty in climates where the cooling load exceeds the heating load. In other climates, HPWHs should be located either in unconditioned spaces or in an area where they can be isolated, thus preventing them from cooling the home during the heating season; otherwise, they add to the home's heating bill.

To reduce consumption, several basic steps should be taken in conjunction with installing any new standard water heater. Installing a low-flow showerhead still ranks as the largest single savings feature. Bonneville studies show that even on energy-efficient models, adding extra insulation to the tank is cost effective. Anticonvection valves, which are installed on inlet and outlet pipes to stop the migration of hot water out of the tank, are inexpensive and effective energy-saving devices.

Fueled by either gas or electricity, demand or tankless water heaters are more efficient than standard models with tanks [77]. These units eliminate the standby tank losses of standard water heaters. During the heating season, some of the losses from standard water heaters can help heat the home. In energy-efficient homes, however, waste heat is less useful because of the home's low heating requirements. During the cooling season, demand water heaters eliminate this extra heat, reducing the load on the air conditioner. Although efficiencies vary, demand water heaters are quite effective when hot water requirements are small.

Gas demand water heaters are expensive, usually over $600. In addition, a large family might require more than one demand heater for proper service. However, demand models should last longer than conventional gas water heaters; models with tanks accumulate sediment in the bottom of

tests to determine their influence on the recovery efficiency and energy factor. In addition, the pilot light power consumption was measured to determine the effect of a variable pilot light power rate on the energy factor. The use of recovery efficiency as a performance index seems appropriate for these units. However, the use of energy factor, as currently calculated, needs further study.

Idaho Power Solar Water Heater Program. Second Interim Report: January 14, 1982 to November 1984. (July 1984). Boise, ID: Idaho Power Company; 54 pp.

Discusses the Solar and Heat Pump Water Heater Demonstration Program begun by Idaho Power in January 1982. With the installation and testing of 52 systems, Idaho Power has (1) examined performance, costs, and operating problems for 31 distinct types of water heating technologies; (2) developed performance profiles to assess possible future impacts on utility loads; (3) demonstrated the use of these technologies to the public across southern Idaho; and (4) evaluated the effectiveness of, and problems with, a utility program for implementing alternate technologies.

Kutscher, C.; Davenport, R.; Farrington, R.; Jorgensen, G.; Lewandowski, A.; and Vineyard, C. (July 1984). *Low-Cost Collectors/Systems Development Progress Report.* SERI/RR-253-1750. Golden, CO: Solar Energy Research Institute; 226 pp. Available NTIS: Order No. DE84013032.

Describes research done in FY 1982 at the Solar Energy Research Institute to lower the installed cost of residential solar space-heating and domestic hot water systems. After surveying candidate system designs, the drainback system was chosen for further analysis. Criteria for filling, draining, and establishing a siphon were determined analytically and experimentally. The effects of different heat-exchanger locations were investigated using computer simulations, and a method for reducing pumping power was established. The use of polybutylene piping and low-cost storage tanks was identified as a major contributor to cost reduction. To identify low-cost collector concepts, two detailed materials surveys were conducted—one for absorbers, the other for glazings. The new lightweight, laminated polymers were identified as promising glazing materials. It was concluded that the installed cost of the drainback system, using polybutylene piping and currently available low-cost collectors, could be brought down to about $270/m^2 ($25/ft^2). Further development of new low-cost collector concepts is needed to bring this price down to $150/m^2 ($14/ft^2), which is the cost required to supply a five-year discounted payback period versus electricity (based on national averages and assuming no tax credits).

the tank, which leads to corrosion and tank failure, whereas all the parts in tankless models can be cleaned or replaced. The longevity of demand water heaters should be a major justification for purchase because their cost-effectiveness on a yearly basis is questionable when compared to a standard energy-conserving model.

Another approach to heating water is to use active or passive solar water heaters. These systems gained popularity in the early 1980s, but with the loss of the federal energy tax credits in 1985, the number of solar water heater installations has dropped dramatically. However, these installations can still be cost effective and contribute to peak-load reduction. Manufacturers are working hard to cut system and installation costs. New products tend to be simpler than the active systems designed during the first solar decade. Passive solar water heaters tend to be the most cost-effective choice in warm to moderately cold climates (Figure 3-10) [78,79].

Upgrading Existing Systems

Various studies around the country have proven that water heater upgrades are generally cost effective. The best methods are simple and well established and have not changed in a decade. For example, the no-cost approach of turning the thermostat down to 120° F often saves more energy than any other step. Installing a $6 to $10 low-flow showerhead usually saves enough hot water to pay for the showerhead in a few months.

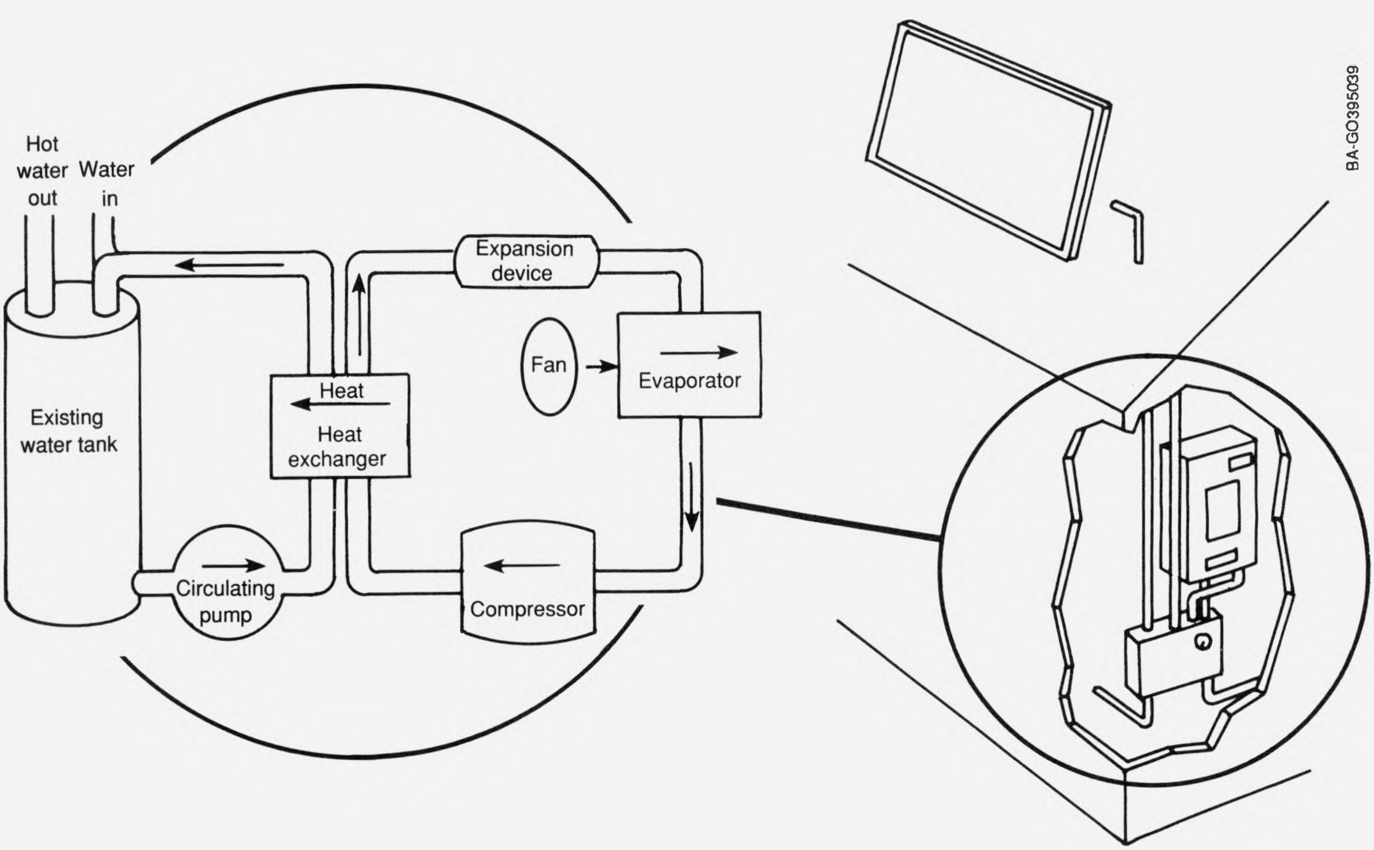


Figure 3-10. No moving parts or temperature sensors in a passive solar water heater; water lines must be freeze protected in all climates, with special precaution in northern states

Losses from water heater tanks can be minimized by adding an extra layer of insulation, R-6 to R-11. This measure makes sense even when the tank is an energy-conserving model. Savings from covering a minimum of 5 ft of the hot- and cold-water pipe lines with R-4 insulation should pay for material costs in the first year.

A device called the hot-water saver cuts losses by drawing standing hot water back through the pipes to a small expansion tank and replacing it with cold water until the next use. In limited field monitoring by Battelle Pacific Northwest Laboratories, this device saved 13.5% of the cost of heating water. With an installed price of $225, the hot water savings paid for the device in approximately three years (seven years with gas water heaters).

CASE STUDY

In Seattle, Washington, an extensive retrofit program for electric water heaters saved customers an average of 30% to 35%. The program relied on setting the thermostat back 20 deg (to 130 deg), wrapping the hot water heater tank in R-10 insulation, placing thermal traps on hot- and cold-water lines, and using rigid foam insulation beneath the electric water heating unit. An EPRI analysis of utility surveys found that extra insulation for water heaters saved $42/year and bottom-board insulation another $6 ($0.082/kWh) [80].

More options exist for improving electric water heaters than just the standard tank upgrades. Heat pumps can be added to existing electric water heaters. An EPRI analysis indicates that the average cost is $800 installed, although some heat pumps are as low as $600. Using the add-on heat pump saved 39% over conventional electric resistance water heaters; other studies of add-on heat pumps report savings of as much as 50%. Several utilities report a somewhat higher incidence of repair problems with HPWHs than with resistance heaters. Performance surveys of the most up-to-date models are more positive. However, the concern about reliability has not been fully resolved.

A slightly different approach is to use a *heat-recovery water heater,* or desuperheater, which is installed on either a central air conditioner or a heat pump. This unit recovers a portion of the waste heat generated by a vapor compression cycle. On air conditioners, the heat-recovery process operates only during the cooling season. For this reason, the system has been used the most in southern climates such as in Florida, where air conditioners run a longer portion of the year. In moderate climates, structural or mechanical upgrades reduce air conditioning loads to such an extent that the heat-recovery function does not operate enough to justify the cost.

The EPRI analysis referred to in the previous case study shows that heat-recovery water heaters average $545 installed. The savings averages 25%. EPRI says that better savings are likely when the heat-recovery devices are installed on heat pumps rather than air conditioners.

Replacing Existing Systems

Price is the major impediment to replacing the average gas water heater with the highest-efficiency unit. The best high-efficiency unit costs over $1000 installed; a conventional unit is in the $300 range. Most homeowners might be more willing to add a medium-efficiency (65%) unit, which, according to the American Gas Association, costs roughly $100

Review of Energy-Efficient Technologies in the Residential Sector, Volumes 1 and 2. (February 1986). EPRI EM-4436. Palo Alto, CA: Electric Power Research Institute; Volume 1: Executive Summary, 45 pp.; Volume 2: Data Review and Syntheses; 323 pp. Available from EPRI Research Reports Center, Box 50490, Palo Alto, California.

Integrates information on the cost, performance, and load impacts of nine residential energy-efficient technologies. Grounded in utility field experience, the analysis should help engineers and planners evaluate equipment for water heating and space heating and cooling as well as retrofit measures to improve the thermal integrity of buildings. Researchers selected 34 technology evaluation programs conducted by 26 utilities for detailed analysis. The target technologies included water heater retrofits; heat pump and heat-recovery water heaters; air-source, add-on, and ground-source heat pumps; high-efficiency central air conditioners; and building standards and retrofits for improving the thermal integrity of structures. Information on promotional and monitoring techniques was summarized qualitatively.

more than the more common model. Once the 1987 Appliance Energy Conservation Act takes effect, this price difference is expected to drop somewhat. Regardless of the replacement model selected, installing check valves on both the cold- and hot-water lines is a cost-effective measure.

When electric resistance water heaters fail, they can be replaced with HPWHs. Utility data comparing before-and-after consumption of replacements is limited. One small Pennsylvania study indicated that for a family of four, the yearly savings from installing a HPWH was roughly $150. The utility maintained that the savings paid for the added first cost within three years. However, the added first cost is typically quite large ($300 for an energy-efficient electric heater versus $800 to $1200 for a HPWH). Using replacement HPWHs is always more cost effective in a warm climate.

Appliance Choices for New Homes

The opportunity for saving energy through widespread use of today's most energy-efficient appliances is significant. End-use surveys indicate that between one-fourth and one-third of all household energy goes to operate refrigerators, freezers, lights, and miscellaneous appliances. Discretionary appliances, such as hot tubs and large home entertainment centers, are increasing in popularity and are also major energy users.

The appliances available for consumers and builders to select from have widely varying efficiencies. Energy-efficient appliances tend to cost more than their less efficient counterparts, but the energy savings will more than pay back the difference in purchase price before the appliance wears out. Because many heavily used appliances will cost much more to operate than to buy over their useful lifetimes—as much as six times the purchase price—careful initial selection pays solid dividends.

During the winter, conventional homes located in climates with a high heating load can put the excess heat given off by lights and appliances to good use. However, today's most energy-conserving homes require so much less energy for space heating that excess heat from appliances is less useful, particularly during the spring and fall. Furthermore, in homes heated by non-electric sources, it is often more costly to use electric appliance heat than to increase the reliance on heat provided by oil or natural gas. Although actual heating needs might increase slightly with efficient appliances, total energy bills drop.

In areas where local utilities install demand meters (measuring how fast homes use energy, not just the total amount they use), a load controller might be recommended. *Load controllers* provide homeowners with the ability to limit the number of electric appliances that can be used simultaneously in a home. For example, if a dryer, refrigerator, and hot water heater are all operating, and the homeowner turns on the oven, the load controller automatically shuts off the lowest-priority appliance.

