PATH

Partnership for Advancing Technology in Housing

TECHNOLOGY ROADMAP:

ENERGY EFFICIENCY IN EXISTING HOMES

Volume One: Technology Brainstorming

U.S. Department of Housing and Urban Development

Office of Policy Development and Research

PATH (Partnership for Advancing Technology in Housing) is a private/public effort to develop, demonstrate, and gain widespread market acceptance for the "Next Generation" of American housing. Through the use of new or innovative technologies, the goal of PATH is to improve quality, durability, environmental efficiency, and affordability of tomorrow's homes.

PATH is managed and supported by the U.S. Department of Housing and Urban Development (HUD). In addition, all federal agencies that engage in housing research and technology development are PATH Partners, including the Departments of Energy, Commerce, and Agriculture, as well as the Environmental Protection Agency (EPA) and the Federal Emergency Management Agency (FEMA). State and local governments and other participants from the public sector are also partners in PATH. Product manufacturers, home builders, insurance companies, and lenders represent private industry in the PATH Partnership.

To learn more about PATH, please contact

PATH

PARTNERSHIP FOR ADVANCING TECHNOLOGY IN HOUSING

451 7th Street, SW
Washington, DC 20410
202-708-4277 (phone)
202-708-5873 (fax)
e-mail: pathnet@pathnet.org
website: www.pathnet.org

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Prepared for:

U.S. Department of Housing and Urban Development
Office of Policy Development and Research
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Prepared by:

NAHB Research Center
Upper Marlboro, Maryland

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About the NAHB Research Center

The NAHB Research Center, located in Upper Marlboro, Md., is known as America's Housing Technology and Information Resource. In its nearly 40 years of service to the home building industry, the Research Center has provided product research and building process improvements that have been widely adopted by home builders throughout the United States. The Research Center carries out extensive programs of information dissemination and interchange among members of the home building industry and between the industry and the public.

Disclaimer

This report was prepared by the NAHB Research Center for the U.S. Department of Housing and Urban Development, Office of Policy Development and Research. The contents of this report are the views of the contractor and do not necessarily reflect the views or policies of the U.S. Department of Housing and Urban Development, the U.S. Government, or any other person or organization.

FOREWORD

This document, *PATH Technology Roadmap: Energy Efficiency in Existing Homes*, is one in a series of technology roadmaps created to serve as guides to help the housing industry make decisions about research and development investments.

The Partnership for Advancing Technology in Housing (PATH), administered by the Department of Housing and Urban Development, is focused on improving the affordability and value of new and existing homes. Through public and private efforts, PATH is working to improve affordability, energy efficiency, environmental impact, quality, durability and maintenance, hazard mitigation, and labor safety. To accomplish this, PATH has identified research and established priorities for technology development that will enable the home building industry to work toward the PATH mission. This priority setting process, known as "Roadmapping," has brought together many industry stakeholders, including builders, remodelers, trade contractors, material and product suppliers, financial representatives, codes and standards officials, and public sector R&D sponsors. This is the fourth roadmap produced by the PATH Program. The earlier technology roadmaps were: *Information Technology to Accelerate and Streamline Home Building*, *Advanced Panelized Construction*, and *Whole House and Building Process Redesign*.

This document focuses specifically on improving energy efficiency in existing housing. It describes the challenges, and outlines activities and accomplishments that will lead to the achievement of the vision. These include promoting new technologies, evaluating products and processes for retrofit, building capabilities among trade contractors, and identifying potential consumer incentives.

By addressing these issues through research, the home building industry will continue to play a key role in providing affordable, durable housing for America's families.

Harold L. Bunce
Deputy Assistant Secretary for
Economic Affairs

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PATH PROGRAM GOALS

The Partnership for Advancing Technology in Housing (PATH) advances technology in the home building industry to improve the affordability and value of new and existing homes. Through public and private efforts in technology research, information dissemination, and barrier analysis, PATH is adding value to seven of the nation's key housing attributes: affordability, energy efficiency, environmental impact, quality, durability and maintenance, hazard mitigation, and labor safety.

As such, three overarching goals have been established that all bear on those attributes:

- **To determine the needs for improved housing technology development and provide relevant strategic services.**

  PATH will investigate the institutional barriers that impede innovation; will propose alternative, improved, or negotiated services to overcome those barriers; and will develop networks and agreement among participants to implement these services.

- **To develop new housing technologies.**

  PATH will support and perform technological research at all R&D levels of the home building supply chain with governmental and industrial funds and resources.

- **To disseminate new and existing technological information.**

  PATH will coordinate dissemination of innovation information (both for specific technologies and for industry-wide technological information) that remains unbiased, technically accurate, and relevant to specific housing audiences to increase the familiarity with, availability, and use of technologies in the home building and homeowner communities.

Partners in the PATH program—the U.S. Departments of Housing and Urban Development (HUD) and Energy (DOE), the Environmental Protection Agency (EPA), the Department of Agriculture (DOA), the Department of Commerce, the Federal Emergency Management Agency (FEMA), home builders, researchers, and manufacturers of building materials and products—have long recognized the importance of injecting current and emerging technologies into the home building process. The PATH program has identified many of the relevant technologies and has facilitated implementation of research, pilot, demonstration, and evaluation projects across the United States. In addition, PATH program partners recognize the importance of planning research and setting priorities for technology development that will enable the home building industry to work toward the PATH mission. This priority setting is known as "Roadmapping."

ROADMAPPING PROCESS

The objective of PATH technology roadmapping is to identify technology areas for immediate technological research in home building to serve as a guide for research investments by government and industry. The PATH Industry Steering Committee (ISC), comprising builders and manufacturers of building products and materials, oversees the development of all technology roadmaps.

As the primary planning activity for PATH's research, the Roadmaps dictate the main areas for research and development in PATH's research portfolio (which includes background, applied, and development activities), as well as provide the home building industry with a strategic plan for future technology development. Roadmaps approved by the PATH ISC will be provided to private sector interests to guide their technology development and to the government to guide its investment in research and development. Through this process, new technologies and additional research work are generated as the Roadmaps are implemented.

The ISC initiated the roadmapping process during the first quarter of 2000. A group of 40 builders, materials and products suppliers, academicians, researchers, and other stakeholders identified and rank ordered technologies that hold the promise of guiding PATH's research. The ISC then assembled the technologies with the highest potential benefits into four technology portfolios as follows:

- *Energy Efficiency in Existing Homes;*
- *Information Technology to Accelerate and Streamline Home Building;*
- *Advanced Panelized Construction;* and
- *Whole House and Building Process Redesign*.

The PATH ISC recommended development of technology roadmaps for each of the three areas, with *Energy Efficiency* in October 2000, *Information Technology* initiated in November 2000, *Advanced Panelized Construction* in December 2000, *Whole House* in March 2001.

The roadmapping reports are available on both the PATH website (www.pathnet.org) and the NAHB Research Center's ToolBase Services website (www.toolbase.org).

This report deals specifically with *Energy Efficiency in Existing Homes*.

VISION

By 2010, consumers will be able to substantially improve the energy efficiency of their homes and achieve positive cash flow in the process. That is, energy savings on monthly utility bills will more than offset the monthly costs for financing the installation of the energy efficient technologies. An organized infrastructure for marketing and installing the necessary technologies will also be in place.

The latest authoritative information about how energy is used throughout the U.S. housing stock comes from the 1997 Residential Energy Consumption Survey (RECS), performed by the Energy Information Administration (EIA) of the U.S. Department of Energy. Results appear in *A Look at Residential Energy Consumption in 1997* (November 1999), publication DOE/EIA-0632 (97).[1] Information from the 2001 RECS survey that would supplement this picture is not yet available.

According to the RECS, in 1997 there were over 101 million U.S. housing units, with total energy use of 10.25 quadrillion BTUs (quads) as measured at the building site.[2] This represents dramatic improvement on a per-household basis since 1978, when the 77 million housing units in the U.S. used a total of 10.6 quads of site energy. EIA attributes this improvement primarily to reduction of energy required for space heating, which would in turn represent changes such as improved insulation, windows, and heating equipment throughout the housing stock.

Figure 1 below shows this trend from 1978 through 1997 for the housing stock as a whole. Average site energy use per housing unit was 101 million BTUs in 1997, compared to the 138 million BTU average in 1978. Yet the entire drop had occurred by 1987, with no systematic change since that time. Looking to the future, the EIA *Annual Energy Outlook* for 2002 calls for residential consumption to grow at one percent per year from 2000 through 2020.[3] Assuming the housing stock grows at a comparable rate, residential consumption per housing unit would remain relatively steady.

The EIA RECS report includes a great deal of information that can be used to "ballpark" potential energy savings from different types of technological improvements, and therefore can be helpful in assessing potential energy retrofit technologies for use under PATH. A two-page summary of key points from the 1997 RECS is reproduced on the following pages. It covers all types of housing units (single-family, multifamily, and mobile homes).

