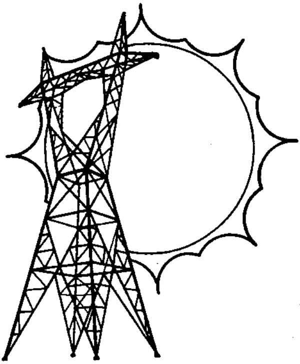
DSM Pocket Guidebook



Western Area Power Administration
Energy Services

Volume 1: Residential Technologies

DSM Pocket Guidebook

Volume 1: Residential Technologies

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FOREWORD

In previous years of low-cost energy, many demand-side management (DSM) technologies simply were not cost effective. Today, however, with rising energy prices and the mandate to conserve, utility DSM programs and advanced energy-efficient technologies offer utilities significant opportunity for economic means to reduce operating costs and shift or defer load growth. Furthermore, recent developments in DSM technologies have improved energy quality and reduced customer maintenance costs.

This series of guidebooks is intended as a tool for utility personnel involved in DSM programs and services. Both the novice and the DSM expert can benefit from the information compiled.

Efficient energy utilization through DSM applications helps Western meet one of its primary objectives—elimination of wasteful energy practices and adoption of conservation programs that meet customer needs in an era of diminished resources and increased environmental concerns.

PREFACE TO THE DSM POCKET GUIDEBOOK

INTRODUCTION

It has been estimated that if electricity were used more efficiently with commercially available end-use technologies, 24%–44% of the nation's current demand for electricity could be eliminated. Almost all major electric utilities in the west are investigating such demand-side management (DSM) opportunities. In some service territories, for example, improved efficiency could soon produce as much power as that from new coal-fired plants (Figure P-1) and produce it at a lower cost (Figure P-2). Even utilities that currently have excess capacity are finding that DSM offers an opportunity to build efficient end-use stock to help them meet their future load shape objectives.

Utility DSM programs typically consist of several measures designed to modify the utility's load shape (for example, innovative rate structures, direct utility control of loads, promotion of energy-efficient technologies, and customer education). The coordinated implementation of such measures requires planning, analysis of options, engineering, marketing, monitoring, and other coordination activities (Figure P-3). This guidebook addresses one facet of an overall DSM program: selection of end-use technologies within the electrical utilities.

TECHNOLOGY SELECTION

All facets of a utility's DSM program, including technology selection, must be planned with the utility's overall objectives in mind. Selected technologies must make the utility better able to serve its customers by providing low-cost reliable power. Yet the utility must also be able to recover its fixed and operating costs. In

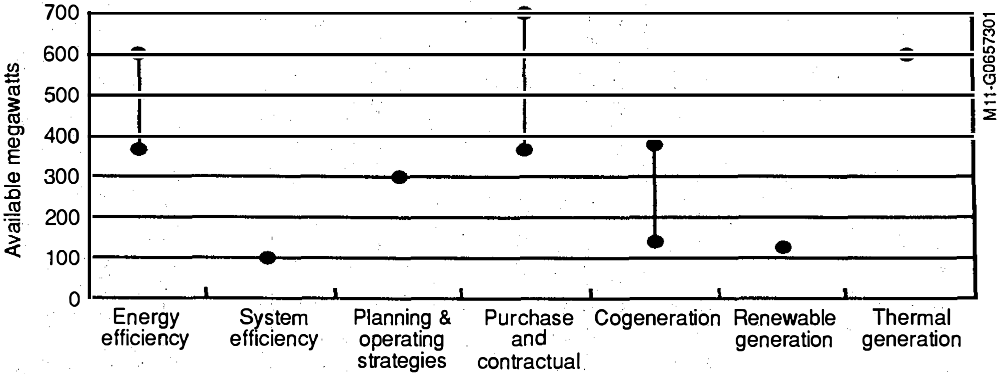


Figure P-1. Source: "Planning for Stable Growth, Pacific Power and Utah Power Resource and Market Planning Program, Volume 1—Summary Report" (Nov. 1989).

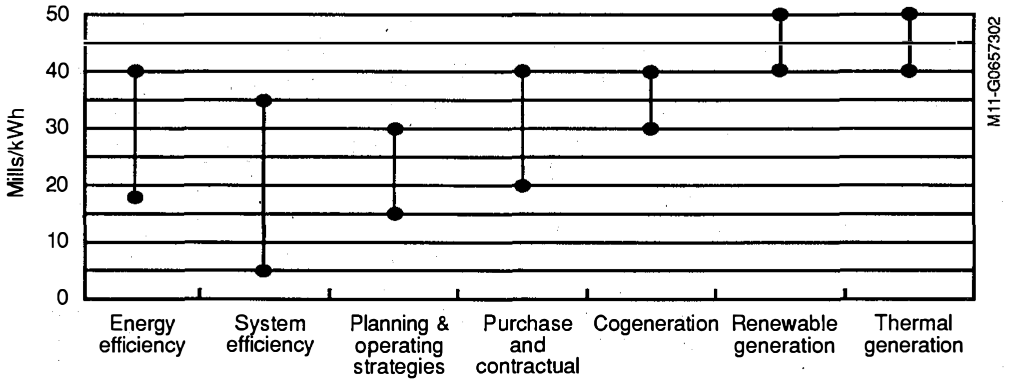


Figure P-2. Source: "Planning for Stable Growth, Pacific Power and Utah Power Resource and Market Planning Program, Volume 1—Summary Report" (Nov. 1989).

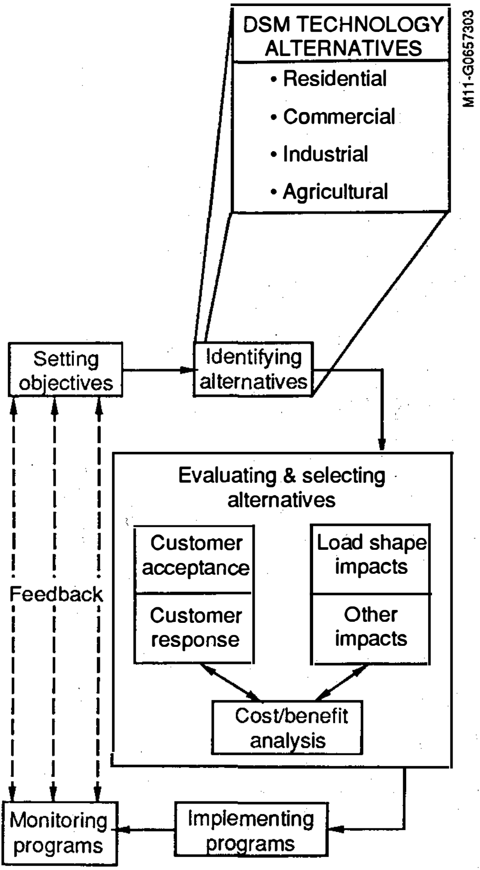


Figure P-3. DSM technology alternatives—position in the overall DSM program process. Source: Electric Power Research Institute, "DSM Technology Alternatives," EPRI EM-5457 (Oct. 1987).

practice, this usually means that the technology must provide the same or expanded cost-effective energy service to the customer while also smoothing out the utility's load curve and delaying the need for additional power plants. This guidebook directly addresses these requirements by estimating the simple payback (to the end user) for energy-efficient end-use technologies and their impacts on the utility's load curve.

A number of additional factors must be considered in technology selection. Primary among these are customer acceptance of different end-use technologies, the type of marketing effort required to promote each, and the potential impact on the utility's revenues. These are not addressed in this guidebook.

INTENDED AUDIENCE

This guidebook is intended to be a quick reference source both for utility field representatives in their customer interactions and for utility planners in the early stages of developing a DSM program. It is designed to allow a quick screening of commercially available electric end-use technologies with emphasis on the residential, commercial, and agricultural sectors. Only a limited number of technologies applicable to industrial processing (motors, adjustable-speed drives) are included because industrial customers usually are better informed about their energy options, they have more resources and incentive to investigate such options in detail, and the full range of industrial processes is beyond the scope of this guidebook.

Finally, this guidebook is directed primarily at small municipal utilities and rural electric cooperatives within the Western Area Power Administration (Western) service area (see Figure P-4). Large utilities with more abundant resources may find the guidebook useful as only a starting point. Their technology selection process will undoubtedly also include review of other source documents and detailed system and engineering analyses of the options.

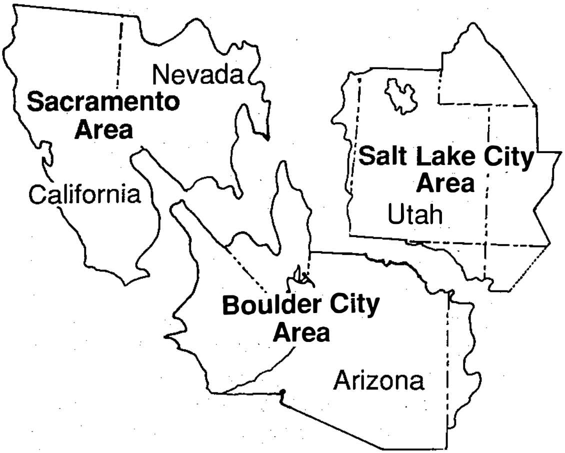


Figure P-4. Western Area Power Administration area map

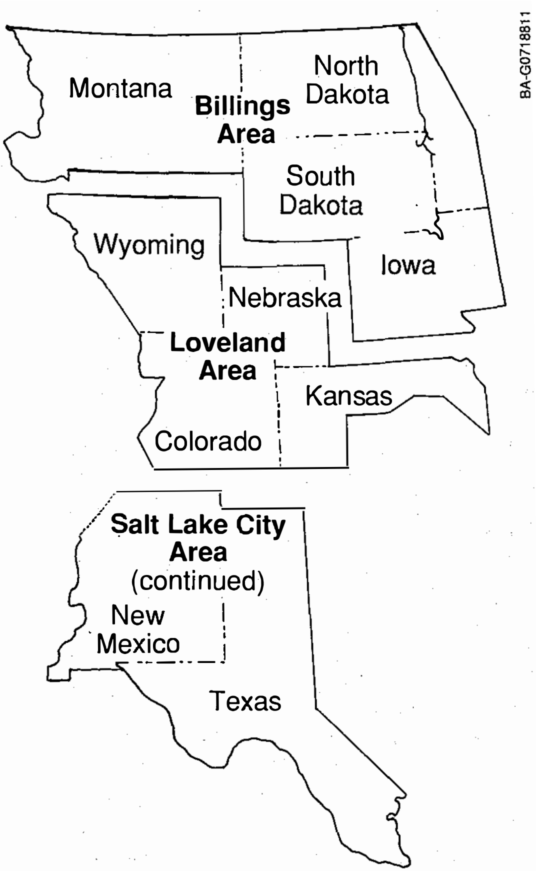


Figure P-4 (continued). Western Area Power Administration area map

METHODOLOGY/DATA

For each technology the guidebook presents a short numbered "technology brief"—text that describes the option, its relevant applications, and its potential impact on the utility's load duration curve. Each brief also includes a summary table (usually not specifically referred to by number) with quantitative estimates of initial costs, energy savings, and simple payback to the customer. All costs are expressed in 1990 dollars. For most technologies, capital cost and energy savings are estimated for one or more energy-efficient options and a reference case—usually an electric technology.

Where sufficient data exist, payback (to the end user) for the energy-efficient option is also compared to that for the reference case. Payback is determined by dividing the capital cost (incremental over the reference case) by the annual dollar savings (relative to the reference case). For simplicity, regional utility variations in electricity prices are ignored; the payback calculations use electricity prices of $0.08/kWh, $0.07/kWh, and $0.07/kWh in the residential, commercial, and agricultural sectors, respectively. To estimate payback using actual local electricity prices, multiply the payback by actual electricity price in dollars per kilowatt hour/assumed electricity price in dollars per kilowatt hour. For technologies such as replacement windows or insulation in which payback varies based on the climate, a payback range is given or the energy savings and payback are calculated for more than one climate.

Demand charges generally are not included in the payback calculations, because demand rates and possible reductions vary widely by region and utility, and for most of the options demand savings is small. For those technologies that have a large impact on demand (e.g., commercial building cool storage), a range of demand savings is presented and included in the payback calculations.

In almost all cases, the quantitative estimates of costs and energy savings have been taken from existing literature, including documentation of completed utility DSM programs, field studies and experiments, manufacturers' data, laboratory experiments, and computer simulation and analysis. The sources used varied depending primarily on the availability of data and the complexity of the technology. For example, manufacturers' data were used for several cost estimates, but only rarely for performance estimates, and then only in conjunction with data from field studies or simulations. On the other hand, for more complex technologies such as passive solar home design, the data were drawn from field studies and simulations to capture all the interactions that occur between building components and the local climate.

As might be expected, cost and performance values drawn from different sources are frequently inconsistent. (The reasons for such variations and the resulting uncertainties in the guidebook data are addressed later in this preface.) To reconcile such inconsistencies, the reports were first examined in detail and, in many cases, their authors contacted to identify the higher-quality studies and/or reasonable causes for the differences. For some technologies, we eliminated conflicting sources, either because the system or climate was not like the one being described in the guidebook, or because one analysis was clearly superior. If no clear distinction could be made between the analyses, the guidebook presents either a range of values or an average value.

Because of the condensed nature of this guidebook and our desire to keep it simple, we have provided only limited references for the source materials and computations. The guidebook is not intended to substitute for a detailed analysis, but rather to point the reader toward those technologies most likely to benefit both the end user and the utility. For more details, the reader should consult the references (in sections titled "For More Information") at the end of each brief.

DATA VARIABILITY AND UNCERTAINTY

A problem with guidebooks like this is that the data can at best present only a simple overview of each technology. Yet hundreds of volumes have been written describing the application of these technologies. Consequently, the cost and performance estimates presented here should be used with a clear understanding of the sources of variability and uncertainty.

Variations in performance occur with climate and with the technology's design and configuration, the system within which it is applied, and the way it is used. Cost varies with the quality or brand of an individual component, the size (e.g., cost per ton for large commercial air conditioning systems is less than for small unitary systems), the quantity ordered (e.g., cost per lamp for a major commercial retrofit will be less than the retail purchase price of a single lamp), and/or the time of purchase (inflation and technological improvements change costs over time). Generally, the only variation quantified in this guidebook is the range in performance with different climatic conditions.

Similarly, there are significant sources of uncertainty in the cost and performance data. The uncertainties, which largely result from drawing cost and performance statistics from a number of different sources, include

- Lack of complete documentation of the assumptions, data, and methods used in many of the studies
- Lack of statistically valid generalizations because of small sample sizes (i.e., results in the referenced studies are frequently based on only a few applications or systems)
- Reference study results based on simulations and limited testing, not field testing
- The use of multiple studies or sources for the cost and performance values of a single technology.

Where possible, we have avoided such problems by identifying excellent sources. However, as might be expected, we are more confident of some of the results than others. Thus for many technologies, we have included a rough measure (high, medium, low) of our confidence and the extent of the data variability and uncertainty. We expect that future revisions of this guidebook will provide the opportunity to reduce some of these uncertainties.

ORGANIZATION AND USE OF THE GUIDEBOOK

The guidebook consists of three pocket-sized volumes, each introduced by this preface. The first volume considers end-use technologies for the residential sector. The second volume includes technologies for the commercial sector as well as motors and variable-speed drives applicable to the commercial, industrial, and agricultural sectors. The third volume discusses energy-efficient technologies for the agricultural sector with an emphasis on the central and western United States (see area map in Figure P-4).

A number of technologies (e.g., energy-efficient windows) apply to more than one end-use sector. Where applicable, cross references are provided in the briefs. They are also summarized in Table P-1.

Each volume contains two sets of matrices to allow a quick screening of the technologies. One matrix addresses payback values, and the other identifies the most likely impact of each technology on the utility load duration curve (see Figure P-5). A utility planner who has identified the types of load changes desired and the appropriate end-use sectors can use the matrices to quickly identify candidate technologies. The text in the briefs provides background information.

Table P-1. Cross-Sector References

Technology	End-Use Sector / Volume Number Residential 1	Commercial 2	Agricultural 3
Insulation	1,3	■	
Windows	4,5,6	1	
Weatherstripping	7	■	
Duct leaks	15	■	
Passive solar	8	2	
Heat pumps	9	9	
Efficient air conditioners	13	8	
Energy management	■	10	■
Hot water efficiency	17	16	7
Solar hot water	19	■	■
Fluorescent lamps	21	11	
Cooking	25	18	
Swimming pools	26	■	
Motors		19–28	■

Each number refers to a written brief that describes the technology. A solid box (■) indicates that the technology is of interest in the sector, but is not written up. For example, see Vol. 1 (residential), technology brief #17, for a thorough discussion of hot water efficiency. See Vol. 2 (commercial), technology brief #16, or Vol. 3 (agricultural), technology brief #7, for additional information. If you are interested in motors in the agricultural sector (Vol. 3), the black box directs you to consult technology briefs #19–#28 in Vol. 2 (commercial).

