Chapter H

RESIDENTIAL ENERGY USE AND EFFICIENCY STRATEGIES

Chapter II.-- RESIDENTIAL ENERGY USE AND EFFICIENCY STRATEGIES

TABLES

FIGURES

Chapter II

RESIDENTIAL ENERGY USE AND EFFICIENCY STRATEGIES

Technologies available now can substantially reduce home energy use with no loss in comfort. This chapter demonstrates that total energy use in new and existing homes can typically be reduced by 30 to 60 percent and that these energy savings produce a large dollar saving over the life of the home. The review focuses on the "thermal envelope" —the insulation, storm windows, and other aspects of the building shell —the equipment used to heat and cool the home, and energy uses of the principal home appliances.

This chapter presents calculations showing how new homes can be built that use substantially less energy than those built just prior to the embargo. It then discusses experiments on existing houses which indicate that similar savings are possible through retrofit measures. Cost analyses are given that show these energy saving packages significantly reduce the cost of owning and operating these homes.

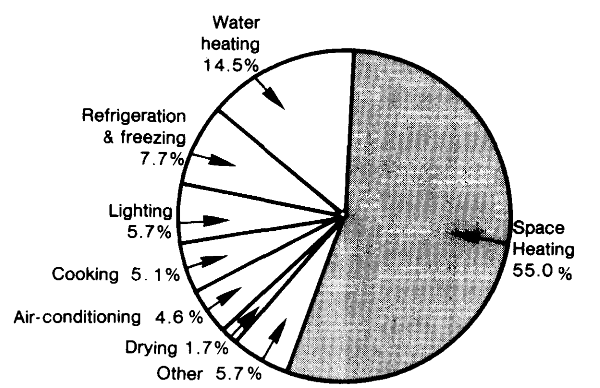
There is little measured data on energy use in a "typical" home. Experiments are difficult to perform because of individual variations in construct ion, equipment, and appliances; moreover, the living and working patterns of the occupants can change energy use by a factor of two.

Most of the data on residential energy use is based on the interpretation of aggregate consumption data. Monthly gas sales are analyzed to determine the weather-dependent portion that is used for heating; information on light bulb sales is combined with the average bulb lifetime to determine the average household use of energy for lighting; and similar determinations are made for other appliances and uses. The average residential use pattern as determined by Dole[1] after reviewing previous studies and performing additional analysis is shown in figure 6. This figure shows "primary" energy usage, which accounts for distribution losses for all fuel types and for electric generation losses.

Calculations based on aggregate consumption do not show the interactions that occur between appliance usage and heating and cooling needs, nor do they show the sources of heat loss that greatly influence total energy usage. It is necessary to consider a particular house for these purposes. Since no single experiment documents all of the interactions that occur, they will be illustrated with computer analysis performed by Hittman Associates.[2]

Additional data is based on analysis performed by Oak Ridge National Laboratory (ORNL), and experiments by the National Bureau of Standards (NBS) and Princeton University on real homes.

Figure 6.—Residential Energy Use in the United States



Residential primary energy consumption, 1970—13 quadrillion Btu

SOURCE: Stephen H. Dole, "Energy Use and Conservation in the Residential Sector: a Regional Analysis," RAND Corporation, R-1641-NSF, June 1975, p. vi.

[1]Stephen H. Dole, "Energy Use and Conservation in the Residential Sector: A Regional Analysis, " (RAND Corporation, June 1975),R-1641 -NSF

[2]Hittman Associates, Inc. , "Development of Residential Buildings Energy Conservation Research, Development, and Demonstration Strategies, " H IT-681, performed under ERDA Contract No EX-76-C-01-2113, August 1977

HEAT LOSSES AND GAINS

The first calculation is based on a single-story, three-bedroom, 1,200 ft^2 home in Baltimore, Chicago, or Houston. Identified as the "1973 house," it has a full, unheated basement and is constructed of wood frame with brick veneer. Insulation levels and other characteristics are shown in tables 19 through 25 at the end of this chapter. It is sufficiently characteristic of the existing housing stock to illustrate typical energy use patterns.

The energy use patterns of the 1973 house are shown in figure 7 for a variety of fuel systems. Figures 7(a), (c), and (d) show the energy used at the home and do not include losses in generation or production and transmission of energy. If these are included so that primary energy is shown instead, the percentage distribution is changed dramatically. This is illustrated in figure 7(b) for the fuel case corresponding to figure 7(a).

Heat loss or gain through the building shell results primarily from heat conduction through the walls, windows, ceiling, and floors, and by infiltration through cracks around windows, doors, and other places where construction material is joined. Figures 8 (a) and (b) show, for the typical house in two climates (Chicago and Houston) that heat losses are well distributed across the various parts of the thermal envelope (as are infiltration losses). Thus, major reduction in heat loss will require that more than one part of the shell be improved. Houses will vary widely in this regard. For example, if the house used in figure 8 had been built without any attic insulation, roof losses would have accounted for about 40 percent of total heat loss rather than the 12 to 14 percent shown. Even though substantial reduction in heat loss would occur if the attic were insulated, there would still be room for substantial improvement in other parts of the shell as well.

Mechanical or electrical heating systems are generally the principal source of heat to make up for these losses to keep a home at a comfortable temperature. Other sources of heat, however, are also significant. Figures 8 (c) and (d) show the distribution of heat gain for the Chicago and Houston cases. Internal heat gain comes from cooking, lighting, water heating, refrigerator and freezer operation, other appliances, and the occupants themselves. Although none of these internal gains is large, they combine to provide nearly one-fifth of the heat in the colder climates. Heat available from sunlight depends primarily on the window area and orientation and can be considerably Increased if desired.

Everything (except the floor) that contributes to the heating load also contributes to the cooling load. (The floor helps cool the house in summer.) Internal gains and solar gain from windows that reduce the heating load requirements add to the cooling load, but in very different proportions. As shown in table 3 internal heat gains constitute about half the cooling load There is less infiltration in summer than in winter, because of lower wind speed and smaller indoor-outdoor temperature differences, but humidity removal requirements increase. Thus, infiltration contributes about as much fractionally to the cooling effort as it does to heating. Additions to cooling load from windows are much larger than to heating because their conductive heat gain adds to the solar radiation gain when cooling is considered Other parts of the building shell contribute only 9 to 13 percent of the cooling load in the three simulated locations. The floor, however, does reduce cooling requirements significantly.

Table 4 shows internal gains for the prototypical house in Chicago and Houston. Major sources are the occupants, hot water, cooking, lighting, and the refrigerator/freezer. All other appliances together contribute about as much as any one of the major sources.

The Thermal Envelope

Current practice in residential energy conservation often begins with attempts to reduce the normal tendency of a house to lose heat through the structure. The rate at which a particular component of a building loses heat

Information dissemination centers were set up in each city. The trained specialist would utilize the conventional daytime photography to locate a particular family's home on the IR pictures; would interpret the prints, pinpointing areas of needed roof insulation, and discussed many effective energy conservation options that would help the consumer. The cost was estimated to be approximately 30¢ per home. Thousands of Minnesota homeowners were reached through this program and informed on what they can best do to save energy and dollars.

Photo credits: U.S. Department of Energy

Since heat rises, poorly insulated attics usually result in situations like the one shown above

Figure 7.— Disaggregated Energy Usage in the "Typical 1973" House Located in Baltimore, Md., for Three Different Heating and Hot Water Systems

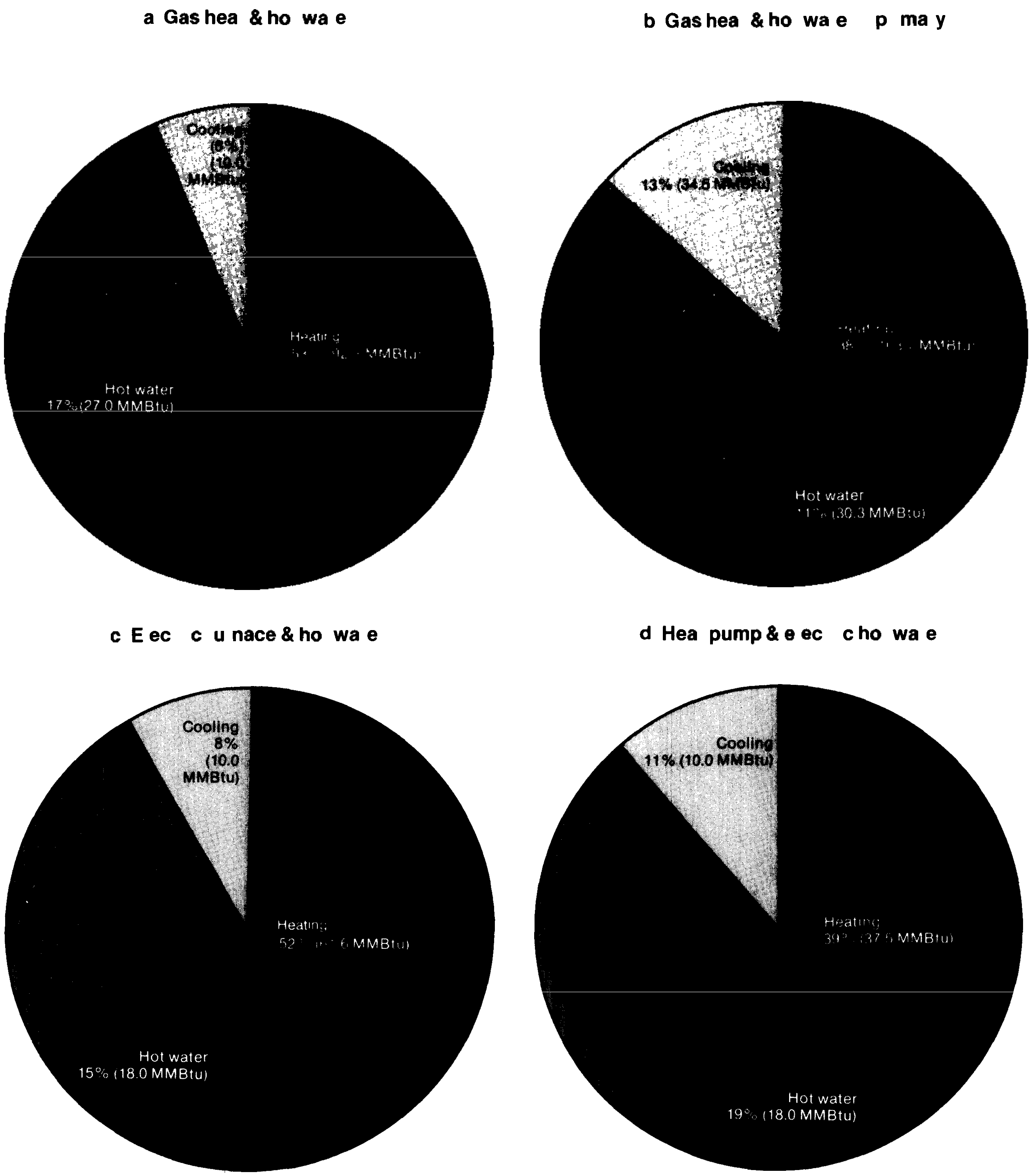
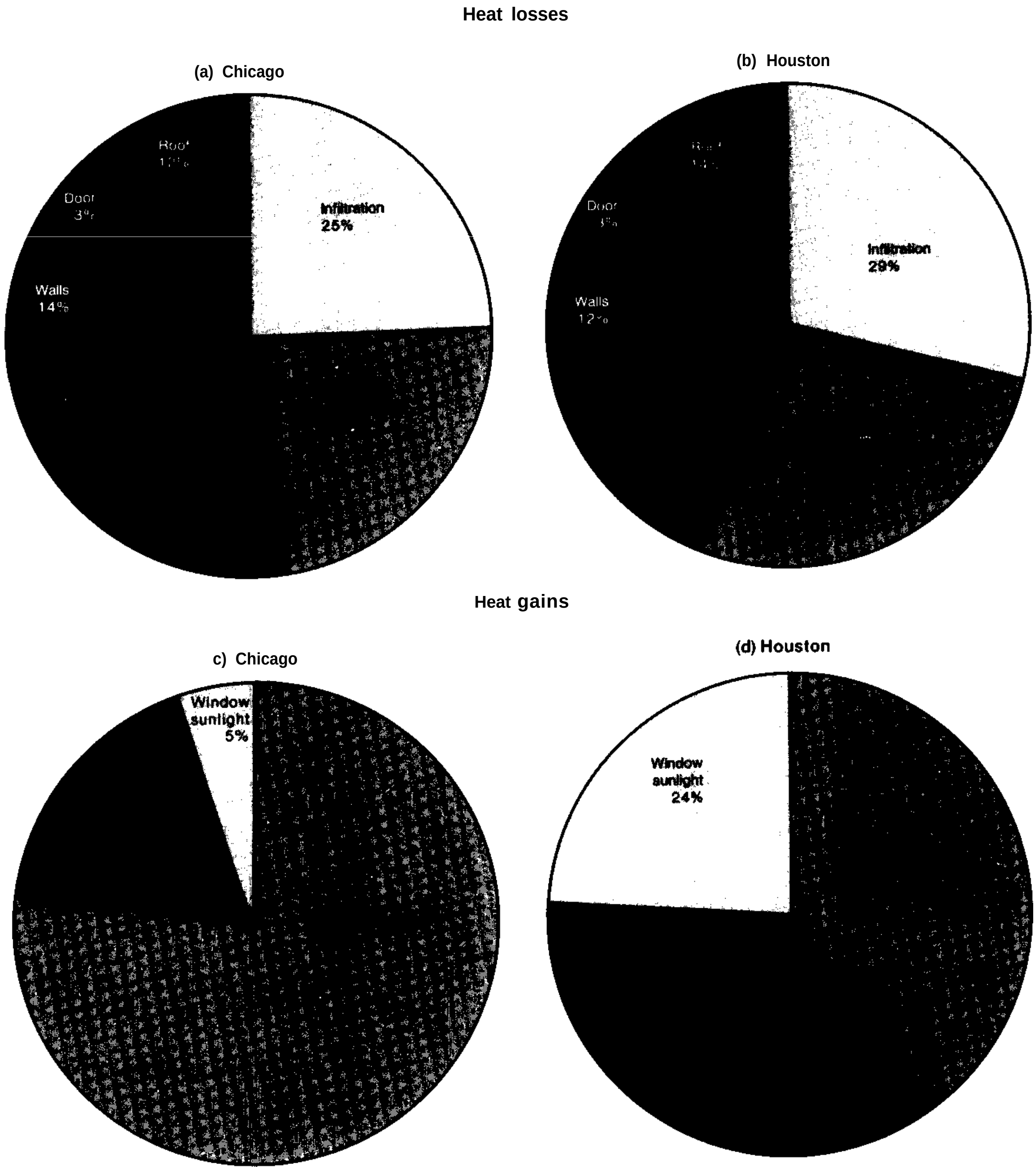