A load controller will not actually save energy, but if a utility charges for peak-demand use, a family in an all-electric home can significantly reduce its total electric bill by installing a load controller. This situation is particularly true for an energy-efficient all-electric home because the potential for short periods of high use is eliminated. Load controllers also allow a utility to limit its problems with peak demands from homeowners. Reducing peak demand can make it possible for the utility to use its existing plant effectively and delay the need to add new production capacity.

Energy-efficient appliances generally make the best buy for homes in climates that require cooling systems. There, the excess heat is rarely useful and adds to mechanical cooling loads. The majority of energy-efficient residential lighting systems are coming from European suppliers, but many small energy-efficient appliances are imported from Asia [81].

Refrigerators

A refrigerator is the typical home's third-largest energy user, after space conditioning and water heating. According to ACEEE, a homeowner with a 15- to 20-year-old refrigerator has paid three times more for purchased energy than the refrigerator originally cost.

The efficiency rating of refrigerators has improved more than 40% over the last 15 years. The average refrigerator sold in 1985 used 1100 kWh of electricity per year compared to nearly 2000 kWh for a comparable unit sold in 1972. The best 18-ft^3 refrigerator available today uses 840 kWh ($69/year at $0.082/kWh). These efficiency improvements stem from upgraded insulation, better sealing, improved motor and compressor operation, and more flexible control functions.

The new standards for refrigerators and freezers take effect in 1990. The 1987 Appliance Energy Conservation Act will require that every new refrigerator perform as well as the better units on the market today. These standards will be based on the amount of electricity consumed compared to the storage volume and other features. ACEEE reports that only 25% of refrigerators currently meet these new standards.

Aside from homeowner habits, two factors contribute to energy consumption differences between models. One difference is storage size; the other is freezer location, whether top mounted or side by side. Top-mounted models consume less energy.

Finally, it is worth noting that customer satisfaction with energy-efficient refrigerators is likely to rise because of a special amenity they offer; because the motor runs less frequently, the new models are a less obtrusive source of noise in the home.

Lights

Although not technically appliances, lighting systems account for roughly 8% of the average household's energy consumption. As a result of new technology, a wide selection of fluorescent bulbs are now available that cut energy use by 70% to 80% over incandescent bulbs. Screw-in compact fluorescent bulbs cost considerably more than incandescent bulbs. However, even at $10 to $20 apiece, the new bulbs make good economic sense in the most frequently used light fixtures in any home. Unfortunately, they are not readily available through major retail outlets and do not fit all fixtures.

Roughly 90% of an incandescent bulb's energy turns to heat. Fluorescent bulbs are much more efficient. They produce 80 or more lumens per watt of energy compared to 17 for the typical incandescent bulb. Furthermore, screw-in fluorescent bulbs should last 10 to 20 times longer than incandescent bulbs.

Two criticisms have been leveled at these new bulbs. When the first models came out, their light quality lacked the warmth normally associated with residential lighting. However, fluorescent bulbs are now available in shades that give the lighting quality that used to be available only with incandescent bulbs. The other problem with fluorescent bulbs is size (Figure 3-11). Many bulbs are too large for most residential light fixtures. Some down-sized bulbs are now available, but the larger diameter and the length of the fluorescent bulbs still limit their use.

Furthermore, several types cannot be used inside globelike enclosures or in standard recessed light fixtures with rheostats (i.e., dimmers). Lamp manufacturers are beginning to design fixtures that are compatible with these bulbs as well [82].

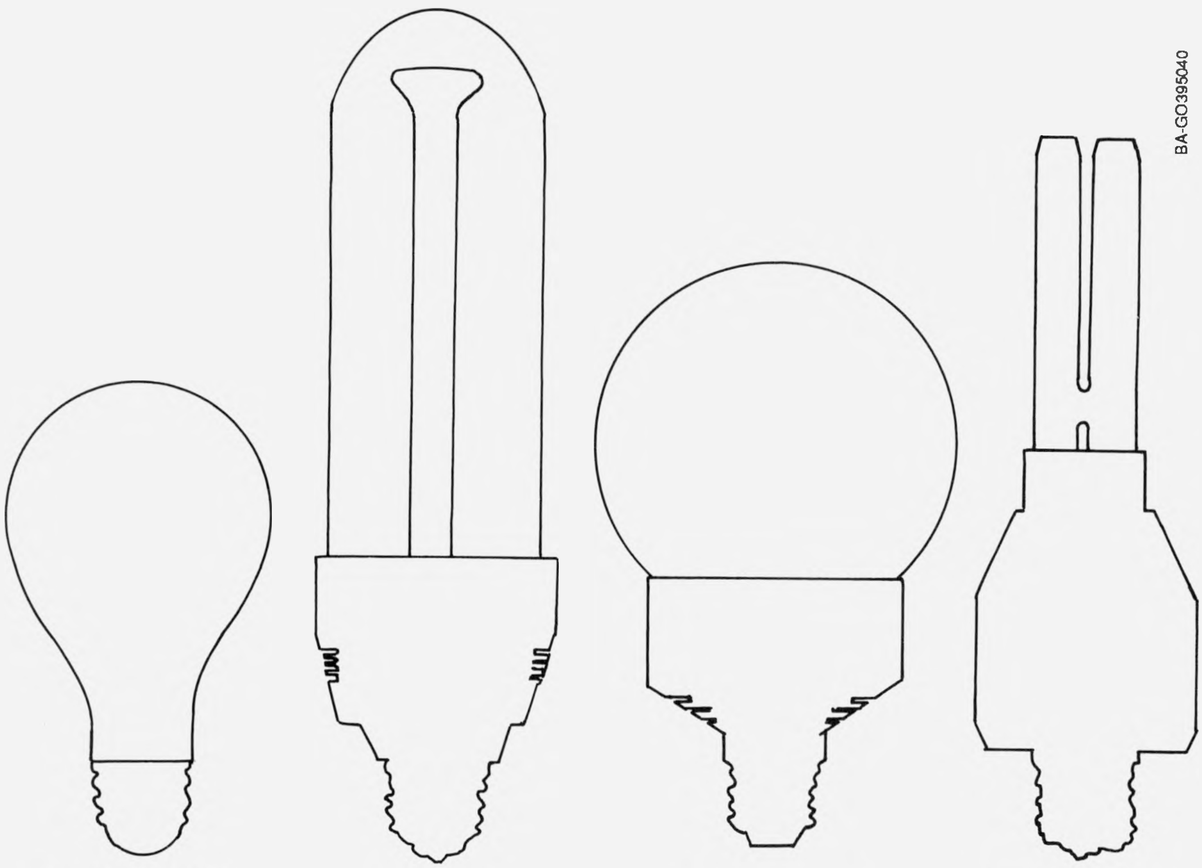


Figure 3-11. One-half the actual size of fluorescent bulbs

Ranges, Washers, Dryers, and Dishwashers

Stove-top cooking tends to be inefficient. As little as 10% of the delivered heat from natural gas might actually heat food. However, changes in gas ranges have significantly decreased overall stove-top energy consumption. The elimination of standing pilot lights cuts consumption by roughly 40%. In addition, a new gas-top burner that is nearly twice as efficient as older versions will soon be on the market.

Progress is not limited to gas cook tops. According to ACEEE, electric models now using induction coils, as opposed to resistance coils, save roughly 20% by cutting back on heating element losses.

The new national standards for dishwashers and clothes washers took effect in 1988. Most of today's better models include the required features: Dishwashers have a cool-drying cycle, and clothes washers offer a cold-water rinse cycle. The biggest energy consideration with washers is the efficiency of the home's water heater.

Clothes dryers have improved significantly and will continue to become more efficient. Good gas dryers no longer require a standing pilot light. Automatic moisture sensors can also eliminate overdrying, with variable savings depending on homeowner habits. One manufacturer has introduced an electric dryer with a heat pump that dries by dehumidification. Although the initial cost might run two or more times the normal purchase price, this appliance should be an attractive investment in areas with high electric rates.

Hot Tubs and Water Beds

All the savings gained from investing in efficient appliances, extra insulation, and house tightening can be offset by installing a discretionary appliance, such as a hot tub. Hot tubs and water beds are popular items, though, and if one is installed, there are several ways to hold down the potentially large operating costs.

Hot tubs are usually sprayed with foam insulation in thicknesses ranging from 1 to 4 in. At least 2 in. should be used in mild regions and 3 in. in colder climates. Insulated covers should also be used. Covers have anywhere from 1 to 4 in. of rigid foam insulation; the highest levels make good economic sense, assuming the cover fits properly.

In any climate where heating costs exceed cooling costs, a hot tub should be enclosed. To avoid humidity problems, the enclosure should be isolated from energy-efficient homes. Water should be heated using the least expensive fuel available, typically, natural gas. Adding an in-line filtering system can also help conserve energy.

Electric costs for a heated water bed can vary from $50 to $150 a year, depending on climate and electric rates. A typical conventional waterbed uses 125 kWh/month, or $120/year; at $.08/kWh, the cost is about as much as a large refrigerator. Homeowners can minimize energy use by lining the sides and bottom of their bed with rigid foam insulation or purchasing a soft-sided waterbed. Buying a smaller water bed (queen versus king sized) can cut heating costs by roughly 25%. In a study by the California Department of Consumer Affairs, it was found that simply placing a heat reflector under the water bed heater saved 12%. It also helps to cover the bed with several bedding layers or a thick comforter and to turn down the bed's thermostat set point. The use of a water bed thermostat allows the house thermostat to be set back on winter nights and kept at 80 deg or higher during the summer; therefore, total energy use can be relatively low. Waste heat from a water bed can be helpful, however, during the heating season.

Appliance Choices for Existing Homes

The information about energy-efficient appliances for new homes applies to appliance selection for existing homes as well. Unfortunately, there is one major difference. When most consumers shop for a replacement appliance, the overriding concern is usually to fill an immediate need. Anyone whose refrigerator has just broken will not want to rely on a neighbor for long to store what is left of their perishable goods. The homeowner wants to know what is immediately available and what the purchase price is, not operating costs and potential savings.

The phased-in implementation of the 1987 Appliance Energy Conservation Act will gradually upgrade the efficiency of all replacement appliances. Until this time, increased effort can be made to inform consumers about the cost-effectiveness of purchasing energy-efficient replacement appliances.

Little potential exists for retrofitting appliances with energy-saving features. Potentially large energy users such as hot tubs can be retrofitted with thick insulating covers—a simple step—but modifying a refrigerator or a gas stove is currently too costly and complex to consider.

Can one justify replacing an old but still functioning appliance with a new, more efficient one purely on the basis of the energy savings involved? For appliances with intermittent use, such as a clothes washer, the economics are typically negative. The outlook is much more positive when considering replacing a large-draw continual use appliance such as a 15-year-old refrigerator. In a region with high utility rates and a significant cooling load, the energy saved by replacing the old refrigerator might look quite attractive. In general, despite favorable economics, it is unlikely that consumers will purchase a replacement appliance based solely on the projected life-cycle energy savings unless other incentives are available.

Rebates

One way utilities can encourage customers to replace their older, less efficient appliances with new, more efficient ones is to offer rebates. Many different approaches to rebates have been tried. The most common are for air conditioners, heat pumps, and refrigerators; one utility provides grown trees as summer shading devices. Some of the most successful programs have focused on rewarding appliance dealers for helping customers choose the most efficient models. A recent report outlines the characteristics and successes of programs operated by 132 utilities around the country [83].

Calwell, Chris. (January-February 1988). "Appliance Rebates: More than a Free Ride." *Home Energy* (5:1); pp. 33–35.

Summarizes a report by the American Council for an Energy-Efficient Economy and the Consumer Energy Council of America on rebate programs at 132 public and private U.S. utilities. Of the 132 utilities that responded to the survey, 59 had working rebate programs, a myriad of incentives labeled by one utility manager as "a grab bag of tricks, games, and gimmicks." The report contains detailed responses about the rebate programs at each utility. In addition, it discusses the types and dollar amounts of rebates offered and provides insights for both consumers and utilities on how to get the greatest savings from rebate programs.

Compendium of Utility-Sponsored Energy Efficiency Rebate Programs. (December 1987). EPRI EM-5579. Palo Alto, CA: Electric Power Research Institute; 273 pp. Available from EPRI Research Reports Center, Box 50490, Palo Alto, CA.

Contains information on 59 energy-efficiency rebate programs based on a survey of 157 utilities. Rebate programs are becoming increasingly popular among utilities across the country as a method to persuade customers to purchase more energy-efficient appliances, space-conditioning systems, lighting products, and motors. The information on each rebate program was cross-tabulated and analyzed to identify such variables as program characteristics, products, efficiency levels, rebate amounts, funding levels, energy and peak-power savings, and the cost of peak-demand reduction. Conclusions about these variables are also presented.

Ongoing Research Efforts

Results from ongoing R&D efforts should continue to improve both the efficiency of HVAC products installed during retrofits and the ability to make cost-effective equipment choices. An ongoing problem is the lack of monitored data on a significant number of houses to determine the amount of energy a particular feature will save. It is estimated that 20% to 50% of energy consumed in the existing single-family home sector still remains to be saved.

Penney, T. R.; Groff, G. C.; Parsons, B. K. *Advances in Desiccant Cooling Systems for Building Space Conditioning*. Draft. Golden, CO: Solar Energy Research Institute; 8 pp. Presented at Second European Symposium on Air Conditioning and Refrigeration, in connection with Expo Clima, the European Exhibition of Refrigeration, Heating, Ventilation, Air Conditioning and Drying, November 22–26, 1988; Brussels, Belgium.

A summary follows of new products that will have an impact on the HVAC retrofit market in the near future:

- One manufacturer is developing a diagnostic tool for measuring the seasonal efficiency of combustion systems. This tool will be easy to use, relatively inexpensive, and reliable.
- GRI is nearing completion with a 90+% efficient condensing boiler appropriate for the 200,000 hydronic systems that are installed each year. The boiler uses an innovative ceramic fiber matrix burner and is expected to cost significantly less than the high-efficiency units now on the market.
- GRI is also working with Japanese manufacturers to test in the United States the performance of heat pumps powered by natural gas.
- The commercialization of a pulse combustion space heater—another GRI product—is planned.
- Work is being conducted at the Solar Energy Research Institute (SERI) to understand and improve desiccant materials for use with thermally activated heat pumps, which are being developed by ORNL to better address the problem of latent heat loads [84].
- A waste-water heat-recovery heat pump is nearing commercialization.
- The Sacramento Municipal Utility District is monitoring the performance of an integrated heat pump system that uses off-peak electricity to supply space conditioning and heat water. Two 350- to 500-gallon storage tanks are charged (with hot water or ice) during off-peak hours, and space conditioning or hot water can then be supplied, as needed, during peak hours but at a significantly lower cost.