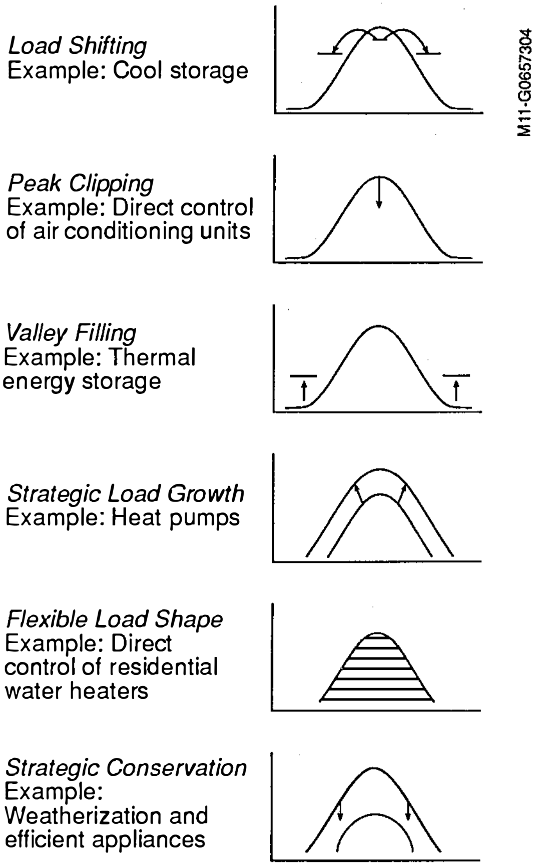


Figure P-5. Typical load shape changes resulting from selected demand-side alternatives. Adapted from Clark W. Gellings, highlights of a speech presented to the 1982 Executive Symposium of EEI Customer Service and Marketing Personnel.

INTRODUCTION

In 1988, 36% of all energy used in the United States was used in buildings—for heating, cooling, lighting, heating domestic water, running appliances, and other uses. Of this amount, approximately 60% was used in homes.

There are many ways to make a home more energy efficient. For example, it's possible to construct new homes or modify existing homes to use less energy for space heating, the largest single residential energy requirement. The thermal integrity factor for space heating (an index of the heat required for each square foot of a house per heating degree day [Btu/ft^2/HDD]) for the existing housing stock is approximately 8. For new houses built since 1980, it is 5, and for low-energy homes—homes specifically designed to be energy efficient—it is 2.5. Many houses have been built with even lower thermal integrity factors, even in very cold climates.

This volume provides a general description of the residential electric energy-efficiency options for building structure, heating and cooling systems, domestic water heating, lighting, appliances, and pool heating. These options can be used not only to save energy but also to modify a utility's load profile to meet its demand-side management objectives. Table R-1 identifies technologies that can be used to reduce or shift peak load, increase demand during off-peak periods (valley filling), provide strategic conservation or load growth, or allow for flexible load management. Table R-2 shows the simple payback for the energy-efficiency options evaluated. All paybacks are based on electricity costs of $0.08/kWh.

Table R-1.
Demand-Side Management Strategies: Residential Measures

	PC*	VF*	LS*	SC*	SG*	FLS*
BUILDING STRUCTURE						
1. Insulation				■		
• Walls						
• Ceiling						
2. Radiant barriers	■			■		
3. Foundation insulation				■		
• Basement exterior						
• Crawl space interior						
• Slab-on-grade exterior						
• Floors						
4. Windows				■		
• Triple pane						
• Low-E glazing						
• Gas-filled						
5. Storm windows				■		
• Interior						
• Exterior						
6. Window treatments	■			■		
• Moveable window insulation						
• Solar control						
7. Weatherstripping/caulking	■			■		
8. Passive solar design			■	■		
• Direct gain						
• Sunspace						
• Thermal storage						
HEATING AND AIR CONDITIONING						
9. Heat pumps	■			■	■	
• Air source						
• Ground source						
10. Whole-house and ceiling fans	■			■		
11. Heat storage		■	■			
12. Zoned heating	■				■	
13. Energy-efficient air conditioning	■			■		
14. AC cycling control	■					■
15. Duct thermal losses	■			■		
• Duct leaks						
• Duct insulation						
16. Distributed photovoltaic systems	■			■		

Table R-1.
Demand-Side Management Strategies: Residential Measures (Continued)

	PC*	VF*	LS*	SC*	SG*	FLS*
WATER HEATING						
17. Domestic water heating				■		
• Water heater blanket						
• Thermal traps						
• Pipe wrap						
• Low-flow shower head						
18. Heat pump	■			■	■	
• Water heaters						
• Heat-recovery water heaters						
19. Solar water heaters				■		
• Drainback system						
• ICS						
• Thermosyphon glycol loop						
20. DHW cycling control	■		■			■
LIGHTING						
21. Incandescent alternatives				■		
• Efficient incandescent						
• Compact fluorescent						
• Efficient interior incandescent floodlights						
• Efficient exterior floodlights						
• Tungsten/halogen lamps						
APPLIANCES						
22. Refrigerators/freezers				■		
• 1992 models						
• Improved models						
23. Low-water clothes/dishwashers				■		
• Front-load washer						
• Efficient dishwasher						
24. Clothes dryers				■		
• Moisture sensor						
25. Cooking equipment				■		
• Improved cooktops						
• Induction cooktops						
• Improved oven						

Table R-1.
Demand-Side Management Strategies: Residential Measures (Concluded)

	PC*	VF*	LS*	SC*	SG*	FLS*
SWIMMING POOLS/SPAS						
26. Pool/spa pump control	■		■	■		
27. Solar pool heaters/covers				■		
• Swimming pool heater						
• Pool cover						

*PC = peak clipping; VF = valley filling; LS = load shifting; SC = strategic conservation; SG = strategic growth; FLS = flexible load shape

Table R-2.
Payback for Demand-Side Management Strategies: Residential Measures[1]

	No. of Years			
	<2	2–5	6–10	>10
BUILDING STRUCTURE				
1. Insulation				
• Walls		■	■	
• Ceiling		■	—	■
2. Radiant barriers			■	■
3. Foundation insulation				
• Basement exterior		■	—	■
• Crawl space interior	■	—	■	
• Slab-on-grade exterior		■	—	■
• Floors		■	■	
4. Windows				
• Triple pane			■	
• Low-E glazing		■	■	
• Gas-filled			■	
5. Storm windows				
• Interior		■		
• Exterior		■	■	
6. Window treatments				
• Moveable window insulation			■	
• Solar control		■		

Table R-2.
Payback for Demand-Side Management Strategies: Residential Measures[1] (Continued)

	No. of Years			
	<2	2–5	6–10	>10
BUILDING STRUCTURE (cont'd)				
7. Weatherstripping/caulking	■			
8. Passive solar design				
• Direct gain		■		
• Sunspace			■	■
• Thermal storage			■	
HEATING AND AIR CONDITIONING				
1. Heat pumps				
• Air source		■		
• Ground source		■	■	
2. Whole-house and ceiling fans	■	—	■	
3. Heat storage		N/A		
4. Zoned heating	■			
5. Energy-efficient air conditioning		■	—	■
6. AC cycling control			N/A	
7. Duct thermal losses				
• Duct leaks	■			
• Duct insulation	■	■		
8. Distributed photovoltaic systems			N/A	
DOMESTIC HOT WATER				
1. Energy efficiency improvements				
• Water heater blanket	■			
• Thermal traps	■			
• Pipe wrap		■		
• Low-flow shower head	■			
2. Heat pump				
• Water heaters		■		
• Heat-recovery water heaters			■	
3. Solar water heaters				
• Drainback system			■	
• ICS			■	
• Thermosyphon glycol loop			■	
4. DHW cycling control			N/A	

Table R-2.
Payback for Demand-Side Management Strategies: Residential Measures[1] (Concluded)

	No. of Years			
	<2	2–5	6–10	>10
LIGHTING				
21. Incandescent alternatives				
• Efficient incandescent	■			
• Compact fluorescent		■		
• Efficient interior incandescent floodlights	■			
• Efficient exterior floodlights	■			
• Tungsten/halogen lamps	■			
APPLIANCES				
22. Refrigerators/freezers				
• 1992 standards	■			
• Improved models		■		
23. Low-water clothes/dishwashers				
• Front-load washer		■		
• Efficient dishwasher	■			
24. Clothes dryers				
• Moisture sensor			■	
25. Cooking equipment				
• Improved cooktops	■			
• Induction cooktops				■
• Improved oven	■			
SWIMMING POOLS				
26. Swimming pool pump control	■			
27. Solar pool heaters/covers				
• Solar pool heaters		■		
• Pool cover	■			

■ = The payback falls in the category indicated.

■—■ = The payback falls in the range of time indicated. For insulation, for example, the payback will depend on the amount of existing insulation. For ceiling fans, payback will depend on the number of hours they are used.

1 The paybacks shown were determined based on conditions described in the text. Paybacks will vary based on climate, fuel costs, system characteristics, and other factors. See the text of the technology brief for more information.

RESIDENTIAL BUILDING STRUCTURE

■ ■ ■

In the residential sector the largest end use of energy is for heating and cooling buildings. The amount of energy used in a given home is directly related to the climate and the thermal integrity of the building (how well it's insulated). In many existing homes and in new home construction, it is possible to reduce heating requirements up to 60% through proper insulation (Table R-3). For homes heated with electric heat, Figure R-1 and Table R-4 provide guidelines for the recommended insulation levels. In this section costs and savings are estimated for insulation, weatherstripping, window improvements, and passive solar design. All heating savings assume electric resistance heating at 100% efficiency.

Many thermal improvements in building structure will reduce the required size of the building's heating and cooling systems. This potential reduction in HVAC costs is generally not accounted for in the cost and payback calculations.

Table R-3. Effect of Insulation on House Heating Requirements

Insulation[1] Addition	Based on a 1500-ft[2] house in climate zone D — Btu/h (thousands) 10 20 30 40 50 60 70	Btu/h	kW	Electric Furnace Cost[2] $/Year
BASE HOUSE[3]		71,000	21	1772
R-30 in ceiling		65,300	19	1628
R-19 in walls		57,500	17	1431
Triple windows and insulated doors		46,900	14	1166
R-7.5 slab insulation		43,200	13	1079
Reduce infiltration to 1.0 ACH		27,400	8	681

[1] These are minimum standards for climate Zone D (see Figure R-1).

[2] Based on electricity price of $0.08/kWh. Heating energy savings was calculated based on maintaining an indoor temperature of 70°F and an outdoor design temperature of –3°F. The total savings amounts to a 62% reduction in installed capacity and an annual savings of $1091 in heating cost. Further savings in equipment cost and energy use can come from a reduction in air conditioning requirements.

[3] The base house has R-11 ceiling insulation, R-6 wall insulation, single-pane windows, conventional doors, and an infiltration level of 1.5 air changes per hour (ACH).

Source: National Rural Electric Cooperative Association (1987), *Consumer's Guide to Efficient Energy Use.*

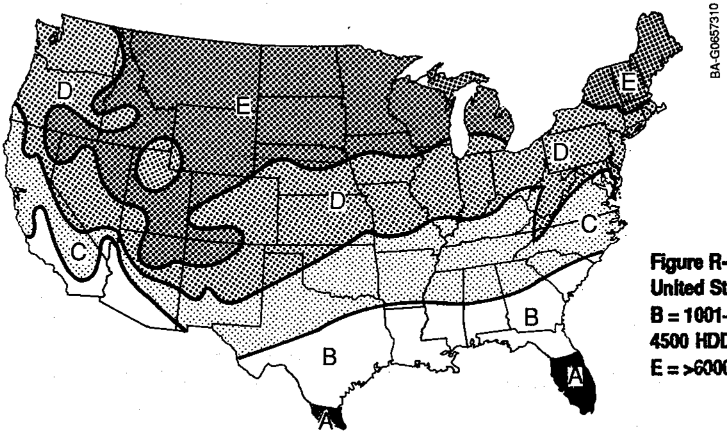


Figure R-1. Climate zones of the United States. A = less than 1000 HDD; B = 1001–2500 HDD; C = 2501–4500 HDD; D = 4501–6000 HDD; E = >6000 HDD.

Table R-4. Guidelines for Recommended Insulation Levels for Homes Heated with Electric Heat[1]

Feature	Zone A	Zone B	Zone C	Zone D	Zone E
Ceiling insulation	R-30	R-38	R-38	R-49	R-49
Wall insulation	R-11	R-13	R-19	R-19	R-19
Floors over unheated spaces	None	R-11	R-19	R-19	R-19
Foundation walls of heated spaces	None	None	R-6	R-11	R-11
Slab foundation perimeter	None	R-5	R-7.5	R-7.5	R-7.5
Number of glass layers for windows	1	2	2	3 or low-E[2]	3 or low-E[2]
Storm door or thermal door	No	No	No	Yes	Yes

[1] The insulation guidelines are DOE recommendations taken from Insulation Fact Sheet (DOE/CE-0180), Jan. 1988. The glazing and door recommendations are based on the Department of Housing and Urban Development (HUD) Minimum Property Standards.

[2] For more information on low-E glazings, see technical brief #4 on windows.

INSULATION

WALL, CEILING, AND FLOOR

DESCRIPTION During initial construction, insulation is placed inside wall, attic, and floor cavities. In older structures it may have been omitted and can be retrofit. Fiberglass batt or blanket insulation is available in various thicknesses and can be friction fit in open joists (for example in unfinished attics) or under floors (in basements). Loose-fill insulation is made from a variety of materials including fiberglass, rock wool, cellulose, or vermiculite. It can be poured in place or pneumatically blown or pumped into cavities.

Ceiling insulation retrofits are the most cost effective shell retrofit measure documented in the Building Energy-Use Compilation and Analysis (BECA) data base. The cost effectiveness of wall insulation retrofits is more uncertain because of the complexity of installation, higher costs, and variability in actual savings. However, if a ceiling has some insulation and the walls are not insulated, insulating the walls has been documented in BECA to be more cost effective than adding more insulation to the ceiling.

DEFINITIONS AND TERMS

BECA Building Energy-Use Compilation and Analysis data base. This is the largest energy savings and cost data base on energy retrofits for single-family homes. It is housed at the Lawrence Berkeley Laboratory.

CONDUCTION HEAT FLOW (Q) The amount of heat that is conducted through a building depends on three factors: area, temperature difference, and material properties. (Q = area x U-factor x temperature difference)

INSULATION A material that retards the flow of heat. Good insulators have low k- and U-values (thermal conductivity) and high R-values (thermal resistance)

k-VALUE The rate of heat flow in Btu/hr through one square foot of building material, one inch thick, in one hour with a temperature difference of one degree between the two surfaces. (Units = Btu-in/hr-ft^2-^oF)

R-VALUE The rate at which insulation or a building material on a building structure resists the passage of heat in any direction. It is equal to 1/U. (Units = hr-ft^2-^oF/Btu)

U-FACTOR The rate of heat flow through one square foot of a structural section (wall, glass, ceiling) in one hour with a temperature difference of one degree across the section. It is equal to 1/R. (Units = Btu/hr-ft^2-^oF)

Note: To convert to watt/ft^2, multiply the U-factor by the temperature difference and divide by 3.413.

■ *APPLICABILITY*

CLIMATE See Figure R-1 and Table R-4 for specific recommendations by location.

BUILDING TYPES All.

DEMAND MANAGEMENT OBJECTIVES Strategic conservation.

OTHER CONSIDERATIONS A vent should be added to an attic to provide adequate ventilation when the attic is insulated. ■ A vapor barrier is normally recommended for insulated walls and should be installed on the warm side of the insulation to limit moisture migration into the wall. This type of installation is difficult in cavity wall retrofits, although a vapor barrier paint may work. Caution should be used if the wall encloses a space that has occasional or constant high humidity. ■ When insulating a ceiling with recessed lights, to avoid a fire hazard, don't cover the vents in the lights with insulation.

Table R-5. Wall, Ceiling, and Floor Insulation: Costs and Benefits (based on 1000 s.f. of insulation)

Options	Retrofit Cost ($ per 1000 ft^2)[1]	Energy Savings (kWh/yr per 1000 ft^2)[2]	Cost Savings ($/yr per 1000 ft^2)	Simple Payback (yr) [Range][4]	Life[5] (yr)	Confidence[6]
WALL INSULATION						
Adding loose fill (R-9) to uninsulated cavity (aluminum or wood siding)	800	2831	226	3.5 [4.6–1.2]	50	M
Adding loose fill (R-9) to uninsulated cavity (brick siding)	950[3]	3320	265	3.6 [4.8–1.2]	50	M
CEILING INSULATION						
Adding R-30 batt to unfinished attic floor with no insulation	1140	4916	393	2.9 [3.8–1.0]	50	M
Adding R-19 batt to unfinished attic floor with R-11 insulation	722	1004	80	9.0 [12–2.9]	50	M

Table R-5. Wall and Ceiling Insulation: Costs and Benefits (Concluded)

1 The cost estimates are found in Table R-8. (Costs in this table represent the midpoint unless noted.)

2 The performance characteristics for ceiling and wall insulation are calculated from Tables R-6 and R-7 as follows: The overall U-value in the pre- and post-retrofit is taken from Tables R-6 and R-7 and multiplied by the 1000-ft^2 area (A). The equation to calculate energy savings in Btu is (Old UA – New UA) × DD × 24 × C_d/E, where DD = degree days; E = efficiency of heating system; and c_d = a HDD correction factor as follows:

C_d Factors for a House of Average Construction

HDD, 65°F base	1000	2000	3000	4000	5000	6000	7000	8000	9000
C_d factor	0.80	0.76	0.70	0.65	0.60	0.61	0.62	0.69	0.67

Source: *ASHRAE Handbook of Fundamentals* 1981. Atlanta, GA: American Society of Heating, Ventilating and Air-Conditioning Engineers.