Figure 8.— Heat Losses and Gains for the Typical 1973 House in Chicago and Houston— Heating Season



1 MMBtu = 1.05 gigajoule (GJ).
SOURCE: Based on tables 19-25

Table 3.—Disaggregated Cooling Loads for a Typical 1,200 ft^2 "1973" House in Three Different Climates

	Baltimore	Chicago	Houston
	percent	percent	percent
Structural heat gains			
Roof	4	4	5
Doors	1	1	1
Floor	—	—	2
Walls	4	4	5
Window conduction and radiation	18	17	19
Infiltration	22	19	24
Total structural gains	49	45	56
Internal heat gains	51	55	44
Total heat gains	100	100	100
Heat losses			
Floor	33	40	—
Cooling system	67	60	100
Heat removed by cooling system (MMBtu)	18.0	14.0	56.9

1 MMBtu = 1.05 GJ
SOURCE: Based on table 20.

Table 4.—Sources and Amounts of Internal Heat Gain During the Cooling Season for Chicago and Houston (1973 House)

	Chicago		Houston	
	MMBtu	Percent of total heat gain	MMBtu	Percent of total heat gain
Hot water[a]	2.5	10	4.6	8
Occupants	2.8	12	5.2	9
Cooking	1.3	5	2.4	4
Lighting	2.3	10	4.3	7
Refrigerator/freezer	2.0	8	3.6	6
Miscellaneous	2.3	10	4.2	7

1 MMBtu = 1.05 GJ
aHot water *gains were* assumed to be jacket losses plus 25 percent of the heat added to the water.
bOccupant heat gains were assumed to be 1,020 Btu Per hour for 3.75 months and 7 months respectively based on an average of 3 people in the house.
cThe *remaining categories are* based on usage levels shown in table 18 for 3.75 and 7 months for Chicago and Houston, respectively.
dThis category includes the TV, dishwasher, clothes washer, iron, coffee maker, and miscellaneous uses of table 17. The clothes dryer input is neglected since it is vented outdoors.
SOURCE: OTA.

through conduction (and conversely, gains heat in hot weather) is governed by the resistance to heat flow (denoted by the R-value) and the indoor/outdoor temperature difference. Engineers and designers commonly express the R-value of various components in Btu per hour per ft^2 per ^{0}F, which means the number of Btu of heat that would flow through 1 ft^2 of the component in an hour when a temperature difference of 10 F is maintained across the component. Different parts of a house have R-values differing by a factor of 10 or more, as shown in table 5(a). Tables 5(b) and 5(c) show the R-values of a variety of common building materials and how they are added to obtain the R-value of a specific wall.

Infiltration is described in terms of air changes per hour (ACPH)— and 1 ACPH corresponds to a volume of outside air, equal to the volume of the house, entering in 1 hour. The rate of infiltration is affected by both the wind and the difference between indoor and outdoor temperatures; it increases when the wind rises or the temperature difference increases.

Less is understood about how to measure and describe infiltration than about heat flow. It is clear that specific actions can help lower infiltration such as using good-quality windows and proper caulking and sealing. It is also clear that the general quality of craftsmanship throughout construction is important, and that there may be factors at work that are not yet well understood. Half an air change per hour is considered very tight in this country, although rates below 0.2 have been achieved in buildings in the United States and Sweden. Many U.S. houses have winter air change rates of two or more. Tightening houses must be combined with attention to possible increases in the indoor moisture level and quality of the indoor air (see chapter X).

What can be done to reduce the heating and cooling energy use? As an example, the 1973 home has been subjected to a number of changes in the building shell by computer simulation.[3] Two levels of change have been made, one improves the thermal envelope so it is typical of houses built in 1976 and another uses triple glazing and more insulation — it is described as the "low-energy" house. Each modification was done in the three climate zones represented by Baltimore, Chicago, and Houston.

The 1973 house uses R-1 1 wall insulation and R-1 3 ceiling insulation and has no storm windows or insulating glass. The 1976 house increases ceiling insulation to R-19 and features weather-stripped double-glazing and insulated

[3] Ibid

Table 5.—R-Value of Typical Building Sections and Materials

a) R-value of typical building sections

Building section	R-value	Building section	R-value
Exterior frame wail	4.5	Attic with 6" blown fiberglass	15.0
Exterior wall with 3½" fiberglass batts	13.0	Attic with 12" fiberglass batts	40.0
Exterior wall with 5½" blown cellulose	22.0	Single-glazed window (excl. frame)	.9
Uninsulated frame floor	4.6	Double-glazed window (excl. frame)	1.6
Uninsulated attic	4.0		

b) Calculation of the R-value for an exterior wall

Construction	Resistance	Construction	Resistance
1. Outside surface (15mph wind)	0.17	5. ½" gypsum board	0.45
2. Brick veneer (4 in. face brick)	0.44	6. Inside surface (still air)	0.68
3. I/2" insulation board sheathing	1.32		
A.S1/2" fiberglass batt — R-1 1, 2x4 stud— R-4.53 (insulation w/studs on 16" centers)*	10.34	R-value of complete wall	13.40

'The R-value of the stud/insulation wall section is the weighted average (1 5/8" width, 14 3/8" Insulation width) of the two component R-values.

c) R-values of other common building materials

Component	R-value	Component	R-value
1/2" Plywood	0.62	5½" fiberglass batt	19.0
1x8 wood siding	0.79	3½" blown cellulose	13.0
4" common brick	0.80	3½" expanded polystyrene foam	17.5
Single-glazed window	0.94	3/4" still air space (nonreflecting surfaces)	1.01
Double-glazed window (¼" air space)	1.54	4" still air space (nonreflecting surfaces)	1.01
Single-glazed window plus storm window	1.85		

NOTE: The R-values given here are based on the values and methodology given in the *ASHRAE Handbook of Fundamentals*, Carl MacPhee, cd., American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., New York, N Y., 1972, chs. 20,22.

doors. The low-energy house is very heavily insulated, with R-38 ceilings, R-31 walls, and R-30 floors. It is carefully caulked and weather-stripped to reduce infiltration and has triple-glazing and storm doors. Results of the computer simulation of these houses are shown in table 6. Detailed thermal properties and energy flows are given in tables 19 through 25. (The computer program did not provide hourly simulation; if it had, it is likely that the low-energy house in Houston would have required a small amount of heating.)

Heat losses in winter are about 16 percent less for the 1976 house than the 1973 house in Chicago and Baltimore, but the calculations show that the heat that must be supplied here by the furnace is reduced by more than 20 percent. This is because the newer house receives a higher proportion of its heat gain from sunlight, appliances, and other internal gains. (Extra glazing slightly reduces heat gain from sunlight, but other internal gains are unchanged.) Fractional savings for the 1976 house are even larger in Houston, for the same reason. The "1976" summer heat gains are 8 to 10 percent lower than the 1973 house, and cooling system loads are reduced by about 10 to 12 percent. Reduction in the cooling load between the two houses is less than the reduction in heating load, because the thermal improvements do not affect the internal heat gains.

Modifications in the low-energy house cut the heating requirements dramatically. Thermal losses are cut by more than 50 percent. When this is done, the low-energy Houston house no longer needs a heating system (one burner of an electric range at high heat would keep this house warm in the coldest Houston weather), and the heating requirements for Chicago and Baltimore are reduced by 75 and 82 percent from the 1973 levels. Cooling requirements in Baltimore and Chicago increase, as the heavily insulated floor no longer loses as much heat to the relatively cool ground. In

Table 6.—Performance Comparison for Three Thermal Envelopes in Three Different Climates

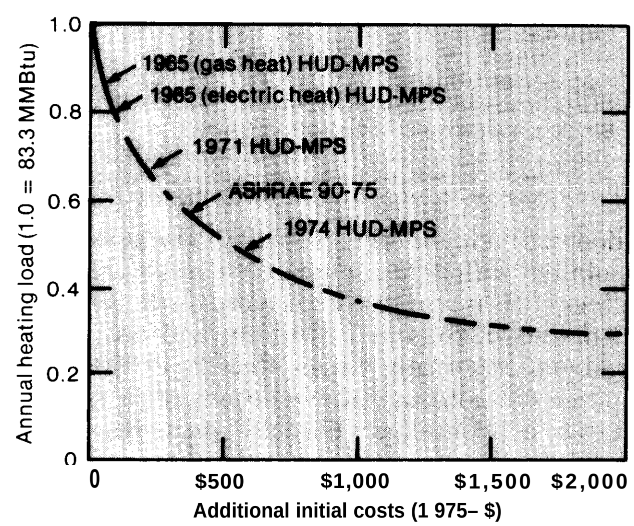
City	Winter heat losses MMBtu	Winter heat losses Percent of 1973 losses	Heat system load MMBtu	Heat system load Percent of 1973 losses	Summer heat gains MMBtu	Summer heat gains Percent of 1973 losses	Cooling system load MMBtu	Cooling system load Percent of 1973 losses
Baltimore								
"1973" house	794	—	554	—	269	—	180	—
"1976" house	661	83	437	79	247	92	158	88
Low-energy house	287	36	99	18	219	81	204	113
Chicago								
"1973" house	1,057	—	811	—	236	—	140	—
"1976" house	887	84	647	80	218	93	123	88
Low-energy house	405	38	202	25	195	83	179	128
Houston								
"1973" house	211	—	84	—	569	—	569	—
"1976" house	153	73	52	62	513	90	513	90
Low-energy house	—	—	0	0	434	76	434	76

1 MMBtu = 1.05 GJ.
SOURCE: Summarized from tables 19-21.

Houston, however, the cooling load is still lower for the low-energy home, as floor heat losses do not aid cooling in this climate.

A similar analysis was performed by Hutchins and Hirst of ORNL.[4] This study used the NBS heating and cooling load program to calculate changes in these loads for "typical" new construction of a 1,200 ft^2 home in 11 cities of differing climates. The results of that analysis are in substantial agreement with those discussed here. Figure 9 shows the heating load reduction for a home in Kansas City, Kans. as more and more improvements are made to the building shell. The cost scale refers to the additional investment needed to install these improvements in a new home. It is a net investment in that it accounts for the added cost of the additional materials (insulation, storm windows, etc.) as well as the reduced heating equipment cost that occurs because the heating system size is reduced as the heating load decreases. It is important to remember that these costs are for new homes; similar changes for existing homes will be more expensive in some cases (e. g., adding wall insulation).

Figure 9.— Heating Load/Cost Relationship— Kansas City



SOURCE Paul F. Hutchins, Jr., and Eric Hirst, "Engineering-Economic Analysis of Single-Family Dwelling Thermal Performance, " Oak Ridge National Laboratory, ORNL/CON-35, November 1978, p. 16.