Many appliance manufacturers are participating in the development of the SMART house. This effort, coordinated by the National Association of Home Builders, will bring the latest in home security, computer technology, and home energy management to homeowners. Appliances going into the newest generation of homes will have more efficient and flexible control functions than are commonly available today. Homes built with conventional wiring will benefit because some of the same efficiency improvements are expected to spill over into the appliance market.

Efficiency improvements in refrigerators are expected to continue. New developments in self-cleaning ovens should be on the market within the next few years, and the use of microwave technology to dry clothes is being explored. Finally, government researchers are checking into using vacuum insulation for all types of cooking and refrigeration appliances. For instance, SERI is studying the use of improved nonfoam insulation in refrigerator sidewalls and doors that not only affects efficiency but has the potential to reduce the volume of space taken up by current refrigerator insulation. This foam also has the environmental benefit of not being made from cholorofluorocarbons. One approach uses ultrafine powders under a soft vacuum with the equivalent of R-20/in.; the other uses hard-vacuum insulation with spacers that can provide insulation values as high as R-15/0.1 in. [85].

Discusses the significant advances that have been made during the last five years in desiccant cooling both in the private sector and the national research laboratories. Recently, stimulated by gas utilities and the Gas Research Institute, demonstrations of desiccant cooling systems are appearing in a variety of heating, ventilating, and air conditioning plans. Fundamental heat- and mass-transfer research has been conducted on advanced desiccant materials and dehumidifier geometries at the Solar Energy Research Institute. These advances have been analyzed and are shown to have significant advantages and a simple two-year payback. Applications with humidity control or high ventilation rates have been the recent candidates for successful demonstration. By 2005, one utility estimates that nominal market penetration by desiccant cooling results in annual electric usage savings for it on the order of 1100 MW.

Potter, T. F.; Benson, D. K.; and Smith, L. K. (July 1988). *Impacts of Advanced Refrigerator Insulation.* SERI/TP-254-3380. Golden, CO: Solar Energy Research Institute; 12 pp. Available NTIS: Order No. DE88001180.

Analyzes recent developments in advanced insulations, such as powders under a soft vacuum (R = 20/in.) and hard-vacuum insulation with spacers (R = 15/0.1 in.), that merit evaluation for their practical use in refrigerator-freezers. Researchers selected two different refrigerator-freezer base cases for this analysis; one had the typically used chlorofluorocarbon (CFC) foam (R = 7.7/in.), and the other featured non-CFC foam (R = 5.3/in.) in the exterior walls and doors. (In keeping with industry practice, both refrigerator doors were insulated with fiberglass.) Two simulated modifications of both base cases, based on the DOE closed-door test, included replacing part of the wall and door insulation with either 1 in. of powder or a 0.1-in. layer of hard-vacuum insulation with spacers. Both modifications met the standard, even when the non-CFC foam base case was simulated. Three other cases were tried, replacing the base design insulation with various thicknesses of the new insulations. When two layers of hard-vacuum insulation were used, energy consumption was reduced by 44%, enabling it to meet the standard. A benefit of each of these configurations is that the interior volume of the refrigerator-freezer is increased (to an additional 6 ft^3), thereby increasing the market value. In general, savings of more than 50% in energy use appear possible. Associated increases in salable refrigerated volume might offset some or all of the anticipated cost of the improved insulation.

Chapter 4

Understanding and Controlling Indoor Air Quality

Indoor air pollution, especially radon, has been making the headlines since the mid-1980s. Some studies indicate that air pollution inside many homes might be considerably worse than it is outside. From all indications, home buyers will become increasingly aware of, and concerned about, this topic during the next few years.

Concerned groups have raised questions about the wisdom of building tight homes or tightening existing homes. Indeed, a tighter home can lead to higher levels of some indoor pollutants. However, with the information gathered to date, researchers at Lawrence Berkeley Laboratory (LBL) and elsewhere conclude that tightening a home can be done safely. In fact, LBL staff members state that with a few simple precautions, such as controlling indoor pollutant sources and using simple ventilation strategies, the air in energy-efficient homes can be just as clean or cleaner than the air in less efficient homes [86].

Continuously controlled ventilation in residences is a relatively new concept. When installing controlled ventilation features in either new or existing homes, careful weatherization offers a key advantage. Controlling where and when fresh air is brought into a home is generally easier in a tight home than in its leakier counterpart.

The following sections discuss indoor air quality and include an analysis of the four major pollutants. Ways to minimize pollution in new homes and solve air-quality problems in existing homes are explored.

Turiel, I. (1985). *Indoor Air Quality and Human Health.* New York: Chapman and Hall; 200 pp.

Provides a summary of indoor air-quality problems in homes, offices, and public buildings. It covers problems with formaldehyde and other household contaminants, radon, particulates, combustion products, involuntary smoking, energy-efficient buildings and indoor air quality, control of indoor air pollutants, indoor air-quality problems in office buildings, and legal and regulatory issues.

Tight Homes and Fresh Air

How much fresh air do homes need? Homes with high levels of internally generated pollutants need more fresh air than homes with few pollutants. Kitchen and bath fans exhaust some pollutants. Natural air infiltration from winds and temperature differences also removes some pollutants; however, natural infiltration might not be present when and where pollutants are generated in order to help clear them from a home.

Researchers with the American Society for Heating, Refrigerating, and Air-Conditioning Engineers are currently amending standards for recommended ventilation in new homes. Their draft recommendations (dated June 1986) indicate the following:

- For homes with air-infiltration rates of approximately 0.20 air changes per hour (ACH) or less, air infiltration is almost never sufficient to achieve adequate indoor air quality. Specific mechanical ventilation is probably required at all times when the windows are closed.
- For homes with air-infiltration rates of approximately 0.20 to 0.50 ACH, infiltration might or might not be sufficient, depending on conditions within the home. Mechanical ventilation might be required in some cases, but existing intermittent bathroom- and kitchen-type exhaust fans might be sufficient.

Sherman, Max. (July 1986). *Exegesis of Proposed ASHRAE Standard 119: Air Leakage Performance for Detached Single-Family Residential Buildings.* LBL-21040. Berkeley, CA: Lawrence Berkeley Laboratory; 23 pp. Available NTIS: Order No. DE86015192.

Presents the derivation of American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 119 and includes an interpretation of its potential effect. This standard sets airtightness requirements for single-family residential buildings and defines a classification method suitable for all buildings. ASHRAE has been actively developing consensus standards to govern and recommend energy use in buildings.

- For homes with air-infiltration rates of approximately 0.50 ACH or more, infiltration is normally sufficient to meet ventilation requirements.

The recommendations end with a warning: For all leakage classes and in all climates, conditions can exist where infiltration is insufficient to meet ventilation requirements without natural ventilation (open windows) or mechanical ventilation to augment the infiltration [87].

Are energy-efficient homes the problem? A growing perception exists that *tight homes are less safe than leaky homes.* Indoor air-quality experts indicate that this concern is misplaced, is inaccurate, and misses the main point.

Scientists heading the Indoor Environment Program at LBL report that most air-quality problems in houses can be traced to high pollutant sources rather than low infiltration rates. The two keys to maintaining good indoor air quality are (1) minimizing pollutant sources and (2) providing simple mechanical ventilation. At Brookhaven National Laboratory, scientists report that good indoor air quality is best achieved through sealing or direct ventilation of pollutant sources rather than natural or mechanical ventilation of the entire home [88].

Building leaky homes is clearly not the solution. Unfortunately, eliminating all pollutant sources is not feasible either. Improved construction materials can limit some sources of pollutants: Low-fuming particleboards, paints, adhesives, and formaldehyde-free carpet underlayment are on the market today. Unfortunately, few builders have chosen to include these healthier materials in their buildings. However, the few builders who do choose these new products still have no control over the unhealthy cleansers, sprays, and formaldehyde-laden furniture that buyers might bring into a home.

The Four Major Pollutants

A number of air pollutants need to be considered in the construction of a new home, for example, outgases, airborne particulates from cooking, and cigarette smoke. However, builders should generally be most concerned about the four greatest hazards: radon, formaldehyde and other volatile organic compounds (VOCs), combustion gases, and excessive humidity. If these sources are understood, and builders make provisions to solve the problems they pose, the majority of potential concerns are likely to be successfully addressed.

Radon

Radon is a naturally occurring inert gas that comes from the decay of uranium in the soil. It breaks down into radioactive decay products that become trapped in the lungs and increase the risk of lung cancer. According to the Environmental Protection Agency (EPA), scientists estimate that in the United States, from 5000 to 20,000 lung cancer deaths a year can be attributed to radon.

Radon gas enters most homes through crawlspaces or cracks and openings in basement walls and slabs (Figure 4-1). Field researchers from LBL indicate that energy-efficient homes are generally no more or less susceptible to radon problems. Clearly stating that radon problems do not relate to how tight or leaky a home is, the researchers contend that three factors determine the scope of any radon problem: (1) the presence of radon gas in the soil beneath a home; (2) the soil porosity, which affects the ability of radon gas to move through the soil; and (3) the extent to which a home exerts negative pressure on the soil beneath it, thus pulling radon into the home.

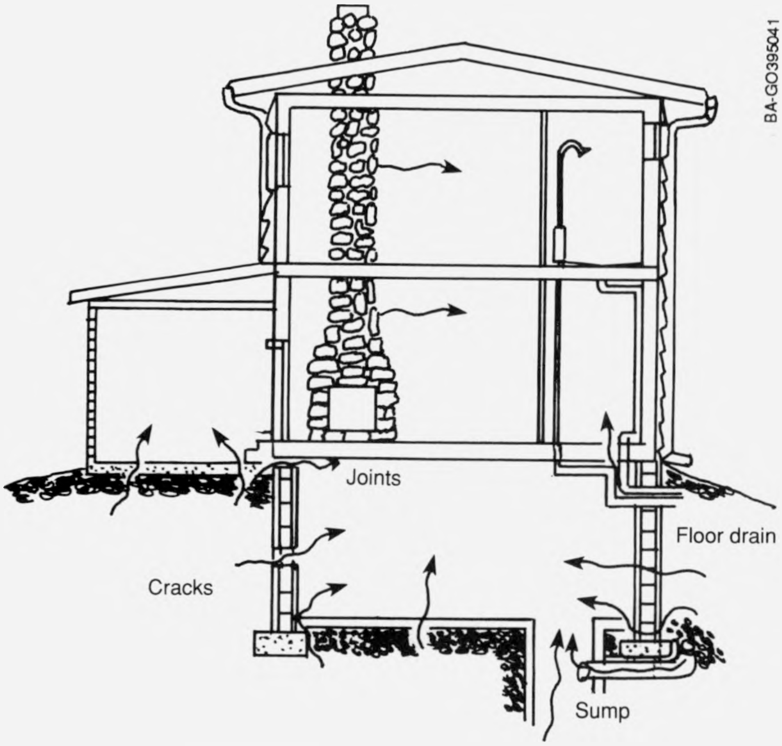


Figure 4-1. Radon entry points

Formaldehyde and Other Volatile Organic Compounds

Formaldehyde is a gas released into the home by products, materials, combustion, and cigarette smoke. The most common sources are glues and adhesives used in plywood, particleboard, laminates, furniture, cabinets, and carpeting. The health risk of long-term exposure to low levels of formaldehyde is unknown [89].

As products containing formaldehyde age, they begin releasing the gas. The amount given off is greater when the products are new and decreases over time; this amount also varies with temperature and humidity. As a house is made increasingly airtight, concentrations of formaldehyde tend to increase. However, the number and strength of formaldehyde-laden products within a home are still the primary determinants of indoor levels of formaldehyde. A tight home with a tiled slab floor should have lower formaldehyde levels than a leakier home with carpeting over wood subfloors.

In Europe, standards exist that limit the amount of formaldehyde used in building products. No uniform standard exists in the United States for conventional single-family homes. The U.S. Department of Housing and Urban Development sets a ceiling of 0.4 parts per million on formaldehyde concentrations for homes built to their specifications. The Consumer Products Safety Commission and EPA are considering formaldehyde standards but have not implemented them.

The National Particleboard Association initiated remedial action that has resulted in reduced formaldehyde emissions from many of the wood

Cairns, Elton J., and Grimsrud, David T. (May 1987). *Applied Science Division Annual Report: Indoor Environment Program FY 1986.* LBL-22153. Berkeley, CA: Lawrence Berkeley Laboratory; 45 pp.

Consists of a collection of papers reporting the accomplishments of the five groups that compose the Indoor Environment Program for Fiscal Year 1986. The program examines the scientific issues associated with the design and operation of buildings to optimize building energy performance and occupant comfort and health. The program's five groups are conducting research in the following areas: indoor radon, volatile organic contaminants in indoor air, indoor exposure assessment, ventilation and indoor air-quality control, and energy performance of buildings. Several important hypotheses evolved from this work: Air quality in buildings is dominated by sources, air pollution is a buildings problem, and ventilation is the best control strategy for indoor pollution.

products sold today. A few formaldehyde-free products, such as particle-board and carpet underlayment, are now available from some U.S. companies.

In addition to formaldehyde, other organic products contribute to indoor pollution, such as methylene chloride found in paint removers and aerosol finishes. LBL is studying the effects of different exposure levels on human health [90].

Combustion Gases

Chimneys and flues are designed to mix warm air with incomplete combustion by-products: carbon monoxide, carbon dioxide, nitrogen dioxide, aldehydes, and water vapor. The warm air and the by-products are then vented to the outdoors (Figure 4-2).

Large exhaust appliances (see Table 4-1) often try to force air out of a house at the same time that combustion by-products go up the flue. Thus, each element contributes to negative pressure inside a home. In this tug of war, exhaust fans can easily overpower flues, causing *backdrafting,* or the spilling of dangerous combustion by-products into the home (Figure 4-3). Unvented space heaters (e.g., kerosene heaters) should not be used in tight dwellings because of the combustion air requirements as well as the combustion by-products released into the home.