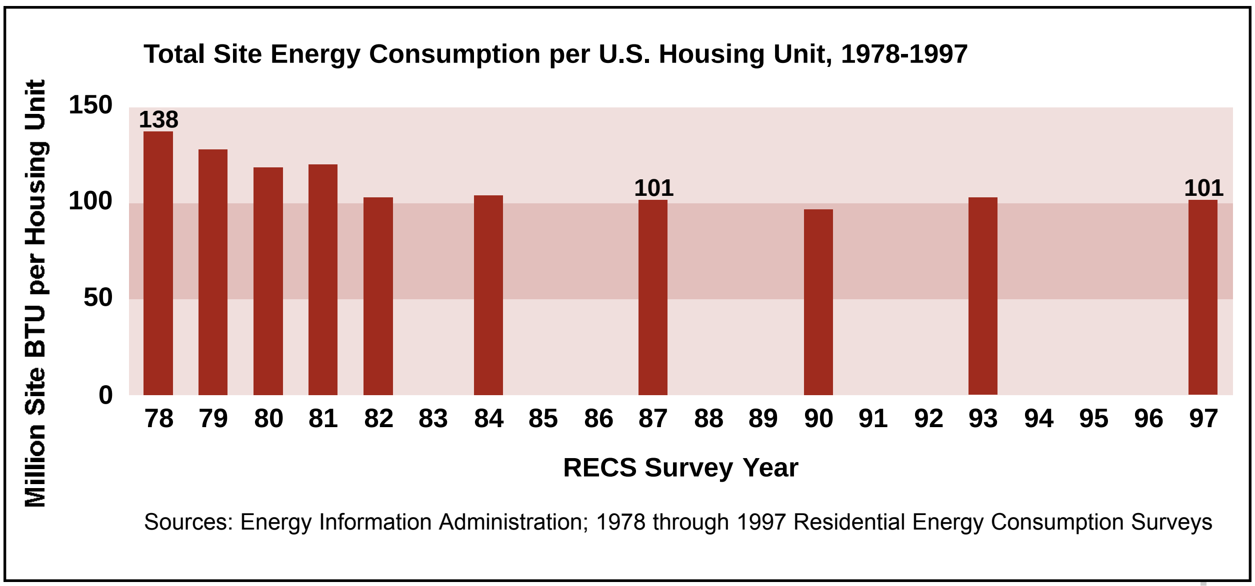


Figure 1

[1] The full report can be downloaded at http://www.eia.doe.gov/pub/pdf/consumption/063297.pdf.

[2] "Site" energy consumption excludes all energy consumed in the generation and transmission processes.

[3] For an overview of the 2002 *Annual Energy Outlook*, see http://www.eia.doe.gov/oiaf/aeo/index.html.

SINGLE-FAMILY HOMES	Number of Households: 73.7 million Portion of all U.S. Households: 73%
Owner-occupied homes: 83% Homes with a... ...clothes washer: 92% ...clothes dryer: 86% ...personal computer: 40% Eligible for the Low-Income Home Energy Assistance Program: 27% Total energy consumed: 115 million BTU per household Amount spent on all energy: $1,492 per household	Homes where main space heating energy source was... ...natural gas: 58% ...electricity: 24% ...fuel oil: 10% ...LPG: 5% ...kerosene: 1% Energy consumed for space heating: 60 million BTU per household Amount spent for space heating: $482 per household Homes with air conditioning: 73% ...with a central air conditioning system: 50% ...with room/wall units: 23% Electricity consumed for air conditioning: 6 million BTU per household Amount spent for air conditioning: $150 per household

Table 1

The summary for single-family homes shows that average site energy consumption in 1997 for the 74 million existing homes was 115 million BTUs. Space heating was more than half of the total. On an expenditure basis, average expenditures were $1,492, about one-third of which went for space heating and 10 percent for cooling in the 73 percent of homes with air conditioning. The balance of site energy use, and the majority of energy expenditures, went to operate water heaters, refrigerators, washers, dryers, other large and small appliances and lights.

End-Use Consumption of Electricity by End Use and Appliances, 1997

End Use/Appliance	Households (millions)	Units (million)	Electricity Consumption for 1997: Annual Consumption kWh per unit	kWh per household	Total (billion kWh)	Percent
Total Households	101.5			10,215	1,036.7	100.0
Refrigerators	101.3	117.5	1,1141	1,323	134.1	12.9
Air Conditioning					121.8	11.8
Central Air Conditioners	47.8			2,109	100.8	937
Room Air Conditioners	25.8	40.6	519	817	21.1	2.0
Space Heating					117.9	11.4
Main Space-Heating Systems	29.6			3,760	111.2	10.7
Secondary Space-Heating Equipment	12.4			536	6.7	0.6
Water Heating	40.2			2,835	113.9	11.0
Lighting Appliances (indoor and outdoor)	101.5			[a]940	95.4	9.2
Other Appliances (total of list below)	101.5			4,470	453.6	43.8
Clothes Dryer	55.9			1,090	60.9	5.9
Freezer	33.7	36.9	1,013	1,110	37.4	3.6
Color TV	100.2	213.0		[b]307	30.8	3.0
Cooking[c]	65.0			451	29.4	2.8
Furnace Fan	67.1			[d]398	26.7	2.6
Dishwasher	50.9			[c]410	20.9	2.0
Microwave Oven	84.2			[d]135	11.4	1.1
Personal Computer	35.6	43.0	[d]262	317	11.3	1.1
Waterbed Heater	8.4	10.1	[d]1,070	1,286	10.8	1.0
VCR	88.9	132.2	[b]70	104	9.3	0.9
Clothes Washer	78.5			[d,f]108	8.5	0.8
Ceiling Fan	61.7	155.6	[e]50	126	7.8	0.8
Pool/Hot Tub/Spa Heater	2.7			[e]2,300	6.3	0.6
Stereo	69.8			[d]71	4.9	0.5
Swimming Pool Pump	5.5			[d]792	4.3	0.4
Laser Printer	12.6			[e]250	3.2	0.3
Large, Heated Aquarium	3.9			[e]548	2.1	0.2
Answering Machine	59.3			[e]35	2.1	0.2
Battery Charger	44.4			[e]44	2.0	0.2
Cordless Telephone	62.3			[e]26	1.6	0.2
Fax Machine	6.3			[e]216	1.4	0.1
Well Pump	14.3			[d]83	1.2	0.1
Copier	3.8			[e]25	0.1	0.0
Residual	101.5				159.4	15.4

a 1993 Residential Energy Consumption Survey.
b ***Energy Use of Televisions and Videocassete Recorders in the U.S., Lawrence Berkeley National Laboratory, 1999.***
c See Appendix C, "End-Use Estimation Methodology" for a definition of the households using electricity for cooking.
d Electricity Consumption by Small End Uses in Residential Buildings, Arthur D. Little, Inc., 1998.
e ***Energy Data Sourcebook for the U.S. Residential Sector***, Lawrence Berkeley National Laboratory, 1997.
f Does not include energy used to heat water coming into the washer.

Notes: "Residual" includes appliances not listed, such as dehumidifiers, evaporative coolers, crankcase heaters, automatic drip coffee makers, irons, air cleaners, and a myriad of other small electrical appliances. "Residual" also includes errors that may be present in estimates of annual consumption. Totals may not equal sum of components due to independent rounding. This table does not reflect the interactive effects of appliance usage, especially when mixing the estimates from RECS with those from outside sources. For example, for a home with an electric oven, range, and a microwave, the use of the microwave may not add 132 kWh to the cooking consumption. For more discussion of this problem, see Appendix C, "End-Use Estimation Methodology."

Sources: Energy Information Administration, Office of Energy Markets and End Use, Forms EIA-457A-C, E, and H of the 1997 Residential Energy Consumption Survey (RECS), RECS Public-Use Data Files, American Electric Power Service Corporation, and Southern California Edison.

Table 2

In-depth information about how energy was used in residential housing units that were occupied year-round is provided by the EIA in this analysis of the 1997 RECS results. The uses and costs of residential energy (excluding vehicle fuels, primarily gasoline) were analyzed by using households' energy-related characteristics, such as location, type (i.e., single-family), size, number of household members and vehicles, and age.

THE AVERAGE HOUSEHOLD SPENT $1,338 ON ENERGY IN 1997 AND USED 101 MILLION BTU OF ENERGY

The average household spent most of their energy dollars on refrigeration, other appliances, and lighting, followed by space heating. Over 45 percent of the average household's energy costs was for energy used in appliances and lighting, while space heating accounted for another 30 percent. Water heating and air conditioning expenditures accounted for the remaining energy expenditures in the average household.

The 101 million BTU value reflects the energy content of all energy sources, including electricity, as they are used in the home (so-called "site energy"). However, large amounts of additional energy are used to generate and transmit electricity for residential use. If the energy losses in electricity generation and transmission are added to the energy value of the electricity as it enters the home, then the total energy requirement associated with the average household (so-called "primary energy") becomes 172 million BTU.

About half of the average household's site energy consumption was used for space heating. Another 22 percent was used for appliances. On a per-household basis, site energy consumption was 27 percent lower in 1997 than in 1978. Most of the decrease was in the amount of energy used for space heating and occurred between 1978 and 1987. The 1997 site energy consumption was the same as in 1987.

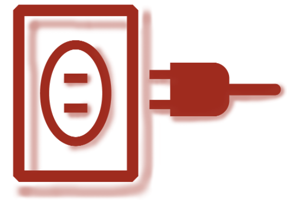
HOUSEHOLDS SPENT MORE MONEY ON ELECTRICITY THAN ON ALL OTHER FUELS COMBINED

Households spent a total of $136 billion on energy and almost two-thirds of the total ($88 billion) was used to purchase electricity. The remaining amount was spent on natural gas ($36 billion), fuel oil ($7 billion), LPG ($4 billion), and kerosene ($0.5 billion).