The Kansas City results show a possible heat load reduction of up to 70 percent with an investment of less than $2,000. (The baseline house for the case had no insulation.) These dollar levels compare well with those calculated for the two houses discussed above. In this case it was estimated that the low-energy house would cost about $3,200 more than the 1973 house while the 1976 house would be about $600 more expensive. I n nearly all cases,

[4] Paul F. Hutchins, J r., and Eric Hirst, "Engineering-Economic Analysis of Single-Family Dwelling Thermal Performance" (Oak Ridge National Laboratory, November 1978), ORNL/CON-35.

however, this added cost would be more than recovered in reduced fuel bills over the life of the home.

The results from these two models show that, within the limits of computer simulation, a substantial reduction in heating load is possible from homes built in the early 1970's. When cooling is considered, additional energy is saved in most cases.

Insulation Effectiveness

What is possible for new homes based on computer simulation and the stated characteristics of materials used to increase the efficiency of the building shell has been shown. A key assumption is that the materials perform at their specifications. For most of the items used in improving the shell —weather-stripping, storm doors, and windows — the assumption is a safe one. With insulation, however, problems, may arise.

Researchers have only recently begun to try determining the actual field effectiveness and durability of insulating materials. (For information on health and safety questions about insulation, see appendix A). Van der Meer[5] and McGrew[6] contend that insulation is often less effective than commonly believed, owing to degradation over time, and to the effect of solar heat gain on the net heat loss through a wall or attic over a heating season. It appears from their work that uninsulated south walls or attics, in particular, tend to collect significant amounts of solar heat in the climates of Colorado and New Mexico. The absorbed sunshine can offset a larger fraction of the heat lost through a wall if the entire winter season is considered.

Sunshine striking the roof or walls of a building can significantly change the energy flows. This is the basis for the use of "Solair" temperatures to calculate summer heat gains. However, similar concepts have not received much attention when dealing with winter heat loss. When sunlight strikes a wall or roof, particularly a dark-colored one, it will be heated. If the wind is blowing hard, the solar heat will be removed so rapidly that it will have a very small effect on the surface temperature of the wall and hence on the heat flowing from inside to outside. If the wind is relatively calm, the surface can be heated considerably, and if the outdoor temperatures are mild enough, the flow will be greatly reduced and can even be reversed so that heat is flowing into the house when the outdoor temperature is below the house temperature.

The heat loss through building components and the economic value of insulation are generally calculated from the R-values discussed earlier and the winter temperatures as expressed in degree-days. (A measurement of the relative coldness of a location.) [f the effect of the Sun on a roof or wall as just described is accounted for over the entire winter, the total heat loss can be much smaller than a calculation based only on temperature. This led van der Meer and Bickle[7] to propose the use of an effective R-value (reference discusses an effective U-value, which is the inverse of R-value; R-value is used here for consistency with the earlier discussion). If a wall had an R-value of 5 but lost only half as much heat as expected over the course of the winter because of solar effects, it would have an effective R-value of 10.

Van der Meer and Bickle calculated effective R-values for a variety of different types of wall construction for 11 different climatic regions of New Mexico, which ranged from 2,800 to 9,300 degree-days and received different amounts of sunshine. Their results are summarized for three wall types in table 7. Results are shown for north- and south-facing walls and for light and dark colors. (Results for other colors and orientations will be intermediate among those shown.) Clearly color is very important. The effective R-value of a light-colored south wall is very close to the lab-

[5] Wybe van der Meer, Jr., "Energy Conservation Housing for New Mexico, " Report No. 76-163, prepared for the New Mexico Energy Resources Board, Nov. 14,1977.

[6] George Yeagle, Jay McGrew, and John Volkman, "Field Survey of Energy Use in Homes, Denver, Colo. " (Applied Science and Engineering, Inc., July 1977).

[7] Wybe van der Meer, Jr., and Larry W. Bickle, "Effective "U" Factors— A New Method for Determining Average Energy Consumption for Heating Buildings, " prepared for the New Mexico Energy Resources Board, Contract Nos. 76-161 and 76-164, Nov. 10, 1977.

Table 7.—Effective R-Values for Different Walls in a Range of New Mexico Climates

	Wall orientation			
	North		South	
	Light	Dark	Light	Dark
Brick veneer wall with 3%" insulation (R = 13.3)	11.6 -13.0	14.5 -17.2	12.8 -14.1	20.8 -90.9
Uninsulated frame wall (R = 3.7).	3.7- 4.0	4.5- 5.3	3.9- 4.4	6.3- 41.7
Brick veneer wall with 6" insulation (R = 19.2) . .	16.4 -18.5	20.8 -23.8	17.9 -20.0	29.4-111

oratory value for all three walls shown. However, the dark north walls all have an effective R-value slightly higher than the laboratory value. The effective R-values of dark south-facing walls show dramatic increases above the theoretical values. The extremely high effective values for uninsulated walls occur only in the warmer parts of New Mexico.

Several caveats must be applied to the interpretation of this work. Effective R-values in most parts of the country will be closer to the steady state values than for the sunny New Mexico climate. These results consider only the winter heating season, and unless overhangs or other shading measures are employed, increased heat gain in summer could offset much of the benefits of the winter gain.

This is another illustration of the need to make standards responsive to the site. Although increased amounts of insulation almost always reduce the total heat loss of a house, it will not have as large an effect as anticipated in some cases, and hence will be less cost effective than calculated using standard values.

Insulation can also degrade in several ways as it ages. Loose-fill insulation in attics can settle, foam insulation can shrink and crack, and moisture buildup can reduce the effectiveness of different types of insulation. The Minnesota Energy Agency recently measured the properties of retrofitted insulation in 70 homes where the insulation ranged in age from a few months to 18 years (with an average age of 2½ years).[8] The R-values of the cellulose and urea-formaldehyde insulation were 4 percent lower on average than expected based on the density of the insulation. The R-values of the mineral fiber (fiberglass and rock wool) insulation varied from 2.35 to 4.25 Btu^{-1} hr ft^{2} °F; but the wide variation was due to differences in the material itself rather than to differences in age or thickness. McGrew[9] measured the R-values of insulation installed in several houses and found that while thin layers of insulation had R-values corresponding to their laboratory values, thicker layers fell below their laboratory values. Three inches of rock wool with a lab value of R-11 had a measured value of 9.9, and 6 inches of fiberglass with a lab value of R-1 9 had a measured value of 13.4. These are consistent with the general trend of his other field measurements.

Neither of these studies can be regarded as definitive since both sample sizes were small and limited to particular geographic areas. It is also possible that the moisture content and R-value will vary throughout the year in a significant manner. More work is needed to establish the long-term performance of different types of insulation in various climates.

A related problem, which seems to have received very little attention, is provision of vapor barriers for insulation retrofits, particularly walls. With the exception of foamed plastics, the insulations used to retrofit wall cavities are degraded by the absorption of water vapor. Exterior walls that were built without insulation seldom include a vapor barrier. This problem is now being investigated. One solution may be the development and use of paints and wallpapers that are impervious

'Minnesota Energy Agency, "Minnesota Retrofit Insulation In-Site Test Program, " HCP/W 2843-01 for U.S. Department of Energy under Contract No. EY-76-C-0202843, June 1978.

'Jay L. McGrew and George P. Yeagle, "Determination of Heat Flow and the Cost Effectiveness of Insulation in Walls and Ceilings of Residential and Commercial Buildings" (Applied Science and Engineering, Inc., October 1977) to water vapor. While some paints are marketed with vapor barrier properties, most of the work on coatings impervious to water vapor appears to have been done by the paper industry for use in food packaging. Application of this work to products for the housing industry appears desirable.

Heating, Ventilation, and Air-Conditioning Systems

The efficiency of heating and air-conditioning systems varies widely depending on the quality of the equipment and its installation and maintenance, but the average installation is less efficient than generally realized. This is partially due to the fact that efficiencies listed by the manufacturer are those of the furnace or air-conditioner operating under optimum conditions. These estimates do not include the losses from the duct system that distributes conditioned air to the house. The confusion between potential and actual efficiency is increased by the fact that the performance of different equipment is defined in different terms —the "efficiency" of a furnace, the "coefficient of performance" (COP) for heat pumps, and the "energy efficiency ratio" (EER) for air-conditioners. These different approaches are explained in a note at the end of this chapter. For purposes of comparison, this discussion will emphasize the seasonal system performance, which attempts to measure the actual performance of the system in a real home situation.

Furnaces

The average seasonal efficiency of oil furnace installations is about 50 percent (including duct losses) as shown in figure 10. However, the Department of Energy (DOE) has determined that the seasonal efficiency of a properly sized and installed new oil furnace of 1975 vintage is 74 percent,[10] which suggests that inadequate maintenance, duct losses, and oversizing may be increasing the amount of oil burned in home heating systems by 50 percent. DOE also determined that it would be possible to achieve an industry-wide production-weighted average seasonal efficiency of 81.4 percent by 1980.[11] These improved furnaces would incorporate stack dampers and improved heat exchangers. While the efficiencies cited by DOE do not include duct losses, these losses can be eliminated by placing the furnace and the distribution ducts within the heated space.

The average seasonal efficiency of gas furnace installations is 61.4 percent. This is much closer to the seasonal efficiencies that DOE found for 1975 gas furnaces –61.5 percent– than would be expected. While gas furnaces do not require as much maintenance as oil furnaces and can be made more easily in small sizes, duct losses would be expected to introduce a larger discrepancy than observed. DOE estimates that use of stack dampers, power burners, improved heat exchangers, and the replacement of pilot lights with electric ignition systems can improve the average seasonal efficiency of new furnaces to 75.0 percent.[12]

Steady-state and seasonal efficiencies above 90 percent have been measured for furnaces and boilers employing the "pulse combustion" principle, A gas-fired pulse combustion boiler will be marketed in limited quantities during the latter part of 1979 and an oil-fired unit has been developed by a European manufacturer who has expressed interest in marketing it in the United States. Research on a number of fossil fuel-fired heat pumps is underway and is sufficiently advanced that gas-fired heat pumps with coefficients of performance of 1.2 to 1.5 may be on the market in as little as 5 years. These furnaces and heat pumps are discussed in chapter XI.

Furnace Retrofits

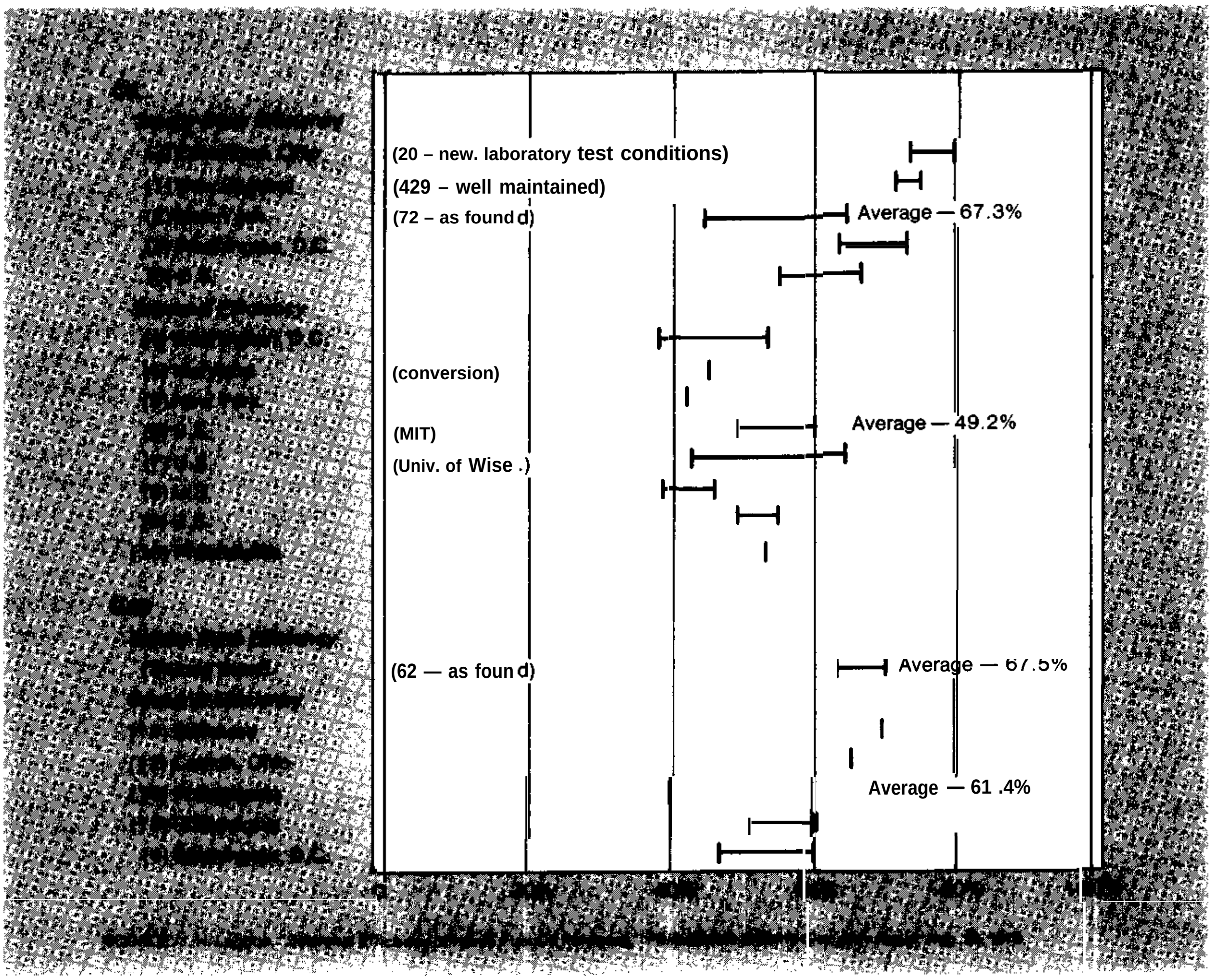
A number of different organizations are conducting tests of the improvements in furnace efficiency that can be achieved by retrofits, including the American Gas Association (AGA),

[10] Department of Energy, "Final Energy Efficiency Improvement Targets for Water Heaters, Home Heating Equipment (Not Including Furnaces), Kitchen Ranges and Ovens, Clothes Washers, and Furnaces," *Federal* Register, vol. 43, no. 198 (Oct. 12, 1978), 47118-47127.