Carbon monoxide is the greatest single pollutant concern. A relatively small difference exists between the levels of carbon monoxide that are harmless and those which can render homeowners unconscious and, possibly, cause death. Typically, a smoldering fire is the largest potential

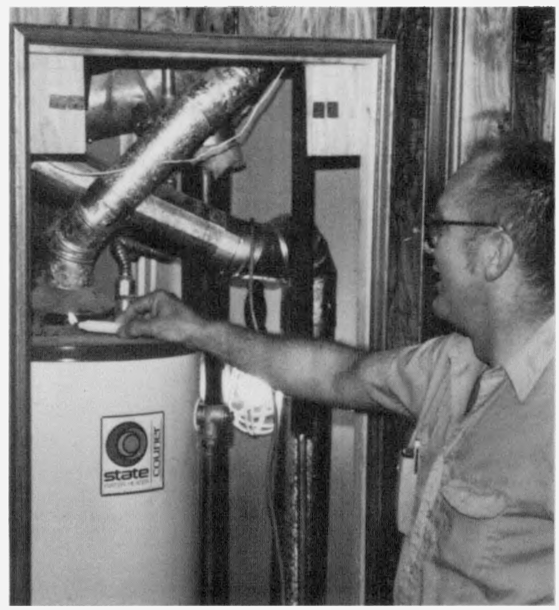


Figure 4-2. Checking to see if combustion appliances (natural draft–type) are susceptible to backdrafting of combustion gases (candle shows direction of air flow). (Photograph by Steve Andrews)

Table 4-1. Estimated Airflow for Typical Exhaust Devices

Device	Installed Rating[a] (cfm)
Bath fan	24–90
Clothes dryer	100
Range hood	30–120
Downdraft stove exhaust fan	250
Central vacuum	110
Fireplace	170
Open wood stove	65
Airtight wood stove	30
Gas, oil, and propane furnaces and boilers	21–72

[a] Manufacturers will rate the fans on this list with higher ratings. The items here have been corrected for restrictions such as elbows, straight ducts, louvers, and grease filters.

cfm = cubic feet per minute.

Source: Moffatt, Sebastian, 1986, "Back-Drafting Woes," *Progressive Builder.*

source of carbon monoxide. Under certain circumstances, carbon monoxide can be produced by fossil fuel heating appliances. A tight home with exhaust fans and conventionally designed combustion appliances can increase the potential for a carbon monoxide problem.

Excessive Humidity

Moisture generated inside a home or filtered up from a crawlspace eventually migrates outdoors. In leaky conventional homes, humidity moves out so quickly that it is difficult to maintain a desirable level for human comfort—around 40% in winter. For this reason, humidity is rarely viewed as a pollutant. However, most biological pollutants are a condition of excess humidity.

The wintertime use of a humidifier is not all that uncommon in a leaky home or a home in a dry climate. However, in today's tighter homes, the humidity level can rise above 60%. At this level, condensation can begin forming on cold surfaces, especially windows on cold nights, and can lead to surface mold and dry rot in walls and ceilings. Humidifiers should not be necessary in energy-efficient homes. In fact, fans controlled by a dehumidistat might be desirable to prevent humidity from rising to the point where it can cause mold and mildew.

Minimizing Pollution Problems in New Homes

The solution is not to hope that a naturally leaky home will eliminate indoor air-quality problems. Rather, the best strategy involves three basic steps: (1) blocking pollutants at the source, (2) providing spot ventilation, and (3) providing whole-house ventilation. Ways in which to carry out this three-step plan are outlined in the following paragraphs.

In all cases, the first step should be to block out, isolate, or seal off the pollutants. Specific methods follow for treating each of the previously discussed pollutants:

- Radon: Block airflow paths from the ground into the home. This strategy is recommended to homebuilders by EPA and the National Association of Home Builders (NAHB). However, because new homes shift and settle considerably, a home with most access points (slab joints, sumps, floor drains, etc.) sealed might have radon-emitting leaks appear after a few years.

  Another antiradon strategy that has worked in several locations around the country is to depressurize the areas underneath basement floors or at the base of walls. Such preventative schemes can cost as little as $200 [91]. In a comparative study conducted by LBL of three different approaches to reducing radon, the slightly depressurized subsurface ventilation approach showed a reduction of a factor of 10 over baseline readings [92].

- Formaldehyde: Switch to low-formaldehyde products, such as those mentioned earlier. Apply a sealant over exposed particleboard surfaces if they are high in formaldehyde.
- Gas combustion appliances: Use draft-induced or sealed combustion models.
- Fireplaces: Supply outside air directly to the firebox, and use tight-fitting glass doors.
- High humidity: Prevent moisture from entering the crawlspace. Cover earth exposed in crawlspaces with durable polyethylene.

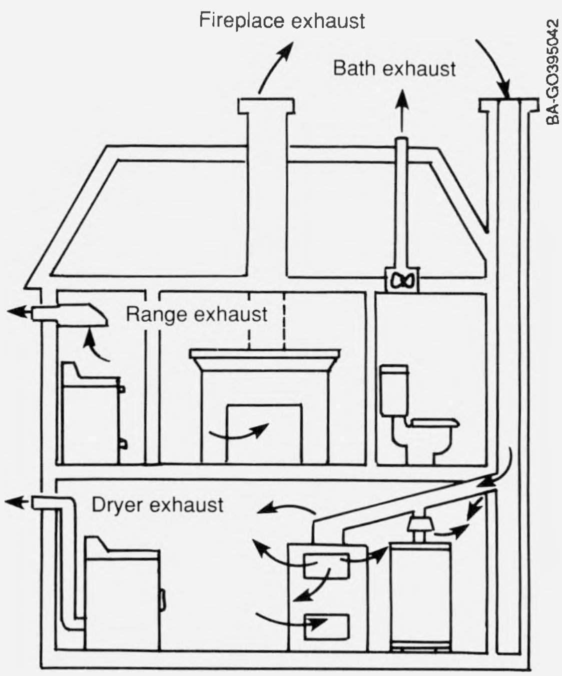


Figure 4-3. Chimney backdrafting occurring when house depressurization from exhaust reverses the chimney draft. (Source: Adapted from Lischkoff, James K., and Joseph Istiburek, 1986, *The Airtight House: Using the Airtight Drywall Approach. A Construction Manual.* Ames, IA: Engineering Extension Service, Iowa State University)

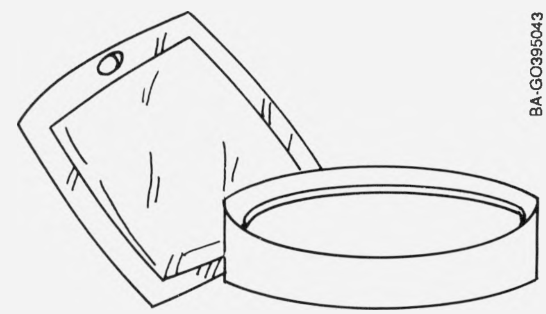
Radon Reduction in New Construction: An Interim Guide. (August 1987). OPA-87-009. Washington, DC: United States Environmental Protection Agency; 10 pp.

Provides radon information for those involved in new construction. It also introduces methods that can be used during construction to minimize radon entry and facilitate its removal after construction is completed.

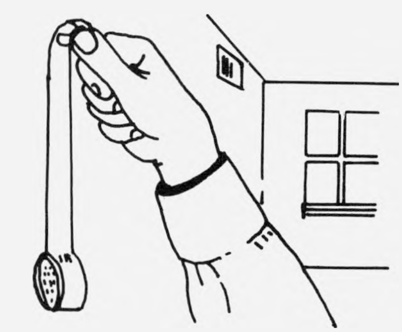
Second, provide spot ventilation with upgraded controls. Kitchen and bath fans can be connected to on-off switches and wired in series with a dehumidistat control. Humidity in excess of desirable levels operates the fans independent of the switch. Fans can still be operated with on-off switches. (This strategy might not work in large-volume homes.) A time-of-day clock can be installed to override both the on-off switch and the dehumidistat. Thus, the fan exhausts a specified amount of stale air independent of the humidity-generating activities. It can be preset to operate for certain hours of each day, depending on the occupancy patterns.

Third, provide whole-house ventilation, with or without heat recovery. Air-to-air heat exchangers (also known as heat-recovery ventilators [HRVs]) often include the type of sophisticated controls discussed earlier. Their three advantages are (1) they preheat (and precool during the cooling season) incoming fresh air for comfort and some energy savings; (2) they provide balanced ventilation—the flow from exhaust air ducts equals that coming in from the fresh air supply ducts (when properly installed); and (3) they can be ordered with all the necessary parts in one package. The second feature helps avoid the creation of negative pressure, which can draw in radon or combustion gas by-products. The primary disadvantage of a heat exchanger is the high installed cost.

Note: At a minimum, the Scandinavian countries, Germany, and France encourage the installation of whole-house ventilation systems in all new homes. In the United States, only a few smaller builders of energy-efficient homes now include whole-house ventilation as a matter of course.



Charcoal canisters for radon testing: 1–4 day test period
Cost: $12–$25 (mail order)



Track-etch detector: 1 month–1 year test period
Cost: $25–$50

Figure 4-4. Radon testers

Testing for Pollution Problems in Existing Homes

Tests designed to measure the level of pollutants in existing homes are available for all the pollutants described earlier.

The most common radon-testing devices are available through mail-order firms for $10 to $50. Short-term measuring devices—two to seven days—use an activated charcoal screen to test for the presence of high levels of radon. When these measurements show evidence of elevated radon levels, longer-term follow-up testing (1 to 12 months) with alphatract detectors is the next step (Figures 4-4, 4-5). Radon abatement contractors sometimes use expensive grab-sample testing devices to pinpoint high radon sources. Contractors can also use the grab-sample technique to check the effectiveness of their efforts to eliminate these sources. EPA has issued guidelines concerning the safe use of these testing devices [93].

As mentioned earlier, researchers find little correlation between radon concentrations and air-infiltration rates in existing homes. Extensive measurements by LBL for the Bonneville Power Administration indicate that the presence of high radon levels in homes depends more on location than on tightness or type of construction [94].

Combustion gases can be checked for with a backdraft test. It is an important safety check used by today's most knowledgeable weatherization crews. However, it is also the most frequently overlooked test.

During a backdraft test, weatherizers simulate lower indoor air pressure by turning on a blower door and in-place exhaust fans while the furnace is operating. An airflow gauge is inserted into the furnace's combustion chamber plenum. If the gauge indicates readings in the safe range, no further action is necessary [95].

Ronco-Battista; Magreo, P.; and Nyberg, P. (November 1986). *Interim Protocols for Screening and Follow-up Radon and Radon Decay Product Measurements; Draft.* EPA/520/1-86-014. Washington, DC: U.S. Environmental Protection Agency; 17 pp.

Provides guidelines for using the radon and radon decay product measurement methods outlined in the protocols. Two measurement methods are discussed. The first is a screening measurement made under maximized conditions. The second is a measurement that is used to estimate health risks and determine the need for remedial action. These guidelines are primarily intended as an aid to states for radiation control programs, other organizations that conduct measurements, and homeowners who want detailed information on measurements.

A Citizen's Guide to Radon: What It Is and What to Do about It. (August 1986). OPA-86-004. Washington, DC: U.S. Environmental Protection Agency; 14 pp.

Discusses concerns of the U.S. Environmental Protection Agency and the U.S. Center for Disease Control about the increased risk of persons exposed to above-average levels of radon in their homes developing lung cancer. This pamphlet helps readers understand the radon problem and decide if they need to take action to reduce radon levels in their homes.

Professional testing for formaldehyde using the chromatropic acid method is the best way to determine whether formaldehyde levels are safe; however, this method is also the most costly, ranging from $100 to $500 [96]. Test kits for the homeowner or weatherizer range from $20 to $100 but are less commonly available than radon kits. The less expensive kits must typically be left in place for a predetermined time of 24 hours to seven days.

Finally, tests for high humidity are a simple matter of using a humidity gauge, which costs between $20 and $25. The wintertime level should not read higher than 50% to 60%. Window condensation on cold mornings is often a sign of high humidity. However, this danger sign might not be evident to anyone but a homeowner, who does not recognize it as a serious problem. If unchecked, excess humidity can cause structural damage. The problems can range from rotting floor joists in the humid south to deteriorating walls and sheathing in the colder northern states.

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Reiland, P.; McKinstry, M.; and Thor, P. (January 1986). *Preliminary Radon Testing Results for the Residential Standards Demonstration Program. Program Results No. 3.* DOE/BP-582. Portland, OR: Bonneville Power Administration; 38 pp.

Reports measurements for heating season radon concentrations in indoor air for 289 homes in the Pacific Northwest. The homes are part of the Bonneville Power Administration Residential Standards Demonstration Program and include 143 dwellings constructed to the Model Conservation Standards (MCS) proposed by the Northwest Power Planning Council (MCS homes) and 146 control dwellings built over the last several years to current building codes (control homes). The results indicate that the location of the dwelling was a more important determinant of indoor radon concentration than was use or nonuse of the standards. Previous studies have shown that radon levels in dwellings are only weakly correlated to air-exchange rates and that control of radon sources is a more practical and effective method of reducing indoor concentrations.

Spiegle, Scott R. (1987). *House Tightening and Building Science Manual.* Denver, CO: National Thermal Performance Institute; 121 pp.

Presents methods for controlling natural and induced air leakage. The blower door concept is introduced, and testing by fan depressurization, infrared scanning, and leak location are described. Three major problem areas are examined: combustion appliances and backdraft testing, moisture movement and humidity, and indoor air quality and ventilation. After summarizing the basic sealant types, methods for new construction sealing and retrofit sealing are presented, with a list of basic tools and materials. The appendixes include the Colorado Thermal Insulation Association's standards for determining airtightness and a new residential construction leakage ratio.