THEY USED MORE NATURAL GAS THAN ALL OTHER FUELS COMBINED

Households used a total of 10 quadrillion BTU of site energy in their homes. Natural gas (5.3 quadrillion BTU) and electricity (3.5 quadrillion BTU) dominated. Fuel oil (1.0 quadrillion BTU), LPG (0.4 quadrillion BTU), and kerosene (0.1 quadrillion BTU) accounted for the remainder. The relatively high cost of electricity per BTU accounts for the fact that more was spent on electricity despite the fact that more natural gas was consumed.

APPROXIMATELY TWO-THIRDS OF THE ELECTRICITY USED IN HOMES WAS USED TO OPERATE APPLIANCES, REFRIGERATORS, AND LIGHTS



Appliances, refrigerators, and lights accounted for approximately two-thirds of the electricity consumed in homes; no single appliance was clearly dominant. The remaining one-third was approximately equally divided among air conditioning, space heating, and water heating.

THE GREATER SHARES OF MOST OTHER FUELS WERE USED FOR SPACE HEATING

Sixty-eight percent of natural gas consumption was devoted to space heating, as was 72 percent of LPG and 84 percent of fuel oil. Kerosene was used almost exclusively for space heating.

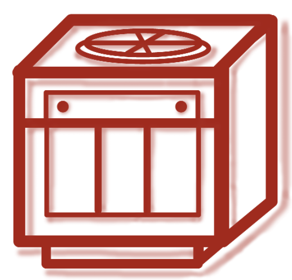
NATURAL GAS REMAINED THE PREDOMINANT FUEL FOR SPACE HEATING

Natural gas was used as the main space heating fuel in over half of all homes in 1978 and in 1997. In 1978, fuel oil was the second most prevalent space heating fuel, while only 16 percent of homes had electric heat. By 1997, the situation was reversed; close to one-third of homes had electric heat, while only 9 percent were heated with fuel oil.

REFRIGERATORS, COLOR TELEVISIONS, RANGES, AND OVENS ALL WERE FOUND IN TYPICAL U.S. HOMES IN 1997

The market penetration of refrigerators and color televisions was almost universal. More precisely, 99.9 percent of the homes had at least one refrigerator and 98.7 percent had at least one color television. (In fact, nearly two-thirds of the households had two or more color televisions.) Similarly, 99.2 percent of the households had ranges and 98.8 percent had ovens.

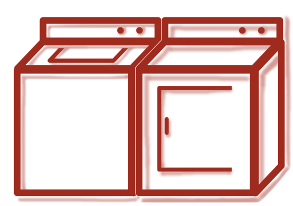
HOWEVER, THE PRESENCE OF CENTRAL AIR CONDITIONING DEPENDED ON THE LOCATION OF THE HOME



Nationally, on average, 47 percent of the homes had central air conditioning. In the South, the warmest region, 70 percent of the homes had central air conditioning. In the Northeast, in contrast, only 22 percent of homes had central air conditioning.

THE PRESENCE OF A CLOTHES WASHER AND DRYER DEPENDED ON THE TYPE OF HOME

The share of households with clothes washers and dryers varied substantially by type of home. Among single-family homes, 92 percent contained a clothes washer and 86 percent contained a clothes dryer. By contrast, among units in apartment buildings with five or more units, 21 percent contained a clothes washer and 18 percent contained a clothes dryer.



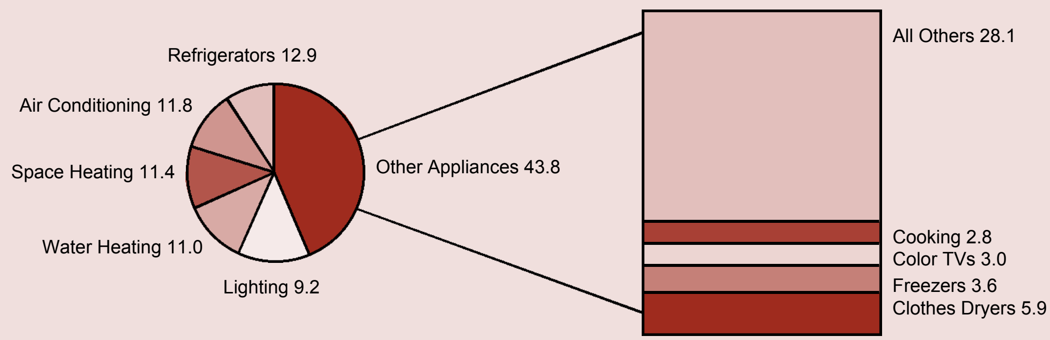
THE PRESENCE OF A DISHWASHER DEPENDED ON THE AGE OF THE HOME

Not surprisingly, the share of households with dishwashers was higher among new homes than among old homes. The percent of homes with dishwashers was 30 percent for old homes (built in 1949 or before) and 77 percent for new homes (built from 1990 through 1997).

Table 2 (page 5) disaggregates electricity consumption by end use and shows the market penetration of different types of electric appliances. Total electricity usage per household for all purposes averaged 10,215 kWh in 1997. This was 35 percent of total site energy usage in BTUs and 65 percent of total expenditures on energy. Note that more than 50 percent of electricity is used for lighting and appliances other than refrigerators, water heaters, and air conditioners.

A graphical breakdown of average electricity consumption by appliance type is in Figure 2 below. The proportions showing relative usages for refrigerators, air conditioning, lighting, water heating, and other purposes reflect a combination of market penetration (the proportion of households that have electric appliances of each type) and appliance energy intensity (the average energy usage by each such product).

Percent of Total Electricity Consumption in U.S. Housing Units, 1997



Source: Energy Information Administration, Forms EIA-457A, B, C, E, and H of the 1997 Residential Energy Consumption Survey

Figure 2

U.S. Residential End-Use Consumption of Natural Gas, 1993

End Use/Appliance	Households (millions)	Annual Therms* Consumed per Household for End Use Indicated	Natural Gas Consumption for 1993	
			Trillion BTU	Percent
Total Households Using Natural Gas	58.7	899	5,274	100
Main Space Heating	51.4	709	3,644	69
Secondary Space Heating	1.2	215	26	([a])
Water Heating	51.4	255	1,312	25
Air Conditioning	0.1	238	2	([a])
Appliances	37.8	77	290	5

* A therm is 100,000 BTU.

[a] Less than 0.5 percent.

Notes: Appliances include ranges, ovens, clothes dryers, outdoor gas lights and gas grills, hot tubs, and swimming pool heaters.

Sources: Energy Information Administration, Office of Energy Markets and End Use, Forms EIA-457 A-C and F of the 1993 Residential Energy Consumption Survey (RECS), and RECS Public Use Data Files.

Table 3

Finally, Table 3 from the 1993 RECS disaggregates residential natural gas consumption by end uses such as space heating and water heating. (Note: Data from 1997 was not available.)

Any overview of the current environment for energy efficiency in existing homes must also consider other important developments, including recent developments. These include:

- Growth in family incomes, which tends to increase overall energy use associated with a rising standard of living
- Rising consumer interest in the "environmental" attributes of products, including building products, leading to greater concern about recycled content and recyclability, embodied energy used in manufacture and production, and emissions to air and water during production, use, and disposal
- The popularity of mortgage refinancings as homeownership periods lengthen, especially when interest rates drop
- The overall stability of nominal energy prices at the consumer level in recent years, and the corresponding decline in inflation-adjusted energy prices
- The deregulation of natural gas at the wholesale level in the 1980s and at the retail level in the 1990s
- The gradual move towards deregulation of electricity at the retail level, beginning in the late 1990s, with the development of new wholesale markets and the potential for lower electricity costs to end users
- The decline in utility-sponsored energy efficiency programs and the rise in time-of-day rate schedules, both resulting from deregulation and other forces
- The visible disruptions to the California economy in 1999 and 2000 associated with blackouts, electricity shortages, and wholesale price spikes in a deregulated market, and the success in reducing consumption during the crisis through behavioral responses by building occupants
- The expanded scope of federal minimum appliance efficiency requirements, and periodic tightening of those minimums, such as newly adopted rules requiring more efficient central air conditioners, heat pumps, and water heaters in coming years
- The rapid growth in performance of microcomputers, the breadth and intensity of Internet use, and the growing comfort of consumers with computer technology in homes and appliances

In order to be relevant to tomorrow's market, a sound plan for improving energy efficiency should be developed in light of these larger, longer-term trends. Where possible it should also attempt to take advantage of them.

BARRIERS/CHALLENGES

In order to identify strategies for improving energy efficiency in the existing housing stock, it is very helpful to start by considering the range of barriers or impediments to achieving the goal, and some potential steps for mitigating or eliminating those barriers. The current marketplace includes many product and system choices that have the potential to reduce energy consumption in the housing stock. However, they are surrounded by a series of economic, institutional, and practical obstacles that inhibit their deployment on a large scale.