[11] Ibid.

[12] Ibid.

Figure 10.— Residential Heating Systems



Brook haven National Laboratory (BNL), NBS, and the National Oil Jobbers Council. Only a few results are available now, but these indicate that meaningful savings can be achieved by retrofits.

The AGA program, which is known as the Space Heating System Efficiency improvement Program (SHEIP), involves tests in about 5,000 homes in all parts of the country. Preliminary findings based on the installations that were retrofitted prior to the 1976-77 winter found that adding vent dampers, making the furnace a more appropriate size, and other combinations all saved energy.[13] The size of the data sample is small and not adequate for generalizations. The savings provided by the adjusted system apparently depended on the initial condition of the heating system, the degree of oversizing, the location, and the vent system design.

Northern States Power Company (Minneapolis, Minn.) is participating in SHEIP and has monitored 51 homes that had been retrofit prior to the winter of 1977-78.[14] A variety of different retrofits were installed ranging from simply derating the furnace and putting in a vent restrictor to replacement of the furnace. While the sample is too small to draw conclu-

[13] ‘American C-as Association, “The Gas Industry’s Space Heating System Efficiency Improvement Program — 1976/77 Heating Season Status Report."

[14] Northern States Power Company, “1977-78 Season SHE I P Report “

sions about most of the individual retrofits, it is interesting to note that the retrofits resulted in an average reduction in fuel use (adjusted for weather) of 14. I percent for a cost savings of $42. The average installation cost of the retrofits was $163, but did not include the markup on the materials, which would have added $20 to $25 per installation on average. These results were achieved on furnaces that were all in good enough condition that they were expected to last for at least 5 years, so it is likely that their annual efficiencies were slightly higher than average. Thus, it seems probable that seasonal efficiencies of 70 percent can be achieved in gas furnaces that are in condition adequate for retrofitting. These retrofits did not include duct system insulation, which is clearly effective if the exposed ducts are in unconditioned space.

Heat Pumps

The seasonal performance factor for 39 different heat pump installations was recently measured in a study conducted by Westinghouse. " The heat pumps studied were made by several different manufacturers and were installed in 8 different cities. Figure 11 shows the actual performance of the installations (o and △) measured over two winters and the solid line represents the average measured seasonal performance factor as a function of the heating degree-days. Manufacturers performance specifications were used together with the measured heating demands of each house to calculate the theoretical seasonal performance factor for each installation, and the results were averaged to obtain the broken line shown in the figure. The horizontal dotted line represents the performance of an electric furnace. The figure shows that the average installation achieves 88 percent of the expected electricity savings in a 2,000 degree-day climate, but only 22 percent of the expected savings in an 8,000 degree-day climate.

The study also found that of the 39 installations, only three exceeded the theoretical seasonal performance factor[16] and four others had a seasonal performance factor at least 90 percent of the theoretical value. Six of the systems that performed near or above specification were located in climates with less than 3,000 heating degree-days, including all three that exceeded the theoretical value. (Duct losses were not included in either measuremerit.)

The deviation between the measured and the theoretical performance did not correlate with the age or size of heat pump model, but there was some indication that the theoretical performance underestimated the defrost requirements. Measurements made by NBS[17] on a single heat pump installation found a difference between measured and calculated seasonal performance factors virtually identical to that given by the equations on figure 11 for Washington, D.C. Much of this difference was due to inadequate consideration of defrost requirements in the calculated seasonal performance factor. While it was not possible to place a quantitative measure on installation quality, there seemed to be a qualitative correlation between the experience of the installer and the performance of the installation.[18] Inadequate duct sizing and improper control settings appeared to degrade the performance. Thus, it seems plausible that a combination of improved installer training and experience and modest technical improvements in heat pumps can result in more installations that achieve the theoretical performance levels.

Air-Conditioners

The average COP of air-conditioners on the market in 1976 was 2.0 under standard test

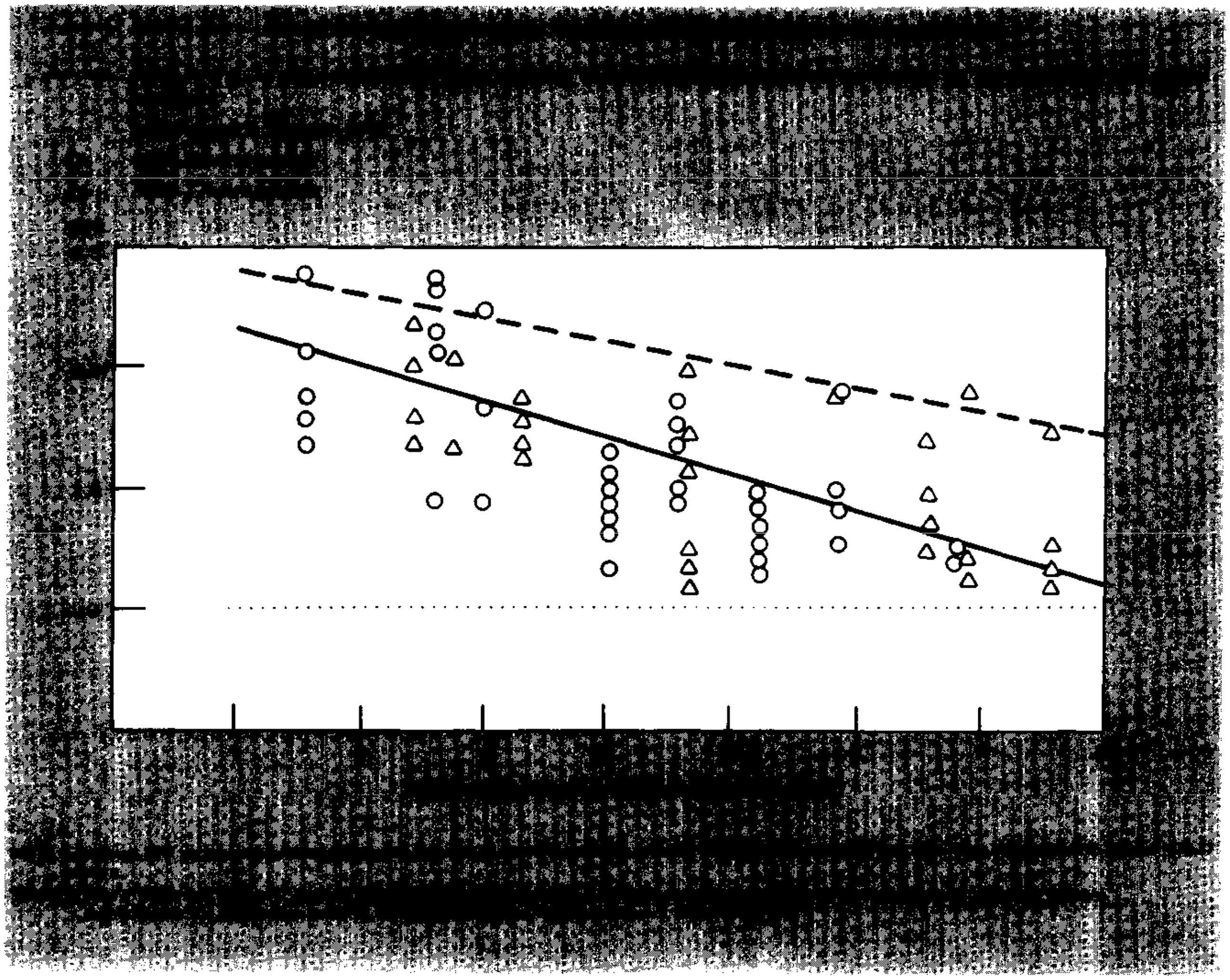
[15] Paul J. Blake and William C. Gernert, "Load and Use Characteristics of Electric Heat Pumps in Single-Family Residences," prepared by Westinghouse Electric Corporation for EPRI, EPRI EA-793, Project 432-1 Final Report, vol. 1, June 1978, pp. 2,1-12,13,

[16] "Insufficient data was available to calculate the theoretical performance factor for one of these cases, but the measured performance exceeded the theoretical performance of any other installation in that location.

[17] George E. Kelley and John Bean, "Dynamic Performance of a Residential Air-to-Air Heat Pump," National Bureau of Standards, NBS Building Science Series 93, March 1977.

[18] Paul Blake, Westinghouse Electric Corporation, personal communication, December 1978.

Figure 11 .—Performance of Installed Heating Systems



conditions.[9] However, some units were on the market that had COPS of 2.6. California will not allow the sale of central air-conditioners with a COP below 2.34 after November 3, 1979, and 11 5-volt room air-conditioners must have a COP of at least 2.55 after that date. It is estimated that the cost of increasing the COP of air-conditioners from 2.0 to 26 is about $10 per MBtu of hourly cooling capacity.[20] T o meet these standards and the Federal standards to be developed as directed by the National Energy Act, air-conditioners with larger condensers and evaporators, more efficient compressors, two-speed compressors, multiple compressors, etc., are coming into the market.

“George D Hudelson, (Vice President-Engineering, Carrier Corporation), testimony before the California State Energy Resources Conservation and Development Commission, Aug. 10,1976 (Docket No *75;* Con-3).

[20] I bid.

Appliance Efficiency and Integrated Appliances

Although the discussion so far has concentrated on the building shell and heating and cooling equipment, large savings can be achieved in other parts of residential use. I n figure 7, it was seen that appliances, lighting, and hot water account for 36 percent of the energy for the 1973 house. Therefore the potential is great, particularly for retrofit, because of the accessibility of appliances compared to some components of the building shell, such as the walls.

The effect of appliances includes the energy used to operate them and changes in the house's internal heat gains that change the heating and cooling load. As most appliances are used in conditioned space, they exhaust some heat into that space. As with any other change in the house, a careful examination of the system interaction must be made to determine the overall effect of an apparently simple change.

The overall effect of an improved appliance that consumes 100 kWh per year less than the unimproved version is illustrated in table 8. This figure shows the effect of such a change on two electric homes, one with resistance heating and one with a heat pump, in two climates. I n Chicago, where heating is the largest need, the improved appliance reduces total consumption only by half of the appliance savings when resistance heat is in use, but by 79 percent when a heat pump is used. This results from a drop in the appliance contribution to heat gain, due to greater appliance efficiency. I n Houston, where cooling is more important, total savings are greater than the savings of the appliances alone, since internal heat gain is reduced.

The Department of Energy has published what it has determined to be the maximum feasible improvements, technically and economically, for major appliances by 1980.2' 22 If appliances in the prototypical home were improved according to these estimates, the consumption of the improved appliance would be that shown in table 9. These target figures do not represent final technological limits, but only limits the Department believes can soon be achieved industry-wide. Some appliances now on the market equal or exceed these performance levels. A British study has estimated that the average energy use of the appliances shown in table 9 (other than water heaters) could be reduced to 41 percent of present consumption.[23]

As water heating is the second largest use of home energy (after heating) in most locations, a number of methods are under study to reduce this demand below the incremental improvements reflected in table 9. Heat pumps designed to provide hot water are in the works, and proponents expect they may be able to operate with an annual water heating COP of 2 to 3.[24] Because a heat pump removes heat from the air around it, a typical heat pump water heater will also provide space cooling about equal to that of a typical small window air-conditioner (one-half ton) in summer. Such a heater is expected to cost about $250 more than a conventional water heater.