The numbers in the table were calculated based on 6000 HDD. The efficiency of the electric heating system was assumed to be 1. The cooling savings can be calculated in the same way. The efficiency of the cooling system would equal the system's COP. (The C_d factor would not be used.)

3 The cost for this application was assumed to be the maximum specified in Table R-8 for wall insulation because it is more costly to blow insulation through a brick wall than through siding.

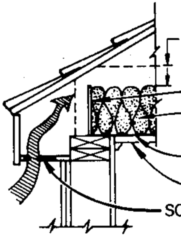
4 The numbers in the brackets represent a range for the simple payback (SP) of the measure in a 2000- to 8000-HDD climate. The colder the climate, the faster a heat-savings retrofit will pay for itself. Since absolute energy savings are proportional to heating degree days (HDDs) this can be calculated as SP2 = SP1 (HDD1/HDD2).

5 The life of insulation is assumed to be as long as the life of the building.

6 The actual energy savings from insulation depends greatly on occupants' habits. Calculation methods for estimating savings are well documented.

Table R-6. Overall U-Values for Ceiling Assembly[1]

Amount of Insulation (in.)	Unfinished Attic Floor 0[2]	2	3.5	6	9	12
Fiberglass batt	0.22[0]	0.092[7]	0.070[11]	0.046[19]	0.031[30]	0.024[38]
Cellulose	0.22[0]	0.092[7]	0.061[13]	0.041[22]	0.028[33]	0.022[44]
Loose fiberglass	0.22[0]	0.11[5]	0.079[9]	0.055[15]	0.039[22]	0.031[30]
Loose mineral wool	0.22[0]	0.11[5]	0.074[10]	0.052[16]	0.035[25]	0.028[33]



1 The R-value of only the insulation—not the overall assembly—appears in brackets. For additional (rigid-board) insulation or sheathing with a high R-value, the overall U-value of the assembly is calculated as shown below.

$$\text{Overall U-value} = \frac{1}{\frac{1}{U \text{ from table}} + R_{insulation}}$$

1 Read the U-value from this table for the construction as tabulated.
2 Take the reciprocal of this U-value for the overall R of the construction as tabulated.
3 Add the R of the extra insulation observed to the R from step 2.
4 Take the reciprocal of step 3 for the overall U-value of the assembly.

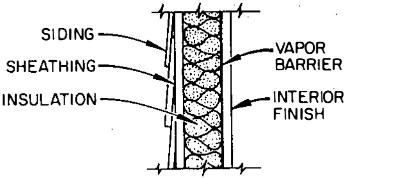
2 The U-value of the uninsulated ceiling cavity is based on a composite ceiling resistance assuming 2 in. by 6 in. attic floor joists spaced 24 in. on center. It is assumed that the joists account for 10% of the total attic floor area.

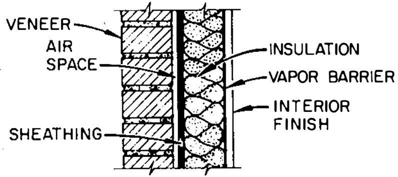
Source: The table format and the drawing were taken from Oak Ridge National Laboratory (1983), Residential Conservation Service Model Audit Manual (ORNL/CON-103). The base-case U-value was taken from U.S. Department of Energy (1989), Affordable Housing through Energy Conservation (DOE/SF/00098-H3).

Table R-7. Overall U-Values for Walls[1]

Amount of Insulation (in.)	Cavity Insulation 0	2	3.5	6	Brick Veneer 0	2	3.5	6
OVERALL WALL ASSEMBLY—EXTERIOR WALLS								
Fiberglass batt	0.19[0]	0.092[7]	0.071[11]	0.049[19]	0.213[0]	0.097[7]	0.074[11]	0.050[19]
Cellulose	0.19[0]	0.092[7]	0.063[13]	0.043[72]	0.213[0]	0.097[7]	0.074[13]	0.045[22]
Loose fiberglass	0.19[0]	0.11[5]	0.080[9]	0.058[15]	0.213[0]	0.115[5]	0.084[9]	0.060[15]
Loose mineral wool	0.19[0]	0.11[5]	0.075[10]	0.055[16]	0.213[0]	0.115[5]	0.078[10]	0.057[16]

$$\text{Overall U-value} = \frac{1}{\frac{1}{U \text{ from table}} + R_{insulation}}$$





[1] The R-value of only the insulation—not the overall assembly—appears in brackets. For additional (rigid-board) insulation or sheathing with a high R-value, use the procedure shown under "roof/ceiling assembly" (see footnote, Table R-6) to calculate the overall U of the wall assembly. The U-value of the uninsulated cavity is based on a composite frame wall resistance assuming 2 in. by 6 in. wall construction 24 in. on center. It is assumed that 20% of the wall area is studs. (This includes fire breaks and window framing.) Source: Oak Ridge National Laboratory (1983). Residential Conservation Service Model Audit Manual (ORNL/CON-103). The base-case U-value was taken from U.S. Department of Energy (1989) *Affordable Housing Through Energy Conservation* (DOE/SF/00098-H3).

Table R-8. Insulation Retrofit Costs

Type of Insulation	Cost
Attic insulation (batt or loose fill)	
• Attic floor	$0.026–0.050/s.f./R
• Sloped ceiling	$0.026–0.068/s.f./R
• Kneewall	$0.032–0.086/s.f./R
Wall insulation (3.5 in.) (loose fill)	$0.650–0.950/s.f.

Costs taken from ORNL/CON 303 (May 1990), *The National Fuel Efficiency Field Test: Energy Savings and Performance of an Improved Energy Conservation Measure Selection Technique*. (Costs represent the actual cost to install the measures in 100 homes in Fall, 1988 in Buffalo, NY. The costs vary depending on installation techniques and existing conditions.)

Based on data from the R. S. Means Co. The installed cost of fiberglass batt and cellulose loose-fill insulation per ft^2-R is essentially the same. The cost for insulation blown into walls varies based on the type of exterior siding. The cost is lowest for aluminum, wood, or stucco, highest for brick.

RADIANT BARRIERS

DESCRIPTION

A radiant barrier is a foil material coated on one or both sides with a low-emissivity material (typically aluminum). It is placed in an airspace between a heat-radiating surface (such as a hot roof) and a heat-absorbing surface (such as conventional attic insulation). The best place to attach it is the bottom chord of the roof truss or the bottom of the roof rafters. The radiant barrier reduces heat gain through the ceiling by about 40%. However, only about 20%–30% of the air conditioning load in summer is due to heat gain through the ceiling. Thus the 40% reduction merely lowers the total cooling load of the home by 8%–12%. In winter the heat transferred upward through attics won't be affected as much by a radiant barrier because a greater part of the upward heat transfer occurs by convection. This is why radiant barriers are more effective as a cooling rather than a heating conservation strategy. A radiant barrier can also be used in walls to reduce the heat gain caused by solar radiation striking the exterior of the walls.

DEFINITIONS AND TERMS

LOW EMISSIVITY A quality in a material that enables it to restrict the transfer of infrared radiation across an airspace. It does this by reflecting the radiation that strikes it. The lower the emissivity, the better the radiant barrier.

APPLICABILITY

CLIMATE Figure R-2 provides a climatic recommendation for the installation of radiant barriers. Attic radiant barriers may be effective in other climates as well, but claimed comfort improvements and lower energy consumption have not been firmly established by research.

BUILDING TYPE All

DEMAND MANAGEMENT STRATEGY Strategic conservation, peak clipping

FOR MORE INFORMATION

EPRI (no date). Technical brief: "Radiant Barriers" (RP2034-23).

Florida Solar Energy Center (FSEC) (1984). Design note: "Designing and Installing Radiant Barrier Systems" (FSEC-DN-7-84). Cape Canaveral, FL.

FSEC (1987). Energy note: "Radiant Barriers: A Question and Answer Primer" (FSEC-EN-15-87).

FSEC (1986). Design note: "Radiant Energy Transfer and Radiant Barrier Systems in Buildings" (FSEC-DN-6-86).

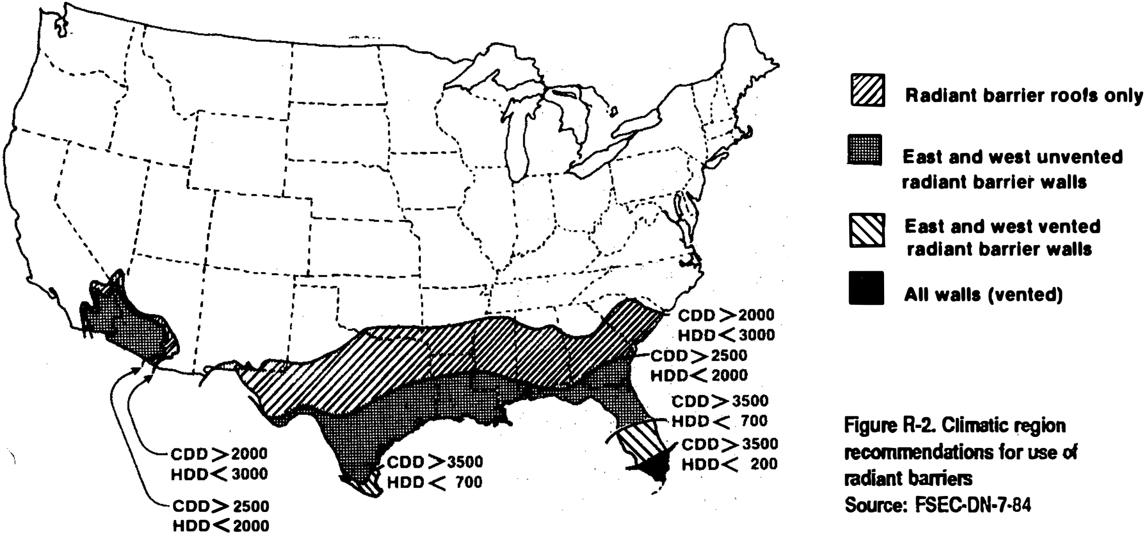


Figure R-2. Climatic region recommendations for use of radiant barriers
Source: FSEC-DN-7-84

Table R-9. Radiant Barriers: Costs and Benefits

Options	Costs ($)[1]	Energy Savings[2] (kWh/yr)	Cost Savings ($/yr)	Simple Payback[3] (yr)	Life (yr)	Confidence
Radiant barrier	837.00	698	55.80	15	Unknown	L[4]

1 A midpoint cost of $0.53/ft^2 was selected from the materials-only cost range of $0.07–$1.00/ft^2. Installation cost varies from $0.10 to $1.00 per square foot. Roof area = 1580 ft^2.

2 Dollar savings was based on cooling calculations for a 1500-ft^2 home in a 2500-CDD climate. The formula used to compute the electrical energy requirements is E = 24 h × (29800 Btu/h) (100° F–68° F) × 2500 CDD/(1000 × 8) based on 1987 NRECA *Consumer's Guide to Efficient Energy Use*
= 6984 kWh/yr
Typically the SEER information source (usually the manufacturer) will stipulate whether the auxiliary equipment power for the inside blower is included in the SEER. A radiant barrier can reduce this cooling load by 8%–12% (EPRI). A midpoint of 10% was used to yield a savings of 698 kWh/yr.

3 FSEC cites a typical simple payback of 6–7 years. In our example the cost of the material would need to be approximately $0.25 for such a payback. This is within the range of material costs.

4 The confidence is rated as low because claimed comfort improvements and energy savings have not been firmly established by research in climates other than Cape Canaveral, FL.

FOUNDATION INSULATION

DESCRIPTION

There are several ways to insulate the foundation of a building depending on whether the building has an unconditioned or conditioned basement or is built on a slab on grade. Insulation can be installed on the exterior, covering only half the wall; on the exterior, covering the entire wall; and on the interior, covering the entire wall. If the basement is unconditioned, in addition to the methods listed for the conditioned basement, insulation can be placed between the floor joists in the ceiling above the basement.

For crawl spaces, insulation is generally placed vertically either on the interior or exterior. For slab-on-grade construction, the three most common approaches to insulating foundations are to place insulation vertically on the entire wall on the exterior (2 or 4 feet deep), vertically on the entire wall on the interior (2 or 4 feet deep), and horizontally under the slab perimeter.

Foundation insulation is difficult to retrofit. Based on measured data from several studies to determine the energy savings from foundation retrofits, the payback periods are long. The Minneapolis Energy Office showed a payback of 17 years for interior and 19 years for exterior foundation insulation. The extra living space gained from insulating and finishing a basement is a significant non-energy benefit that may make interior foundation insulation an attractive retrofit.

APPLICABILITY

CLIMATE Some level of foundation insulation is recommended in new construction in almost all climates.

BUILDING TYPES New construction

DEMAND MANAGEMENT STRATEGY Strategic conservation

OTHER CONSIDERATIONS If the basement is unconditioned and insulation is placed between the floor joists in the ceiling above the basement, the basement will be thermally isolated from the above-grade space, resulting in lower basement temperatures in the winter. This usually requires insulation of exposed pipes and ducts in the basement. ■ Water pipes located in an unconditioned space should be insulated to prevent freezing when a floor above is insulated.

■ *FOR MORE INFORMATION*

Carmody, John, Jeff Christian, and Ken Labs (1990, draft). "Buildings Foundation Handbook." Minneapolis, MN, University of Minnesota, Underground Space Center.

Quaid, M. A., and M. O. Anderson. "Measured Energy Savings from Foundation Insulation in Minneapolis Single-Family Homes." Proceedings of the 1988 ACEEE Summer Study on Energy Efficiency in Buildings.

Table R-10. Costs and Benefits: Foundation Insulation

Options	Costs ($/lineal ft)	Energy Savings[1] (kWh/yr/lineal ft)	Energy Cost Savings ($/lineal ft/yr)	Simple Payback (yr) [Range][2]	Life (yr)	Confidence
UNCONDITIONED BASEMENT						
Partial exterior (4 ft deep) Insulation (R-10)	6.54	17.2	1.38	4.7 [14.1–3.5]	50	M
Interior insulation (8 ft) (R-11)	6.48[3]	28.8	2.30	2.8 [8.4–2.1]	50	M
CRAWL SPACE Partial exterior (2 ft deep) Insulation (R-10)	2.12	12.3	0.98	2.2 [6.6–1.7]	50	M
SLAB ON GRADE Partial exterior (4 ft deep) Insulation (R-10)	4.83	15.5	1.24	3.9 [11.7–2.9]	50	M
FLOOR INSULATION[4] (R-11)	0.34/ft^2	2.4 kWh/ft^2	0.19/ft^2	1.7 [5.1–1.3]	50	M

1 Performance and costs calculated based on the procedure cited in Carmody et al. (1990) with 6000-HDD climate. The costs include materials, labor, and profit, and are based on new construction. Retrofit costs can be substantially higher. ■ 2 Corresponds to a simple payback of the measure in a 2000-to-8000-HDD climate. See footnote 4 of Table R-5. ■ 3 Cost Includes interior wood framing, labor, and fiberglass batts. It excludes drywall at $6.08/lineal ft. ■ 4 Note that costs for this item are per square foot rather than per lineal foot.

WINDOWS

DESCRIPTION

In new construction or when windows need to be replaced, a variety of energy-efficient glazings are available with improved thermal performance compared to typical double glazing. Increased R-values are achieved with the use of low-emittance (low-E) coatings, additional interpane spaces (separated by glass panes or suspended plastic films, possibly with low-E coatings), and/or low-conductance fill gases. Several of these measures involve a reduction in solar transmittance and hence a trade-off between improved R-value and reduced solar heat gains. Conversely, solar heat gains can be increased by the use of low-iron glass and/or antireflective coatings. Glazing can be characterized in terms of the overall heat-transfer coefficient (U-value) and the shading coefficient (SC). U-values and SC for various types of glazing are found in Table R-12.

Different types of spacers between the panes of glass and frames significantly affect the overall window energy performance. Frame type and the ratio of perimeter to glazing area (window size, shape, and whether the window is divided) govern how much this matters overall. A window with a high performance glazing (center-of-glass U-value of 0.27) can have an overall window-unit U-value between 0.30 and 0.72 depending on the details. This is shown in Table R-13.

DEFINITIONS AND TERMS

EMISSIVITY A measure of how much heat a material gives off through radiation. If a material has a low emissivity, it absorbs very little heat and reflects most of the heat back to its source.

LOW-EMISSIVITY (LOW-E) WINDOW A low-E window has a higher insulating value than a standard insulated window. It contains a low-E coating suspended on a film between two panes of glass or on the inside surface of the outer pane of glass. The coating radiates heat back to its source: inside in the winter and outside in the summer.