Some of the barriers identified in Table 4 can only be addressed indirectly, yet considering the whole set of barriers and potential steps to overcome them is central to developing strategies that can achieve new levels of energy savings. In general:

- There is a need to bring a continuing stream of improved technology to market in the form of energy-saving products, materials, and systems that are suitable for use in all or part of the existing home sector, not just products for new homes.

	Barrier to Improving Energy Efficiency	Steps to Address Barrier
1.	Many of the simple, straightforward improvements for existing homes have already been made.	Identify and fill in remaining gaps while also expanding the set of opportunities through availability of new and improved technologies.
2.	Rising incomes and generally stable energy prices have dampened interest in energy efficiency.	Work to create new choices and to make old choices more attractive.
3.	Homeowners are illiquid and burdened with consumer debt.	Promote financing tools and focus on high ROI or low cost; create, implement, or coordinate financial incentives to align public and private goals.
4.	Energy upgrades in existing homes usually face greater technical challenges than in new homes, and frequently involve high investment cost along with high search costs.	Work on technologies that address the unique constraints of existing homes; leverage opportunities at time of product or system replacement for other reasons; and promote low-cost DIY activities and no-cost behavioral steps that save energy.
5.	Under a piecemeal approach to retrofit, it is very difficult to achieve large per-house savings.	Consolidate retrofit opportunities where appropriate; identify and promote opportunities to benefit from synergistic system effects; focus on maximizing total impact rather than per-house savings.
6.	Technical complexity makes accurate analysis, prediction of energy savings, and economic optimization costly and difficult.	Provide basic information through education and outreach without calling for accuracy; ensure that market forces can help guide decision-making.
7.	There is no significant organized infrastructure for marketing and delivering energy savings to homeowners.	Promote branding as in the form of EPA Energy Star; train contractors in energy upgrade technologies and methods to market them in conjunction with other homeowner R&D investments.
8.	There is insufficient R&D in the private sector.	Increase opportunities for cost-shared applied research and government building-related research programs (such as lab programs in building envelopes, HVAC, lighting, and windows) to respond more directly to industry needs.
9.	There is low ROI for retrofit products and the DIY market.	Expand demand and market size through visibility and targeted technical information; expand supply through enhanced technology.

Table 4

- There is a need to raise consumer awareness of the potential benefits and provide ready market access to the technical opportunities to reduce energy consumption.
- There is a need to expand the ability of private sector general and specialty contractors to market, deliver, and properly install energy-saving improvements.
- There is a need to provide consumers who want to invest with financing to support their investments, and to motivate action with incentives that reflect the beneficial social impacts of private decisions to save energy.

With these general approaches in mind, it is appropriate to look to what the future may bring for energy efficiency in existing homes, including approaches that are beginning to see use and possibilities that do not yet exist. These are described in the next section.

ROADMAP

OVERVIEW

For purposes of presentation, the needs and opportunities covered in this section are loosely organized into five categories that are intended to encompass the whole range of approaches available for use in addressing residential energy consumption.

- **Building Envelope Technologies** reduce the heating and cooling loads that must be met.
- **HVAC Systems and Controls** improve the efficiency of equipment and systems in meeting the envelope loads.
- **Appliances and Lighting** use energy for purposes other than space heating and cooling, and represent major (and growing) contributors to overall energy use.
- **Distributed Generation** can allow small-scale, more efficient production of electricity near the point of use.
- **Outreach Strategies and Tools** are not technologies in themselves, but create the linkage between potential end users and available technologies that supports adoption.

Of course, this logical organization and classification are primarily adopted for presentation and do not rule out the popular “systems” approach that cuts across multiple products or categories. Such approaches can be built from the bottom up by identifying interactions and exploiting synergies, and are discussed as appropriate in the sections that follow.

1 BUILDING ENVELOPE TECHNOLOGIES

1.1 Envelope Air Sealing

Air leakage through the building envelope is a major contributor to heating and cooling loads in homes of all ages, but it is particularly problematic in older homes. Significant air leakage around window and door frames or through holes for pipes, wiring, and fixtures results in a drafty, uncomfortable house in winter with noticeable cold spots around the perimeter. An increasing variety of caulks, foams, and other types of weatherstripping or gasket systems are available for use in air sealing. Some products are for general use and others address special purposes; most are sold directly to consumers, but some are sold only to professionals.

One distinguishing feature about air tightening is that most of the materials used deteriorate over periods as short as a few years, especially those directly exposed to harsh exterior conditions, as caulks shrink and crack, or weatherstripping becomes torn and brittle. This means that homes will naturally tend to become more leaky over time, even if they have been previously weatherized.

New homes that have been designed and built to achieve very low air infiltration rates raise special concerns about ventilation, but these need not discourage air sealing in leaky homes. Without extraordinary measures, it would be very difficult or impossible to tighten up most leaky houses after construction to the point where ventilation air is inadequate. And while it is recognized that air tightening will generally tend to raise indoor humidity levels during winter, leaky existing homes typically suffer from low humidity rather than high humidity in cold weather.

Practitioners and researchers have identified several needs and technical opportunities particular to air sealing of existing homes, generally incremental in nature. Air sealing is more complicated than it used to be, but material costs are low and the work does not require a high level of skill.

Sealing Outlet Boxes in Place. Electric outlet and switch boxes located on the inside of exterior walls are a familiar entry point for outdoor air. Better techniques for sealing these boxes tightly to eliminate this infiltration path are needed. This is a real challenge in retrofit where the drywall remains in place, because access is so limited. The most common approach, foam pads inserted under the cover plates, can be almost completely ineffective.

New and Improved Foam Sealants. Foams are the sealant of choice in many uses, since caulks are unsuitable for bridging wide gaps or filling deep gaps. Foams also offer some level of insulation performance that caulks lack. It is likely that new and improved types of foams will be introduced over time, in part because properties of the ideal foam vary by use. Perhaps the most important application is sealing around window and door frames, since stuffing insulation in these voids does little to keep air from leaking under and around the trim. Both low-expansion and high-expansion foams are available for use as sealants. The high-expansion variety can easily fill these gaps but can also expand with such force that they bind windows and doors in their jambs. The minimal expansion foams avoid this problem but must be applied more carefully in order to seal the openings. Both types also cure slowly. Two-part foams that cure and set quickly are available as well, but they are more difficult to apply and less commonly used. One performance goal in new formulations is a one-part foam that expands without exerting large forces, and cures rapidly. A closely related informational goal is providing users with clear, conspicuous performance characteristics, application data, and precautions. This latter goal also applies to the foam products in use today.

Standardized Weatherstripping Profiles for Windows and Doors. The weatherstripping on doors and windows is considered a "wear item" destined to require replacement once it deteriorates and fails to seal adequately. Unfortunately, obtaining replacement parts is often difficult since they must be purchased from the original manufacturer based on the specific product involved. Consumers must otherwise resort to ad-hoc solutions or endure the leaks. What is needed is a set of generic or standard weatherstripping profiles and channel shapes that could be incorporated into new products and facilitate development of a market for the replacement parts. It would take years for this to materialize due to the low replacement rates for windows and doors, but the end result would be products that perform better over longer periods of time.

Removable, Re-usable Caulk. Homeowners who cannot afford to replace old windows that leak air in any particular year could benefit significantly from a reasonably durable, removable caulk or similar product that could be cut to length and pressed into place around window sashes and other leakage paths, then removed without damage to the substrate or itself at the end of the season when the window must be operated again. It could be used alone or in conjunction with tape-on plastic storm windows. The rope caulk available today is overly fragile, adheres poorly, and is not suitable for repeated application. This type of "self-help" product, while low-tech, could be quite inexpensive and is far better than nothing at all for older windows.

Blower Door Assisted Air Sealing with Combustion Safety Test. Using a blower door to identify building envelope air leakage routes by house pressurization or depressurization is a powerful tool for enhancing air sealing compared to other methods. It has been used in weatherization programs and other applications. Complex leakage paths connecting remote parts of the envelope (e.g., unheated attics to crawl spaces or basements) can be identified with the blower door, and major reductions in air leakage can sometimes be achieved at low cost. Experts often recommend combustion safety testing for buildings that have been tightened in this way to ensure that backdrafting of atmospherically vented furnaces or water heaters leading to spillage of combustion gases is unlikely to occur even under extreme conditions. Suggested protocols for such testing can be found in ASTM Guide E1998-99, *Guide for Assessing Depressurization-Induced Backdrafting and Spillage from Vented Combustion Appliances*, as well as in some building codes (for example, see Appendix D to the 1997 International Fuel Gas Code). However, these protocols have yet to achieve broad acceptance due to concerns about repeatability and false positive results. The equipment and expertise needed to perform blower door-assisted air sealing have historically left this technique primarily in the hands of specialists, reducing its use. Additional information about blower door technology is available at www.toolbase.org/techinventory/blower_door.

1.2 Building Insulation

Crawl Space Wall Insulation Retrofit. Crawl spaces are the predominant foundation type in some areas of the country, and are often used under building additions in many different areas. Traditionally, crawl spaces have been built with wall vents to reduce moisture problems, and separated from the conditioned space in the house by an insulated floor. This remains the most common type of crawl space construction, but it can and has led to problems in some homes, particularly in mild, humid climates. The problems include condensation on cooler duct and first floor surfaces that can saturate insulation, destroy finished flooring from below, promote rot in framing members, and lead to other problems. Fortunately, there is an alternative for new construction—crawl spaces with insulated walls. More importantly, where a conventional crawl space is causing problems for an existing home, it can be converted through retrofit into a crawl space with insulated walls.