Other approaches to the problem of heating water include use of heat rejected from the condenser of an air-conditioner, refrigerator, or freezer, or the recovery of heat from drain water. Air-conditioner heat pump recovery units now on the market cost $300 to $500 installed. Estimated hot water production ranges from 1,000 to 4,600 Btu per hour per ton of air-conditioning capacity.[25] The air-conditioner heat recovery unit is identical in concept to the heat pump water heater, but is fitted to existing air-conditioners or heat pumps. A unit installed on a 3-ton air-conditioner in the Baltimore area would reduce the electricity used for heating hot water in a typical home by about 26 percent.[26]

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[21]Department of Energy, "Energy Efficiency Improvement Targets for Nine Types of Appliances, " Federal Register, vol. 43, p. 15138 (Apr. 11, 1978).

"Department of Energy, "Energy Efficiency Improvement Targets for Five Types of Appliances," *Federal* Register, vol. 43, p. 47118 (Oct. 12, 1978),

"Gerald Leach, et al., A Low *Energy Strategy for the United Kingdom* (London: Science Reviews, Ltd., 1979), pp. 104,105.

"R. L. Dunning, "The Time for a Heat Pump Water Heater," proceedings of the conference on Major Home Appliance Technology for Energy Conservation, Purdue University, Feb. 27- Mar. 1,1978 (available from NTIS).

*'David W. Lee, W. Thompson Lawrence, and Robert P. Wilson, "Design, Development, and Demonstration of a Promising Integrated Appliance," Arthur D. Little, Inc., prepared for ERDA under Contract No. EY-76-C-03-1209, September 1977.

"Estimate by the Carrier Corporation for a family using 80 gal Ions of hot water per day.

Table 8.—The Impact of a 100 kWh/Year Reduction in Appliance Energy Usage on Total Energy Consumption

	Chicago		Houston	
	Resistance heat	Efficient heat pump	Resistance heat	Efficient heat pump
Appliance savings	100	100	100	100
Cooling savings	19	12	39	22
Additional heating	69	33	37	14
Total savings	50	79	102	108

NOTE: It is assumed that the resistance heating system has an efficiency of 0.9 (1O-percent duct losses) and a system cooling COP of 1.8. The heat pump system has a heating COP of 1.9 in Chicago and 2.36 in Houston with a cooling COP of 2.6. The heating season is assumed to be 7 months in Chicago and 4 months in Houston. The cooling season is assumed to be 35 months in Chicago and 7 months in Houston.
SOURCE: OTA

Table 9.—Energy Consumption of Improved Appliances for the Prototypical Home

Appliance	Energy consumption
Hot water heater -Gas	216 therms
-Electric	3,703 kWh
Cooking range/oven	1,164 kWh
Clothes dryer	950 kWh
Refrigerator/freezer	1,318 kWh
Dishwasher	290 kWh

NOTE: One therm = 29.3 kWh
SOURCE: OTA.

As knowledge of home energy use increases and prices of purchased energy rise, the use of appliance heat now wasted should become more common. Some building code provisions may have to be adjusted to encourage these uses.

The ACES System

The Annual Cycle Energy System (ACES) is an innovative heat pump system that uses substantially less energy than conventional heat pump systems. ” A demonstration house incorporating the ACES system has been built near Knoxville, Term., and uses only 30 percent as much energy for heating, cooling, and hot water as an identical control house with an electric furnace, air-conditioner, and hot water heater.

The ACES concept, which was originated by Harry Fischer of ORNL, uses an “ice-maker” heat pump in conjunction with a large ice bin that provides thermal storage. During the winter, the heat pump provides heating and hot water for the house by cooling and freezing other water. The ice is stored in a large insulated bin in the basement and used to cool the house during the next summer. After the heating season, the heat pump is normally operated only to provide domestic hot water. However, if the ice supply is exhausted before the end of the summer, additional ice is made by operating the heat pump at night when off-peak electricity can be used.

The efficiency of the system is higher in all modes of operation than the average efficiency of conventional systems. The “heat source” for the heat pump is always near 320 F so it is never necessary to provide supplemental resistance heating and the ACES operates with a measured COP of 2.77 as shown in table 10. When providing hot water, the system has a COP slightly greater than 3, which is com-

Table 10.— Full-Load Performance of the ACES System

Function	Full-load COP
Space heating with water heating	2.77
Water heating only	3.09
Space cooling with stored ice	12.70
Space cooling with the storage > 32° F and < 45° F	10.60
Night heat rejection with water heating[a]	0.50 (2.50)

[a]In the strict accounting used here, only the water heating is calculated as a useful output at the time of night heat rejection because credit is taken for the chilling when it is later used for space cooling. This procedure results in a COP of 0.5. If the chilling credit and the water-heating credit are taken at the time of operation, then a COP of 2.5 results.

[27] A. S. Holman and V. R. Brantley, “ACES Demonstration: Construction, Startup, and Performance Report, ” Oak Ridge National Laboratory report ORNL/CON-26, October 1978.

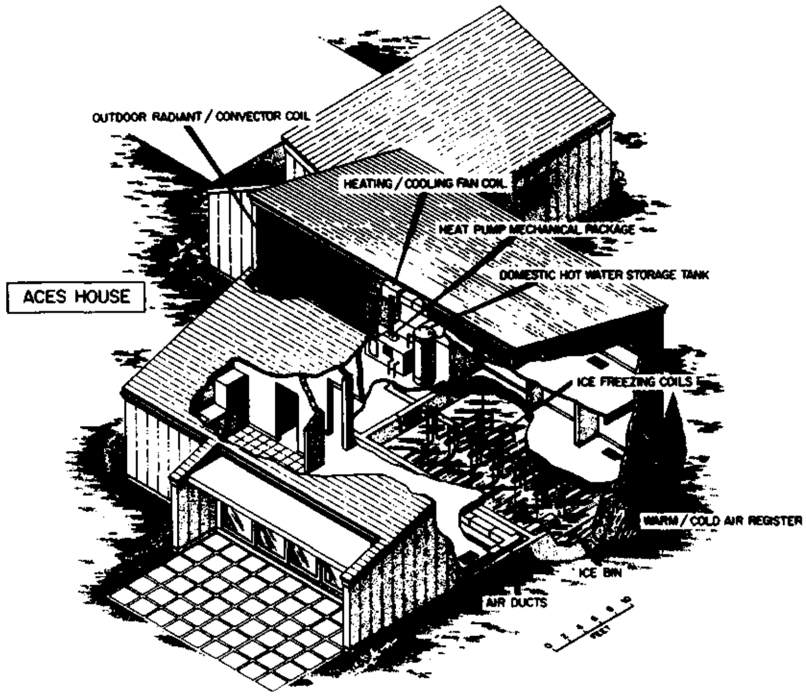


Photo credit: Oak Ridge National Laboratory

The Annual Cycle Energy System (ACES) design is passive energy design utilizing, as its principal component, an insulated tank of water that serves as an energy storage bin

Photo credit: **U.S.** *Department of Energy*

Energy-saving constructed home in California utilizing solar energy

parable to the heat pump water heaters under development and much better than the conventional electric hot water heater COP of 1. The system provides cooling from storage with a COP of more than 10.

The ACES demonstration house is a 2,000-ft^2, single-family house. It is built next to the control house that has a similar thermal envelope so both houses have nearly identical heating and cooling loads. Both houses are well insulated although not as highly insulated as the "low energy house" of this chapter. The thermal shell improvements reduce the annual heating requirements (20.3 MMBtu) to less than half those of a house insulated according to the Department of Housing and Urban Development (HUD) minimum property standards (43.8 MMBtu) but increase the seasonal cooling requirement from 22.7 to 24.1 MMBtu. The use of natural ventilation for cooling when practical lowers the cooling requirements of the ACES house to 17.1 MMBtu.

The actual space- and water-heating energy requirements for the ACES house are shown in table 11 for a 5-month period during the 1977-78 winter. The ACES system used 62 percent less energy than would have been required if the house had used an electric furnace with no duct losses and an electric hot water heater. It used 35 percent less energy than the theoretical requirements of a conventional heat pump/electric hot water heater system. These measurements combined with estimates of the summer cooling requirements show that the ACES system will use only 30 percent of the energy for heating, cooling, and hot water that would be used by the control house with a conventional all-electric system. This is only 21 percent of the energy that would be used for these purposes by this house if constructed to HUD minimum property standards (This is nearly identical to the reduction shown for the low-energy house.)

Table 11.—Actual Space- and Water-Heating Energy Requirements of the ACES Demonstration House[a]

	Load (kWh)	ACES consumption (kWh)	Elec. furnace, elec. water heater consumption (kWh)	Heat pump, elec. water heater consumption (kWh)
Heating	10,546	4,960	10,546	5,021
Hot water	2,657		2,657	2,657
Total	13,203	4,960	13,203	7,678

[a]Covers period from Oct. 31, 1977 through Mar. 26, 1978.

SOURCE: A. S. Holman and V. R. Brantley, "ACES Demonstration: Construction, Startup, and Performance Report," Oak Ridge National Laboratory, Report ORNL/CON-26, October 1978, pp. 43,47.

ENERGY SAVINGS IN EXISTING HOMES–EXPERIMENTS

Although the calculations of heating and cooling loads discussed above were given for new homes, they hold as well for retrofit of existing homes to the extent retrofit is feasible. As the majority of the housing stock between now and the year 2000 is already built, however, it is important to examine the potential for savings by retrofit in more detail. To improve the thermal qualities of the shell, consumers are urged to weatherstrip, caulk, insulate the attic, and add storm windows, often in that order. This is correct for most homes, but resulting savings will vary. Princeton University and NBS have conducted extensive and thoroughly monitored "retrofits" of houses, and Princeton has undertaken an extensive project involving retrofit and monitoring of 30 townhouses in an area known as Twin Rivers, N.J. The results of this work suggest that large savings are possible on real houses through careful work but that much field work is needed before the full impact of changes is understood.

Thirty townhouses near Princeton, N. J., were improved with different combinations of four options thought to be cost-effective. The houses were constructed with R-11 insulation in the walls and attic, and some units had double glazing. Thus, they were more energy efficient than the average existing house built up to that time. Improvements used by the Princeton researchers were: 1) increasing the attic insulation from R-11 to R-30; 2) sealing a shaft around the furnace flue, which ran from the basement to the attic and released warm air past the attic insulation; 3) weatherstripping windows and doors, caulking where needed, and sealing some openings between the basement and fire walls that separate the houses; and 4) insulating the furnace and its warm air distribution system and adding insulation to the hot water heater.[28]

These retrofits showed winter heating savings averaging about 20 percent for the two attic retrofits and up to 30 percent for the total package. [29 30] Savings varied considerably; this was due to changes in temperature and sunlight combined with changing living patterns of the occupants (al I houses were occupied).

The savings measured are consistent with the reduction in heating required in 600 houses that received attic insulation retrofit through the Washington Natural Gas Company (Seattle) in autumn 1973. These houses indicated an average reduction of gas consumption of 23 percent.[31]

While the Twin Rivers retrofits were conventional, there were some choices the average homeowner would have missed. These choices were important. Plugging the space around the flue and the spaces along the firewall stopped heated air from bypassing the insulation. (Closing openings in the basement also contributed.) Engineering analysis indicated that up to 35 percent of the heat escaping from the townhouses as built occurred via the insulation bypass–heated air was flowing up and out of the house by direct escape routes! 32

[28] David T, Harrje, "Details of the First Round Retrofits at Twin Rivers," *Energy and Buildings 1 (1977/78),* p. 271.

*'Robert H. Socolow, "The Twin Rivers Program on Energy Conservation in Housing: Highlights and Conclusions," Energy *and Buildings 1* (1977/78), p. 207.

[30] Thomas H. Woteki, "The Princeton omnibus Experiment: Some Effects of Retrofits on Space Heating Requirements" (Princeton University Center for Environmental Studies, 1976), Report No. 43, 1976.

[31] Donald C. Navarre, "Profitable Marketing of Energy-Saving Services, " *Utility Ad Views, July/August* 1976, p. 26.

"Jan Beyea, Bautam Dutt, and Thomas Woteki, "Critical Significance of Attics and Basements in the Energy Balance of Twin Rivers Townhouses, " *Energy and Buildings 1 (1* 977/78), p. 261.