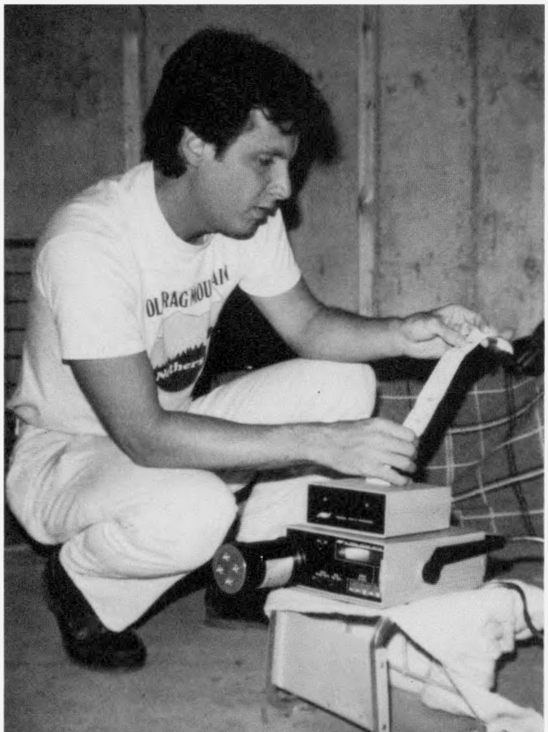

Figure 4-5. Continuous radon monitoring device. (Photograph by Steve Andrews)

Solving Pollution Problems in Existing Homes

The strategies for solving these pollution problems are similar to those listed for new homes. Sealing or blocking out pollutants is the first step. Increasing controlled ventilation is the second. However, in most cases, achieving these objectives is much more complicated in an existing home than in the construction of a new home.

Blocking Pollutants at the Source

EPA has published several documents describing ways of ridding a home of radon. The strategies range from relatively simple tasks that skilled do-it-yourselfers can perform to complex strategies that typically require radon mitigation specialists [97].

Because radon travels up through the soil, covering large areas of exposed earth in crawlspaces or basements is a top priority. Smaller entry points such as cracks or joints in basement walls and floors, open sumps, floor drains, and plumbing penetrations should be sealed. If foundation walls are made of concrete blocks, the open cores are often major radon entry points that must be closed off. When the radon problem is minor, these steps can bring radon levels within EPA guidelines. With higher radon levels, sealing procedures are also important; however, they are less likely to solve the problem without additional measures.

Radon mitigation experts often use fans to continuously draw radon from around floor slabs, basements walls, and crawlspaces before it can enter the home. If there is crushed rock under a slab, contractors drill several holes in the slab and install polyvinyl chloride pipe in the holes. They then link all the pipes together and use a fan to force radon-laden air from under the slab out of the house through a central pipe (Figure 4-6).

Fans are also used to draw the gas from block walls or perimeter drains. Small fans in crawlspaces have proven effective in reducing radon in homes. (Caution is warranted when furnaces or water heaters are located in crawlspaces because exhaust fans can cause backdrafting of combustion gases.)

Increasing a home's supply air (i.e., air that is consciously supplied by some process) at specific sites is another way to reduce radon. Providing additional direct air to such items as fireplaces and furnaces reduces the tendency toward negative indoor air pressure, which, in turn, slows the flow of incoming radon.

In addition to helping reduce radon, supply air strategies can help minimize problems with combustion gases entering homes. Balancing supply air is one way to assure an air supply for standard gravity exhaust furnaces. Another method is to isolate the furnace and water heater by building a box around them and supplying it with outside air.

When an older furnace needs replacing, the most effective safety strategy is to put in a high-efficiency model. Sealed combustion units that use outside air eliminate the potential for backdrafting flue gases. New furnaces with fan-forced exhaust minimize backdrafting risks at a substantially lower initial cost.

Supplying a fireplace with glass doors and an outside air source (if possible) can help reduce the potential of backdrafting down the chimney when a fire has nearly burned out.

Formaldehyde can be dealt with in older homes by educating homeowners about the availability of low-formaldehyde products. Low-fuming particleboard, plywood, and hardboard paneling should be

Radon Reduction Methods: A Homeowner's Guide. (September 1987). OPA-87010. Washington, DC: U.S. Environmental Protection Agency; 21 pp.

Discusses studies by the U.S. Environmental Protection Agency (EPA) of the effectiveness of various ways to reduce high concentrations of radon in houses. The booklet describes methods that have been tested successfully, by the EPA and other research groups, on houses with high indoor radon levels. The information is primarily concerned with radon that enters a house from the underlying soil.

Radon Reduction Techniques for Detached Houses: Technical Guidance. (June 1986). EPA/625/5-86/019. Research Triangle Park, NC: U.S. Environmental Protection Agency; 61 pp.

Provides a general review of potential indoor radon concerns and presents technical information to support the choice of techniques to reduce indoor radon concentrations when unacceptable levels are found. The information is based on many existing sources of information and recent U.S. Environmental Protection Agency research experience. Used in conjunction with selected reference reports, the information provides building trade professionals and homeowners with the basis for an understanding of the source and nature of radon emissions, common radon entry routes into houses, and methods for preventing or reducing indoor radon concentrations. Radon levels in houses can be reduced by four methods: (1) preventing the entry of radon gas into the house, (2) ventilating the air containing radon and its decay products from the structure, (3) removing the source of the radon, and (4) removing radon or its decay products from the indoor air. This guidance concentrates on the first two methods as they relate to radon entry from soil gas.

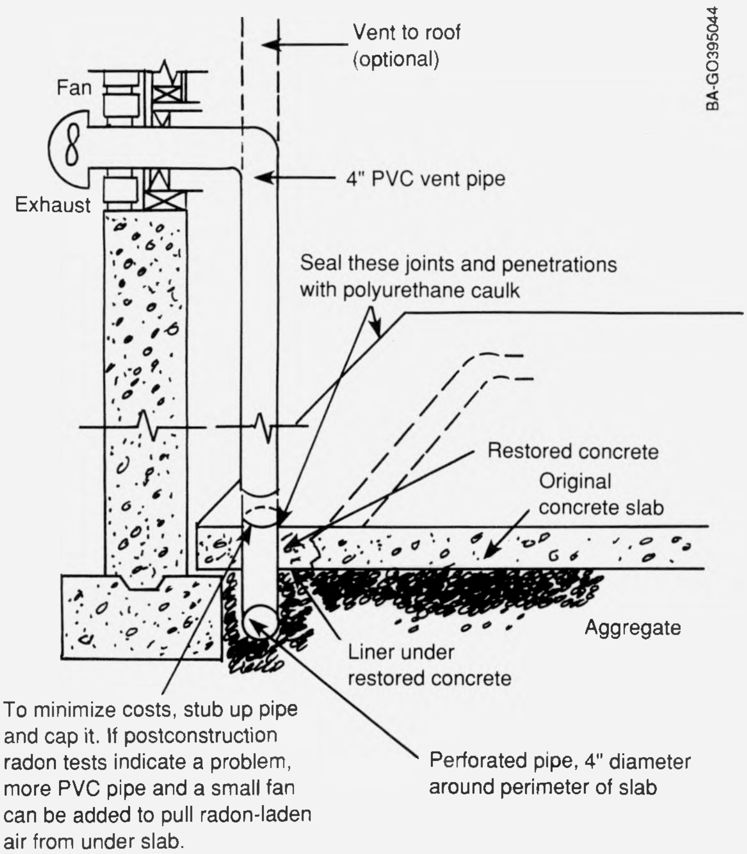

Figure 4-6. Subslab ventilation of radon

selected when putting up an addition or doing major remodeling. Any exposed surfaces on new shelving or cabinetry, often made from particleboard, should be coated with water-based sealants, which either slow or eliminate the release of formaldehyde.

Homes with retrofitted urea-formaldehyde foam insulation in their walls face drastic corrective measures. Interior wall surfaces might have to be removed in order to scrape out the foam, which is then replaced with batt insulation.

Finally, the best strategies for blocking sources of excess humidity can vary a great deal from one climate to another. In a colder climate, the first step is to seal off any contact with uncovered ground. The second step involves ensuring adequate ventilation in moisture-producing rooms, typically, kitchens and baths. Third, sealing to create an air barrier prevents warm air from migrating into walls and significantly reduces the chances of condensation forming on the inside of exterior sheathing or siding.

In warmer climates, the concern is that humid air can migrate into the building from outdoors. In this case, condensation occurs on the backside of interior surfaces. Recent research indicates that providing an exterior air barrier to prevent moist air from moving indoors can reduce condensation problems. (See the discussion of air barriers in Chapter 2.)

Control Ventilation Strategies

Adding mechanical ventilation to a home that has none tends to be a difficult and expensive proposition. A number of the ventilation retrofits that deal simply with radon mitigation can cost well over $1000.

Efforts to mechanically control a home's ventilation rate generally improve indoor air quality and reduce the sense of indoor stuffiness. However, ventilation alone does not always solve pollution problems. For example, if a home has a radon level 10 times higher (40 pC/1) than recommended by the EPA guidelines, normal ventilation approaches will not completely solve the problem. If the home leaks at 0.5 ACH, doubling the home's air-change rate to one per hour only cuts the radon in half. The new level of 20 pCi/1 is still five times higher than the guideline recommends.

New ventilation systems vary in complexity and can be set to operate either continuously or intermittently. Intermittent ventilation is usually provided by conventional kitchen and bath fans. The least expensive solution that still gives improved control is activating these fans with a dehumidistat or a timer. Expensive systems offer both fresh air and heat recovery.

Air-to-air heat exchangers have been used for nearly a decade to provide fresh air in tightly built homes. Most HRVs exhaust between 100 and 250 ft^3 per minute. Installation costs are usually over $1000. Studies in the Pacific Northwest indicate that in moderately cold climates, the energy saved by heat recovery—around 50% of the heat from the exhausted air—does not by itself justify the purchase of an HRV. However, properly installed HRVs can increase occupant comfort and provide control of indoor pollutant and humidity levels.

Ongoing Research Efforts

During the next few years, radon-testing programs by EPA should help confirm the scope of the radon problem nationwide. The NAHB Research Center is working with EPA and New Jersey builders to explore the least expensive and most fool-proof ways to install radon mitigation systems in new homes.

LBL is conducting research in a wide variety of areas, including assessing different mitigation approaches, conducting risk assessments of VOCs, developing a macromodel to characterize indoor exposures to harmful pollutants, and evaluating existing ventilation strategies and developing new ones [98]. Researchers at the Solar Energy Research Institute have developed a laboratory-scale test facility and measurement and modeling approaches to better understand how air flows in a room, how air mixes in various locations throughout a room to dilute pollutants, and how this air movement affects ventilation requirements so that more effective ventilation systems can be designed [99].

In the area of product research, at least one manufacturer is offering whole-house ventilation systems with and without heat recovery. The latter approach costs less. More such products are being developed. At least one manufacturer offers a combined system that uses heating ducts to distribute fresh air as well. As more manufacturers explore the potential for integrating heating, cooling, water heating, and ventilation, costs are expected to drop.

Chapter 5
Design, Analysis, and Diagnostic Tools for Energy Efficiency

Because a home uses energy in so many ways, it is difficult to establish a few rules of thumb that will ensure a cost-effective approach to energy efficiency. For this reason, numerous tools are available to assist builders, architects, and inspectors in selecting, confirming, and evaluating efficient designs. *Energy design tools* help architects and builders design energy-efficient buildings; *energy data analysis* tools help researchers evaluate how well a particular product or design performed compared with predictions; and *energy diagnostic tools,* such as blower doors and infrared cameras, help researchers understand why a home or product performed the way it did.

Energy Tools for New Homes

Energy Design Tools

Energy design tools are analytic methods and computer programs that simulate building performance in all types of climates. They help designers estimate a proposed building's energy consumption, indoor temperatures, and operating costs. The tools allow designers to calculate the energy saved by changing individual elements, such as increasing ceiling insulation or installing better windows. The tools also help designers assess the cost-effectiveness of one energy-conserving measure compared with another or with a combination of others. Although designers' experience and intuition are important, the design tool enables them to evaluate a range of energy design options with speed and accuracy.

The tools are particularly useful for breaking down total building energy use into its component parts. For both heating and cooling, these loads are typically separated into losses from infiltration, conduction through walls and ceilings, losses to the ground through basements or slabs, and solar gains (both useful or undesirable). This information is most useful during the early stages of design because energy-related changes suggested by the analysis are still relatively easy to incorporate.

Design tools can either be computerized or worked by hand. The manual methods include specially designed slide rules and books such as those developed by the U.S. Department of Energy (DOE) for both site-built and manufactured housing [100,101]. Site analysis tools are also available, such as those used to determine solar access when designing passive solar homes. Today, most design tools that focus on energy flows and consumption in homes are computerized. At least one state, California, requires that a computer energy design tool be used during the permitting process [102].

Some of the earliest computer design tools, created through federal efforts, were for use on mainframe computers. Two programs used were DOE-2, developed by DOE, and SERIRES, developed by the Solar Energy Research Institute (SERI). Researchers use both programs extensively because they have substantial engineering modeling capability and are designed to describe as accurately as possible the way energy is used in a building.

Affordable Manufactured Housing through Energy Conservation: A Guide to Designing and Constructing Energy Efficient Manufactured Homes. (July 1984). DOE/CS/20524-7. Washington, DC: U.S. Department of Energy; 120 pp.

Helps manufacturers and retailers sell more houses by offering energy-saving options to potential buyers of manufactured housing that reduce the overall cost of homeownership. The information included in this guide and the accompanying side rule booklet provides everything needed to estimate the savings and costs for most of the conservation options discussed. The options for saving energy in manufactured homes can be grouped into three categories: space conditioning (i.e., heating and cooling), domestic water heating, and appliances. A worksheet is included for each of these categories. The accuracy of the energy values is increased by keying them to more than 1000 specific locations throughout the United States.

Passive Solar Design Strategies: Guidelines for Home Builders.

Contact:
Passive Solar Industries Council
1090 Vermont Avenue, Suite 1200
Washington, DC 20005

Is intended to help builders and designers evaluate the benefits of energy-conserving and passive solar design. The guidelines allow the user to select, in over 2,400 locations nationwide, the best mix of conservation, passive solar, and natural cooling strategies to reduce a home's energy use and actually increase its comfort and marketability. The package was developed with the participation of the National Association of Home Builder Standing Committee on Energy and the Passive Solar Industries Council (PSIC) member organizations and corporations.

Using special software developed at Los Alamos National Laboratory and the Solar Energy Research

Because using mainframe computers is expensive and complex, nearly all energy design tools in use today are specifically formatted for microcomputers. Several of the rigorous mainframe programs have been adapted to personal computers. However, the mainframe programs are considered the standard against which the accuracy of other, more simple computer or manual programs are tested. Many such programs are available; most commercially available energy design software costs between $200 and $800, depending on how much detail the designer requires. A good deal of public domain software is also available and is less expensive.