SHADING COEFFICIENT The ratio of the solar heat gain through the glazing (including the fraction of solar radiation absorbed in the glazing that is subsequently transferred into the room) to the solar heat gain through single glazing. The shading coefficient can be thought of as an effective transmittance relative to single glazing.

U-FACTOR The rate of heat flow through one square foot of a structural section (wall, glass, ceiling) in one hour with a temperature differential of one degree across the section. It is equal to 1/R (Units Btu/hr-ft^2-^{o}F) Note: To convert to watts/ft^2, multiply the U-factor by the temperature difference and divide by 3.413.

APPLICABILITY

CLIMATE Windows with high R-values are more cost effective in colder climates. Windows with low SC can be used in hot climates to reduce cooling loads. In new construction the use of high-R windows may allow an owner to downsize the furnace and realize dollar savings on first cost of equipment.

BUILDING TYPE All

DEMAND MANAGEMENT STRATEGY Strategic conservation, peak clipping

OTHER Windows with high R-values improve comfort by reducing drafts.

FOR MORE INFORMATION

Sullivan, R., and S. Selkowitz (Nov. 1986). "Residential Heating and Cooling Energy Associated with Window Type." Berkeley, CA: Lawrence Berkeley Laboratory. LBL-21578.

Table R-11. Windows: Costs and Benefits

Options	Costs ($/ft²)[1]	Energy Savings[3] (kWh/ft²/yr) North	Energy Savings[3] (kWh/ft²/yr) South[4]	Cost Savings ($/ft²/yr)[3] North	Cost Savings ($/ft²/yr)[3] South[4]	Simple Payback (yr)[5] North	Simple Payback (yr)[5] South[4]	Life (yr)	Confidence[6]
COLD CLIMATE (7860 HDD, 425 CDD)									
Double pane low-E on glass	2.75	6.3	4.5	0.51	0.40	5.4	6.9	20	M
Triple pane	3.30	6.3	6.0	0.51	0.48	6.5	6.9	20	M
Double pane low-E coated film argon fill	6.00[2]	10.8	8.6	0.87	0.69	6.9	8.7	20	M
HOT CLIMATE (1765 HDD, 3334CDD)									
Double pane low-E on glass	2.75	6.5	4.3	0.45	0.34	6.1	8.1	20	M

1 Incremental cost per square foot of glass area over double-pane glass. (The cost is for material only.)

2 $4.50/square foot for the low-E on suspended film, $1.50 for the gas fill.

3 Energy savings are in terms of square feet of glass area based on hourly simulation for a ranch house with the glazing representing 12.9% of the total floor area. Cost savings includes reductions in air conditioning requirements (COP = 2.1) and heating (efficiency = 1.0).

4 "North" = window on the north side; "South" = window on the south side.

5 The hot and cold climates are the two extremes found in the Western region. Paybacks for other climates will fall somewhere between these two extremes.

6 Confidence is rated medium because occupants' habits, weather, and house characteristics will affect actual savings.

Table R-12. Glazing Characteristics

Glazing Type	Gas Fill	U-value ($Btu/h.ft^2\text{-}^\circ F$) Winter	U-value ($Btu/h.ft^2\text{-}^\circ F$) Summer	Shading Coefficient	Solar Transmittance
Single pane	Air	1.10	1.10	1.0	0.87
Double pane	Air	0.50	0.56	0.88	0.71
Triple pane	Air	0.33	0.39	0.79	0.61
Double pane/low-E on glass	Air	0.34	0.35	0.73	0.58
Double pane/low-E on glass	Argon	0.28	0.35	0.73	0.58
Double pane/low-E suspended on film	Air	0.23	0.24	0.71	0.52
Double pane/low-E suspended on film	Argon	0.19	0.23	0.72	0.52

Source: R. Sullivan and S. Selkowitz (Nov. 1986), "Residential Heating and Cooling Energy Associated with Window Type." Berkeley, CA: Lawrence Berkeley Laboratory. LBL-21578.

Table R-13. Complete Window U-Values for Typical Residential and Commercial Windows

Spacer Type	Center-of-Glass U-Value	Frame Type: Aluminum Residential	Aluminum Commercial	Aluminum with Thermal Break Residential	Aluminum with Thermal Break Commercial	Wood Residential	Wood Commercial
DOUBLE GLAZING							
Aluminum	0.50	0.88	0.73	0.65	0.59	0.50	0.50
Steel	0.50	0.86	0.72	0.65	0.59	0.49	0.49
Wood	0.50	—	—	—	—	0.48	0.49
Glass	0.50	0.85	0.71	0.63	0.57	0.47	0.48
DOUBLE GLAZING, LOW-E, ARGON FILLED							
Aluminum	0.27	0.72	0.54	0.50	0.41	0.35	0.32
Steel	0.27	0.71	0.53	0.49	0.40	0.34	0.31
Butyl	0.27	0.70	0.53	0.48	0.39	0.33	0.31
Glass	0.27	0.69	0.52	0.46	0.39	0.31	0.30

Table R-13. Complete Window U-Values for Typical Residential and Commercial Windows (Concluded)

Spacer Type	Center-of-Glass U-Value	Frame Type: Aluminum, Residential	Aluminum, Commercial	Aluminum with Thermal Break, Residential	Aluminum with Thermal Break, Commercial	Wood, Residential	Wood, Commercial
TRIPLE GLAZING, TWO LOW-E (E = 0.05) FILMS, KRYPTON FILLED							
Aluminum	0.10	0.61	0.40	0.38	0.27	0.24	0.19
Steel	0.10	0.59	0.39	0.37	0.26	0.23	0.18
Fiberglass	0.10	0.57	0.38	0.35	0.24	0.21	0.17
Insulated[1]	0.10	0.56	0.38	0.34	0.24	0.20	0.16

1 An insulated spacer is a hypothetical material with a conductivity of 0.017 Btu/ft/hr°F, or R-2.45 for a half-inch thickness.

ASHRAE has defined standard-size residential and commercial windows as a common basis for representing overall window U-values. A residential window is defined as a 36-by-48-in. double-hung. A commercial window is 48 by 72 in.

Source: *Progressive Architecture*, June 1990.

STORM WINDOWS

DESCRIPTION

Storm windows are installed over existing windows and doors to create an insulating air space that reduces heat loss through the glass. Interior storm windows with plastic or glass glazing add an R-value of 1.0 to that of the existing window. Exterior storm windows with permanent or removable glass glazing also have an approximate R-value of 1.0.

APPLICABILITY

CLIMATE Climates with over 3500 HDD

BUILDING TYPE All

DEMAND MANAGEMENT STRATEGY Strategic conservation

OTHER Storm windows also reduce drafts, soiling of window sills, and noise.

Table R-14. Storm Windows: Costs and Benefits

Options	Retrofit Costs ($\$/ft^2$) (Installed)	Energy Savings ($kWh/ft^2/yr$)[1]	Cost Savings ($\$/ft^2/yr$)	Simple Payback (yr) [range][2]	Life (yr)	Confidence[2]
Interior storm windows (vinyl and acrylic)	2.50	9.5	0.76	3.2 [5.2–2.3]	—	M
Glass storm windows	5.00	9.5	0.76	6.5 [10.6–4.6]	—	M

1 Savings is relative to single glazing in a heating climate.

2 The measure is applicable in climates with >3500 HDD. Payback in table is based on 5750 HDD. The numbers in brackets represent a range for the simple payback (SP) of the measure in a 3500-to-8000-HDD climate. See footnote 4 of Table R-5.

WINDOW TREATMENTS

DESCRIPTION

A window treatment is a product or device installed inside or outside to help reduce heat loss or gain through a window. Several types of interior or exterior window treatment are available.

MOVEABLE WINDOW INSULATION Moveable insulation can be thermal drapes or shutters made of heavy quilted materials, rigid foam panels, flexible joined wood tongue-in-groove slats, or flexible roll-up shades made of foam- and fabric-laminated slats. The most effective coverings include edge seals to minimize convective heat loss. Although moveable insulation can reduce heating energy use, the way the occupants use the moveable insulation systems affects performance. Monitoring of passive solar buildings has shown that buildings with disappointing performance had problems with operable system components or occupant behavior. Table R-16 concerns heating load reduction for moveable insulation in selected locations.

SOLAR CONTROL Reflective window films and solar screens reduce window heat gains in summer by blocking and reflecting solar heat. Exterior films attach directly to the window pane. Polyester sheets with a transparent aluminized coating on one side can also be installed on inside panes. Solar screens, which reflect solar radiation and look much like regular window screens, are available as weaves of vinyl-coated fiberglass yarn and aluminum and bronze alloys.

**Table R-15.
Heating Load Reduction
with Moveable Insulation[1]
(kWh/ft^2 glazing/yr)**

City	One-Pane	Two-Pane
Albuquerque, NM	7.8	2.9
Denver, CO	9.7	3.5
Minneapolis, MN	15.4	5.7
Phoenix, AZ	3.4	1.2
San Francisco, CA	3.2	1.2
Seattle, WA	6.8	2.5

1 The numbers in the table were simulated using DOE-2 (an hourly building energy simulation program) for a 1540-ft^2 house with 231 ft^2 (15% of floor area) of glazing area in each of the locations in the table. The total R-value of the insulation is 3 (ft^2/h/^{o}F/Btu). This includes an R-value of 2 for the insulating product plus R-1 for the air space between the insulation and the window. In order to achieve this added R-value, it is assumed that the window covering is tightly fit and sealed about the edges.

APPLICABILITY

CLIMATE Moveable insulation is most useful in climates with high heating loads. Solar control films are most useful in climates with high cooling loads. In new construction, the use of solar control films or shades may allow the owner or builder to install a smaller air conditioner and realize dollar savings on equipment cost.

BUILDING TYPES All

DEMAND MANAGEMENT STRATEGY Peak clipping, strategic conservation

Table R-16. Window Treatments: Costs and Benefits

Options	Retrofit Costs ($/ft^2)	Energy Savings (kWh/ft^2/yr)	Cost Savings ($/ft^2/yr)[2]	Simple Payback (yr)	Life (yr)	Confidence
Moveable insulation	6.50	9.7	0.78	8.3	15	M
Solar control[2]	1.85	4.75	0.38	4.8	3–15	L

1 Performance for the moveable insulation was taken from Table R-16 for a home in Denver, CO.

2 Annual energy savings is based on a 10% reduction in cooling loads due to solar films for a 1500-ft^2 house with medium thermal integrity in a climate with 2500 CDD.

WEATHERSTRIPPING AND CAULKING

DESCRIPTION

Weatherstripping and caulking prevent the uncontrolled leakage of air into or out of a building through cracks, ceilings, walls, floors, and so on. Air infiltration can account for 15%–40% of all heat transfer through a building shell. Caulking should be applied where different building surfaces (roof and walls, walls and foundation) are joined. It should also be installed where wires and ducts penetrate the building, in cracks and holes, around window glass, and wherever water collects. Silicon, acrylic latex, polyurethane, and rubber compounds can be used. Reinforced felt, rubber fiberglass, foam, and tape weatherstripping are used to form a seal between moveable parts of windows, doors, and skylights. Preformed door sweeps, door shoes, and threshold gaskets are applied at the base of exterior doors.

Blower doors have become a widely used diagnostic tool to locate and measure building leaks and, more recently, to indicate when to stop tightening a building. ASHRAE Standard 62-1989 recommends a minimum ventilation rate of 15 cubic feet per minute (cfm) per person. This can be converted to a recommendation for household air changes per hour, which is commonly measured at a pressure differential of 50 pascals. Using a blower door, a weatherization crew can determine when a house has reached the appropriate level of tightness.

DEFINITIONS AND TERMS

Air changes per hour (ACH) is a measurement of the number of times that the house volume of air is replaced in one hour. For example, if the house volume is 10,000 cubic feet and 5,000 cubic feet of air escapes—and is replaced by outside air—in one hour, the ACH is 0.5.

APPLICABILITY

CLIMATE All

BUILDING TYPE All

DEMAND MANAGEMENT OBJECTIVE Strategic conservation

FOR MORE INFORMATION

Butterfield, Karen (Jan./Feb. 1989). "How Effective Are Blower Doors?" *Home Energy.*

Schlegel, Jeff (March/April 1990). "Blower Door Guidelines for Cost-Effective Air Sealing." *Home Energy.*

Table R-17. Weatherstripping and Caulking: Costs and Benefits

Options	Retrofit Costs ($) (Installed)	Energy Savings (kWh/yr)[1]	Cost Savings ($/yr)	Simple Payback (yr)	Life (yr)	Confidence[2]
Weatherstripping/caulking	230	1852	148	1.6	2.5[3]	L

1 The costs were based on the average cost of Northeast Utilities weatherization program costs. The energy savings was based on computer simulation of heating season savings that could be identified using a blower door (6200 HDD climate). The average savings equals a 23% reduction in ACH measured at a pressure differential of 50 pascals.

2 Confidence is rated low because actual savings depends on the condition of the existing house, occupant behavior, and climate.

3 Depending on quality.

PASSIVE SOLAR DESIGN

DESCRIPTION

A passive solar building is designed to maximize useable solar heat gain in the winter and minimize heat gain in the summer to create a comfortable interior living environment. A passive solar design is site specific, varying with the local climate and building type. System components to increase heat gain may include south-facing windows and moveable insulation, walls or floors that use masonry or water to store heat, and a sunspace or greenhouse. System components to prevent heat gain include overhangs or shades, landscaping, and vents. Good passive design involves a balance of conservation and solar design features. Conservation makes the passive solar system's job easier; likewise, passive solar features reduce the need for auxiliary heat.

DEFINITIONS AND TERMS

ANNUAL SOLAR SAVINGS The annual solar savings of a solar building is the energy savings attributable to a solar feature relative to the energy requirements of a nonsolar building.

DIRECT GAIN In direct-gain buildings, sunlight directly enters the home through the windows and is absorbed and stored in massive floors or walls. These buildings are elongated in the east-west direction, and most of their windows are on the south side. The area devoted to south windows varies throughout the country. It could be as much as 20% of the floor area in sunny cold climates, where advanced glazings or moveable insulation are recommended to prevent heat loss at night. These buildings have high insulation levels and added thermal mass for heat storage.

PROJECTED AREA The net south-facing glazing area projected on a vertical plane.

SUN TEMPERING A sun-tempered building is elongated in the east-west direction with the majority of the windows on the south side. The area of the windows is generally limited to about 7% of the total floor area. A sun-tempered design has no added thermal mass beyond what is already in the framing, wall board, and so on. Insulation levels are generally high.

THERMAL STORAGE WALLS (MASONRY OR WATER) A thermal storage wall is a south-facing wall that is glazed on the outside. Solar heat strikes the glazing and is absorbed into the wall, which conducts the heat into the room over time. The walls are generally 8 inches thick or thicker. Generally, the thicker the wall, the less the indoor temperature fluctuates.

■ *APPLICABILITY*

BUILDING TYPE Primarily new residential construction. Because most passive solar design components are an integral part of the building, application is best suited to new construction. Retrofitting is generally limited to adding a greenhouse or a sunspace.

CLIMATE Passive solar design is applicable to all climate zones. The optimal passive solar system size varies by location and is shown in Figure R-3. Figures R-4, R-5, and R-6 show the annual savings from solar for different system types. The sizes are based on the assumption that the building is well insulated.

DEMAND MANAGEMENT STRATEGY Strategic conservation, load shifting

■ *FOR MORE INFORMATION*

Balcomb, J. D. (1986). "Conservation and Solar Guidelines," *Passive Solar Journal,* 3 (3), pages 221–248.

Solar Energy Research Institute (1984). "Passive Solar Performance," Summary of the 1982–1983 Class B Results. Golden, CO: SERI/SP-271-2362.

Table R-18. Passive Solar Design: Costs and Benefits

Options	Costs ($) (Installed)[1]	Energy Savings (kWh/yr)[2]	Cost Savings ($/yr)[3]	Simple Payback (yr)[3]	Life (yr)[4]	Confidence[5]
Direct gain	2340	6856	548	4.3	50	M
Semi-enclosed sunspace	7020	10020	801	8.8 [11.1, 12.8]	50	M
Thermal storage wall	5004	6856	548	9.1 [7.6, 9.4]	50	M

1 All costs are added costs for new construction. Retrofit costs will generally be higher. Added cost is based on a 2000-ft^2 house with 240 ft^2 of glazing (12% of floor area) in a cold sunny climate. For all cases, the passive system equals 360 ft^2 (based on Figure R-3). For direct gain, cost is based on adding 120 ft^2 of glazing at \$19.50/ft^2 (for good-quality operable windows with low-E coating) to the house. It assumes all existing glazing faces south and the house has adequate storage mass. The cost for the sunspace assumes a cost premium for a sunspace of 30% over standard construction at \$65.00/ft^2. The cost for the thermal storage wall is based on an added cost of 120 ft^2 of fixed glazing (\$12.00/ft^2) plus 360 ft^2 of masonry at \$9.90/ft^2.