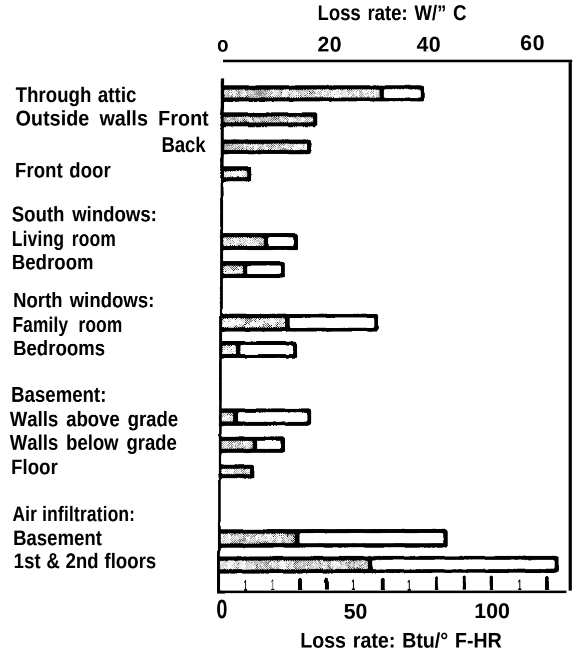
This experience suggests that retrofit will be most effective when based on an energy audit by someone who can identify specific characteristics of the structure, and it further suggests the need for more carefully monitored experiments to identify other common design defects.

Princeton researchers also conducted an intensive retrofit on a single townhouse with careful before-and-after measurements. Attic insulation was increased to R-30 as in the group retrofit, and the hole around the flue and gaps along the firewall were plugged as before. For this experiment, however, the old insulation was lifted and additional holes around pipes and wires entering the attic were plugged. More holes along the partition walls at the attic were filled; the joint between the masonry and the wood at the top of the foundation was sealed, and basement walls were insulated. Careful caulking and weather-stripping was used, and a tracer test to locate small air leaks identified tiny holes. Total labor involved in reducing infiltration was 6 worker-days, and the final infiltration rate was less than 0.4 air changes per hour, even with winds higher than 20 mph.

Different treatments were used for windows. Sliding glass doors were improved through adding a storm door. Windows not used for visibility were covered with plastic bubble material placed between two sheets of glass. This type of window covering created an R-value of 3.8, compared with 1.8 for single glass plus a storm window. The living room windows were equipped with insulating shutters, to be closed at night.

Figure 12 shows engineering estimates of the losses through various parts of the house, before and after retrofit. Largest reductions came from lowered infiltration, but it is clear that total reduction in thermal losses was produced by many small adjustments. Thermal losses were reduced to 45.5 percent of their preretrofit value, and annual heating requirements (calculated considering internal heat gain and sunlight) showed the heating system would have only one-third the load of the original system. These impressive numbers are especially significant because the house

Figure 12.— Handbook Estimates of Loss Rates Before and After Retrofit



SOURCE: F. W. Slnden, "A Two-Thirds Reduction in the Space Heat Requirement of a Twin Rivers Town house," *Energy and Buildings* 1, 243, 1977-78.

Shaded areas indicate loss rate following retrofit

was built in 1972, and thus had lower thermal losses as built than most existing stock.

The materials cost $425 and required some 20 worker days for installation. Some items were hand built, so labor requirements were high. Since this work, additional loss mechanisms have been discovered in the party walls of adjoining townhouses,[33] and correction of these flaws should reduce the heating requirement to 25 percent of the original value.

The National Bureau of Standards monitored the heating requirements of a 2,054 ft[2] house (commonly called the Bowman house) in the winter of 1973-74, and continued to monitor during a three-stage retrofit the following winter.[34] A single-story wood-frame house with unheated half basement and crawl space, the house was built with R-11 attic insulation, and uninsulated walls and floors. Windows were single-glazed except for a living room picture window. The house is surrounded by trees on all sides and has dense shrubbery along the north wall. It showed evidence of above-average craftsmanship in construction. All these factors combined to produce air infiltration rates ranging from one-quarter to two-thirds air change per hour in extreme conditions; this is unusually low.

First retrofits were planned to reduce infiltration — careful caulking, weather-stripping, replacement, or reglazing of window panes. The fireplace damper was repaired, a spring-loaded damper was installed on the kitchen vent-fan, and the house was painted inside and out. There was no measurable difference in infiltration after the retrofits.

The next step was to install wooden-sash storm windows, which cut the heat loss of the house by 20.3 percent.

Finally, blown cellulose insulation was added to increase the attic to R-21, al I exterior

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[33] Robert H Socolow, "1 ntroduction, " *Energy and Buildings 1 (1977/78),* p. *203.*

[34] D. M Burch and C M Hunt, "Retrofitting an Existing Wood-Frame Residence for Energy Conservation – An Experimental Study," NBS Building Science Series 105, July 1978.

walls were insulated (with blown fiberglass, blown cellulose, and urea-formaldehyde foam in different walls), R-11 insulation was placed under the floor over the basement, and R-1 9 over the crawl space. The addition of this insulation cut the heat loss from the house by another *23* percent, but actually resulted in a slight increase in the infiltration rate, a result not fully understood.

Table *12* shows the resulting reduction in thermal losses of the house, based on an assumed occupancy pattern. Thermal losses went down 43.3 percent, and the annual heating system load was reduced by 58.5 percent. Tables 13 and 14 show calculated steady-state heat losses before and after retrofit.

Table 12.—Comparison of Reductions in Heat-Loss Rate to Reductions in Annual Heating Load

Retrofit stage	Reduction in heat-loss rate %	Reductions in annual heating load, %.
Preretrofit (and Stage 1) . .	0	0
Stage 2	20.3	25.2
Stage 3	23.3	33.3
Combination . . . .'. . .	43.3	58.5

SOURCE: D. M. Burch and C. M. Hunt, "Retrofitting an Existing Wood-Frame Residence for Energy Conservation-an Experimental Study," NBS Building Science Series 105, July 1978.

Table 13.—Preretrofit Steady-State Winter Heat-Loss Calculations

Heat-loss path	Heat-loss-rate Btu/h		Percent of total	
Walls.	9,617		28.0	
Ceiling	4,020		11.7	
Floor				
Over crawl space. .	3,201	3,493	9.3	
Over basement . . .	292		0.9	
Windows				
Single pane	8,395	„272	24.4	29.9
Insulating glass. . .	1,877		5.5	
Doors	924		2.7"	
Air Infiltration	6,010		17.5	
(1 = 0.51 h^{-1})[a]				
Total	34,336		100	

aBased on preretrofit air-infiltration correlation, indoor temperature of 68° F and outdoor temperature of 32" F.

SOURCE: D. M. Burch and C. M. Hunt, "Retrofitting an Existing Wood-Frame Residence for Energy Conservation-an Experimental Study," NBS Building Science Series 105, July 1978.

Table 14.—Postretrofit Steady. State Winter Heat-Loss Calculations

Heat-loss path	Heat-loss-rate Btu/h		Percent of total
Walls			
Cellulose.	2,845	3,284	15.6
Glass fiber	210		
Urea formaldehyde	229		
Ceiling.	2,057		9.8
Floor			
Crawl space	844	1,077	4.0
Basement	233		1.1
Windows			
Double pane	4,115	5,992	28.5
Insulating glass	1,877		
Doors.	924		4.4
Air Infiltration.	7,659		36.5
(I = 0.51 h^{-1})[a]			
Total	20,993		100

[a]Based on postretrofit air-infiltration correlation, indoor temperature of 68°F and outdoor temperature of 32° F.

SOURCE: D. M. Burch and C. M. Hunt, "Retrofitting an Existing Wood-Frame Residence for Energy Conservation—an Experimental Study," NBS Building Science Series 105, July 1978.

The summer cooling load was slightly increased. Insulation added to the walls and attic reduced heat gain and a polyethylene sheet placed in the crawl space reduced the moisture entering the house, but these reductions were offset by the reduction in cooling resulting from the passage of air through the floor to the basement space.

The experiments at NBS and Princeton suggest possible heating savings of at least 50 percent through straightforward improvements, even in well-constructed houses. They also show that these levels will be reached only through careful examination of the structure, and that our general knowledge of the dynamics of retrofit is not very sophisticated. Additional careful monitoring of actual houses is needed. Such data will help us to obtain better values for public and private investments.

INTEGRATING IMPROVED THERMAL ENVELOPE, APPLIANCES, AND HEATING AND COOLING EQUIPMENT

The overall reduction in household energy use is not determined solely by the thermal envelope improvements; it is also influenced by the type and efficiency of heating, cooling, and water heating equipment used as well as the other appliances. This can be seen in table 15, which shows the total primary energy consumption for five different sets of equipment in the three different simulation houses discussed earlier.

The equipment packages assumed range in performance from that typical of many existing installations to systems with above average but still below many existing commercial facilities. Gas and electric heating equipment is used to illustrate around the country. Price, availability or other considerations lead to the choice of oil, wood, or solar in many new homes.

The effect of the thermal envelope or equipment improvements is rather similar in Chicago and Baltimore. The extra attic insulation, storm windows, and insulated doors of the 1976 house reduce consumption by 12 to 14 percent. Replacing the electric furnace with a heat pump cuts consumption to 72 percent of the baseline 1973 performance. The low-energy, all-electric house starts with a well-insulated and tight thermal shell, uses a heat pump installed to meet predicted performance, and improved appliances. The only equipment not now commercially available in residential sizes is the heat pump providing the hot water. This house uses 36 to 39 percent of the energy of the 1973 house. The low-energy gas-heated house is comparably equipped, except that it uses an improved furnace, air-conditioner, and hot water heater as shown in table 16. It uses about 55 percent of the energy of the baseline gas-heated house. The reduction is smaller than for the all-electric house, as heating represented a much larger fraction of the primary energy consumption in the baseline all-electric house than in the gas-heated house.

In Houston, the qualitative changes observed are similar, but the absolute and fractional reductions observed are generally considerably smaller since heating and cooling are initially a smaller fraction of the total consumption. For the 1976 house, the heating load is already small enough that the heat pump cuts only 3 percent from total consumption. It

Table 15.—Primary Energy Consumption for Different House/Equipment Combinations (in MMBtu)

	Chicago		Bait i more		Houston	
	Consumption	Percent of 1973 use	Consumption	Percent of 1973 use	Consumption	Percent of 1973 use
All-electric houses						
"1973" house with electric furnace.	491	100	400	100	294	100
"1976" house with electric furnace.	424	86	351	88	271	92
"1976" house with heat pump	353	72	286	72	261	89
Low-energy house with heat pump.	176	36	154	39	161	55
Gas-heated houses						
"1973" house	311	100	271	100	252	100
"1976" house	277	89	244	90	240	95
Low-energy house	168	54	150	55	160	63

NOTES: Primary energy consumption is computed assuming that overall conversion, transmission, and distribution efficiency for electricity is 0.29 and that processing, transmission, and distribution of natural gas is performed with an efficiency of 0.89
1 MMBtu = 1.05 GJ.
SOURCE: OTA

Table 16.—Equipment Used in Prototypical Baltimore Houses

House	Heating system	Cooling system	Hot water	Appliances
All electric				
"1973" house with electric furnace.	Electric resistance furnace with 90°/0 system efficiency incl. 10°/0 duct losses.	Central electric air-conditioning system with COP = 1.8 incl. 10% duct losses.	Electric hot water heater with 800/0 efficiency.	Appliances and usage as shown in table 19.
"1976" house with electric furnace.	Same as above.	Same as above	Same as above.	Same as above.
"1976" house with heat pump	Electric heat pump with seasonal performance factor of 1.26 (Chicago), 1.48 (Baltimore), or 1.88 (Houston) incl. 1O°/. duct losses.	Electric heat pump with COP = 18 incl. 10% duct losses,	Same as above.	Same as above.
Low-energy house with heat pump.	Electric heat pump with seasonal performance factor of 1.90 (Chicago), 2.06 (Baltimore), and no duct losses. Houston has no heating system.	Electric heat pump with COP = 2.6 and no duct losses.	Electric heat pump with COP =2. Hot water supplied by heat recovery from air-conditioner during cooling season.	Same as above except usage given by table 9 for appliances listed there.
Gas heated				
"1973" house	Gas furnace with 60% seasonal system efficiency.	Central electric air-conditioning system with COP = 18.	Gas hot water heater with 44% efficiency.	Appliances and usage as shown in table 19.
"1976" house	Same as above.	Same as above	Same as above.	Same as above
Low-energy house	Gas furnace with 75% seasonal system efficiency,	Central electric air-conditioning system with COP = 2.6 and no duct losses.	Gas hot water heater with 55% efficiency.	Same as above except usage given by table 9 for appliances listed there.

is also interesting to note that in all three cities, the primary energy requirement for the gas-heated low-energy house is almost the same as that of the one with the heat pump.

The changes that have been incorporated in the low-energy house vastly alter the fraction of total consumption that goes to each end use. Figure 13 shows that appliances and lighting now use 61 percent of the total (in Baltimore) while they used only 25 percent of the total for the 1973 house. Appliance use has been reduced slightly, but the total for other uses has been reduced by 80 percent. The disaggregate use for each house is shown in tables 23, 24, and 25.

Part of the reductions shown in table 15 are due to the use of improved heating and cooling equipment. The low-energy gas-heated house uses a furnace with a seasonal efficiency of 75 percent while the 1976 house has an efficiency of only 60 percent. The improved furnace is equivalent to thermal envelope im-

Figure 13.—Disaggregated Point, of Use Energy Consumption for the Low-Energy House With Heat Pump in Baltimore, Md.