The retrofit and conversion of an existing crawl space involve sealing the vents, insulating the walls and a strip of floor around the perimeter, and covering exposed dirt on the floor with polyethylene sheeting or a similar material to limit the entry of water vapor from the soil. Some method of pressurizing the crawl space relative to the building and the outdoors is also recommended. The likelihood that HVAC equipment cabinets and ducts are located inside the crawl space makes the retrofit more attractive, because insulating the crawl space walls effectively moves such ducts and any associated duct leakage into conditioned space and thereby improves energy efficiency.

Basement Wall Insulation Retrofit Systems. Innovative methods of insulating basement walls in place have great market potential in existing homes. Basements in many areas were commonly built without wall- or floor-above insulation well into the 1990s, and unless those basements have been finished, the walls most likely remain uninsulated today. Inexpensive, easily-installed systems that provide even modest insulation value along with a finished interior wall surface that allows for utilities through raceways and is acceptable from an aesthetic and fire protection standpoint could find acceptance in existing homes. The wall system also must not harbor mold or mildew growth and must be designed to resist deterioration in a basement environment that experiences greater temperature and humidity swings than other living spaces.

Insulating Encapsulating Panel. Some types of wall construction that are too expensive or inconvenient to retrofit with cavity insulation could be materially improved by installing relatively thin interior panels, possibly as simple as 3/8-inch gypsum adhered to 1/2-inch foam, against existing walls (and possibly ceilings). Electrical outlets would be extended to the new surface, as would window and door trim. Such a product could add R-3 or so to an existing wall, as well as cutting air infiltration (particularly with lath and plaster walls). Proper sealing and detailing would also allow the panels to encapsulate any lead-based paint. It would be cut to size in the field and come in narrow sections (e.g., 2-foot width) to minimize scrap. The product would be applicable in homes with frame or concrete block walls that lack wall insulation, especially with interior lead-based paint. A 1997 study by Argonne and Oak Ridge National Laboratories involving possible application of such a product is available on the web at www.eren.doe.gov/buildings/partner_compwall.html.

Thin, High-R Leveling Board for Re-siding. Re-siding of existing homes is a relatively common major replacement project in which older, often deteriorated products are typically replaced with low maintenance alternatives. Consumer survey data from 1999 and 2000 shows that each year, between 2 and 3 percent of existing homes underwent major siding replacement. One utility product that has become popular is a thin foam leveling board installed under the new siding. Its primary purpose is to provide a smooth, level surface over existing wall sheathing prior to re-siding, but other advantages include adding some insulating value to the wall (about R-1 for a 1/4-inch thickness) and providing an air barrier and drainage plane for the re-sided area. The potential energy savings are greatest when it is used with underinsulated walls built without panel sheathing products. Enhancing the R-value of a leveling board or making sure the product reduces infiltration effectively could stimulate usage and help address the very difficult problem of retrofitting wall insulation.

1.3 Windows

Economical Replacement Windows. The high installed cost of replacement windows is a tremendous disincentive to their use, leading occupants to endure poorly performing windows for years, even decades, before taking action. Typical replacement costs for contractor jobs averaged almost $600 per window, according to consumer survey data from 1999 and 2000, and the average wood window being replaced was about 40 years old. Even though new windows are generally far more energy efficient than those being replaced, the high cost of replacing functional windows simply cannot be recovered from energy savings except in the most extreme circumstances.

Development and introduction of more economical replacement window units could potentially increase the replacement rate. One possible approach involves an “adjustable” replacement window designed to be able to accommodate small dimensional irregularities and eliminate the need to custom manufacture each replacement unit to fit the exact dimensions of each opening. This could allow mass production of replacement windows in a relatively small number of standardized sizes, potentially reducing cost.

Advanced Replacement Windows. The U.S. Department of Energy has recently sponsored development of a Window Industry Technology Roadmap, calling for incorporating many advanced, mostly energy-related product features into windows over the next 20 years. Some of the technologies identified in that Roadmap are electrochromic glazings that can be switched from transparent to opaque, aerogel-filled insulated glass units, and windows with integrated photovoltaics. If variations of the new construction products are also made available in the replacement window market, their impact is likely to be much larger and much faster.

Vacuum Glazing for Existing Sash and Frame. The window industry has considered the possibility of using evacuated insulated glass units for new windows in order to achieve extremely high glass R-values with a thin profile. A vacuum glass panel manufactured in Japan became commercially available in 1997. This dual pane glazing has a total thickness of just 6 mm (less than 1/4-inch), and can be installed into existing wooden window frames for single panes where it would cut heat loss through the glazed area by 75 percent. More information is available at www.caddet-ee.org/infostore/details.php?id=2834.

Depending on the extent to which the sash must be modified during installation, this product, or some improved variation along similar lines, could prove to be ideal for retrofit applications in wood-frame windows where the underlying window structure is sound.

Window Films. There is a market for field-applied solar control window films in the commercial building sector. Similar products for residential windows could be easily imagined. Two specific products come to mind. The first is a low-e film for installation on the outside of prime windows that are used with storms, or on the inside of storm windows. This could improve assembly U-factor substantially. The second is a spectrally selective film that would cut direct solar gain in summer, ideally with very little impact on visible light. It would represent an advance on the bronzed or grey-tinted plastic films that have existed for years, and could be used on existing windows whether or not storms are also used. Such products might come in a roll and could be easily cut to size, held in place without adhesive, and removed to allow re-use. In principle, each product could be used at the appropriate times of the year. This would allow optimizing window performance for both winter and summer, which is difficult or impossible using permanent factory-applied coatings (i.e., direct heat gain is very desirable in winter but very undesirable in summer). As described here, these would be removable films, but permanent applications could also be effective and offer a better appearance.

1.4 Attic Radiant Barrier Paint

A low-emissivity paint or coating suitable for spray application to the underside of a roof deck and to rafters or top chords of trusses could save cooling energy in hot, sunny locations by limiting radiative heat gain to ducts and to the attic floor or top of the insulation pack. Ease of application in tight spaces is particularly important for retrofit. New construction can use structural sheathing with a reflective face, but this is not practical in an existing home. The goal would be an emissivity comparable to that of aluminum foil (= 0.05), representing a considerable improvement over current radiant barrier paints, which are reported to have emissivities of around 0.3. Energy savings potential from lower attic temperatures is greatest for homes that have their cooling ducts and equipment located in the attic. Technical concerns about implementation of this technology primarily reflect the potential for elevated roof deck temperatures to reduce the service life of asphalt shingles.

1.5 Diagnostic Equipment

Inexpensive blower door equipment that could be purchased and used by more remodeling contractors would make this weatherization method more widely available. Methods for accurately estimating supply and return duct leakage with the blower door and without using a separate duct blaster could reduce the labor requirement and total cost of diagnostic testing. The potential benefits of comprehensive air sealing in leaky houses are significant, and the positive implications for comfort are in addition to the energy savings. However, the small market for blower doors has led to few producers, complicating the realization of economies of mass production. Furthermore, more research is needed to develop and validate indirect methods for estimating duct leakage rates.

2 HVAC SYSTEMS AND CONTROLS

2.1 HVAC Monitoring and Trouble Alert System

Studies have found that large numbers of air conditioning systems and heat pumps suffer from improper refrigerant charge, leading to problems that range from reduced operating efficiency to system freeze-up. Field testing during maintenance work or trouble calls is presently the only way to identify the affected systems. A sensor or sensors and monitoring hardware that would detect low refrigerant charge and notify the occupant would help correct these problems at an earlier stage. While the system could monitor these parameters directly, an alternative approach that was reportedly investigated during the 1980s at Oak Ridge National Laboratory, but not further pursued, involved analyzing the "motor current signature" electronically. Improvements in digital signal processing speed and cost may make this approach much more practical today than it was 15 years ago. Whatever the design, it would be best if a monitoring system could be retrofit into existing equipment as well as being designed and built into new systems. Many new systems may already have the basic sensors and interface required to collect this information and use it internally. The purpose here is to bring the homeowner into the information path.

Other enhancements can be easily imagined and incorporated into this type of system. These include monitoring for other "trouble" conditions, such as low combustion efficiency in oil or gas furnaces, or excessive pressure drop across the air filter in any type of equipment signaling time to replace the filter. The latter problem might also be identified by measuring airflow downstream of the filter. Modern automobiles have been very successful in networking low-cost sensors in order to maximize performance of emission control systems, improve fuel economy, and assist service personnel.

As the functionality of an HVAC monitoring and trouble alert system becomes more advanced, the advantages of attaching it to a communications gateway become more apparent. One possibility is automatic notification of the manufacturer or service company when their assistance is warranted. This could be beneficial even if the homeowner is the principal or sole recipient of the information, by providing more flexibility in where and how it is displayed. A simpler approach might be to use an enhanced thermostat as the display and input/output device rather than using hardware mounted on the equipment, since occupants might go for long periods of time without seeing or checking on a system that is not in an accessible location.