2 The performance is based on a home in Denver, CO. The home is assumed to have the following level of energy conservation: R-21 walls, R-33 ceiling, R-15 foundation perimeter, double glazing with night insulation on the north, east, and west orientations, and 0.27 air changes per hour. The annual energy savings for each system (in Btu/yr/ft^2 of system area) is given in Figures R-4, R-5, and R-6. These figures were taken from the article listed below.

3 Paybacks in brackets are given for a northern and southern climate in the Western regions. The paybacks for direct gain in both climates is omitted because based on Figure R-4, the systems require a reduction in south-facing windows. The payback for the sunspace in Denver is better than that in either the northern or southern climate.

4 The passive design should last as long as the building. Glazing materials and moveable insulation may have shorter lives (see briefs on these topics for further details).

5 Confidence is rated medium. The savings varies by location and occupant habits. The cost of system varies as well.

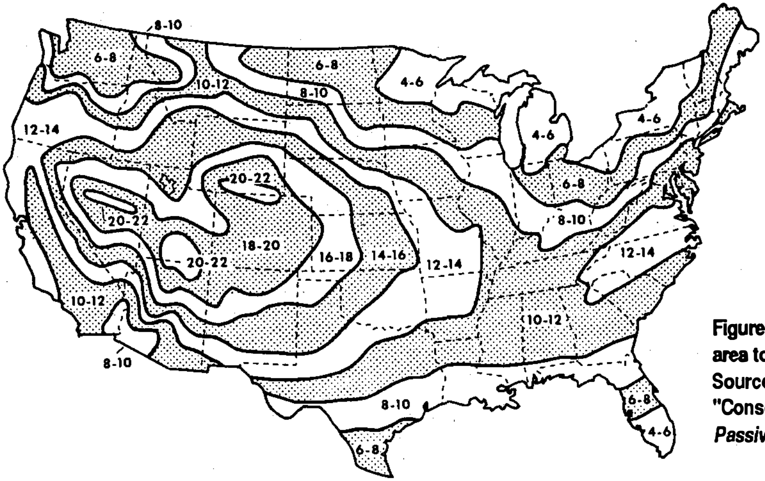


Figure R-3. Ratio of solar projected area to building floor area (%)
Source: Balcomb, J.D. (1986). "Conservation and Solar Guidelines" *Passive Solar Journal*, 3(3), pp. 221-228

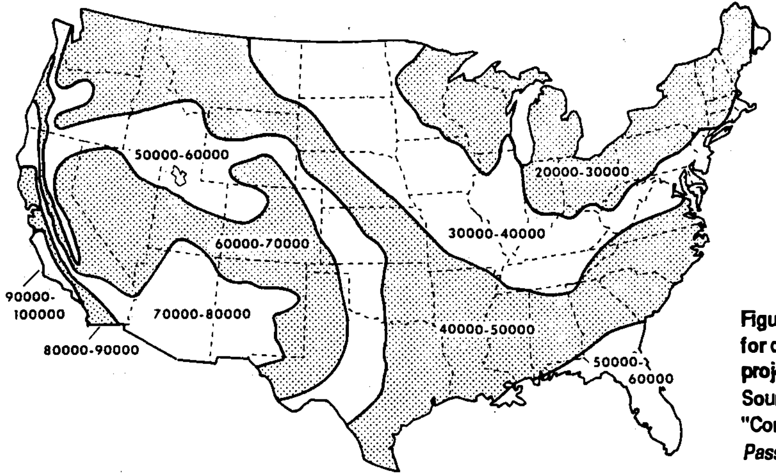


Figure R-4. Annual solar savings for direct-gain, Btu/ft^2 of projected area per year
Source: Balcomb, J.D. (1986). "Conservation and Solar Guidelines" *Passive Solar Journal*, 3(3), pp. 221-228

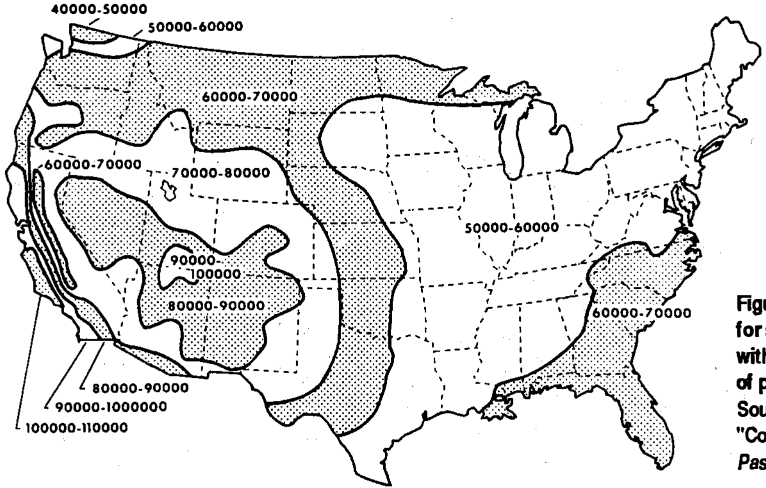


Figure R-5. Annual solar savings for semienclosed sunspace system with 50° sloped glazing, Btu/ft² of projected area per year
Source: Balcomb, J.D. (1986). "Conservation and Solar Guidelines" *Passive Solar Journal*, 3(3), pp. 221-228

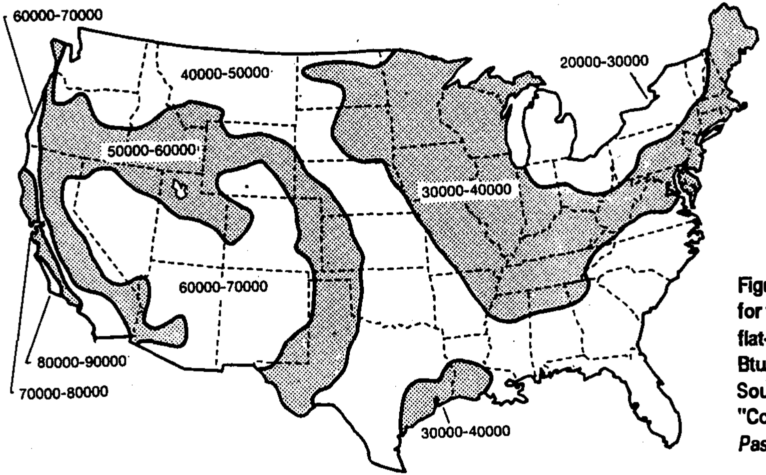


Figure R-6. Annual solar savings for the unvented, double-glazed, flat-| Trombe wall system, Btu/ of projected area per year
Source: Balcomb, J.D. (1986). "Conservation and Solar Guidelines" *Passive Solar Journal*, 3(3), pp. 221-228

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RESIDENTIAL HEATING AND AIR CONDITIONING

■ ■ ■

Heating uses the most energy in most homes in the United States, and air conditioning is becoming a standard feature in new home construction. Approximately half the homes in the United States are electrically heated. In this section, retrofit options that are more energy efficient than a standard electric furnace and air conditioning system are discussed. They include heat pumps, whole-house fans, heat storage, zoned heating, high-efficiency air conditioners, air conditioning cycling control, and repairing duct thermal losses.

HEAT PUMPS

DESCRIPTION

Like an air conditioner or refrigerator, a heat pump moves heat from one location to another. Both an air conditioning unit and a heat pump operating in the cooling mode reduce indoor temperatures in summer by transferring heat from the indoor air to the outdoors. Unlike an air conditioning unit, however, a heat pump's cycle is reversible. In winter, a heat pump can extract heat from the outdoors and transfer it inside. The energy value of the heat thus moved can be more than three times the cost of the electricity required to perform the transfer process.

Heat pumps are chosen from among four principal types, depending on the source of heat and the type of house space conditioning system used.

- During the cooling cycle the most common heat pump, the air-to-air heat pump, extracts heat from air in the house and discharges it into the outdoor air. During the heating cycle, the pump extracts heat from the outside air and discharges it in the house.
- The water-to air pump takes heat from or discharges it to a water source (well or lake) and delivers warm or cooled air to the house.
- The air-to-water and water-to-water pumps are the same, except the indoor coil heats water which is then distributed through a hydronic system.
- Add-on heat pumps are used in combination with warm air furnaces. Each heating system operates when it is most efficient. The heat pump operates when temperatures are moderate, and the furnace operates at colder temperatures when the heat pump efficiency is low. Add-on heat pumps are especially suitable for

colder climates with high heating demand. If the furnace air handler can accommodate an air conditioner coil, it is generally possible to add on a heat pump coil for electric heating and cooling. If the furnace is a hydronic boiler, an add-on heat pump would provide heat only. In warmer climates, add-on heat pumps might be considered by homeowners who are planning to install or replace a central air conditioning system.

TERMS AND DEFINITIONS

ENERGY-EFFICIENCY RATIO (EER) This is used to compare the performance of cooling equipment including air conditioners and heat pumps in the cooling season. EER is calculated by dividing cooling capacity (in Btu/hr) by the power input (in watts) under a given set of rating conditions.

COEFFICIENT OF PERFORMANCE (COP) This is used primarily to compare the performance of heat pumps in the heating cycle. For this use, it is determined by dividing the total heating capacity provided (Btu), including the circulating fans but not including supplemental heat, by the total electrical input in watt-hours times 3.413. The higher the COP, the more efficient the heat pump.

HEATING PERFORMANCE FACTOR (HPF) HPFs and COPs are similar and the terms often are used interchangeably. Performance factor is a measure of COP at various outdoor temperatures. Standard ratings call for two conditions, "high-temperature heating" and "low-temperature heating." In both cases, the air entering the indoor coil is at 70°F, with a maximum 55% relative humidity. The high-temperature conditions require that the air entering the outdoor coil be at 47°F. The low-temperature conditions require it to be at 17°F. The HPF allows comparison of the efficiency of fossil-fuel furnaces and heat pumps.

SEASONAL ENERGY-EFFICIENCY RATIO (SEER) The ratio of the total seasonal cooling requirement measured in Btu to the total seasonal watt-hours (Wh) of energy used, expressed in terms of Btu/Wh. (The SEER rating equals 3.413 times the seasonal COP.)

APPLICABILITY

CLIMATE Air-source heat pumps must be supplemented (generally with electric resistance heating) in climates where temperatures are below 30°F–40°F a significant amount of time. This may increase energy costs significantly. Groundwater heat pumps are suitable wherever minimum groundwater temperatures are greater than 40°F; most areas of the country can meet this requirement.

BUILDING TYPE Groundwater and ground-source heat pumps require access to water or sufficient ground area.

DEMAND MANAGEMENT OBJECTIVE Strategic conservation, strategic load growth, peak clipping

FOR MORE INFORMATION

Electric Power Research Institute (EPRI) and the National Rural Electric Cooperative Association (Aug. 1985), "Heat Pump Manual." EPRI/NRECA (EPRI EM-4110-SR).

Aadland, S., and G. Bunce (1986), "Heat Pump Fundamentals." Longwood, FL; AHP Systems.

Table R-19. Heat Pumps: Costs and Benefits

Options	Costs ($)[1]	Energy Use (kWh/yr)[2]	Energy Savings (kWh/yr)	Cost Savings ($/yr)	Simple Payback[3] (yr)	Life (yr)	Confidence
COLD (6000 HDD, 1000 CDD)							
Electric furnace air conditioning	3020	13,240	—	—	—	15	M
Air-source heat pump	4130	10,005	3190	255	4.3	15	M
Ground-source heat pump	5400	7,831	5409	432	5.5	15	M
WARM CLIMATE (2500 HDD, 2500 CDD)							
Electric furnace air conditioning	3020	15,432	—	—	—	15	M
Air-source heat pump	3920	11,548	3884	311	2.9	15	M
Ground-source heat pump	5620	10,377	5055	404	6.4	15	M

1 Costs include equipment for heating and air conditioning, installation, accessories, and ductwork in new construction.

2 Energy use in kWh was calculated as follows:

Heating furnace $E = 24 \times DHL/(t_1 - t_0) \times HDD \times C/3413$

Heat pump $E = 24 \times DHL/(t_1 - t_0) \times HDD \times C/3413/HPF$

The SEER of the air conditioner in the base case and the heat-pump cases remains the same.

Table R-19. Heat Pumps: Costs and Benefits (Concluded)

The assumed parameters for the different cases were	Climate		
	2500 HDD	6000 HDD	8000 HDD
HPF air source	2.05	1.5	1.3
HPF ground source	3.0	2.3	
Design heat loss (DHL)*	26,000	26,400*	26,400
C_d	0.73	0.61	0.61
Inside design temperature (°F) (t_1)	68°F	68°F	68°F
Winter design temperature (°F) (t_o)	22°F	–3°F	-3°F

*These were based on computer simulations for 1500-ft^2 residences in each climate. The R-values for ceilings, walls, and floors were assumed to be the minimum recommended levels for the climate zone (see Table R-4 in the introduction).

3 The cold and warm climates represent the extremes of all the climatic zones in the Western regions where both heating and cooling are used. In an 8000-HDD climate, using the assumptions for a 6000-HDD climate except a heating performance factor of 1.3, the simple payback would be 4.7 years.

WHOLE-HOUSE AND CEILING FANS

DESCRIPTION

Whole-house fans, once simply called attic fans, can reduce the use of air conditioning and cut energy costs throughout the United States. In summer a whole-house fan can cut an air conditioning bill by as much as 20%. At reasonable humidity levels, it can provide comfort at outdoor temperatures up to 85°F. It increases air flow and thus improves comfort by drawing in cooler outdoor air in the evening and forcing out hotter indoor air. Thus, less air conditioning is needed. In some parts of the country a whole-house fan would be a cost-effective retrofit option. In other locations it may not be cost effective as a retrofit to a home with central air conditioning; but for new construction, it could meet most of the cooling needs and make central air conditioning unnecessary.

Another option is a ceiling fan, which can produce enough air movement to make occupants comfortable when the ambient temperature is 82°F with 80% relative humidity. The average ceiling fan allows the homeowner to raise the air conditioning setpoint temperature by 4°F without any decrease in comfort. This could result in significant cost savings, because each degree that the thermostat is raised above 78°F saves on electric cooling costs.

Table R-20 provides some guidelines for sizing ceiling fans for rooms. Research shows that using a downrod to lower the fan 8 to 10 inches from the ceiling will give much better air movement and cool more efficiently.

Table R-20. Ceiling Fan Guidelines

Largest Room Dimension	Minimum Fan Diameter
12 feet or less	36 inches
12–16 feet	48 inches
16–17.5 feet	52 inches
17.5–18.5 feet	56 inches
18.5 feet or more	Two fans

Source: Vierra, R., and K. Sheinkopf (1988), "Energy-Efficient Florida Home Building." Cape Canaveral, FL, Florida Solar Energy Center.

APPLICABILITY

CLIMATE Whole-house and ceiling fans are excellent alternatives to air conditioning for windless locations, densely developed neighborhoods, or townhouses with high cooling requirements.

BUILDING TYPE Residential

DEMAND MANAGEMENT STRATEGY Strategic conservation, peak clipping

OTHER During winter or in summer when an air conditioner is being used, the whole-house fan louvers should be sealed with an insulated and weatherstripped or gasketed panel to prevent air infiltration.

Table R-21. Whole-House and Ceiling Fans: Costs and Benefits

Options	Costs ($) (Installed)[1]	Energy Savings/yr[2] (kWh/yr)	Cost Savings ($/yr)	Simple Payback	Life (yr)	Confidence
Whole-house fan (warm climate)	415	2666	213	1.9	10	M
Whole-house fan (moderate climate)	415	495	40	10.3	10	M

1 Installed costs range from $275–$550.

2 Energy saved is based on running a 550-W fan when the ambient temperature is between 80^{o}F and 85^{o}F. In the warm climate (Dallas, TX) this would be for 675 hours. A three-ton air conditioner (SEER = 8) used during those hours would require 3 (12000 Btu/hr)/(8 $\times$ 1000) = 4.5 kW or 3037 kWh for 675 hours versus a fan at 550 W $\times$ 675 = 371 kWh. In the moderate climate (Denver, CO) the fan offsets a 1.5-ton air conditioner for 284 hours.

HEAT STORAGE

DESCRIPTION

Electric thermal storage is used to shift electricity used for space heating off peak. Electric thermal storage heating units consist of electric resistance heating coils interwoven in a stack of ceramic bricks or crushed rocks inside an insulated cabinet. During off-peak hours—11 p.m. to 7 a.m.—the bricks (or rocks) are charged by the heating coil. During the day the heating coil is turned off and the bricks discharge their heat to the home. Both central and zoned thermal storage systems are available for residential applications, although zoned systems are more widely available. Characteristics of zoned and central systems are shown in Table R-23.

APPLICABILITY

BUILDING TYPE Central systems are applicable for residences having high heating loads, adequate space for location of the unit, and duct work for delivery of the heated air to individual rooms. Zoned thermal storage can be used in most residential applications where individual room heating is desired.

CLIMATE Cool climates

DEMAND MANAGEMENT STRATEGY Load shifting, valley filling

Table R-22. Heat Storage: Costs and Benefits

Options	Costs ($) (Installed)	Energy Savings (kW/house)[1]	Cost Savings ($/yr)[2]	Simple Payback (yr)	Life (yr)	Confidence[3]
Zoned storage system	6,000	6.0	N/A	N/A	—	H

1 Savings is reported in terms of ability to shift peak loads (in kilowatts) to off-peak periods only.
2 Because residential customers are rarely on a demand rate structure, payback is not applicable.
3 Utilities have extensively tested the ability of thermal energy storage systems to shift peak loads.