1 MMBtu = 105 gigajoule (GJ)
Source Based on tables 19-25

provements that reduce the heating load by 20 percent, which points out that the retrofit of equipment needs to be considered for existing housing. It may pay to consider an improved furnace before retrofitting wall insulation. Each case must be decided separately, but where insulation already exists in accessible places (attic, storm windows) the heating system offers considerable potential.

A number of additional steps— not considered in the computer simulation — could be taken to reduce consumption even further. Cooling requirements could be reduced by using outside air whenever temperatures and humidity are low enough. South-facing windows could easily be increased to reduce the heating requirements and it might be possible to reduce the hot water requirements by lowering the water temperature or using water-conserving fixtures. Appliance usage could clearly be cut because no fluorescent lighting is used, and the "efficient" appliances used represent only the industry-weighted average performance, which can be achieved by 1980.

LIFECYCLE COSTING

Dramatic savings in energy consumption have been shown to be readily achievable through existing technology. However, most consumers are more interested in saving money than saving energy. Comparison of two alternative purchases— buying additional equipment now and making smaller operating payments versus paying less now but assuming larger operating cost– is always difficult. Few homeowners resort to sophisticated financial analysis, but they may consider the "payback" time required for operating savings to return the initial capital investment. This figure is frequently calculated without considering future inflation in the operating costs— and hence in operating savings —or interest on the money invested.

A more sophisticated approach involves "lifecycle costing," which can be useful for policy purposes even if individual homeowners do not use it. Lifecycle costing, as used in this section, combines the initial capital investment with future fuel and operating expenditures by computing the present value of all future expenditures. The levelized monthly energy cost is then computed as the constant monthly payment that would amortize over 30 years a loan equal to the sum of the initial investment and the present value of al I future expenditures. The methodology and assumptions used are described in detail in volume 11, chapter I of the OTA solar study .35 The "interest rate" assumes that three-quarters of the investment is financed with a 9-percent mortgage and that the homeowner will receive a 10-percent after tax return on the downpayment. It also considers payments for property taxes and insurance and the deductions from State and Federal taxes for interest payments. Future operating expenses include fuel costs, equipment replacement, and routine equipment operating and maintenance costs, all of which assume that inflation occurs at a rate of 5.5 percent. The present value of these expenses is calculated using a discount rate of 10 percent. It is generally agreed that future energy costs will not be lower than now (in constant dollars), but beyond that projections differ as a result of the different actions possible by the Government, foreign producers, and consumers. This study calculates levelized monthly costs for three different energy cost assumptions: 1) no increase in constant dollar prices; 2) oil and electricity prices increase by about 40 percent, while gas prices double (in constant dollars) by the year 2000 as projected by a Brook haven National Laboratory (BNL) study; and 3) a high projection where prices approximately triple by the year 2000 (see figure 4, chapter I). The detailed assumptions about the energy costs are given in volume 11, chapter I I of the OTA solar study above.

The levelized monthly costs for each of the houses described in table 15 are presented in tables 17 and 18 for each of the energy price increase trajectories described above. Two different starting prices are assumed, correspond-

[35] *Application of Solar Technology to Today's* Energy Needs (Washington, D. C.: U.S. Congress, Office of Technology Assessment, September 1978), vol. 11.

Table 17.—Levelized Monthly Energy Cost in Dollars for Energy Price Ranges Shown (All electric houses)

All-electric houses	Primary energy consumption[a] (MMBtu)	Gas: 1.08 Electricity: 2.5	1.08-2.40 2.5-3.6	1.08-3.52 2.5-8.2	3.22 4.4	3.22-7.03 4.4-6.4	3.22-10.60 4.4-14.4
		Price range 1976-2000 in 1976 dollars[b]					
Chicago							
"1973" house with electric furnace......	491	183	244	492	293	398	828
"1976" house with electric furnace......	424	170	224	442	268	362	743
"1976 house with heat pump.....	353	175	221	408	260	341	668
Low-energy house with heat pump...	176	138	165	273	192	240	435
Baltimore							
"1973" house with electric furnace......	400	158	209	416	252	341	703
"1976" house with electric furnace......	351	150	195	381	235	315	641
"1976" house with heat pump..........	286	156	195	351	230	297	573
Low-energy house with heat pump......	154	136	160	257	185	229	407
Houston							
"1973" house with electric furnace......	294	129	168	328	204	273	556
"1976" house with electric furnace......	271	128	165	315	199	264	530
"1976" house with heat pump..........	261	150	185	331	218	282	541
Low-energy house.....	161	123	147	248	173	219	403

[a]Primary energy consumption is Computed assuming that overall conversion, transmission, and distribution efficiency fOr electricity is 0.29 and that processing transmission, and distribution of natural gas is perfor-med with an efficiency of 0.89
[b]Gas prices in $/MMBtu and electricity in ¢/kWh.

Table 18.— Levelized Monthly Energy Cost in Dollars for Energy Price Ranges Shown (Gas heated houses)

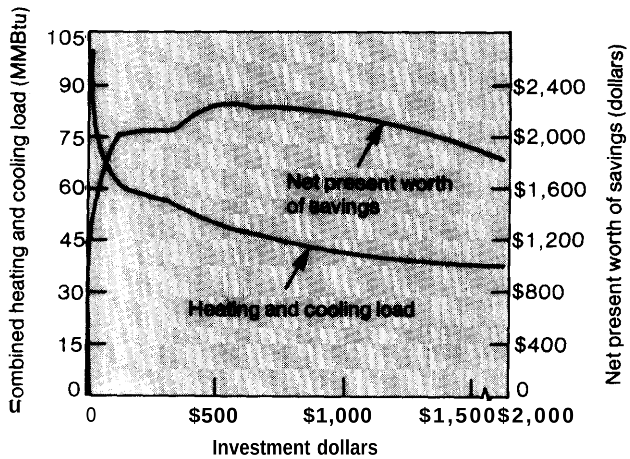
Gas-heated houses	Primary energy consumption (MMBtu)	Gas: 1.08 Electricity: 2.5	1.08-2.40 2.5-3.6	1.08-3.52 2.5-8.2	3.22 4.4	3.22-7.03 4.4-6.4	3.22-10.60 4.4-14.4
		Price range 1976-2000 in 1976 dollars[b]					
Chicago							
"1973" house.........	311	111	160	272	204	323	553
"1976" house.........	277	111	155	261	193	298	511
Low-energy house.....	168	117	144	232	168	225	387
Baltimore							
"1973" house.........	271	106	148	257	188	288	507
"1976" house.........	244	107	145	249	181	270	475
Low-energy house.....	150	110	135	221	157	206	364
Houston							
"1973" house.........	252	114	151	280	186	261	501
"1976' 'house..........	240	115	150	274	184	254	484
Low-energy house.....	160	117	142	238	169	217	397

[a]primary energy consumption is computed assuming that overall conversion, transmission, and distribution efficiency for electricity is 0.29 and that Processing, transmission, and distribution of natural gas is performed with an efficiency of 0.89
[b]Gas prices in $/MMBtu and electricity in ¢/kWh
1 MMBtu = 1.05 GJ.

ing to prices in different parts of the country. The price ranges shown at the top are those in 1976 and in 2000, both expressed in 1976 dollars. Only in the case of gas-heated homes and constant energy prices for low-priced gas ($1.08/MMBtu) does it appear not to pay to go to the low-energy home. Thus, not only can investment in conservation provide substantial energy savings but also significant dollar savings as well. It is interesting that heating requirements for the 1976 house in Houston are so small that the added capital investment for a heat pump is not justified.

It is important that although the low-energy home reduces lifecycle costs it does not necessarily represent the combination of improvements that would have the lowest possible levelized monthly costs for a given set of economic assumptions. Although such a calculation has not been performed for this set of houses, one has been done for the houses modeled by ORNL discussed above. The ORNL calculations show only improvements to the building shell, rely on an uninsulated baseline house, and require a higher return on investment than the OTA calculations. Figure 14 shows the combined heating and cooling energy savings relative to the base case, and total costs (investment and fuel) over the life of the house plotted against the initial investment. While energy savings continue to increase as investments grow, the total dollar savings reach a maximum (corresponding to minimum lifecycle cost) at an investment of about $550. After that the increase in investment to get more energy savings grows faster than the increase in fuel cost savings. This calculation was done for the BNL fuel cost projection, and if one used the higher price range, the investment for minimum lifecycle cost would be much greater than $500 — meaning greater energy savings.

Figure 14.—Lifecycle Cost Savings vs. Conservation Investment for a Gas-Heated and Electrically Air-Conditioned House in Kansas City



1MMBtu = 105 glgajoule (GJ)

SOURCE Paul F Hutchins, Jr., and Eric Hlrst, "Engineering-Economic Analysis of Single-Family Dwelling Thermal Performance, " Oak Ridge National Laboratory Report ORNL/CON-35, November 1978, tables 7 and 8.

Although one could not reasonably expect a person to go beyond the point that gives a minimum lifecycle cost (indeed, this is the point assumed in the projections discussed in chapter I), additional energy savings are possible. If these savings are desirable from society's point of view, then other economic incentives, such as tax credits, are called for to make the additional investments attractive.

TECHNICAL NOTE ON DEFINITIONS OF PERFORMANCE EFFICIENCY

At least eight different terms are used to describe the energy efficiency of furnaces, heat pumps, and air-conditioners, and the list could grow. Manufacturers have traditionally used efficiencies based on operation under specified steady-state conditions, but there has been growing interest in seasonal measures that would more nearly reflect performance of a home installation. The Energy Policy and Conservation Act (EPCA– Public Law 94-163) as amended by the National Energy Conservation Act (NEPCA — Public Law 95-619) required DOE to establish testing standards for the determination of estimated annual operating costs and "at least one other measure which the Secretary determines is likely to assist consumers in making purchasing decisions" for heating and cooling equipment and a number of appliances. Manufacturers are required to use these test procedures as the basis for any representations they make to consumers about the energy consumption of their equipment. The test procedures developed by DOE emphasize the use of seasonal efficiency measures. These should eventually be more useful to consumers but are likely to lead to increased confusion at first.

The performance of furnaces is customarily described in terms of efficiency. The "steady state efficiency" of a furnace refers to the fraction of the chemical energy available from the fuel (if burned under ideal conditions), which is actually delivered by the furnace when it is properly adjusted and all parts of the system have reached operating temperature. An actual home installation is seldom in perfect adjustment, heat is lost up the chimney while the furnace is not operating, and the duct systems that distribute heat always have some losses unless they are completely contained within the heated space. Thus, the "seasonal system efficiency" is typically much lower than the steady state efficiency. DOE has developed procedures for determining a seasonal efficiency, which is called the "annual fuel utilization efficiency."

Air-conditioners "pump" heat out of the house and are able to remove more than a Btu of heat for each Btu of electrical input. The usual measure of air-conditioner performance has been a somewhat arbitrary measure called the "energy efficiency ratio" or EER, which is defined to be the number of Btu of cooling provided for each watt-hour of electric input. The standard conditions for determining the EER have been 800 F dry bulb and 670 F wet bulb indoors and 950 F dry bulb and 750 F wet bulb outdoors.[36] DOE has retained the use of the EER for room air-conditioners in its test procedures[37] but has also adopted the use of a seasonal energy efficiency ratio (SE E R) for central air-conditioners.[38] The seasonal energy consumption of an air-conditioner is increased by cycling the machine on and off since it does not operate at full efficiency for the first minute or so after it is turned on. An offsetting factor is provided by the increase in EER that occurs as the outdoor temperature drops. The seasonal energy efficiency ratio incorporates both of these effects and is defined on the basis of a typical summer use pattern involving 1,000 hours of operation, Use of the SEER became effective January 1,1979.

A final word should be added about heat pumps and their air-conditioning mode. The proposed DOE standards for heat pumps define tests for the heating seasonal performance factors (HSPF) in each of six different broadly defined climatic regions of the country. Cooling seasonal performance may be specified by a cooling seasonal performance factor (CSPF) or an SEER. In addition, an annual performance factor (APF) is defined as a weighted average of the HSPF and the CSPF based on the number of heating and cooling hours in different parts of the country.[39]

Since heat pumps, as their name implies, pump heat into the house from outdoors, they can provide more heat to the house than would be provided if the electricity were "burned" in an electric heater or furnace. The Coefficient of Performance (COP) is the ratio of the heat provided by the heat pump to that which would be provided by using the same amount of electricity in an electric heating element. The COP of a heat pump decreases as the outdoor temperature drops, and the Air Conditioning and Refrigeration Institute has specified two standard rating conditions for

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[36] Air-Conditioning and Refrigeration Institute, "Directory of Certified Unitary Air-Conditioners, Unitary Heat Pumps, Sound-Rated Outdoor Unitary Equipment, and Central System Humid ifiers," 1976 (Arlington, Va.), p. 85.