2.2 Improved Field Connection System for Refrigerant Lines

An alternative to conventional brazed or soldered connections on refrigerant lines for air conditioners and heat pumps would be welcomed if it could provide a positive, long-lasting connection without requiring any significant skill on the part of the installer. It could be applicable to any newly-installed HVAC system with refrigerant lines. The previous item noted the potential benefits of automatic detection of refrigerant leakage, while this item may be preferable because it could do much toward eliminating those leaks in the first place.

2.3 Duct Sealing in Place

Duct leakage adversely impacts overall HVAC system efficiency, especially when the leakage occurs to unconditioned or semi-conditioned space. But the inaccessibility of many duct systems and the practical difficulties of air sealing in place have made it difficult to address leaky ducts in a finished house. An emerging technology addressing this challenge, developed by government scientists, is dubbed "Aeroseal" and is now being privately commercialized. Adhesive particles spray applied from inside and forced through the ducts under pressure are able to seal leaks and bridge gaps up to 1/4-inch in size. More information is at www.toolbase.org/techinventory/aerosol_duct_sealing.

2.4 Next Generation Programmable Thermostats

Programmable thermostats have been available for years, but still remain relatively uncommon in existing homes. They can save energy through more sophisticated operation of the HVAC system, yet they are not installed as standard equipment even with replacement furnaces or air conditioners. One persistent problem has been complexity that leads homeowners to ignore them, or defeat their features in frustration. Their functionality also remains surprisingly limited.

Advances in embedded digital systems, display technology, and networking combine to enable development of a next generation of programmable thermostats. Some of the possibilities include user-friendly features such as voice programmability, or relieving the user of the programming burden through a process of adaptive learning. Government-sponsored research into a thermostat design with a variable deadband that could reduce equipment cycling and improve efficiency is also relevant.

The thermostat offers bigger possibilities as well. It represents a convenient, familiar user interface that can become a platform for new services. Thermostats with modern display capabilities can provide an interface to furnace and air conditioner diagnostics, informing users about any fault conditions as well as the need for maintenance such as changing filters, as discussed elsewhere. Another very important step forward would be to add the equivalent of a utility interface that would automatically adjust system settings in response to real-time energy price information or requests from the energy supplier. These functions might require additional specialized wiring of the thermostat itself, or they could be implemented with wireless network technologies.

3 APPLIANCES AND LIGHTING

3.1 Programmable Load Monitoring and Management

Some type of system providing occupants with programmable control over multiple energy-using devices seems certain to emerge in the coming years. This could allow improved management of the energy used by water heaters, refrigerators, fixed lighting, and possibly other devices by enabling, disabling, or even “scaling back” activity according to time-of-day, power availability, real-time energy cost, or any other parameters that can be monitored. It probably should be integrated with HVAC thermostatic control and general home automation, and represents a more sophisticated version of current devices that control single appliances, coupled with the flexibility of a dedicated communications interface for remote operation.

There are many design options. Local communications could be by power line carrier or might build on recent advances in wireless local area networks. Control logic and the communications gateway could reside on a local PC, or control could even be distributed entirely across the embedded systems found in many of today’s appliances, similar to the way multiple devices are networked in modern automobiles. Most existing homes could manage significant loads in this way. Even if average consumption is not greatly reduced, loads can readily be shifted away from peak usage periods or unoccupied times, which would save money for the occupant and potentially improve the load profile faced by the energy supplier as well. Of course, from an energy standpoint, it would be very important for direct energy savings (or cost savings) through load management to outweigh the additional stand-by power requirements necessary to support the underlying switching, monitoring, and communication activities. A management system that achieved even small net savings every day could represent an excellent economic ROI over time.

Some form of home automation is inevitable, including home automation in existing homes. The direction is obvious even if the timing is uncertain, and the proliferation of embedded computer systems in modern appliances already provides a basic platform for these services. A standardized interfacing protocol would be required, and multiple compatible devices would be needed for maximum effectiveness.

3.2 Advanced Light Switches

Light switches with advanced performance that could be installed in existing switch boxes are potentially a useful retrofit device. Possible features include proximity sensing operation, day/night modes, and timers. They could have a convenience value as well as an energy-saving value, although the two might conflict in some situations. For example, automatic operating modes might shut lights off sooner but could also turn them on sooner than manual operation. Potential savings are small since all lighting only totals about 10 percent of average electricity use, but where children are present or lights remain on unnecessarily for any reason, an automatic solution could be simple and effective.

3.3 Minimized Appliance Stand-by Energy Usage

Electronic appliances dating back more than 30 years to "instant-on" TVs have consumed small amounts of power even when not in use, so long as they remain plugged into the wall. This was originally designed to keep circuits warmed up so the device could be switched on quickly. More recently, power-consumption-when-off has been used to support remote control (TVs, VCRs, stereos) and/or built-in continuous displays (e.g., microwave ovens). Some stand-by power usage levels recently measured with a digital power meter included 3.2 watts for a 21-inch color TV with remote, and 2.2 watts for a microwave oven with a clock.

Other devices powered by AC transformers, rechargeable batteries, or wall adapters also use some energy so long as the transformer is plugged in, even when the device is not turned on or even connected to the transformer or charging station. Examples include answering machines, portable radios, external modems, computer printers, and many other electronic devices. Illustrative values for a radio, external modem, and computer speakers ranged from 0.5 to 0.7 watts, while the AC adapter for an inexpensive color computer printer used 3.6 watts whenever it was plugged into the wall. Finally, even devices that do not use wall adapters and provide no functionality at all when switched off may consume power, totally unknown to the user, because by design the main power switch is located downstream of the internal power supply. For example, a compact stereo system (one piece) was measured at 1.2 watts with the power switched off, and an early Pentium-class PC (133 MHz) used 1 watt when turned off, so long as the power cord was plugged into a receptacle.

Based on these numbers, total "parasitic" energy consumed in this way would almost certainly exceed 2 percent of typical residential electricity use, and is probably growing as small appliances proliferate. Researchers from the Department of Energy have dubbed these devices "energy vampires" and reported that an average home has more than 20 appliances consuming stand-by power which is responsible for about 5 percent of electricity use. The topic has received much recent media attention, and more information is provided at a special website sponsored by Lawrence Berkeley Laboratory (LBL): http://standby.lbl.gov/. Ironically, there is generally no way for users to measure these power draws without special equipment, or to determine stand-by usage from published specifications or markings on appliances or transformers. Furthermore, where such appliances are used infrequently, they can easily consume more power when "off" than when in operation. Self-help steps such as using switchable outlet strips can effectively eliminate this form of energy use, but one drawback of this approach is experienced whenever devices such as televisions "forget" preset stations or volume levels whenever the power is disconnected.

Appliances can undoubtedly be built to reduce or even eliminate these continuous energy drains, which probably would be better than self-help solutions. Several approaches are available. LBL reports that new technologies cut stand-by power by 90 percent without sacrificing convenience or features. Manufacturers can also inform users about stand-by energy use just as they report power draw during normal operation. The Environmental Protection Agency recently announced that Energy Star appliances will be limited to one watt of stand-by energy consumption, which should be beneficial for some devices but irrelevant for others. A similar standard has found its way into legislation and federal procurement policy during 2001. Work to achieve or surpass the one-watt value offers potential benefits throughout (and beyond) the entire housing stock.

3.4 Waste Heat Recovery

Refrigerator Waste Heat Recovery or Disposal. The energy consumed by refrigerators, averaging over 1,300 kWh per household in 1997, is ultimately released into the living space as heat. Even in winter it might be possible to use this heat more productively, and in summer it would reduce cooling loads or improve comfort if this heat could be diverted or used in some other way. While new units are much more efficient than older ones and it could be impractical to retrofit older refrigerators, the possibility of design changes to new units remains. All heat reductions in summer would reduce the cost of cooling.

Drainwater Waste Heat Recovery. Production of hot water is recognized as one of the most energy-intensive activities in the home. Where electric water heating is present, it accounts for over 25 percent of total electricity use. Gas water heating is slightly more common, and is responsible for a similar fraction of total gas use. What is less known is the fact that most of the energy used to heat water, even in gas systems, is ultimately lost down the drain. Centralized drainwater heat recovery devices have been developed in an attempt to use this waste energy, but they are not widely used and there is uncertainty about their economic performance. The savings from drainwater heat recovery from current devices is also constrained because they are only effective when supply and drainwater flow are simultaneous. More information about this technology is available at www.toolbase.org/techinventory/drainwater_heat_recovery.

Clothes Dryer Waste Heat Recovery. Clothes dryers account for about 6 percent of residential electricity use, as well as a portion of residential natural gas use. Well over half of the energy used to operate clothes dryers is vented out of the building as heated exhaust air. While alternative dryer technologies are also a possibility, it is clear that a system for recapturing some portion of the waste heat exhausted by conventional electric and/or gas clothes dryers and using it for space heating or other domestic purposes would also reduce overall energy use. The challenges presented here result from the substantial amounts of moisture, lint, and particulates in the exhaust stream.