Table R-23. Characteristics, Zoned Versus Central Heating Storage

System Type	Capacity (kW)	Storage (kWh)	Weight (lb)	Size Requirements (in.)		
				Width	Depth	Height
Central	14–30	200	1700	34	32	64
Zoned	2–6	16–50	700	23–53	10	26

ZONED HEATING

DESCRIPTION

Zoned electric heating systems are comprised of electric heaters and separate manual or programmable thermostats in each room to provide the level of heat that is desired. They use less energy than central systems because (1) thermostats can be turned down or off in rooms not in use during the day; (2) they eliminate heat loss from duct work where it runs through unheated spaces such as basements, garages, and crawl spaces; and (3) when radiant heat is used, the radiant energy effect allows for lower room temperatures and thus lower heat loss to the outdoors. A zone heater can be added to a room to provide task heating in conjunction with a central system, or it can be used throughout a house instead of central heating. For new construction, a zoned system is more energy efficient than a central electric furnace and air conditioning.

APPLICABILITIY

BUILDING TYPE All

CLIMATE All

DEMAND MANAGEMENT STRATEGY Strategic load growth, peak clipping

FOR MORE INFORMATION

National Rural Electric Cooperative Association (1987), "Consumer's Guide to Efficient Energy Use." Washington, DC: NRECA.

Table R-24. Zoned Heating: Costs and Benefits

Options	Costs ($)	Energy Savings (kWh/yr)	Cost Savings ($/yr)	Simple Payback (yr)	Life (yr)	Confidence
Zoned electric	Less than central electric	25%	25%	Immediate	15	M

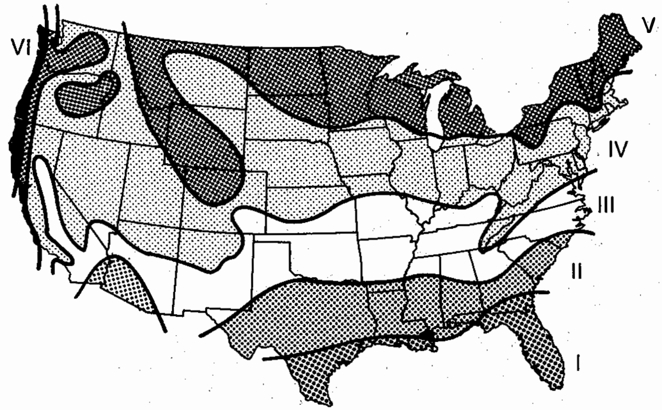
ENERGY-EFFICIENT AIR CONDITIONING

DESCRIPTION

There are two main types of air conditioners—room and central. Room air conditioners are placed in a window or wall to cool a single room. Central air conditioners require a duct system to carry the cool air to the entire house. An air conditioner provides space cooling and dehumidification using a vapor compression refrigeration cycle to remove indoor heat and reject it to the outdoors. Central air conditioning is now being installed in about 70% of new single-family homes in the United States. Typical sizes for central air conditioning vary from 1.5 to 4 tons. For room air conditioners, the sizes typically range from less than 0.5 ton for single rooms to 3 tons for a small apartment. Figure R-7 illustrates the cooling loads in the United States.

The average SEER of central air conditioning systems sold in 1988 was 8.0. The most efficient systems on the market today have SEER ratings in the 12.0–15.0 range. The improvements are due to larger heat exchangers and lower temperature gradients across them, more efficient motors, and improved compressors. A more innovative development has been the introduction of systems with two-speed compressors. Two-speed operation provides higher efficiencies through better matching of input and output loads.

The National Appliance Energy Conservation Act requires a minimum efficiency of 10.0 SEER for all split-system central air conditioners manufactured after January 1, 1992, and 9.7 SEER for all packaged units manufactured after January 1, 1993.



Regional Heating (Cooling) Load Hours

I	750	(2400)
II	1250	(1800)
III	1750	(1200)
IV	2250	(800)
V	2750	(400)
VI	2750	(200)

BA-G0657309

Figure R-7. Heating and cooling load hour regions. Source: Electric Power Research Institute (EPRI) and the National Rural Electric Cooperative Association "Heat Pump Manual" (Aug. 1983), EPRI/NRECA (EPRI EM-4110-SR).

DEFINITIONS AND TERMS

COOLING LOAD HOURS (or EQUIVALENT FULL LOAD COOLING HOURS) This is a theoretical number. It represents the number of cooling degree hours in a year divided by the design temperature difference ($t_i - t_o$).

EER See definition under residential heat pumps.

HIGH-EFFICIENCY AIR CONDITIONERS These are air conditioners whose EERs and SEERs exceed 10. They are available in both room unit and central unit configurations.

PACKAGED SYSTEMS The packaged or unitary system mounts into or on the outside wall with all components in one cabinet, similar to a window unit. Size is usually limited to between 1.5 and 2.5 tons, so application is primarily suited to apartments or small houses.

SEER See definition under residential heat pumps.

SPLIT SYSTEM This is the most common residential system. It has a separate outdoor unit in a cabinet located outside the house. Included in the outdoor section are the compressor, fan, and condenser. The indoor coil and expansion device are located above the furnace and use the furnace fan for air movement. The two parts are connected with insulated refrigerant lines.

APPLICABILITY

CLIMATE These units are available throughout the country, although some manufacturers are concentrating their effort in southern states.

BUILDING TYPE All residential

DEMAND MANAGEMENT STRATEGY Strategic conservation, peak clipping

Table R-25. Energy-Efficient Air Conditioning: Costs and Benefits

Options	Costs ($/ton)[1]	Energy Savings (kWh/ton/yr)[2]	Cost Savings ($/ton)	Simple Payback (yr) [range][3]	Life (yr)	Confidence
High-efficiency air conditioner[1] (SEER = 12)	300	600	48	6.2 [18.8–4.2]	15	M

1 This cost represents the added cost per ton of increasing the SEER from 8 to 12.

2 Performance is based on a 1-ton system and 1200-h cooling hours/yr. (Cooling load hours vary around the country, based on climate, from 2400 to 200 hours/yr. 1200 hours is typical of a city in a hot climate such as Phoenix, AZ. Figure R-7 shows cooling and heating load hours throughout the U.S.)
Standard AC (SEER = 8):
1 ton × (12,000 Btu/ton) / (8 Btu/Wh) × (1 kWh/1000 Wh) × 1200 h/yr = 1800 kWh
High-efficiency air conditioner (SEER = 12)
1 ton × (12,000 Btu/ton) / (12 Btu/Wh) × 1 kWh/1000 Wh × 1200 h/yr = 1200 kWh

3 A payback range is shown in brackets for a 1-ton high-efficiency air conditioner operating from 400–1800 hours per year. This usage is typical in the Western region.

AIR CONDITIONING CYCLING CONTROL

DESCRIPTION

Air conditioner cycling involves direct, real-time utility control over the operation of residential air conditioners. The peak demand for a typical residential air conditioner is approximately 1.5 kW/ton. The standard method of intentional cycling is to shut off the compressor for some fixed period, allow it to resume operation for some fixed period, and then shut it off again. A 25% cycling strategy—7.5 minutes off and 22.5 minutes on—is a typical cycle.

APPLICABILITY

Air conditioning cycling is generally implemented on central air conditioning systems or large through-the-wall air conditioners. Small window units are rarely cycled. Cycling significantly undersized units can result in excessive customer discomfort, and cycling oversized units can result in little or no load relief.

CLIMATE Warm climates

BUILDING TYPE All residential

DEMAND MANAGEMENT STRATEGY Peak clipping, flexible load shape

OTHER Cycling may shorten the life of the compressor and other system components.

Table R-26. Air Conditioning Cycling Control: Costs and Benefits

Options	Costs ($)	Power Savings (kW/Air Conditioner)[1]	Life (yr)	Confidence[2]
Air conditioning cycling control	75–200	1.10	Unknown	H

1 Performance is based on numerous utility tests in western states. The savings presented in the table shows how much of the peak load can be controlled directly by the utility. Cost savings and simple payback are not calculated because this measure only indirectly saves money for the resident, because residences generally are not on a demand rate structure.

2 Confidence is high because the savings is based on reports from numerous utilties.

DUCT THERMAL LOSSES

DESCRIPTION

More than 50% of the households in the United States have air distribution ducts for central warm air furnaces and/or air conditioning systems. This translates into more than a million miles of residential ducts. Leaks in duct work can cause the energy use for residential heating (and cooling) to increase dramatically. When ducts run through unconditioned space, leaky ducts cause infiltration heat losses (gains) by pressurizing or depressurizing the entire building. In the hot humid climate of Florida, duct leaks cause air infiltration rates to triple when the air conditioning is turned on. In addition, leaks from supply ducts to unconditioned zones waste conditioned air during system operation.

The impact of duct leaks is even greater on energy demand than on energy use in utility districts where the time of the peak power requirement coincides with the residential peak energy usage period for heating or cooling.

When the air conditioner or furnace is operating, leaks in supply ducts can be felt by hand. It is more difficult to detect leaks in return air ducts. Smoke sticks used with a blower door can produce a more accurate assessment of the size and location of a duct leak. Leaky ducts are traditionally repaired with duct tape or duct sealer or both. The major drawbacks to this method are uncertainty regarding the longevity of the material and difficulty gaining access to the ducts.

Duct insulation is another energy conservation measure to consider. It is recommended where the temperature difference between the delivered air and the duct surface is greater than 25°F. Recommended R value for duct insulation ranges from R-2 to R-7, depending on that temperature difference.

DEFINITIONS AND TERMS

BLOWER DOOR A large fan that is mounted in a doorway and used to pressurize and depressurize a space to determine air leaks. One way to determine leaks through ducts is to measure with a blower door the leakage with the registers and return first sealed, then open. The difference between the two readings is the amount of air leaking through ducts.

APPLICABILITY

CLIMATE All

BUILDING TYPE Residential and commercial

DEMAND MANAGEMENT STRATEGY Peak clipping, strategic conservation

FOR MORE INFORMATION

The Florida Solar Energy Center has several reports available on the topic of duct leaks.

Modera, M. P. (1989), "Residential Duct System Leakage: Magnitude, Impacts, and Potential for Reduction." *ASHRAE Transactions.*

Table R-27. Duct System Leaks and Insulation: Costs and Benefits

Options	Costs ($) (Installed)[1]	Energy Savings (kWh/yr)	Demand Savings (kW)	Cost Savings ($/yr)	Simple Payback (yr)	Life (yr)	Confidence
Repair duct leaks	110	2300–4000[2]	0.66–1.5	184–320[3]	0.6–0.3	Unknown	M
Duct insulation	0.85/LF[5]	2.0–7.25/LF[4]	—	0.16–0.58/LF[5]	5.3–1.5	25	M

1 The average repair cost based on a study of 80 homes by the Florida Solar Energy Center.

2 The energy savings is over the heating and cooling season. It is based on a computer simulation for a heat-pump system and assumes that the duct system is 50% supply ducts and 50% is return ducts, and that the return ducts are located in an unconditioned crawl space. The energy savings from the duct repairs is even greater when the return ducts are located in the attic. The savings range is for a mild climate (1300 cooling load hours, 2800 heating hours) to a hot humid climate (4900 cooling hours, 500 heating hours).

3 The cost savings is for the energy use only.

4 The energy savings in kWh/yr/LF is for heating only in a hot climate (<2000 HDD) and a cold climate (8000 HDD). The savings is based on adding R-2 insulation to a bare duct located in an unheated space.

5 LF = lineal foot

DISTRIBUTED PHOTOVOLTAIC SYSTEMS

DESCRIPTION

Photovoltaic (PV) systems convert sunlight directly into electricity through the use of specially designed semiconductors. PV power is still too expensive to compete with conventional coal or nuclear plants for centralized electricity generation, or to be used for homes that are already connected to the utility grid. But it is practical and economical for many specialized applications, particularly those with small power needs in remote locations away from power lines. In these locations, PV power, when compared to systems of batteries and diesel generators, can offer advantages in reliability, cost, and convenience. Other benefits include less noise and pollution than diesel engines and the possibility of PV additions.

Any cost advantage of a remote PV system over a utility-connected system is based on the cost of a utility line extension (about $10 per foot). If a line must be extended more than one-third of a mile with no possibility of additional future customers on the line extension, a utility-connected system will be more expensive than a small PV system for a single-family home. As the cost of PV continues to decline, this break-even distance should also decline.

DEFINITIONS AND TERMS

PV SYSTEM A PV system includes PV cells, batteries to store the electricity, electronic components to control the flow of electricity and, in some cases, components to convert direct current to alternating current.

PEAK WATTS The size of a PV module is generally expressed in terms of its ability to produce peak watts (Wp) at noon on a sunny day with the panel facing the sun.

■ *APPLICABILITY*

CLIMATE All

BUILDING TYPE Remote residential

DEMAND MANAGEMENT STRATEGY Peak clipping, strategic conservation

Table R-28. Distributed Photovoltaic Systems: Costs and Benefits

Options	Costs ($) (Installed)[1]	Energy Savings (kWh/yr)	Cost Savings ($/yr)[2]	Simple Payback[2] (yr)	Life (yr)	Confidence
Utility line extension (1/3 mile)	30,000					
1.2-kW PV system	30,000	4200	336	Immediate	25	M

1 The cost represents the current value of both options. (Key assumptions: inflation 5.5%/yr; loan interest rate 14%/yr; utility cost of capital 11.5%/yr; system life 25 years; O&M for line extension 0.98% of capital cost/month; utility rate $0.095/kWh; PV system cost $10–$15/watt; fixed O&M $25/kW; variable O&M $0.008/kWh; battery backup capacity 30 kWh).

2 The payback is Immediate because the capital costs of the two options are the same.

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RESIDENTIAL WATER HEATING

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Water heating is the second largest user of energy in the residential sector, accounting for almost 20% of total residential end-use energy consumption in the United States. Most people prefer 50-gallon water heaters with a 4.5-kW power input. Water heater retrofit programs are frequently used in the demand-side management strategies of electric utilities for several reasons:

- A significant portion of residential customers (32%) use electricity to heat water.
- Low-cost measures are available to reduce energy use for water heating
- Residential water heaters are amenable to load control because of their large storage capacity.

Domestic water heating retrofit strategies covered in this section include water heater blankets, thermal traps, pipe insulation, low-flow shower heads, heat-pump water heaters, solar water heaters, and direct utility control.

DOMESTIC WATER HEATING

DESCRIPTION

Older residential electric water heaters typically were manufactured with R-3 insulation in the tank walls. Newer water heaters are insulated to R-16. If your existing water heater is an older model, the insulation can be increased, and energy saved, by wrapping a water heater blanket around the tank. The blanket typically consists of fiberglass or foam insulating material with vinyl or paper backing. Table R-30 is a guide for estimating the thermal savings provided by adding an insulation blanket. The table provides an estimate of how much the blanket reduces heat loss through the side walls of the water heater or the jacket of the tank. The savings will vary based on how well the existing tank is insulated. According to studies by several utilities, actual savings achieved with water heater blankets may exceed the estimates of Table R-30.

Even when there is no demand for hot water, heat can be lost to the surrounding air, because water rises naturally through the hot and cold water feed lines that extend from the top of the storage tank. Small one-way valves, also known as thermal traps, eliminate such a convection loop. Only a small fraction of water heater tanks are sold with such valves, but they can be retrofit in place of standard connection nipples.

Reducing usage is another way to reduce energy requirements for water heating. Water-saving devices such as low-flow shower heads and faucet aerators lessen the amount of hot water used. Leaks and drips can also be repaired. Table R-31 provides a guide for estimating savings from fixing leaky faucets. Reducing water temperature is another alternative. Table R-32 provides a guide for estimating savings from temperature reductions. Washing machines and dishwashers typically account for half of the total hot water used in a household when they are both present. Please see the briefs on these appliances for more information.

APPLICABILITY

BUILDING TYPE Residential and commercial. (In residential buildings, homes with high pre-retrofit energy use have the greatest potential for energy savings. Typically these are larger homes, households with two or more showers, and households with older water heaters.)

CLIMATE REGIONS All

DEMAND MANAGEMENT OBJECTIVES Strategic conservation

Table R-29. Domestic Water Heating: Costs and Benefits

Options	Retrofit Cost ($)	Energy Savings (kWh/yr)	Cost Savings ($/yr)	Simple Payback (yr)	Life (yr)	Confidence[4]
Heater wrap (R-8)	21.00[1]	273[2]	19.11	1.1	10	L
Thermal traps	8.00	380[3]	30.00	0.3	15	L
Pipe wrap (R-3), 5 ft	5.00	20	1.60	3.1	10	L
Low-flow shower head	9.00	275	22.00	0.4	10	L

1 Costs are material costs only and assume installation by occupant.

2 Savings is based on adding 2 in. of fiberglass (R-8) to a 40-gallon tank (R-3) as per table R-30. This value is consistent with the results of four field studies which measured savings from water heater wraps between 180 and 775 kWh/water heater/yr.