[37] "Test Procedures for Room Air Conditioners," *Federal Register,* vol. *42, 227, Nov 25, 1977,* pp. 60150-7 and *federal Register, vol. 43, 108, June* 5, 1978, pp. 24266-9.

[38] "Test Procedures for Central Air Conditioners," *Federal Register,* vol. 42,105, June 1, 1977, pp. 27896-7.

[39] "Proposed Rulemaking and Public Hearing Regarding Test Procedures for Central Air Conditioners Including Heat Pumps," *Federal Register,* vol. *44, 77,* Apr. 19, 1979, pp. 23468-23506.

heat pump heating performance. [40] Both specify indoor temperature of 700 F dry bulb and 600 F wet bulb with outdoor temperature for the "high temperature heating" condition being 470 F dry bulb and 430 F wet bulb, and specifications for "low temperature" being 170 F dry bulb and 150 F wet bulb. Heat pumps are usually sized so that part of the heating load must be met by supplementary resistance heat at lower temperatures, lowering the overall COP still further. A useful measure of the total heating performance is the "seasonal performance factor," which is the average COP over the course of the winter for a typically sized unit in a particular climate. The seasonal performance factor includes the effects of supplementary resistance heating and cycling but does not include any duct losses.

[40] Air-Conditioning and Refrigeration Institute, op. cit., pp. 8,85.

Table 19.—Structural and Energy Consumption Parameters for the Base 1973 Single-Family Detached Residence

Structural parameters:	
Basic house design	3-bedroom rancher, one story, 8-ft stories.
Foundation	Full basement, poured concrete.
Construction	Wood frame, 2x4 studs 16" on ctr.
Exterior walls:	
Composition	Brick vener, 4" ½" insulation board 3½" fiberglass batts ½" gypsum board
Wall framing area, ft²	203 sq. ft.
Total wall area, ft²	935 Sq. ft.
Roof:	
Type	Gable
Composition	Asphalt shingles, 3/8" plywood sheating, air space, 6" fibreglass loose-fill insulation, ½" gypsum board
Roof framing area, ft²	78 sq. ft.
Total roof area, ft²	1,200 Sq. ft.
Floor:	
Total floor area, ft²	1,200 Sq. ft.
Windows:	
Type	Double hung, wood
Glazing	Single
Area, ft²	105 Sq. ft.
Exterior doors:	
Type	Wood frame
Number	Two
Area, ft²	40 Sq. ft.
Patio door(s):	
Type	Aluminum, sliding
Glazing	Double
Area, ft²	40 Sq. ft.
Energy consumption parameters:[a]	
Energy consuming equipment:	
Heating system	Gas, forced air
Cooling system	Electric, forced air
Hot water heater	Gas (270 therms/year)
Cooking range/oven	Electric (1 200 kWh/year)
Clothes dryer	Electric (990 kWh/year)
Refrigerator/freezer	Electric (1 830 kWh/year)
Lights	Electric-incandescent (21 40 kWh/year)
Color TV	Electric (500 kWh/year)
Furnace fan	Electric (394 kWh/year)
Dishwasher	Electric (363 kWh/year)
Clothes washer	Electric (103 kWh/year)
Iron	Electric (144 kWh/year)
Coffee maker	Electric (106 kWh/year)
Miscellaneous	Electric (900 kWh/year)
Heating/cooling load parameters:	
People per unit	Two adults, two children
Typical weather year	5 yr. average (1 970-75)
Monthly heating degree days[b]	
Monthly cooling degree days[b]	
Monthly discomfort cooling index[b]	

[a]Figures shown in parentheses represent energy input to Structure for each appliance.
[b]Dependent on location.

SOURCE: Hittman Associates, Inc., "Development of Residential Buildings Energy Conservation Research, Development, and Demonstration," HIT-681, performed under ERDA Contract No. EX-76-C-01-21 13, August 1977, p. III-4.

Table 20.—Specifications and Disaggregate Loads for "1973" Single-Family Detached Residence

Specifications		
Component	Conductance	Comments
Roof	0.065	6" loose fill insulation (R-13)
Doors	0.413	Wood doors
Floor	0.200	Uninsulated
Walls	0.084	3 ½" glass fiber batts (R-11)
Windows	1.01	Single glazing

Infiltration parameters	Yes	No
Weatherstripping		X
Storm windows		X
Storm doors		X
Caulking		X

Disaggregated heating loads						
	Baltimore		Chicago		Houston	
Component	Therms*	Percent	Therms	Percent	Therms	Percent
Structural heat losses						
Roof	95	12	131	12	30	14
Doors	29	3	28	3	6	3
Floor	216	27	260	25	30	14
Walls	96	12	132	12	30	14
Window conduction	179	23	245	23	57	27
Infiltration	186	23	261	25	58	28
Total heat losses	794	100	1057	100	211	100
Heat gains						
Window radiation	69	9	53	5	51	24
Internal	171	22	193	18	76	36
Heating system (net heating load)	554	69	811	77	84	40
Total heat gains	794	100	1057	100	211	100
Disaggregated cooling loads						
Structural heat gains						
Roof	11	4	9	4	30	5
Doors	2	1	2	1	6	1
Floor	—	—	—	—	11	2
Walls	11	4	9	4	30	5
Window conduction	20	7	17	7	54	9
Window radiation	28	10	23	10	56	10
Infiltration	60	22	45	19	139	24
Internal heat gains	137	52	131	55	243	44
Total heat gains	269	100	236	100	569	100
Heat losses						
Floor	89	33	96	40	—	—
Cooling system (net cooling load)	180	67	140	60	569	100
Total heat losses	269	100	236	100	569	100

*Therm = 1 x 10^5 Btu = 106 megajoule (MJ)

SOURCE: **Hittman Associates,** Inc "Development of Residential Buildings Energy Conservation Research Development, and Demonstration Strategies, " HIT-681, performed under ERDA Contract No EX-76-C-01-21 13, August 1977 p IV 9

Table 21 .—Specifications and Disaggregated Loads for “1976” Single-Family Detached Residence

[illegible]		
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
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[illegible]						
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

“Therm = 1 x 10^5 Btu = 106 megajoule (MJ)

SOURCE: Hittman Associates, Inc., “Development of Residential Buildings Energy Conservation Research, Development, and Demonstration Strategies,” HIT-681, performed under ERDA Contract No EX-76-C-01-2113, August 1977, p IV-9

Table 22.—Specifications and Disaggregated Loads for Low-Energy Single-Family Detached Residence

Specifications		
Component	Conductance	Comments
Roof	0.031	12" glass fiber insulation (R-38)
Doors	0.102	Metal/foam sandwich and storm doors
Floor	0.033	10" glass fiber insulation (R-30)
Walls	0.038	6" glass fiber insulation and 2" rigid foam (R-31)
Windows	0.420	Double glazing and storm windows

Infiltration parameters	Yes	No
Weatherstripping	X	
Storm windows	X	
Storm doors	X	
Caulking	X	

Component	Baltimore		Chicago		Houston	
	Therms*	Percent	Therms	Percent	Therms	Percent
Disaggregated heating loads						
Structural heat losses:						
Roof	38	13	54	13	No heating required	
Doors	4	1	6	1		
Floor	32	11	38	9		
Walls	36	13	51	13		
Window conduction	62	22	88	22		
Infiltration	115	40	168	42		
Total heat losses	287	100	405	100		
Heat gains:						
Window radiation	45	16	36	9		
Internal	143	50	168	41		
Heating system (net heating load)	99	34	202	50		
Total heat gains	287	100	495	100		
Disaggregated cooling loads						
Structural heat gains:						
Roof	4	2	3	2	10	2
Doors	1	0	1	0	1	0
Floor	—	—	—	—	2	0
Walls	4	2	3	2	10	2
Window conduction	6	3	5	3	16	4
Window radiation	26	12	21	11	52	12
Infiltration	41	19	31	16	100	23
Internal heat gains	137	62	131	68	243	57
Total heat gains	219	100	195	100	434	100
Heat losses:						
Floor	15	7	16	8	—	—
Cooling system (net cooling load)	204	93	179	92	434	100
Total heat losses	219	100	195	100	434	100

*Therm = 1 x 10^5 Btu = 106 megajoule (MJ)

SOURCE Hittman Associates, Inc. "Development of Residential Buildings Energy Conservation Research Development and Demonstration Strategies," HIT-681 performed under ERDA Contract No EX 76-C-01 -2113, August 1977 p IV 9

Table 23.—Disaggregated Energy Consumption for Different Combinations of Thermal Envelope and HVAC Equipment for Houses in Houston, Tex. (in MM Btu*)

House & equipment	Energy consumption by source			Energy consumption by end use			
	Primary consumption[a]	Electric consumption	Gas consumption	Heating	Cooling	Hot water	Miscellaneous electric
All electric houses							
"1973" house with electric furnace	294	85.3	—	9.3	31.6	14.8	29.6
"1976" house with electric furnace	271	78.7	—	5.8	28.5	14.8	29.6
"1976" house with heat pump	261	75.7	—	2.8	28.5	14.8	29.6
Low-energy house with heat pump	161	46.6	—	0	15.6	3.7[b]	27.3
Gas-heated houses							
"1973" house	252	61.2	41.0	14.0	31.6	27.0	29.6
"1976" house	240	58.1	35.7	8.7	28.5	27.0	29.6
Low energy house	160	42.9	10.8	0	15.6	10.8[c]	27.3

[a] Primary energy consumption is computed assuming that overall conversion, transmission and distribution efficiency for electricity is 0.29 and that processing, transmission, and distribution of natural gas has an efficiency of 0.89.
[b] This figure includes only the electricity used by the hot water heat pump. Some hot water is provided by heat recovery from the heat pump which heats and cools the house.
[c] This figure includes only the gas used by the hot water heater. Some hot water is provided by heat recovery from the air-conditioner.
*1 MMBtu = 1.05 gigajoule (GJ)

Table 24.—Disaggregated Energy Consumption for Different Combinations of Thermal Envelope and HVAC Equipment for Houses in Baltimore, Md. (in MM Btu*)

	Energy consumption by source			Energy consumption by end use			
House & equipment	Primary consumption[a]	Electric consumption	Gas consumption	Heating	Cooling	Hot water	Miscellaneous electric
All-electric houses							
"1973" house with electric furnace	400	116.0	—	81.6	10.0	14.8	29.6
"1976" house with electric furnace	351	101.8	—	48.6	8.8	14.8	29.6
"1976" house with heat pump	286	82.8	—	29.6	8.8	14.8	29.6
Low energy house with heat pump	154	44.6	—	5.4	7.4	4.5[b]	27.3
Gas-heated houses							
"1973" house	271	39.6	119.3	92.3	10.0	27.0	29.6
"1976" house	244	38.4	99.8	72.8	8.8	27.0	29.6
Low-energy house	160	34.7	27.3	11.1	7.4	16.2[c]	27.3

[a]Primary energy consumption is computed assuming that overall conversion transmission and distribution efficiency for electricity is 0.29 and that processing, transmission, and distribution of natural gas has an efficiency of 0.89

[b]This figure includes only the electricity used by the hot water heat pump. Some hot water is provided by heat recovery from the heat pump which heats and cools the house

[c]This figure includes only the gas used by the hot water heater. Some hot water is provided by heat recovery from the air-conditioner

*1 MMBtu = 105 gigajoule (GJ)

Table 25.—Disaggregated Energy Consumption for Different Combinations of Thermal Envelope and HVAC Equipment for Houses in Chicago, Ill. (in MM Btu*)

House & equipment	Energy consumption by source			Energy consumption by end use			
	Primary consumption[a]	Electric consumption	Gas consumption	Heating	Cooling	Hot water	Miscellaneous electric
All-electric houses							
"1973" houses with electric furnace	491	142	—	90.1	7.8	14.8	29.6
"1976" house with electric furnace	424	123	—	71.9	6.8	14.8	29.6
"1976" house with heat pump	353	103	—	51.3	6.8	14.8	29.6
Low-energy house with heat pump	176	51.1	—	11.4	6.5	5.9[b]	27.3
Gas-heated houses							
"1973" house	311	37.4	162	135	7.8	27.0	29.6
"1976" house	277	36.4	135	108	6.8	27.0	29.6
Low-energy house	168	33.8	45.9	28.8	6.5	17.1[c]	27.3

[a]Primary energy consumption is computed assuming that overall conversion transmission and distribution efficiency for electricity is 0.29 and that processing, transmission, and distribution of natural gas has an efficiency of 0.89

[b]This figure includes only the electricity used by the hot water heat pump. Some hot water is provided by heat recovery from the heat pump which heats and cools the house

[c]This figure includes only the gas used by the hot water heater. Some hot water is provided by heat recovery from the air-conditioner

*1 MMBtu = 105 gigajoule (GJ)