3.5 Enhanced Compact Flourescent and LED Lighting

Compact fluorescent (CF) light bulbs have been on the market for over 10 years, but have yet to achieve a large market share. They are promoted as superior substitutes for ordinary incandescent light bulbs, and prices have dropped at the same time as they have been adapted to work in conventional fixtures rather than special ballasts. Yet there are suggestions that CF light bulbs, while they last much longer and consume only about 25 percent as much electricity as comparable incandescent bulbs, suffer from significant problems. One is spectral drift or deterioration that affects the color and quality of light. Another is loss of lumen output that affects the intensity and usability of light. These issues need to be investigated and, if the concerns are verified, the products should be re-engineered to eliminate them. It is also well known that the electronic components required to operate CF bulbs generate radiofrequency noise and interference that have limited their application. Electronic noise and static may be even more problematic in a future environment that relies more heavily on communications and electronic controls.

Another new lighting technology with significant implications for all homes is white-light LED “bulbs” with edison-type bases. These solid-state products are far more energy efficient than even CF bulbs, and their energy use is insignificant compared to incandescent lights. LED lights are likely to last longer than CF lights as well. They are finding growing use in the commercial market, especially for lighting that remains on continuously, such as exit signs, and their cost is coming down (although still higher than CF alternatives). It would not be surprising to see LED lighting displace CF bulbs as the energy-efficient lighting product of choice at some point in the next decade. More information about LED lighting is available at www.toolbase.org/techinventory/white_LED_lighting.

Wholesale substitution of CF and/or LED lighting as an alternative to incandescent lights in fixtures and portable lamps is an attractive possibility that has the potential to cut residential lighting from 10 percent of average electricity use to essentially nothing. Their potential advantages are clear and very worthwhile, and they have an obvious role to play in any effort to reduce energy use in existing and new homes alike.

3.6 Architectural Daylighting

It is both feasible and popular to use fixed elements such as skylights and, less commonly, light “pipes,” “shelves,” or “tunnels” to supply general lighting or task lighting in residences. The addition of skylights to existing homes is commonplace, primarily for aesthetic reasons. Impacts on heating and cooling energy requirements depend on many factors, but all of these technologies allow the residents to substitute daylighting for artificial light, and some can be much easier to retrofit than skylights. Lighting energy is used in essentially every home and accounts for 10 percent of average residential electricity use, although it is not clear how much of this occurs during daylight hours. In principle, with most residential building envelopes it should be possible to virtually eliminate daytime use of artificial general lighting and even task lighting.

4 DISTRIBUTED GENERATION

4.1 Fuel Cells

Various technologies are now or soon will be available for small-scale generation of electricity on-site. One of the most interesting involves new stationary hydrogen-oxygen fuel cell technologies, which are now being commercialized and studied more closely than ever. A short write-up on fuel cell technology appears at www.toolbase.org/techinventory/fuel_cells.

Local generation offers both advantages (e.g., higher net efficiency than power plants) and disadvantages (e.g., overhead costs to interconnect with the power grid). The power shortage and reliability issues experienced during 2000 and 2001 in connection with the deregulation of electricity supply in California have focused renewed attention on local generation. If a fuel cell, for example, could generate electricity using natural gas at lower cost than purchased electricity from the grid, then it could potentially be installed in an existing home (or a new home) and reduce the cost and/or total resources used to provide electric service.

In principle, any home that uses electricity could take advantage of some form of distributed generation. In practice, the most cost-effective applications of fuel cells would make use of waste heat generated during the reformation stage where natural gas is transformed into hydrogen, as well as heat released from the fuel cell itself. Either might be tapped for producing hot water. As with other innovations, this type of system integration will likely be simpler and less expensive when it can be built into a new home than when such a product is retrofit into an existing home.

4.2 Building Integrated PV

The integration of photovoltaic (PV) cells into functional building products provides another avenue leading to distributed generation of electricity. Opportunities for using PV technology to produce electricity directly from sunlight have been studied intensively for decades, yet these products remain too expensive for use outside of niche applications. However, conversion efficiencies that have grown at the same time as hybrid products such as PV roofing have been developed and introduced as an alternative to conventional solar panels.

5 OUTREACH STRATEGIES AND TOOLS

5.1 Energy Retrofit Delivery Systems

Contractor and Trade Certification. Remodeling contractors perform energy upgrades when they know how to do them and stand to benefit from doing them. However, interest and knowledge in this area may have declined significantly during the 1980s and 1990s, as concern over fuel prices and conservation waned. Educating remodelers and the major trades in energy efficiency technologies and how to sell them is one way to make sure the market can address these concerns. Offering certification to recognize accomplishments and professionalism in this area is a form of "branding" that provides an incentive to becoming trained and an aid to marketing. This could be linked to other certification and image programs in the industry. And tying third-party energy ratings into home improvements might make the selling job easier and the results more beneficial.

Consumer Education and Awareness. Indifference of consumers towards energy efficiency improvements can result from many factors, including lack of information about the opportunities and prospective rewards, and capital constraints or high discount rates. On the one side, it could be beneficial to give consumers better tools for identifying energy upgrades that make sense in their specific circumstances (climate, type of home, family size, etc.) and estimating how they will benefit over time from investing in such upgrades. There is also a role for educating consumers on the best use of technologies they already have, ranging from operation of programmable thermostats and appliances with "energy-saver" user controls, to window management that cuts direct solar gains during hot weather. On the other side, there are various ways to improve the cost/benefit picture from the consumer's standpoint. Examples include special financing products (possibly with some interest rate relief); waiver of increased state and local property tax assessments that result from energy upgrades; income tax credits or waiver of sales tax on energy efficient products (e.g., Energy Star appliances); and programs to "buy back" old appliances being upgraded (both as an economic incentive to replace and a method for ensuring they are actually retired from use).

Leveraging Major Remodeling Work. Many energy efficiency improvements that are just too costly to warrant implementation on their own become more economically attractive when performed in conjunction with other improvements in an existing home. This strategy can effectively cut the overhead associated with the work and reduce the incremental cost of an upgrade. When a furnace is being replaced, for instance, on-site technicians can potentially seal or insulate the duct system at lower cost than if this work was performed in isolation. The same might apply when ducts are being cleaned, an emerging service business for existing homes. When siding is replaced, foam sheathing can be added underneath. When an unfinished basement is converted to finished space, insulation can be installed behind furred-out walls. When central air conditioning is added, ducts can be sealed and window shading treatments added, both reducing the size and cost of the capital equipment and cutting energy use. The point of sale and the point of purchase also represent opportunities for improvements such as new appliances, coupled with the possibility of low-cost, long-term financing. This approach is very powerful because every existing home is destined to pass through points where major work is required (or refinancing is inevitable) at multiple times during its "life-cycle." It can be promoted to consumers as a smart way to upgrade, and to contractors as a smart way to sell supplemental work.

5.2 Energy Analysis Tools and Databases

Retrofit Opportunity Analysis at the House Level. The LBL "Home Energy Saver/Energy Advisor" web tool—http://hes.lbl.gov—is a modern example of a tool that researchers have imagined for many years. The software, developed with support from EPA Energy Star, allows users to put in basic information about the structural and energy-related characteristics of a home, and provides estimates of energy use along with recommendations for upgrades. Similar tools, sometimes more narrowly focused, have been produced in paper-based forms and as calculator and PC programs, as well as in other formats. Usability by homeowners is a big problem because they lack the knowledge or interest to model in detail, but the LBL program includes numerous defaults that simplify getting an answer. Customizing recommendations rather than dispensing generic advice is also a significant challenge.

Regional Model Retrofit Packages. A relatively small set of recommended upgrades tailored to regional energy usage patterns, construction styles, and general house vintage could be developed, published, and promoted. This would help simplify communications with consumers (as well as installing trades) by identifying improvements that would be appropriate in the most common cases (e.g., "pre-1970 houses on crawl spaces in the southeastern U.S. should typically do X, Y, and Z"). The improvements could be whole-house in nature, or broken out by functional area (e.g., HVAC and ducts/distribution; or air sealing, insulation, and windows). Energy Star is also reportedly developing functional packages addressing duct systems and whole-house air sealing. It is an open question whether the simplicity of this approach outweighs the loss of accuracy inherent in presenting "universal" solutions.

Characterization of the Housing Stock. Use the HUD/Census American Housing Survey, the DOE/EIA Residential Energy Consumption Survey, and potentially other data sets to develop a multidimensional profile of the existing house inventory, including numbers of units, age, geographic location, foundation type, fuel, equipment, and distribution system type, and other parameters of interest. The underlying problem is that details about the housing stock available from any one source rapidly become insufficient as questions for study become more complicated. The goal is to be able to make "first order" estimates on numbers of units based on an increasing number of characteristics that are not addressed in any one source. This is done by superimposing or merging nominally independent parameters at different levels of aggregation. Such an approach can be used to develop improved estimates of the energy-saving and economic potential and other implications of a whole array of different kinds of retrofit technologies across the diversity of the existing housing stock, while avoiding double-counting or internal inconsistencies. It is a basic tool that could be used in many ways; for example, in developing and assessing the regional model retrofit packages described earlier in this section.

6 FUTURE WORK

Much thought and effort have gone into creating this Roadmap, but much, much more remains to be done. Many parties are interested and involved from the private sector, and several government agencies also have a stake in moving forward. Yet the program missions and visions of the future are not necessarily identical, or even parallel. In this loosely-organized environment, plans can succeed only to the extent they have inherent merit and are able to serve multiple, possibly disparate interests.