3 Savings was based on five studies with savings ranging from 280-480 kWh/yr.

4 Blanket energy savings reported in the literature is variable. Not much information has been reported on thermal traps, pipe insulation, and low-flow shower heads.

Table R-30. Annual Kilowatt-Hour Savings from Adding Two Inches of Insulation to Hot Water Storage Tanks[1]

Water Temp. (°F)	Tank Size (Gallons) 20	30	40	50	66	80	100	120	250
110	96	147	182	210	242	278	294	336	501
120	120	184	226	262	302	348	368	420	627
130	144	221	273	315	363	417	441	504	752
140	167	259	316	367	423	487	515	588	877
150	192	294	364	420	484	556	588	672	1002
160	215	330	407	472	544	626	662	756	1128

[1] Assumes the air temperature surrounding the tank is 70°F, 2 inches (R-8) of fiberglass insulation are added to the existing tank with 2 inches of manufacturer-installed insulation, and water heater operates year round. kWh savings = tank area x temperature difference x (old transmission loss U-factor – new transmission loss U-factor) x hours per year / (3413 Btu/kWh x 100% efficiency).

Table R-31. Kilowatt Hours Wasted by Hot Water Leaks per Year

Tank Temperature (°F)	Leak Flow Rate: 30 Drop/ Minute	60 Drop/ Minute	90 Drop/ Minute	120 Drop/ Minute	3"-Long Stream	6"-Long Stream	9"-Long Stream
110	176	351	527	703	2003	4008	6019
120	211	421	632	843	2404	4810	7223
130	245	492	738	984	2804	5611	8426
140	281	562	843	1124	3025	6413	9630
150	316	632	948	1265	3606	7215	10834

Table R-32. Annual Kilowatt-Hour Savings by Reducing Hot Water Temperatures[1]

Temperature Reduction (°F)	Tank Size (Gallons) 10	20	30	40	50	66	80	100	120	250
5	21	29	38	46	54	62	71	75	86	110
10	41	58	75	93	108	123	142	150	173	220
15	62	88	113	139	162	185	213	225	259	330
20	82	117	151	186	217	246	284	300	345	440
25	103	146	188	232	271	308	355	376	432	550
30	123	175	226	279	325	369	426	451	518	660
35	144	204	264	325	379	431	497	526	604	770
40	164	234	301	374	433	492	568	601	690	880
45	185	263	339	418	487	553	639	676	777	990
50	206	292	337	465	542	615	711	751	863	1100

[1] Assumes air temperature surrounding tank is 70°F, tank has 2 inches of fiberglass insulation, and water heater operates year round. kWh savings = tank area × 0.15 U-factor × (temperature setting reduction °F) × hours per year / (3413 Btu/kW × 100% efficiency).

HEAT-PUMP AND HEAT-RECOVERY WATER HEATERS

DESCRIPTION

There are two types of heat-pump water heaters—integral and remote. Both have a compressor, a heat exchanger, and a water tank. Remote units are especially suitable for retrofit installations. The integral unit is intended to replace an existing water heater. Heat-pump water heaters operate at a coefficient of performance (COP) of two or greater (i.e., they are at least twice as efficient as conventional electric water heaters).

Heat-recovery water heaters recover superheat from the compressor discharge gas of a heat pump (or central air conditioner) and use it to heat or preheat water. A heat-recovery water heater produces about 15 gallons of heated water per hour per ton of air conditioning. During the hottest summer months, almost all of a home's water heating requirements may be provided by a heat-recovery water heater. In cooler months, when no air conditioning is needed, less discharge heat is available to heat household water.

DEFINITIONS AND TERMS

INTEGRAL UNIT A heat-pump water heater whose heat pump is located on top of the water tank.

REMOTE UNIT The remote heat-pump water heater is an assembly consisting of an air-source evaporator, water-cooled condenser, compressor, fan, and pump.

The unit is connected to the existing water tank by flexible hoses or pipes.

APPLICABILITY

BUILDING TYPE Heat-pump water heaters cool the surrounding air. In residences, they should be located in utility rooms or other conditioned rooms in southern climates and in furnace rooms in northern climates. They should not be installed where temperatures could fall below 40°F. They are also generally applicable in commercial buildings such as restaurants, cafeterias, laundromats, office buildings, and schools where there is a year-round water and air conditioning requirement.

CLIMATE All. A heat-recovery water heater is most attractive for use in warmer climates where air cooling is required throughout much of the year.

DEMAND MANAGEMENT STRATEGY Strategic conservation, strategic growth, peak clipping

FOR MORE INFORMATION

Electric Power Research Institute and the National Rural Electric Cooperative Association (1989), "Heat Pump Manual." EPRI EM-4110-SR, Palo Alto, CA: EPRI.

Table R-33. Heat-Pump Water Heaters and Heat-Recovery Water Heaters: Costs and Benefits

Options	Costs ($)	Energy Use (kWh/yr)	Energy Savings (kWh/yr)	Cost Savings ($/yr)	Simple Payback (yr)[2]	Life (yr)	Confidence[3]
Electric water heater	315	4400	—	—	—	13	—
Heat-pump water heater (best 1985 model)	1350	1620	2780	222	4.7	13	M
Heat-recovery water heater	700[1]	3300	1100	88	7.9	13	M

1 The price for the heat-recovery water heater is in addition to the electric water heater. It is assumed that the heat-recovery water heater provides all the water heating for three summer months. If air conditioning is used throughout the year, savings is significantly higher.

2 The simple payback for the heat-pump water heater (best 1985 model) is calculated based on the difference in cost of the heat-pump water heater and an electric water heater. The payback for the heat-recovery water heater is based on the full cost of the unit.

3 The confidence is medium. Heat-pump water heaters were first introduced in the early 1980s.

SOLAR WATER HEATERS

DESCRIPTION

Solar water heating systems can be designed to operate in nearly any climate. The performance of a system varies based on the amount of solar insolation incident on the collectors and on the outdoor temperature. In most parts of the country, a solar system is designed to meet 100% of a home's water heating requirements in summer months. In winter months, the system may only meet half the home's water heating requirements. Therefore a backup water heater or heating element is necessary to supplement the solar system in winter months.

Active solar water heating systems use pumps to circulate water or other heat-transfer fluid from the collectors, where it is heated by the sun, to the storage tank, where the water is kept until it is needed. Low-flow systems have configurations similar to conventional active systems, but their low flow rate enhances thermal stratification in the storage tank and improves the system's thermal performance.

For freeze protection, active systems can be separated into two general groups: those that use a fluid with a low freezing point (generally an antifreeze solution of ethylene or propylene glycol) in the collector loop and those that use water in the collector loop (which must be protected from freezing). The reliability of active solar systems was problematic in the early 1970s, but today it is greatly improved.

Passive water heaters use the natural convection of the solar-heated water to create circulation. Passive systems are typically integral collector/storage (ICS) or thermosyphon systems. The major advantage of these systems is that they don't use controls, pumps, sensors, or other mechanical parts, so little or no maintenance is required over the lifetime of the system.

DEFINITIONS AND TERMS

DRAINBACK SYSTEMS In these systems, water in the collector loop drains into a tank or reservoir whenever the pump stops because of freezing conditions.

DRAINDOWN SYSTEMS In these systems, water from the collector loop and piping drain into a drain whenever freezing conditions occur.

INTEGRAL COLLECTOR/STORAGE (ICS) SYSTEMS ICS systems are also called "batch" or "breadbox" water heaters. They combine the collector and storage tank in one unit. The sun shining into the collector strikes the storage tank directly, heating the water. The large thermal mass of the water plus methods to reduce heat loss through the tank prevent the stored water from freezing.

RECIRCULATION SYSTEMS These systems circulate warm water from storage through the collectors and exposed piping whenever freezing conditions occur.

THERMOSYPHON SYSTEMS Thermosyphon systems use a separate storage tank located above the collector. Liquid warmed in the collector rises naturally above the collector where it is kept until it is needed. The liquid can be either water or a glycol solution. If the fluid is water, freeze protection is provided by electric heat during freezing conditions. If the fluid is glycol, the heat from the glycol is transferred to water in the storage tank.

APPLICABILITY

CLIMATE All. ICS, recirulation, and thermosyphon systems are not recommended for cold climates.

BUILDING TYPE All

DEMAND MANAGEMENT STRATEGY Strategic conservation

Table R-34. Solar Water Heaters: Costs and Benefits

Options	Costs[1] ($/ft^2)	Energy Savings[1] (kWh/ft^2/yr)	Cost Savings ($/ft^2/yr)	Simple Payback (yr)	Life (yr)	Confidence
Drainback solar system	65	88	7.04	9.2	20	M
Low-flow system	42	81	6.50	6.5	20	M
Integral collector/storage (ICS) system	55	93	7.40	7.4	20	M

1 The costs and savings for the three systems were based on the following assumptions:

	Collector area	Storage volume
Drainback	39.8 ft^2	62.2 gal
Low flow	56.0 ft^2	71.9 gal
ICS	26.9 ft^2	42.3 gal

The savings for the drainback and ICS were based on TRNSYS simulations for Denver, CO. The savings for the low-flow system was based on a WATSUN simulation for Denver, CO. Note: Larger systems (i.e., low flow) have lower energy savings per square foot of collector area but deliver greater overall energy savings.

DOMESTIC WATER HEATER CYCLING CONTROL

DESCRIPTION

Domestic water heating cycling involves direct, real-time utility control over the operation of residential water heaters. Water heating is one of the few residential loads that is truly deferrable, because a water heater can be turned off for extended periods of time (up to six hours in some cases) without affecting the customer's lifestyle. By directly cycling water heaters (though a communication system, rather than using timers or other local controllers), the utility can vary when and how much control is exercised. Water heating cycling is generally exercised only during periods of peak demand or high marginal supply costs. More than 100 utilities are currently practicing water heating cycling.

Because most electric water heaters can heat their full capacity in less than three hours, cycling the heater off during peak utility demand has little impact on the consumer.

APPLICABILITY

CLIMATE All

BUILDING TYPE All

DEMAND MANAGEMENT STRATEGY Peak clipping, load shifting, flexible load shape

Table R-35. Domestic Water Heater Cycling Control: Costs and Benefits

Options	Costs ($) (installed)	Power Savings (kW/water heater)[1]	Life (yr)	Confidence[2]
Communications-based water heater cycling system	75–200	West central states Winter 0.93 Summer 0.70	Unknown	H
		Western states Winter 0.90 Summer 0.52	Unknown	

1 Performance is based on numerous utility tests. The savings presented in the table indicates how much peak load is reduced by direct utility control. Cost savings and simple payback are not calculated because this measure only indirectly saves money for the resident, because residences generally are not on a demand rate structure.

2 Confidence is rated high because the savings is based on reports from 59 utilities.

RESIDENTIAL LIGHTING

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Lighting accounts for about 15% of the typical residential customer's electrical consumption. It is a small load per household, but collectively it can be large. New lighting products offer significant energy savings over standard lamps. The use of fluorescent lamps in place of incandescent lamps, for example, can triple or quadruple lighting efficiency. Fluorescent replacement lamps and energy-efficient incandescent lamps are discussed in this section.

INCANDESCENT ALTERNATIVES

DESCRIPTION

Most lighting in the residential sector is incandescent. Available energy-conserving retrofits include the following:

Replace standard "A-series" lamps with lower-wattage incandescent lamps. These lamps have a 1%–5% higher efficacy than the standard lamps and cost about the same. The higher efficacy is a result of a better lamp filament and, in many cases, krypton filling. These lamps reduce energy usage per lamp 9%–15% and result in a 7%–11% decrease in light level. The light level reduction is rarely perceived by the homeowner.

Another option is replacing standard lamps with compact fluorescent lamps. A compact fluorescent lamp uses approximately one-third the energy of a standard incandescent lamp. The light output of the fluorescent lamp is equivalent to that of the incandescent. The first cost of these lamps is 10–15 times greater than incandescent lamps, but they last approximately 13 times as long. They are most appropriate for heavily used fixtures that are not turned on and off frequently. They are bulkier than incandescents and in some cases they are too long to fit in standard fixtures or table lamps.

Interior 3–3/4" floodlamps (called PAR lamps) typically found in recessed fixtures can be replaced with energy-efficient lamps (typically called ER). These lamps are twice as efficient as conventional alternatives at lower wattages. Table R-36 illustrates energy-efficient substitutions for standard lamps.

Conventional exterior floodlamps can be replaced with either energy-conserving (ER) lamps or tungsten/halogen lamps.

Table R-36.
Energy-Efficient Substitutes for Incandescent Lamps

STANDARD LIGHT BULBS					
Existing lamp	40 W	60 W	75 W	100 W	150 W
Energy-efficient alternative	34 W	52 W	67 W	90 W	135 W
FLOODLAMPS					
Existing lamp	75 W	100 W	150 W	300 W	
Energy-efficient alternative (ER or halogen lamps)	45 W	75 W	90 W	120 W	

DEFINITIONS AND TERMS

A-SERIES OR A-LINE Conventional medium screw-base teardrop-shaped incandescent lamps (usually frosted on the inside), used almost universally in households. "A" refers to the fact that the shape is the standard (versus "F" for flame-shaped, "P" for pear-shaped, and so on)

ER LAMPS ER stands for ellipsoidal reflector. This floodlamp design brings the light to focus several inches in front of the lens, rather than behind it, so that less heat is trapped inside the lamp. "BR" lamps are similar to ER lamps; they use a parabolic silver (rather than aluminum) reflector.

EFFICACY The amount of light produced (in lumens) for a given amount of power input to the lamp (lumens/watt).

TUNGSTEN-HALOGEN A type of incandescent lamp made more efficient by the addition of a halogen gas, usually iodine or bromine. The gas suppresses filament tungsten evaporation, allowing the filament to be operated at a higher temperature and increasing lamp efficacy.

PAR LAMPS PAR stands for parabolic aluminum reflector. Standard floodlamps use this design.

■ *APPLICABILITY*

CLIMATE All
BUILDING TYPE All
DEMAND MANAGEMENT STRATEGY Strategic conservation

Table R-37. Incandescent Alternatives: Costs and Benefits

Options	Costs ($)[1]	Power (W/lamp)	Cost Savings ($/lamp/yr)	Simple Payback (h)	Relative Light Output (%)	Life (h)	Confidence
Standard incandescent	0.83	75	—	—	100	750	H
Efficient incandescent	1.13	67	0.48[2]	469	93	750	H
Compact fluorescent	13.00	18	5.67[3]	2150[4]	100	10,000	H
Standard interior floodlamp	5.38	100	—	—	100	2,000	H
Ellipsoidal reflector floodlamp	8.00	75	2.00	1310	100	2,000	H
Standard exterior floodlamp	7.00	150	—	—	100	2,000	H
Ellipsoidal reflector	9.88	120	2.40	783	100	2,000	H
Tungsten/halogen	12.68	90	4.80	1183	100	2,000	H

Note: Standard fluorescents are covered in Vol. 2 of the *DSM Pocket Guidebook*.

1 Except as noted the prices are retail for GE lamps, material costs only.

2 The cost savings is the operating cost reduction from the operating cost of the standard incandescent for the average life of an incandescent bulb (750 hours).

3 Compact fluorescent annual cost savings (based on 1000 hours of use per year) includes the cost of additional standard bulbs.
(75 W – 18 W) × 1000 hours × (1 kWh/1000 Wh) × $0.08/kWh × ($0.83 × 1000/750) = $5.67.

4 Simple payback (marginal costs): ($13.00 – $0.83)/$5.67 = 2146 hours.

RESIDENTIAL APPLIANCES

American families typically spend $500 to $1000 a year operating household appliances. Table R-38 shows the power draw and average energy use of typical household appliances purchased before 1990. Most appliances purchased after January 1, 1990, will use less energy as a result of standards mandated by the National Appliance Energy Conservation Act (NAECA) of 1987. This law established minimum efficiency standards for major home appliances and heating and cooling equipment. The standards require that all new major appliances be 10%–30% more efficient than previously sold models. NAECA also mandate further appliance efficiency improvements in 1993 and 1998. Table R-39 shows the mandated improvements that have been approved to date.