Two ways exist to simplify mainframe computer programs. One approach is to develop a data base of calculations for different types of buildings in varying climates; the user can then select the type closest to the building the user is interested in, so the user can see the energy costs associated with the selected approach. The Program for Energy Analysis of Residences (PEAR 2.1) (see Refrigeration Air Conditioning in Chapter 2) developed by Lawrence Berkeley Laboratory (LBL) for use by production builders and energy auditors, is a good example of this approach [103].

The second method is to allow designers to determine the energy impact of different design approaches by undertaking their own "what-if" approach to designing a building; a wide variety of elements can be altered that can then undergo simplified calculations based on algorithms used by the mainframe programs. ASEAM 2.1 is an example of this type of program and is used as a teaching tool to assist architectural and engineering students in basic design and cost analysis based on the American Society for Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) bin method [104]. It is particularly useful in the design of multifamily buildings. A similar system developed for architectural students by the University of California at Los Angeles under DOE sponsorship is SOLAR.5, which portrays all information in graphic format, allowing as many as nine different designs to be developed and analyzed simultaneously for performance [105]. Popular commercial programs such as CALPASS and MICROPASS have the capability to analyze buildings that are designed to make optimum use of solar gains in either a passive or active mode.

A recent survey by the International Energy Agency indicated that over 120 computerized residential energy design tools are in commercial use today. Not all these calculation methods have had their accuracy verified against either measured data or a well-validated, detailed program. Some states, such as California, require such analysis to be conducted to meet permit requirements; the software used must first be certified for accuracy.

Building Codes and Standards

Another approach to ensuring that buildings are energy efficient is to use building codes and product standards to specify a minimum level of efficiency. A broad range of organizations help set or upgrade standards. One of the primary organizations setting standards is ASHRAE. ASHRAE handbooks are the basis for new construction standards adopted by building departments around the country. These standards are developed using a consensus process that draws upon research and experience from all parts of the heating, ventilating, and air conditioning and building industries as well as from universities, consulting firms, and national laboratories. Although the standards are primarily designed for use in new construction, they are often incorporated as standards for major renovations as well. ASHRAE Standard 90-75 is the most current standard reflecting energy efficiency.

Institute, PSIC is able to produce site-specific packages for over 2,400 cities and towns nationwide. Each package includes a 40-page booklet and a set of worksheets. The booklet presents detailed information about the range of design options for achieving various levels of energy performance for the site. The worksheets help the builder or designer compare the effects of various passive solar design strategies without doing any complex technical analysis.

During 1989, the guidelines package will be introduced at special workshops throughout the United States. A *Passive Solar Design Strategies* mailing list informs participants when workshops are held in their areas and when a guidelines package becomes available for their location. To be placed on the mailing list, write to the PSIC Guidelines Program.

Ahmed, S. F., and Rittelman, P. R. (1985). "International Energy Agency Task VIII Subtask 'C' Results of Design Tool Evaluation for Passive Solar Design." *Solar 85: Proceedings of the 10th National Passive Solar Conference, the Solar Energy and Utilities Conference, the Daylighting Applications Conference, the Building with the Sun Conference; Raleigh, North Carolina; October 15–20, 1985.* Wilson, Alexander T., and Glennie, William, with Brocon, James P.; Duke, W. A., Jr.; and McPhee, Bruce, eds. Boulder, CO: American Solar Energy Society; pp. 246–251.

Evaluates the design tools for passive solar design as part of the International Energy Agency (IEA) Task VIII Subtask "C." To investigate the discrepancies between the design tool predictions and standard comparison SERI-RES, a simplified buildings analysis was undertaken. The design tool results have also been compared with the TRNSYS and ESP computer programs. Although the heat losses and solar gains, as calculated by various design tools, are in fairly good agreement, the utilization of solar gains to offset heat losses varied considerably. The results of this investigation are presented.

Another important player in standard setting is the American Society for Testing and Materials (ASTM). ASTM technical committees prepare and revise materials standards, test methods, and applications for building energy-related products.

Regional organizations have also taken the lead in developing standards, particularly in the Northwest, where the Northwest Power Planning Council created the Model Conservation Standards for most utility customers in Washington, Oregon, Idaho, and Montana. Standards cover window quality, insulation levels, and the efficiency of heating equipment.

Energy Rating Systems

The purpose of home energy rating systems is to provide home buyers with comparative information similar to the Environmental Protection Agency's ratings on cars (miles per gallon); this information centers on the energy efficiency of a home and its major energy-using equipment [106,107]. Home-builder associations, utilities, states, and other independent parties have developed prescriptive energy criteria or energy performance standards that are often lumped together as home energy rating systems. More than 100 such rating systems are currently being used around the country; most apply only to new homes. Many of these rating systems were developed as a free-market approach to avoiding setting new building codes or upgrading existing ones.

Strictly speaking, these home rating approaches are neither design nor analysis tools but rather are ways of certifying one or more levels of efficiency. Eventually, their influence might increase to the extent that most home buyers will come to rely on them when purchasing a home. These rating schemes are probably used more than computerized energy tools. It is hoped that buyers of homes that qualify under such systems can be given more favorable treatment during the loan qualification process. Both the Federal Home Mortgage Corporation and the Federal National Mortgage Association have accepted several rating systems to identify more energy-efficient homes and purchase second mortgages with a 2% to 4% higher income-to-debt ratio as a way of acknowledging this added efficiency. Unfortunately, local lenders have not shown the same enthusiasm for this approach, and few take advantage of the new lending guidelines.

Hendrickson, Paul L. (November 1986). *Review of Existing Residential Energy Efficiency Certification and Rating Programs.* PNL-6080. Richland, WA: Pacific Northwest Laboratory; 164 pp. Available NTIS: Order No. DE87004045.

Presents information on existing home energy rating systems (HERS) and their features. The principal objective of the HERS program is to facilitate the incorporation of energy-efficiency factors into a housing unit's market value. The report also qualitatively examines the benefits and costs of the HERS program, reviews survey results on the attitudes of various user groups toward the program, and discusses selected design and implementation issues.

Vine, Edward; Barnes, B. K.; and Ritschard, Ronald. (February 1987). *Implementation of Home Energy Rating Systems.* LBL-22872. Berkeley, CA: Lawrence Berkeley Laboratory; 101 pp. Available NTIS: Order No. DE87007898.

Presents the findings of a national survey of home energy rating systems (HERS) and labeling programs. The nature of different implementation problems and the kinds of strategies that have been used to deal with them to ensure the effective penetration of HERS to all HERS users are discussed. Also of special interest is the nature of different delivery systems. Thirty-four HERS, located in 28 states, were examined; thirteen of these were located in the southeast, eight in the midwest, five in the northeast, four in the Pacific mountain region, and three in the southwest. Although the survey does not represent a scientific sampling of HERS, the authors believe the final distribution reflects the distribution of HERS through the country and the full range of likely implementation and delivery programs.

Energy Data Analysis Tools

Several methods of data analysis exist: utility bill comparison, submetering, and multi–data point monitoring equipment. The most common method is *utility bill comparison,* that is, comparing actual performance with predicted performance. This type of analysis can lead to flawed conclusions, however, especially when the structure built differs somewhat from the building modeled. For instance, some 22 homes built in the Canadian R-2000 program used 45% more energy on the average for space heating than had been predicted. The actual air-infiltration rates were higher than predicted, thermal bridging might have reduced effective wall and ceiling R-values, and skylights were added after the design calculations were performed.

By *submetering* one energy-consuming item, an analyst can more accurately pinpoint the amount of auxiliary energy purchased for space

Hirst, Eric. (June 1987). *Cooperation and Community Conservation, Final Report, Hood River Conservation Project.* DOE/BP-11287-18. Portland, OR: Bonneville Power Administration; 53 pp.

Discusses the Hood River Conservation Project (HRCP), which was intended to test the reasonable upper limits of a residential weatherization program. The project had two parts. One was the weatherization of Hood River homes. The other was the research and supporting data collection, which began a year before field activity started and continued for more than a year after measures were installed. This report summarizes both elements. Topics discussed include the background and objectives of the HRCP, the project's design and data resources, implementation and marketing conditioning or some other energy use. As determined through interviews with homeowners, indoor conditions and usage patterns decide whether comparing utility bills or submetering is the more useful approach.

The most informative method is to install extensive (and expensive) monitoring equipment to collect and record weather conditions; indoor temperatures; and energy consumed by heating, cooling, and operating general appliances. One particular monitoring system gathers and records data from 20 or more sources every 15 seconds. One three-day experiment can establish the exact heat loss of the building. With this type of data, researchers can develop an accurate picture of how the building is performing [108]. The Hood River Conservation Project is an example of the valuable insight that can be derived from this type of monitoring [109].

efforts, household participation in the project, weatherization measures installed, levels and changes in electricity use, project cost effectiveness, and several supplemental studies that used HRCP data to address issues beyond the scope of the original project.

Diagnostic Tools

Diagnostic tools help researchers determine precisely why a building is using more or less energy than expected. This physical inspection of essentially unseen heat flows is quite valuable to builders and remodelers intent on improving a home's energy efficiency. Blower doors, thermal scanners, and tracer gas methods are among the most common means of diagnosing air-infiltration levels.

Predicted Compared with Actual Consumption

A combination of predesign calculations and postbuilding analysis makes it possible for builders, designers, educators, and energy officials to learn a great deal about heat losses and gains in homes. However, the two sets of data—predicted and actual consumption—do not always agree. The discrepancy is quite understandable because one family's lifestyle varies from that of another. Studies show that two families occupying the same home at different times have habits that will vary energy consumption by a factor of two. In addition, poorly installed home energy-conservation measures can decrease overall efficiency. For these reasons, energy design programs will continue to be most valuable as comparative, rather than predictive, tools.

Energy Tools for Existing Homes

Energy Audits

The primary energy analysis tool used in existing homes is an on-site computerized energy audit conducted by a trained energy auditor. Utility companies have traditionally done most of the residential audits. Information about a home's energy features and consumption collected during the audit is combined with engineering and local weather data. A computer program is usually used to calculate the energy savings that could be achieved by adding insulation, installing storm windows, tightening the shell, and altering or replacing heating and cooling systems.

The most commonly used energy audit is the Residential Conservation Service (RCS) procedure developed by DOE in 1980. During the first two years of use, over 2 million RCS audits were conducted. The RCS audit began as a manual system but was later released as a computer program called the Computerized Instrumented Residential Audit (CIRA). Various computerized audits for existing homes analyze the interaction between different energy retrofits to produce an optimized package of

MacDonald, J. M.; Karnitz, M. A.; Diamond, R. C.; Ritschard, R. L.; Mixon, W. R.; and Sherman, M. H. (August 1988). *Existing Building Efficiency Research, 1987–1988*. ORNL/CON-268. Oak Ridge, TN: Oak Ridge National Laboratory; 57 pp. Available NTIS: Order No. DE89001307.

Presents the status of the Existing Building Efficiency Research Program of the Office of Buildings and Community Systems of the U.S. Department of Energy for 1987 to 1988. This program covers research on energy-efficiency improvements for the residential and commercial buildings in this country. Improving energy efficiency of existing buildings through retrofit measures offers the largest potential for energy savings in the United States in the next 10 to 15 years. The widespread use of retrofits for residential buildings could save 2.6 quadrillion Btu (quads) per year and reduce annual energy costs by $17 billion. Full penetration of energy retrofits into the commercial building stock,

measures. Both government and private organizations have developed their own audit forms as spinoffs of the RCS model audit procedures.

CASE STUDY

Recently, Oak Ridge National Laboratory (ORNL) developed a new audit for use in conjunction with Wisconsin's Weatherization Assistance Program. Among other things, this effort looked at how an improved audit based on selecting those retrofits with the highest benefit/cost ratio would affect both the amount of money spent on retrofits and the amount of savings achieved. Based on the new audit average, improvement expenditures on each qualifying low-income home were $1600 compared to an average of $2200 normally spent by the program for standard retrofits. Savings based on the new audit averaged an estimated 207 thm/year compared to the 80 to 130 thm experienced by the standard program [110].

Diagnostic tools such as blower doors and infrared cameras are also frequently used during audits. With these tools, trained professionals can determine the size and sources of infiltration areas and insulation gaps.

Energy Audit Accuracy

The Buildings Energy Data Group at LBL compiles and analyzes measured energy use data from existing buildings. The data come from utilities involved in weatherization, low-income programs, research studies, and multifamily retrofits. LBL staff members analyze the energy savings and cost-effectiveness of various conservation measures and practices. Based on findings from 24 retrofit projects, LBL researchers reported in 1985 that predicted savings tend to exceed measured results in large-scale conservation programs.

An ORNL study evaluated the results of 12,000 energy audits conducted by a Minnesota utility company during the early 1980s. The study concluded that on the average, in 346 audited homes with retrofits, predicted savings exceed actual savings by one-third. Similar findings were reported elsewhere.

The inability to accurately predict savings has frustrated auditors, retrofit installers, and researchers alike. As researchers investigate the reasons, they learn more about what affects actual energy savings: installation quality, equipment performance, envelope integrity, climatic differences, and lifestyles of the occupants. The poor predictive accuracy of audits has made homeowners more hesitant to undertake what otherwise appear to be extremely cost-effective actions.

Accelerated Audit-Monitoring Programs

One problem with obtaining good data on the effects of conservation measures is that obtaining meaningful feedback from utility bills about the effectiveness of various retrofit measures can take as long as two years. An alternate to the standard procedure is offered by programs such as the Princeton Scorekeeping Method (PRISM), which can be used to analyze preretrofit and postretrofit annual energy bills. PRISM adjusts measured yearly energy use to reflect consumption under average weather conditions. Complex or computerized monitoring programs can generate data more rapidly but at a considerable cost.

for which initial costs are repaid by energy savings in three years or less, could save 2.5 to 3.5 quads per year and $15 to $20 billion per year. The program is working to overcome the technical, financial, and behavioral barriers to the use of building energy retrofits. The current approach is to develop research results and predictive tools that improve confidence in expected savings and allow appropriate efficiency modifications to be selected and installed. Future plans are to assess what the long-term picture for advancing energy technologies will be and what approaches will have to be taken to best meet the needs associated with continuing to improve the energy efficiency of existing buildings.

deKieffer, Robert; Brown, Doug; Proctor, John; Wilson, Duncan. (1987). *Sun Power Accelerated Monitoring (SPAM); Final Report.* Denver, CO: Sun Power Consumer Association; 42 pp.