What follows is a framework for organizing future work, growing out of five general activity areas. Each activity area calls for involvement by the public and private sectors. Brief descriptions and a suggested rationale for pursuing work in each area are provided.

6.1 Aggressively Promote New Technology Through Cooperative R&D

Objective: Harness the expertise and resources of building product manufacturers to help ensure that a steady stream of new energy-saving technologies for existing homes will come online into the future.

Description: Sponsor cooperative R&D projects with industry to develop new energy-saving technologies with an emphasis on ease of retrofit into existing homes. A competitive solicitation and selection process leading to multiple cost-shared grants proceeding in parallel would be expedient. The earlier, more general PATH solicitation for cooperative R&D provides a model and the technology ideas discussed in this Roadmap provide many suitable, innovative possibilities for cooperative R&D that could be pursued in this way. It would be best to view these ideas as illustrative rather than exhaustive; research into other innovative ideas responsive to the underlying program goals should not be ruled out at this stage. A competitive solicitation would help to steer R&D funding into areas that offer the best overall prospects as viewed by industry and government alike.

Time Frame: Individual cost-shared grant projects would run over a 12- to 24-month period. The overall process of solicitation-award-performance should be repeated throughout the life of this initiative.

Rationale: Government-funded energy efficiency technology research has historically been carried out at a variety of DOE national laboratories, where the focus has often been more on advancing the basic science and less on bringing new applications into a commercial environment. The basic research is important, and has led to some notable successes (such as low-e coatings for windows), but needs to be complemented with cooperative research with private sector organizations that will ultimately market the results in order to maximize impact.

6.2 Conduct Evaluations of Retrofit Products, Materials, and Systems

Objective: Reduce the uncertainties about performance and other issues relating to innovative or underutilized energy-saving technologies through in-place studies that include original installation, energy and environmental monitoring, data analysis, and reporting.

Description: Work with remodeling contractors to develop real-world information about the installed cost, performance and other intended (and unintended) effects of selected energy-saving technologies for existing homes. The technologies (which could be products, materials, or systems) should be chosen to be appropriate to the house design and region where they are to be studied. They need not be completely new or unknown, but they should at least be underutilized relative to their market potential. Document the results in terms of energy performance and other impacts, and disseminate them to interested audiences including manufacturers, contractors, consumers, and researchers. Incorporate the new information as appropriate through ongoing channels of communication to consumers and trade professionals.

Suggested topics for field evaluations that can serve as a starting point for planning are:

- Conversion of a ventilated crawl space that experiences moisture problems into conditioned space; and
- Effectiveness of power-line and wireless home control systems with utility interface in reducing household electricity consumption and cost.

Time Frame: Field evaluations can take anywhere from 12 to 36 months to plan and execute, but multiple items can be studied in one evaluation project. Field evaluations should be ongoing through the life of this initiative.

Rationale: New products that look good on paper or in the laboratory can fail for any number of reasons once they reach the field. Prospective users are well-advised to be skeptical about performance claims, and may also be dissuaded by fear of unknown consequences. This can dampen consumer demand and make contractors reluctant to recommend, sell, or install potentially beneficial products. Well-designed evaluations carried out by researchers independent of the manufacturer provide credible data to smooth over these concerns and reassure potential users.

6.3 Introduce Trade Contractor Energy Upgrade Training and Credentialing

Objective: Increase market "push" by equipping professional remodelers with the tools they need to sell and perform energy upgrades, either alone or in connection with other major remodeling work such as re-roofing, re-siding, window replacement, kitchen and bath makeovers, or building additions.

Description: Create and implement a curriculum for remodeling professionals that addresses building energy audit and energy upgrade technologies, investment analysis, financing options for energy efficiency, and marketing techniques designed to sell energy upgrades in conjunction with other remodeling work. The curriculum might stand alone, or could be incorporated as part of an established professional designation such as the "Certified Graduate Remodeler" program run by NAHB. Its value requires that steps be taken to ensure that those who successfully complete the required coursework are recognized by their peers and clients. The sequence of steps required for this is as follows:

- Compile existing training resources (there are many), develop climate-specific curricula, set credentialing requirements, and identify instructors.
- Publicize and solicit participants for the first round of training and certifications.
- Conduct first-round training in each climate region.
- Evaluate the program and make revisions; repeat based on level of interest.

The possibility that such a program could be offered in conjunction with the EPA Energy Star program for existing homes should be explored. However, in the interests of achieving broad market impact, it seems unnecessary to develop or enforce specific energy standards in conjunction with upgrades provided under this program.

Time Frame: The time period for program development through first-round training implementation would be approximately 24 months. Continuing administration and revisions would be ongoing after that point.

Rationale: Making wise energy upgrades requires research, analysis, and information. Some consumers are motivated to learn enough to make these choices by themselves, but many are indifferent or lack the skills to deal with the complexities. Remodeling contractors are in a position to reach out to these groups and simplify the consumer's decision-making process. They are also well equipped to sell the benefits of energy improvements, and motivated to find ways to perform them more efficiently as they are in the home to perform other work.

6.4 Consumer Outreach and Incentives

Objective: Take steps to raise awareness of home energy use and new (and old) conservation opportunities in the minds of consumers, and sustain this heightened awareness over time. Also, work to improve the underlying incentives and make the economics more favorable where feasible.

Description: Multiple activities fall under this broad heading, as discussed below.

- **Information, analysis tools, and guidance** should be made available on demand both to the do-it-yourselfer and to the homeowner who is researching or planning to contract for improvements. This is not a new or unrecognized need, but it is a continuing one. Extensive materials on energy efficiency in homes are available from multiple sources. For example, the DOE Energy Efficiency and Renewable Energy Network has about 50 fact sheets available on its website at www.eren.doe.gov/consumerinfo/factsheet.html. The California Energy Commission has consumer information at www.consumerenergycenter.org. EPA Energy Star offers access to a whole suite of tools for existing homes in the "home improvement toolbox" at www.epa.gov/hhiptool/remodel.html. Government housing publications for consumers, including many on energy efficiency, are available online through the federal Consumer Information Center at www.pueblo.gsa.gov/housing.htm.

- **Outreach to the media** can take several forms. One that has been used successfully is technology award programs, for example a *Popular Science* contest where the most interesting and promising new products and systems are publicized directly to consumers, along with information about the companies that produce them. A similar program that focuses on the latest retrofit products could have broad appeal. Other strategies commonly used in this area are background articles aimed at a general readership and distributed over the wire services, where they can appear in newspapers and magazines all over the country.

- **Financial incentives to motivate action** are the next logical way to reach out to consumers, after information and education have had a chance to work. There is controversy extending back to the 1970s over whether incentives going beyond the value of energy savings are necessary, how effective they really are, and what to do about "free riders" who cash in on incentives for doing what they would already do without them. It is silly to doubt that incentives will motivate consumers to act, but it is essential to consider whether the results are worth the cost. Incentives from the government could take the form of federal or state deductions, credits, or rebates on income, property, or sales taxes. However, all incentives need not originate with government. Incentives coordinated through lending institutions could involve easy access to and/or below-market-rate financing. Incentives from utilities could involve lump sum payments or a lower marginal cost of energy. Financial or utility incentives might require pressure from regulatory agencies. Before developing specific proposals, a study identifying options and reviewing experience is a must. The study should ideally be performed in conjunction with utilities and lenders.

Time Frame: Outreach must be ongoing over the life of the program, possibly with the level of activity varying inversely with energy prices. Pieces of this activity, such as the promotion of Energy Star appliances and building products in the media and through "big box" retailers, are already underway.

Rationale: Consumer energy awareness rises and falls with energy costs, national crises, the weather, and other factors. This awareness can lead to action (energy upgrades) either through do-it-yourself work, which occurs extensively in existing homes, or through professional jobs. Outreach, in the form of a stream of messages directed at homeowners over time, will help focus attention and raise interest in making improvements now rather than waiting. These messages become even more important when energy prices are stable. As noted above, large amounts of information are readily available, so it is important to avoid duplicative or redundant work creating new materials when existing ones are adequate. Policy options that make investments in energy efficiency more favorable to the consumer can also tip the decision about when and how to act, especially on big-ticket purchases.

6.5 Supporting Activities

Several types of activities that could be very helpful do not easily fall under the earlier headings. Four specific activities are identified in this section.

- **Better characterization of energy-related aspects of the housing stock**, as described in the Section above, would help focus resources and provide a more scientific basis for projecting impacts of specific measures.
- **More research aimed at measuring the capitalized value of energy efficiency in homes** could provide a reliable answer to this largely ignored but critical question. Homeowners are understandably reluctant to invest in measures with longer paybacks because they are unsure whether they can recoup their expenditures at resale. A recent (as yet unpublished) review of the studies dealing with this question shows they are flawed in many ways and are largely inconclusive.
- **Focus groups** with the three key groups (consumers, manufacturers, and contractors) would help confirm current thinking or identify better ways to approach each of these groups and achieve maximum effectiveness.
- **Reconvening the constituencies** involved in this roadmapping work to date on approximately an annual basis would provide an excellent way to review where roadmapping has led and solicit expert input on additional strategies, needs, and opportunities.

U.S. Department of Housing and Urban Development
HUD User
P.O. Box 23268
Washington, DC 20026-3268

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