Table R-38.
Estimated Average Kilowatt Hours Used Monthly by Certain Electrical Household Equipment

Appliance	Average Wattage	Estimated Monthly kWh
Air conditioner (window)	1,000	1 kWh/h
Automatic blanket	200	15
Car heater	1,000	1 kWh/h
Clock	4	3
Clothes dryer	4,350	5 kWh/load
Coffeemaker	850	8
Dehumidifier	300	200
Dishwasher	1,500	30
Floor polisher	340	1
Food blender	290	1
Food freezer (15 cu ft chest)	350	100–190
Food freezer (15 cu ft frostless)	450	150–240
Food mixer	110	1
Frying pan	1,200	15
Furnace (oil)	600	75
Garbage disposal	400	2
Hair dryer	250	3
Heater (portable)	1,500	1.5 kWh/h
Humidifier	80	20
Iron (hand)	11,00	12
Lighting	1,600–4,000	100–150
Microwave	1,450	16

Table R-38.
Estimated Average Kilowatt Hours Used Monthly by Certain Electrical Household Equipment (Concluded)

Appliance	Average Wattage	Estimated Monthly kWh
Radio	20	4
Radio/stereo	40	6
Range	12,000	100–150
Razor	15	1
Refrigerator, standard (12'–16')	265	100–120
Refrigerator, frost-free (16') (1970 vintage)	475	150–230
Refrigerator, frost-free (20') (1970 vintage)	540	225–275
Sewing machine	75	1
Television (black and white)	50–250	25–50
Television (color)	250–350	30–90
Toaster	1,100	4
Toothbrush	2	1.5
Vacuum cleaner	700	3
Washing machine (automatic)	600	8
Washing machine (nonautomatic)	300	5
Water bed heater (varies)	300	100
Water heater (standard)	2,500	350[1]
Water heater (quick recovery)	4,500	500[1]
Water pump	750–2,000	40–80

[1] Varies widely.
Source: ND Rec Magazine (Jan. 1986)

Table R-39. U.S. Appliance Efficiency Standards

	For Products Manufactured After	
	1/1/90	1/1/93
	kWh/yr	
REFRIGERATOR/FREEZERS		
Manual defrost	16.3 AV[1] + 316	19.9 AV + 98
Partial automatic defrost		
Automatic defrost with		
Top-mounted freezer without ice	23.5 AV + 471	16.0 AV + 355
Side-mounted freezer without ice	27.7 AV + 488	11.8 AV + 501
Bottom-mounted freezer without ice	27.7 AV + 488	14.2 AV + 364
Top-mounted freezer/through-the-door ice	26.4 AV + 535	17.6 AV + 391
Side-mounted freezer/through-the-door ice	30.9 AV + 547	16.3 AV + 527
Upright freezer with		
Manual defrost	10.9 AV + 422	10.3 AV + 264
Automatic defrost	16.0 AV + 623	14.9 AV + 391
Chest freezer and all other freezers	14.8 AV + 233	12.0 AV + 124

Table R-39. U.S. Appliance Efficiency Standards (Continued)

	For Products Manufactured After 1/1/90 (EER)
AIR CONDITIONERS	
Room air conditioners	
Without reverse cycle/with louvered sides	8.0–9.0
Without reverse cycle/without louvered sides	8.0–8.5[2]
With reverse cycle/with louvered sides	8.5
With reverse cycle/without louvered sides	8.0

	SEER	SHPF
CENTRAL AIR CONDITIONERS AND HEAT PUMPS		
Split systems (manufactured after 1992)	10.0	6.8
Single packaged systems (manufactured after 1993)	9.7	6.6

Table R-39. U.S. Appliance Efficiency Standards (Concluded)

	For Products Manufactured after 1990 (Energy Factor)[3]
WATER HEATERS	
Electric water heaters	0.95 – (0.00132 × rated storage volume in gallons)

1 AV = adjusted volume = [1.63 × freezer volume (ft^2)] + refrigerator by volume.

2 Depends on size.

3 The savings assumes a water heater with an energy factor of 0.90. The energy factor represents a combination of conversion efficiency (100% for electricity) and standby losses assuming 64 gallons/day of hot water are applied.

ENERGY-EFFICIENT REFRIGERATORS AND FREEZERS

DESCRIPTION

Refrigerators are an important target for residential energy conservation because they constitute a major residential end use of electricity. For example, in California's Pacific Gas and Electric Company utility territory, refrigerators account for 22% of the residential electrical consumption. In the same service territory, freezers account for 6% of residential consumption. The most common type of refrigerator/freezer is an automatic defrost with a top-mounted freezer. The energy usage of models sold in 1983 is approximately 1200 kWh/yr. This is 30% less than models sold in 1971. The best large refrigerator/freezer available from leading manufacturers in the U.S. in 1985 used approximately 750 kWh/yr. In 1989/90, the best mass-marketed automatic-defrost refrigerator/freezers also used about 750 kWh. The national appliance efficiency standards required that further improvements in refrigerator efficiency start in 1990. As a result of these standards, full-size automatic-defrost refrigerator/freezers using less than 700 kWh/yr will become available in the early 1990s. In Table R-40 the energy use for representative refrigerator/freezers built in the mid-1980s is compared to a refrigerator meeting the 1992 California minimum appliance efficiency standards (which is similar to the U.S 1993 standard). Manufacturers can choose several redesign options to meet these standards. The example in Table R-40 assumes a moderately improved compressor (an increase of EER from 3.18 to 3.65), more insulation, a double freezer gasket, and a more efficient fan and motor. A second option is included in

Table R-40 to indicate further improvements that can be made, for example by including a compressor EER of 4.5 and a double refrigerator gasket.

APPLICABILITY

BUILDING TYPES All. These measures are primarily applicable to consumers replacing older units.

CLIMATE TYPES All

DEMAND MANAGEMENT OBJECTIVE Strategic conservation

FOR MORE INFORMATION

Massachusetts Audubon Society and ACEEE (1985), "Saving Energy and Money with Home Appliances." Washington, DC: ACEEE.

"The Most Energy Efficient Appliances, 1989–90 Edition" (1989). Washington, DC: ACEEE.

Table R-40. Energy-Efficient Refrigerators and Freezers: Costs and Benefits

Options	Costs ($)	Energy Use (kWh/yr)[1]	Peak Use (kW)[1]	Energy Savings (kWh/yr)	Cost Savings ($/yr)	Simple Payback (yr)	Life	Confidence
Automatic-defrost refrigerator/freezer (17 ft^3, 1983 vintage)	671	1,200	1.5	—	—	—	20	H[2]
1992 California Standards model	731	610	0.8	590	47.20	1.3	20	H[2]
Improved models	807	460	0.6	740	59.20	2.3	20	M

1 American Council for an Energy-Efficient Economy (1986), "Residential Conservation Power Plants Study, Phase 1—Technical Potential." Washington, DC: ACEEE.

2 Confidence is rated high. The energy usage is determined based on laboratory testing and reported on an Energy Guide label.

LOW-WATER WASHING MACHINES AND DISHWASHERS

DESCRIPTION

A standard washing machine uses between 620 and 1580 kWh/yr. The most energy-efficient top-loading models widely available today use between 650 and 830 kWh/yr. Most of this electricity is for heating water rather than directly running the washer. A front-loading washing machine uses less hot water per pound of laundry than top-loading units use. Front-loading units in standard sizes widely available in 1989/90 can use as little as 300 kWh/yr. According to Consumer Reports (June 1985), these machines are quieter, take up less space, and use less detergent than top loaders.

Front-loading commercial washing machines also use less energy than residential machines. In commercial laundries, front-loading machines are generally designed to wash two or three loads of laundry at a time. They use less hot water per load and their washing process is more energy efficient than a top-loading machine.

Including energy to heat water, dishwashers use between 600 and 1100 kWh/yr. Average electricity use of new dishwashers declined 36% from 1972 to 1984. The most energy-efficient models widely available in 1989/90 used approximately 640 kWh/yr. A booster heater to raise the temperature of the incoming water to 140°F is one available energy-conserving feature. This allows the user to set the temperature of the household water heater at 110°F or 120°F. Another energy-saving feature is a short cycle and an air-dry selection. Energy Guide labels are required on clothes- and dishwashers so consumers can compare the energy use of various models.

APPLICABILITY

BUILDING TYPE Residential and commercial
CLIMATE All
DEMAND MANAGEMENT STRATEGY Strategic conservation

FOR MORE INFORMATION

Massachusetts Audubon Society and ACEEE (1985), "Saving Energy and Money with Home Appliances." Washington, DC: ACEEE.
"The Most Energy-Efficient Appliances, 1989–90 Edition" (1989). Washington, DC: ACEEE.

Table R-41. Low-Water Washing Machines and Dishwashers: Costs and Benefits

Options	Added Costs ($)	Energy Savings (kWh/yr)	Cost Savings ($/yr)	Simple Payback (yr)	Life (yr)	Confidence[2]
Front-loading washer	150	480[1]	38.4	3.9	15	H
Dishwasher/booster heater/air drying	30	201	16.08	1.9	15	H

1 The savings assumes a water heater with an energy factor of 0.90. The energy factor represents a combination of conversion efficiency (100% for electricity) and standby losses assuming 64 gallons/day of hot water are applied.

2 Confidence is high because there are standardized procedures to test and report annual energy use to consumers via the Energy Guide label.

ENERGY-EFFICIENT CLOTHES DRYERS

DESCRIPTION

According to the U.S. Department of Energy, a typical electric clothes dryer sold in 1980 consumed 2.44 kWh per use. Electric clothes dryers use two to three times as much electricity as the theoretical minimum to remove water. One energy conservation feature that is applied to electric clothes dryers is a sensor that measures either the temperature or the moisture exhaust, thereby allowing automatic shutoff of the dryer when the clothes are mostly dry. Most of the clothes dryers sold in 1980 have a temperature control sensor. Moisture sensors are less common. Advanced technology options for electric clothes dryers that might be widely available in the 1990s include exhaust heat recovery, microwave clothes dryers, and heat-pump clothes dryers.

Commercial clothes dryers generally have a larger capacity and dry two wash loads for the same amount of energy and in the same time as a residential dryer.

APPLICABILITY

BUILDING TYPE Residential and commercial
CLIMATE All
DEMAND MANAGEMENT STRATEGY Strategic conservation

FOR MORE INFORMATION

Massachusetts Audubon Society and ACEEE (1985), "Saving Energy and Money with Home Appliances." Washington, DC: ACEEE.
"The Most Energy-Efficient Appliances, 1989–90 Edition" (1989). Washington, DC: ACEEE.

Table R-42. Energy-Efficient Clothes Dryers: Costs and Benefits

Options	Costs ($)	Energy Savings (kWh/yr)	Cost Savings ($/yr)	Simple Payback (yr)	Life (yr)	Confidence[1]
Standard clothes dryer	315	—	—	—	18	
Moisture sensor	390	124	9.92	7.5	Unknown	M

1 An Energy Guide label is not required for electric clothes dryers; thus there is no standardized laboratory testing procedure.

ENERGY-EFFICIENT COOKING EQUIPMENT

DESCRIPTION

From a utility perspective, the energy used by electric ranges is an important consideration because the saturation of electric ranges is increasing and they are generally heavily used during peak load periods.

Simple technology measures can be incorporated into cooktops and ovens. For the oven, they include increasing insulation, improving door seals (resulting in less heat loss through infiltration), reducing the thermal mass of the oven (i.e., the amount of metal used), and changing the oven element to improve heat transfer. For cooktops, energy savings improvements include reducing contact resistance and improving the reflectance of the reflector pans under the burners, which directs more heat back to the cooking utensil.

Further energy savings will result from the use of magnetic-induction cooktops. Induction cooktops have been used in the residential and commercial sectors for about 10 years. The market for these products in the United States is quite small because of expense, and most units in use here are imported. In these cooktops, a magnetic coil is located underneath the cooking area. Running high-frequency (20–40 kHz) electricity into a magnetic coil creates an alternating magnetic field which induces a current in the pan. Because of high resistance, the current is converted to heat. An induction cooktop heats the cooking utensil directly rather than heating a resistance coil which then transfers heat to the pan. The pans must be made out of or contain iron or steel. The cooktop itself remains cool, however.

Induction cooktops have efficiency gains of 20%–40% over conventional electrical resistance ranges.

Microwave ovens and combination microwave/convection ovens are other energy-saving devices. These are not included in Table R-43 because generally they are purchased in addition to a standard oven. Tests show that cooking particular foods in a microwave oven consumes 25%–75% less energy than cooking them in a standard oven. Tests by the Association of Home Appliances indicate that homes with a conventional electric range and oven and a microwave oven use 14% less energy for cooking than households with only a conventional oven.

■ *APPLICABILITY*

BUILDING TYPES All. These measures are primarily applicable to consumers replacing older units.

CLIMATE TYPES All

DEMAND MANAGEMENT OBJECTIVE Strategic conservation. (Microwave ovens offer strong potential for strategic load growth because customers often use them in conjunction with nonelectric cooking appliances.)

■ *FOR MORE INFORMATION*

Massachusetts Audubon Society and ACEEE (1985), "Saving Energy and Money with Home Appliances." Washington, DC: ACEEE.

"The Most Energy Efficient Appliances, 1989–90 Edition" (1989), Washington, DC: ACEEE.

Table R-43. Energy-Efficient Cooking Equipment: Costs and Benefits

Options	Costs ($)[1]	Energy Use (kWh/yr)	Energy Savings (kWh/yr)	Cost Savings ($/yr)	Simple Payback (yr)	Life (yr)	Confidence
Cooktops							
Standard	300	399	—	—	—	18	M
Improved[2]	302	355	44	3.52	0.6	18	M
Induction	1100	307	92	7.36	108	18	M
Ovens							
Standard	200	346	—	—	—	18	M
Improved[2]	215	246	103	8.24	1.8	18	M

1 The costs represent midpoints of ranges.

2 Improved technology for the oven includes increased insulation, improved door seals, reduced thermal mass, and improved heating-element configuration. Improvements for the cooktop include better contact resistance and an improved reflector pan.

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RESIDENTIAL POOLS

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The number of in-ground pools at the end of 1989 was 3.1 million. Approximately 100,000 are built each year. According to the National Spa and Pool Institute, 33% of all pools built in 1988 were sold with heaters. Energy-efficiency measures include controlling the amount of time that the pool or spa filtration system is running, solarpool heating, and swimmingpool/spa covers. Solar pool heating can extend a swimming season and make an otherwise unheated pool more comfortable. According to the National Spa and Pool Institute, 69% of the spas installed in 1988 used electric heat. Solar water heating and heat-pump water heaters (discussed in the water heating section) may be appropriate retrofits for spas.

SWIMMING POOL PUMP CONTROL

■ *DESCRIPTION*

The filtration, sweeping, and heating systems for residential pools use relatively large pumps, typically rated at between 0.5 and 1.5 horsepower (hp). A study described in *Energy Auditor and Retrofitter* (March/April 1986) found that 0.75-hp or smaller pumps were generally adequate for most residential pools and that many pool pumps were oversized. When it comes time to replace the pump, choosing a new pump with energy conservation in mind will almost always result in lower operating cost.

According to the National Spa and Pool Institute, under most conditions a properly sized pool pump operating only eight hours a day should be able to keep the pool clean. Typically the time of day and the duration of pool pump operation are controlled by a customer-owned, manually adjustable clock switch supplied in the pool pumping and filtering control package. These are easily set to allow for off-peak operation and to limit operation to only those hours necessary to maintain pool cleanliness.

■ *APPLICABILITY*

CLIMATE This is most applicable to warm-climate utilities with high saturations of residential swimming pools.

BUILDING TYPE All

DEMAND MANAGEMENT OBJECTIVE Load shifting, strategic conservation, peak clipping

Table R-44. Swimming Pool Pump Control: Costs and Benefits

Options	Cost ($) (Installed)[1]	Power (kWh/yr)[2] (kW)	Cost Savings[3] ($/yr)	Simple Payback (yr)	Life (yr)	Confidence
Swimming pool pump control	28.00	365–435 kWh/yr 0.7–1.3 kW	32.00	0.9	—	H

1 The costs were reported by one utility. Hardware costs are generally low, because the only equipment required is an extra clock tripper.

2 The energy savings as reported by two southern California utilities.

3 Cost savings is based on the midpoint kWh savings/yr.

SOLAR POOL HEATERS AND COVERS

DESCRIPTION

A solar pool heater is generally used to raise the pool water temperature 8°F to 10°F to extend the swimming season by three or four months in most parts of the country. Most solar pool collectors are made of parallel black plastic tubes. No glass or plastic collector covering is used in these systems. Because the pool itself serves as the storage tank, no separate storage unit is needed. The pool's filtration pump is often used to force water through the collectors. An average pool heating system might consist of a 360-ft^2 collector with an electronic controller and a pump.

If a pool is heated, a pool cover is very important. Not using a pool cover is like heating a house without a roof—the heat just goes right out the top. A cover retains more than two-thirds of the heat needed to maintain a comfortable swimming temperature. The size of the required solar heating system would double to heat a pool 12 months of the year without a pool cover.

APPLICABILITY

CLIMATE All

BUILDING TYPE Residential and commercial

DEMAND MANAGEMENT STRATEGY Strategic conservation

Table R-45. Solar Pool Heaters and Covers: Costs and Benefits

Options	Costs ($)	Energy Savings (kWh/yr)	Cost Savings ($/yr)	Simple Payback (yr)	Life (yr)	Confidence
Pool cover	180[1]	12565	1005	0.2	10	M
Solar pool heater	3,805[2]	8171[3]	653	5.8	20	M

1 The cost of a pool cover is $0.40–$0.80/ft^2. (The midpoint is used.) The surface area of the cover is assumed to be 300 ft^2.

2 The cost of a solar pool heater ranges from $8.75 to $12.50 per square foot of collector area. (The midpoint is used.) The collector area is assumed to be 350 square feet.

3 Savings was determined through an FCHART model simulation for Phoenix, AZ, for the months March–November. Savings assumes the pool uses a cover.

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