Presents results of short-term monitoring conducted on 20 homes to determine the effectiveness of three different energy-efficiency programs. Extensive monitoring was done on the furnace operation to define the operational parameters of the heating system. Time-dependent data were added for both the furnace and the whole-house energy use on a biweekly basis. From this information, the efficiency of the heating system and the effective load on the

CASE STUDY

The Sun Power Accelerated Monitoring Program (SPAM), recently developed in Colorado, offers a fast, accurate system, yet it avoids the high cost of extensive monitoring.

SPAM involves combining utility bill analysis with homeowner interviews and limited on-site monitoring. The on-site monitoring includes a timer and counter on the furnace gas valve, weekly readings of electric meters for heating or cooling, and weekly maximum and minimum indoor temperature measurements. After two months, SPAM can generate accurate and relatively quick feedback about the actual energy savings of any energy retrofit measures.

Sun Power monitored 20 homes during the winter of 1986 to 1987 and weatherized 10 of these homes. The three-month monitoring program—including all data analysis, weatherization expenses, and reporting—cost $30,000. The value of an accelerated monitoring program is demonstrated by the following findings:

- The cycle time of a furnace is more a function of the furnace and thermostat adjustments than it is a function of the outdoor temperature. Actual efficiency can be as much as 3% to 4% better in a short-cycling furnace than in a longer-cycling furnace. Cycling time can be adjusted for optimum efficiency. If the fan-off setting is lower (100 deg), shorter cycles are more efficient.
- An overfired furnace won't necessarily be inefficient if adjusted properly.
- The recipe for proper furnace adjustment varies with house style and furnace type. For example, lowering the fan-on temperature, increasing the blower speed, and lowering the fan-off switch (to 95 to 100 deg) was often successful.
- Decreasing the furnace's gas input rate by 20% to 30% didn't necessarily increase efficiency (flue temperatures were unaffected).
- The monitoring program helped Sun Power discover why it didn't save much on four furnace adjustments and helped it improve the savings rate on virtually all its other work [111].

Ordinances

Some cities have taken a regulatory approach to ensuring the efficiency upgrade of older homes. They have passed ordinances that require certain energy features to be present before an older home can be sold. Portland, Oregon, and Berkeley, California, were among the first cities to adopt such measures. Wisconsin and Minnesota have similar programs that apply to rental housing.

CASE STUDY

Berkeley requires R-19 to R-30 attic insulation, insulated piping and duct work, weatherstripped exterior doors, and low-flow showerheads. The maximum required investment in energy upgrades is limited to 0.75% of a home's sale price. Since Berkeley's ordinance was adopted in 1981, over 5000 homes have been audited and certified as meeting the conservation upgrades.

building were determined. The program was run over a three-month time period and used a preexperimental-postexperimental approach. The programs that were evaluated were the Sun Power Furnace Program, the Sun Power "House Nurse" Program (infiltration reduction), and a conventional weatherization program. The furnace program had the lowest payback (3 years). The House Nurse program showed a payback of 4.3 years, and the conventional program had a 7.9-year payback. The conventional program included insulation and had the highest overall savings. The results show that the technique can provide adequate results to assist agencies in evaluating the performance of their programs and allow time for mid-season corrections to improve the energy efficiency of these programs.

Design Tools for Windows

Chapter 2 discusses the WINDOW 2 program developed by LBL. In addition, several programs exist that can model the effects of daylighting in buildings. SUPERLITE and DOE2/Daylighting are both mainframe computer models for analyzing this impact. Another example, QUICKLITE, is a simplified model. In addition, a number of "sky simulators" can be used to test daylighting effects on scale models of buildings [112].

Ongoing Research Efforts

Field validation of energy use in small buildings is being conducted through Brookhaven National Laboratory (BNL). The project aims to reduce energy use through greater understanding of how individual energy-efficient strategies interact and work in occupied buildings. A key part of the effort focuses on detailed instrumentation, analysis, and field validation of whole-building energy use. BNL is also examining improvements in construction details and their impact on actual energy consumption. The objective of the study is to transfer results to architects, engineers, builders, and others in the building industry.

At SERI, a short-term test method was developed (building element vector analysis) that allows in-depth monitoring over a few days to determine the impact of retrofits on building energy use. It is currently undergoing additional testing at a home in Oak Ridge, Tennessee [113].

The Florida Solar Energy Center (FSEC) is developing a low-cost multi–data point monitoring system (level A) using off-the-shelf components so that it can better monitor innovative building systems and the impact of occupant lifestyles. The targeted cost of the installed system is $3000.

The Simulation Research Group at LBL investigates and improves on existing major design tools such as DOE-2. In a parallel effort, researchers are working on an advanced building energy performance program that would provide for interactive analysis not yet available. LBL also maintains a large data base on new and existing buildings. The data base has revealed significant information on trends in energy efficiency. For example, the new generation of energy-efficient homes uses between one-third and one-half the heating energy required by conventional new houses. This data base is particularly useful for utilities and researchers.

ORNL is developing a design tool that will accurately model how heat is lost through building elements that are in direct contact with the ground. Currently, the accuracy of ground loss simulations is subject to debate. After ORNL develops its tool, it will be validated against a series of actual foundation tests.

ASHRAE is studying the process of building energy audits. One of the early problems identified is the lack of a commonly accepted energy audit procedure. ASHRAE and ASTM are working with industry groups to resolve long standing differences regarding the accuracy of laboratory tests for window U-values.

Michigan State University researchers are evaluating the effects of occupant behavior on the performance of weatherization efforts. As part of the two-year extensive monitoring of 10 homes, these researchers will assess the interaction of retrofits, thermostat setting, and operation of ventilation systems such as fans and windows. This information will help in refining analysis tools for energy retrofits.

An upcoming federal program with a potentially large impact on existing practices is the DOE performance standards for new buildings. Although they will be voluntary in the nonfederal sector, the Federal Residential Standards are to be mandatory for federal agencies. Groups for whom the standards will apply (e.g., the military in its housing) will have the option of adopting the mandatory standards or developing their own guidelines that meet or exceed the DOE program. The first demonstration of the standard—still in the development stage—will be in the Northwest, with assistance provided by Pacific Northwest Laboratories.

Finally, LBL and FSEC are developing a new fenestration indices design tool.

References

1. Hirst, Eric; Clinton, Jeanne; Geller, Howard; and Kroner, Walter. (1986). *Energy Efficiency in Buildings: Progress and Promise.* Edited by F. M. O'Hara, Jr. Washington, DC: American Council for an Energy Efficient Economy; 328 pp.

2. *Residential Energy Consumption Survey: Consumption and Expenditures, April 1984 through March 1985; Part 1: National Data.* (4 March 1987). DOE/EIA-0321/1 (84). Washington, DC: U.S. Department of Energy; 189 pp.

3. *FY 1988 Energy Conservation Multi-Year Plan.* (July 1986). Washington, DC: U.S. Department of Energy.

4. Nisson, J. D. Ned, and Dutt, Gautum. (1985). *The Superinsulated Home Book.* New York: John Wiley & Sons; 316 pp.

5. *Blue Book of Major Home-Builders: Major Research Report on Who's Who in Housing.* (1985). Crofton, MD: LSI Systems, Inc.; 397 pp.

6. Sterling Hobe Corporation. (June 1987). *Innovations in Residential Housing Technology.*

7. Schipper, Lee, and Meyers, Stephen. *Coming in from the Cold:Energy-Wise Housing in Sweden.* Cabin John, MD: Seven Locks Press; 85 pp.

8. Cairns, Elton J., and Rosenfeld, Arthur H. (July 1986). *Applied Science Division Annual Report: Energy Efficient Buildings Program, FY 1985.* LBL-20203. Berkeley, CA: Lawrence Berkeley Laboratory; 121 pp.

9. Goldman, Charles A. (May 1985). "Measured Energy Savings from Residential Retrofits: Updated Results from the BECA-B Project." *Energy and Buildings* (8:2); pp. 137–155.

   Goldman, Charles A. (July 1985). *Measured Results of Energy Conservation Retrofits in Residential Buildings.* LBL-20950. Berkeley, CA: Lawrence Berkeley Laboratory; 25 pp.

10. See note 9.

11. Christian, Jeff. (June 1987). "Insulation Levels for Foundations." *Progressive Builder* (2:6); pp. 11–18.

12. See note 11.

13. See note 11.

14. Lstiburek, Joseph. (December 1987). "How to Control Moisture in Houses." *Custom Builder* (2:12); pp. 9–14.

    Moody, Thomas. (October 1985). "Foiling Crawlspace Heat Loss." *Solar Age* (10:10); pp. 59–62.

15. "Ventilation-induced Crawlspace Moisture Problems." (October 1987). *Energy Design Update* (6:10); pp. 8–10.

16. Fairey, Philip. (July 1988). Telephone conversation to the Florida Solar Energy Center.

17. "Frost-Free Shallow Foundation Design Guidelines." (March 1988). Energy Design Update (7:3); pp. 4–10.

    Frost-Protected Shallow Foundations for Houses and Other Heated Structures: Design Details Developed by the Norwegian Building Research Institute. (1 January 1988). Upper Marlboro, MD: NAHB National Research Center; 43 pp.

18. Fisette, Paul. (November 1986). "Sprayed Insulation." *Progressive Builder* (11:10); pp. 23–27.

19. "Wet Spray Insulation for Houses." (September 1985). *Energy Design Update* (4:9); pp. 11–16.

"Cellulose Insulation and Airtightness." (December 1986). *Energy Design Update* (5:12); pp. 4–7.

20. Andrews, Steve. (May 1986). "Selling Homeowners on Energy." *Solar Age* (11:5); pp. 28–30.

21. Ward, Ronald J. (1983). *Thermographic Inspections and the Residential Conservation Service Program.* Providence, RI: Rhode Islanders Saving Energy; 4 pp.

Ward, Ron. (January-February 1986). "Using Infrared for Quality Control of Retrofits." *Energy Auditor and Retrofitter* (3:1); pp. 24–28.

"Retrofit Wall Insulation: Is There Really Quality in That Corner?" (September-October 1985). *Energy Auditor and Retrofitter*; pp. 6–10.

Tsongas, George A. (September 1985). *State-of-the-Art Review of Retrofitted Wall Insulation.* DOE/BP/30575-1. Portland, OR: Bonneville Power Administration; 88 pp.

22. Sackett, James G. (January 1985). *A Development Strategy for Superinsulated Homes.* Washington, DC: Energy Task Force of the Urban Consortium; 83 pp.

Hartkoff, Volker. (1986). *Promoting Energy-Efficient Rehabilitation and New Infill Construction in the Inner City.* Pittsburgh, PA: Carnegie-Mellon University.

23. Barnes, D. M. (June 1982). *A Field Study of the Effect of Wall Mass on the Heating and Cooling Loads of Residential Buildings.* Washington, DC: National Bureau of Standards.

24. "Density and Settling of Cellulose Insulation." (March 1987). *Energy Design Update* (6:3); pp. 9–13.

25. Nelson, B. D.; Robinson, D. A.; Nelson, G. D.; and Hutchinson, M. (September 1986). *Energy Efficient House Research Project.* ORNL/Sub/83-47980/1. Oak Ridge, TN: Oak Ridge National Laboratory; 206 pp. Minnesota Department of Energy and Economic Development.

26. Akeley, Jeff. (May-June 1987). "Bags, Bugs and Rulers: Preventing Insulation Fraud and Upgrading the Quality of Installation." *Energy Auditor and Retrofitter* (4:3); 14–16.

27. Lstiburek, Joseph. (April 1988). "Vented Roofs: Pros and Cons." *Custom Builder* (3:4); pp. 11–14.

28. Fairey, Philip. (1986). *Radiant Energy Transfer and Radiant Barrier Systems in Buildings.* Design Note, FSEC-DN-6-86. Cape Canaveral, FL: Florida Solar Energy Center; 4 pp.

Fairey, Philip. (1984). *Designing and Installing Radiant Barrier Systems.* Design Note, FSEC-DN-7-84. Cape Canaveral, FL: Florida Solar Energy Center; 4 pp.

Melody, Ingrid. (May-July 1987). "Radiant Barriers: A Question and Answer Primer. *Home Resource Magazine*; pp. 13–17.

"Radiant Barriers in Attics." (August 1987). *Energy Design Update* (6:8); pp. 7–10.

Levins, W. P., and Karnitz, M. A. (January 1987). *Heating Energy Measurements of Unoccupied Single-Family Houses with Attics Containing Radiant Barriers.* ORNL/CON-213. Oak Ridge, TN: Oak Ridge National Laboratory; 89 pp.

Levins, W. P., and Karnitz, M. A. (July 1986). *Cooling-Energy Measurements of Unoccupied Single-Family Houses with Attics Containing Radiant Barriers.* ORNL/CON-200. Oak Ridge, TN: Oak Ridge National Laboratory; 53 pp. Available NTIS: Order No. DE86014343.

29. Levins, W. P., and Karnitz, M. A., *Cooling-Energy Measurements.*

30. See note 29.

31. Fairey, Philip. *Radiant Energy Transfer and Radiant Barrier Systems.*

Fairey, Philip. *Designing and Installing Radiant Barrier Systems.*

32. *Passive Solar Performance: Summary of 1982–1983 Class B Results.* (December 1984). SERI/SP-271-2362. Golden, CO: Solar Energy Research Institute; 203 pp.

33. Holtz, Michael; Frey, Donald; Bishop, Robert; and Swisher, Joel. (October 1985). "The Future of Passive Solar Design." *Solar Age* (10:10); pp. 49–56.

34. Vieira, Robin. (November 1986). "Windows for Hot Climates." *Progressive Builder* (11:10); pp. 9–15.

35. Sullivan, R., and Selkowitz, S. (November 1986). *Residential Heating and Cooling Energy Cost Implications Associated with Window Type.* LBL-21578. Berkeley, CA: Lawrence Berkeley Laboratory; 19 pp.

36. See note 35.

37. Selkowitz, Stephen. (July 1988). Personal communication.

38. Fletcher, June. (May 1988). "Homes '88: Windows." *Northwest Portfolio*; 18 pp.

39. Selkowitz, Stephen. (June 1988). *Recent Examples of Industrial Support, Collaboration, and Use of LBL Windows and Daylighting Research.* Internal memo, Lawrence Berkeley Laboratory; 5 pp.

40. Anderson, Gary. (November-December 1985). "Sealing Double Hung Windows." *Energy Auditor and Retrofitter*; pp. 13–16.

41. "Practical Homeowner's 1987 Remodeling Survey." (May-June 1987). *Rodale's Practical Homeowner* (2:5); pp. 43–63, 92.

42. See note 34.

43. Parker, Danny. (1987). "Thermal Performance Monitoring Results from the Residential Standards Demonstration Program." *Solar '87: Proceedings of the 12th National Passive Solar Conference, Portland, Oregon; July 11–16, 1987.* Andrejko, Dennis A., and Hayes, John, editors. Boulder, CO: American Solar Energy Society; pp. 104–109.

44. Dietz, Russell N. (October 1986). *Meeting on the Model Conservation Standards (MCS) Evaluated in the Residential Standards Demonstration Program (RSDP).* Upton, NY: Brookhaven National Laboratory; 4 pp.

45. Lischkoff, James K., and Lstiburek, Joseph. (1986). *The Airtight House: Using the Airtight Drywall Approach. A Construction Manual.* Ames, IA: Engineering Extension Service, Iowa State University; 84 pp.

46. Offermann, F. J.; Dickinson, J. B.; Fisk, N.; Grimsrud, D. J.; Hollowell, C. D.; Krinkel, D. L.; Rosene, G. D.; Desmond, R. M.; DeFrees, J. A.; and Lints, M. C. *Residential Air-Leakage and Indoor Air Quality in Rochester, New York.* LBL-13100. Berkeley, CA: Lawrence Berkeley Laboratory; 106 pp.

47. See note 46.

48. Meier, Alan. (September-October 1986). "Using the Blower Door: Part I." *Energy Auditor and Retrofitter* (3:5); pp. 12–18.

Meier, Alan. (November-December 1986). "Using the Blower Door: Part 2." *Energy Auditor and Retrofitter* (3:5); pp. 30–35.

49. Karwoski, Tony. (1984). *U.S. Department of Housing and Urban Development 1984 Report.* Arlington, VA: Manufactured Housing Institute.

50. Judkoff, R.; Hancock, E.; Franconi, E.; Hanger, R.; and Weiger, J. (December 1988). *Mobile Home Weatherization Measures: A Study of Their Effectiveness.* SERI/TR-254-3440. Golden, CO: Solar Energy Research Institute; 68 pp.

51. See note 32.

52. See note 7.

53. Lass, W.; Jones, R.; and Cerniglia, P. (August 1986). *The Danish House at the Brookhaven International Housing Village: First Year's Preliminary Results.* BNL-38790. Upton, NY: Brookhaven National Laboratory; 76 pp. Available NTIS: Order No. DE87007154.

54. Reilly, Susan, and Arasteh, Dariush. (May 1988). *WINDOW 3.1: A Computer Tool for Analyzing Window Thermal Performance.* LBL-25148. Berkeley, CA: Lawrence Berkeley Laboratory; 7 pp.

55. *Office of Buildings and Community Systems: FY 1986 Research in Progress.* (July 1986). DOE/TIC-11628. Washington, DC: U.S. Department of Energy; 38 pp.

56. Geller, Howard S. (April 1987). National Appliance Efficiency Standards: Utility and Consumer Impacts. Washington, DC: American Council for an Energy Efficient Economy; 13 pp. Paper prepared for the Third National Conference on Utility DSM Programs; 16–18 June 1987; Houston, TX.

Geller, Howard S. (April 1987). *Energy and Economic Savings from National Appliance Efficiency Standards.* Washington, DC: American Council for an Energy Efficient Economy; 13 pp.

57. "Over 50 Percent of Residential HVAC Systems Specified by Builder or Owner, Survey Shows." (March 1987). *Energy Design Update* (6:3); p. 1.

58. "High-Efficiency Gas Furnaces—A Survey of Problems." (April 1987). *Energy Design Update* (6:4); pp. 9–13.

59. "Options for Residential Forced-Air Heating." (January 1987). *Energy Design Update* (6:1); pp. 9–13.

60. Andrews, Steve. (January 1987). "Electric Radiant Heat." *Progressive Builder* (12:1); pp. 29–32.

61. "Special Report: Electric Radiant Ceiling Heat." (October 1986). *Energy Design Update* (5:10); pp. 10–19.

62. See note 56.

63. "Electric Heating Can Compete Economically with Gas, Study Shows." (July 1987). *Energy Design Update* (6:7); p. 63.

64. *Heat Pump Reliability.* (1986). Palo Alto, CA: Electric Power Research Institute; 4 pp.

65. *Ground-Coupled Heat Pump.* (1987). Technical Brief. Palo Alto, CA: Electric Power Research Institute; 2 pp.

66. "Ground-Coupled Heat Pumps: ORNL Research Aims at Lowering Costs." (1987). *Oak Ridge National Laboratory Review* (3); pp. 23–24.

67. "The Vagaries of Cooling Load Calculations." (December 1986). *Energy Design Update* (5:12); pp. 11–13.

68. "DINH Z-Coil—Cooling with Comfort." (July 1987). *Energy Design Update* (6:7); pp. 13–15.

"Comfort-Stat from Trane." (March 1987). *Energy Design Update* (6:3); pp. 14–15.

69. *PEAR 2.1 (Program for Energy Analysis of Residences): User's Manual.* (March 1987). LBL-PUB-610. Berkeley, CA: Lawrence Berkeley Laboratory; 72 pp.

For information on the program, contact Joe Huang at Lawrence Berkeley Laboratory, (415) 451-7082.

70. Wu, Hofu. (31 January 1988). Identification and Evaluation of Cooling Strategies in Residences of Hot, Arid Climates. Task 1: Performance Monitoring of a Two-Stage Evaporative Cooler. Phoenix, AZ: Environmental Testing Laboratory, Arizona State University; 39 pp.

71. See note 67.

72. *Single-Family Building Retrofit Research Multi-Year Plan: FY 1986–FY 1991*. (May 1986). ORNL/CON-207. Oak Ridge, TN: Oak Ridge National Laboratory; 140 pp.

73. Proctor, J., and Foster, B. (1986). "Lost-Cost Furnace Efficiency Program—10,000 Furnaces Later." *Proceedings from the ACEEE 1986 Summer Study on Energy Efficiency in Buildings: Appliances and Equipment, Volume 1; Santa Cruz, California; August 17, 1986*. Washington, DC: American Council for an Energy Efficient Economy.

74. *FY 1988 Energy Conservation Multi-Year Plan*. (July 1986). Washington, DC: U.S. Department of Energy.

75. Proctor, John. (1986). *Low Cost Boiler Efficiency Improvements*. Denver, CO: Sun Power Consumer Association; 9 pp.

76. *The Most Energy-Efficient Appliances*. (1987). Washington, DC: American Council for an Energy Efficient Economy; 18 pp.

77. Harris, James E., and Greenberg, Joseph. (May 1987). *Performance of Instantaneous Gas-Fired Water Heaters*. NBSIR 87-3537. Gaithersburg, MD: National Bureau of Standards; 10 pp.

78. *Idaho Power Solar Water Heater Program. Second Interim Report: January 14, 1982 to November 1984*. (July 1984). Boise, ID: Idaho Power Company; 54 pp.

79. Kutscher, C.; Davenport, R.; Farrington, R.; Jorgensen, G.; Lewandowski, A.; and Vineyard, C. (July 1984). *Low-Cost Collectors/Systems Development Progress Report*. SERI/ RR-253-1750. Golden, CO: Solar Energy Research Institute; 226 pp.

80. *Review of Energy-Efficient Technologies in the Residential Sector, Volumes 1 and 2*. (February 1986). EPRI EM-4436. Palo Alto, CA: Electric Power Research Institute; Volume 1: Executive Summary, 45 pp.; Volume 2: Data Review and Syntheses; 323 pp.

81. Berderber, Rudy. (July 1988). Personal communication. Lawrence Berkeley Laboratory Electronic Ballast Program.

82. See note 81.

83. Calwell, Chris. (January-February 1988). "Appliance Rebates: More than a Free Ride." *Home Energy* (5:1); pp. 33–35.

Compendium of Utility-Sponsored Energy Efficiency Rebate Programs. EPRI EM-5579. Palo Alto, CA: Electric Power Research Institute; 273 pp.

84. Parsons, Brian K.; Bharathan, Desikan; Pesaran, Ahmad A.; and Shelpuk, Benjamin. (April 1987). *Evaluation of Thermally Activated Heat Pump/ Desiccant Conditioning Systems and Components*. Draft. Golden, CO: Solar Energy Research Institute; 89 pp.

85. Potter, T. F.; Benson, D. K.; and Smith, L. K. *Impacts of Advanced Refrigerator Insulation*. SERI/TP-254-3380. Golden, CO: Solar Energy Research Institute; 12 pp.

86. Turiel, I. (1985). *Indoor Air Quality and Human Health*. New York: Chapman and Hall; 200 pp.

87. Sherman, Max. (July 1986). *Exegesis of Proposed ASHRAE Standard 119: Air Leakage Performance for Detached Single-Family Residential Buildings*. LBL-21040. Berkeley, CA: Lawrence Berkeley Laboratory; 23 pp.

88. Dietz, Russell N. (October 1986). *Meeting on the Model Conservation Standards (MCS) Evaluated in the Residential Standards Demonstration Program (RSDP)*. Upton, NY: Brookhaven National Institute; 4 pp.

89. Randegger, Zee, and Randegger, Ed. (1986-1987). "A New Look at Formaldehyde and Health" and "Reducing Formaldehyde Levels." *Environ* (5); pp. 6–12.

90. Cairns, Elton J., and Grimsrud, David T. (May 1987). *Applied Science Division Annual Report: Indoor Environment Program FY 1986*. LBL-22153. Berkeley, CA: Lawrence Berkeley Laboratory; 45 pp.

91. *Radon Reduction in New Construction: An Interim Guide*. (August 1987). OPA-87-009. Washington, DC: U.S. Environmental Protection Agency; 10 pp.

92. See note 90.

93. Ronco-Battista; Magreo, P.; and Nyberg, P. (November 1986). *Interim Protocols for Screening and Follow-up Radon and Radon Decay Product Measurements*. Draft, EPA/520/1-86-014. Washington, DC: U.S. Environmental Protection Agency; 17 pp.

A Citizen's Guide to Radon: What It Is and What to Do about It. (August 1986). OPA-86-004. Washington, DC: U.S. Environmental Protection Agency; 14 pp.

94. Reiland, P.; McKinstry, M.; and Thor, P. (January 1986). *Preliminary Radon Testing Results for the Residential Standards Program*. Program Results No. 3. DOE/BP-582. Portland, OR: Bonneville Power Administration; 38 pp.

95. Spiegle, Scott R. (1987). *House Tightening and Building Science Manual*. Denver, CO: National Thermal Performance Institute; 121 pp.

For training seminars, call (303) 759-1998.

96. "Reducing Formaldehyde Levels." (1986-1987). *Environ* 5; pp. 9–12.

97. *A Citizen's Guide to Radon: What It Is and What to Do about It*.

Radon Reduction Methods: A Homeowner's Guide. (September 1987). OPA-87010. Washington, DC: Environmental Protection Agency; 21 pp.

Radon Reduction Techniques for Detached Houses: Technical Guidance. (June 1986). EPA/625/5-86/019. Research Triangle Park, NC: U.S. Environmental Protection Agency; 61 pp.

98. See note 90.

99. Anderson, Ren. (n.d.) *Project Summary: Ventilation Scale Model Testing*. Golden, CO: Solar Energy Research Institute.

100. *Affordable Housing through Energy Conservation: A Guide to Designing and Constructing Energy Efficient Homes*. (November 1983). DOE/CS/20524-6-Draft. Washington, DC: U.S. Department of Energy; 147 pp.

101. *Affordable Manufactured Housing through Energy Conservation: A Guide to Designing and Constructing Energy Efficient Manufactured Homes*. (July 1984). DOE/CS/20524-7. Washington, DC: U.S. Department of Energy; 120 pp.

102. Ahmed, S. F.; Rittelman, P. R. (1985). "International Energy Agency Task VIII Subtask 'C' Results of Design Tool Evaluation for Passive Solar Design." *Solar 85: Proceedings of the 10th National Passive Solar Conference, the Solar Energy and Utilities Conference, the Daylighting Applications Conference, the Building with Sun Conference; Raleigh, North Carolina; October 15–20, 1985*. Wilson, Alexander T., and Glennie, William, with Brocon, James P.; Duke, W. A., Jr.; and McPhee, Bruce, eds. Boulder, CO: American Solar Energy Society; pp. 246–251.

103. See note 69.

104. W. S. Fleming and Associates. (1988). *ASEAM-2.1: A Simplified Energy Analysis Method, Version 2.1*. Washington, DC: American Consulting Engineers Council Research and Management Foundation. For information, contact Alex Willman, (202) 347-7474.

105. For information on software, contact Harvey Bryan at the Harvard School of Architecture, (617) 495-9741.

106. Hendrickson, Paul L. (November 1986). *Review of Existing Residential Energy Efficiency Certification and Rating Programs.* PNL-6080. Richland, WA: Pacific Northwest Laboratory; 164 pp.

107. Vine, Edward; Barnes, B. K.; and Ritschard, R. (February 1987). *Implementation of Home Energy Rating Systems.* LBL-22872. Berkeley, CA: Lawrence Berkeley Laboratory; 101 pp.

108. See note 32.

109. Hirst, Eric. (June 1987). *Cooperation and Community Conservation, Final Report, Hood River Conservation Project.* DOE/BP-11287-18. Portland, OR: Bonneville Power Administration; 53 pp.

110. MacDonald, J. M.; Karnitz, M. A.; Diamond, R. C.; Ritschard, R. L.; Mixon, W. R.; and Sherman, M. H. (August 1988). *Existing Building Efficiency Research, 1987–1988.* ORNL/CON-268. Oak Ridge, TN: Oak Ridge National Laboratory; 57 pp.

111. deKieffer, Robert; Brown, Doug; Proctor, John; and Wilson, Duncan. (1987). *Sun Power Accelerated Monitoring (SPAM); Final Report.* Denver, CO: Sun Power Consumer Association; 42 pp.

112. See note 39.

113. See note 55.

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