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Regional Analysis of Residential Water-Heating Options: Energy Use and Economics

Dennis O'Neal
Janet Carney
Eric Hirst

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ABSTRACT

This report evaluates the energy and direct economic effects of introducing improved electric water heating systems to the residential market. These systems are: electric heat pumps offered in 1981, solar systems offered in 1977, and solar systems offered in 1977 with a Federal tax credit in effect from 1977 through 1984.

The ORNL residential energy model is used to calculate energy savings by type of fuel for each system in each of the ten Federal regions and for the nation as a whole for each year between 1977 and 2000. Changes in annual fuel bills and capital costs for water heaters are also computed at the same level of detail.

Model results suggest that heat pump water heaters are likely to offer much larger energy and economic benefits than will solar systems, even with tax credits. This is because heat pumps provide about the same savings in electricity for water heating (about half) at a much lower capital cost ($700 - $2000) than do solar systems. However, these results are based on highly uncertain estimates of future performance and cost characteristics for both heat pump and solar systems.

The cumulative national energy saving by the year 2000 due to commercialization of heat pump water heaters in 1981 is estimated to be 1.5 QBtu. Solar energy benefits are about half this much without tax credits and two-thirds as much with tax credits. The net economic benefit to households of heat pump water heaters (present worth of fuel bill reductions less the present worth of extra costs for more efficient systems) is estimated to be $640 million. Again, the solar benefits are much less.

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REGIONAL ANALYSIS OF RESIDENTIAL WATER HEATING OPTIONS: ENERGY USE AND ECONOMICS

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1. INTRODUCTION

This report evaluates the national and regional effects on household energy use and economics of offering improved electric domestic hot water heating systems. These evaluations are conducted with the ORNL residential energy use model.[1]

Four scenarios are analyzed in detail. The first is a baseline that includes only conventional water heaters. Real fuel prices rise in the baseline as projected by the Department of Energy (DOE). Estimates of future growth in Gross National Product (GNP) and in population are from DOE and the Bureau of the Census, respectively. As fuel prices rise, average efficiencies of new water heaters improve through use of additional insulation on the water heater jacket and on the distribution pipe; and, in addition, for gas and oil water heaters, improvements in the burner/flue configuration.

The second case assumes that electric heat pump water heaters become commercially available in 1981. All other assumptions (concerning population, GNP, and fuel prices) are the same as in the baseline. Differences in energy use and expenditures between the two cases allow us to estimate the energy savings and direct economic effects of introducing these heat pump water heaters.

The third and fourth cases deal with solar water heaters using electricity as a backup fuel. In the third case, we assume that solar water heaters become available in 1977. In the fourth case, we also assume that the tax credits proposed in the *National Energy Plan* (about 25% of the initial cost) are in effect from 1977 through 1984.

In each of these four scenarios, we ran our energy model for each of the ten Federal regions (shown in Fig. 1) and for the nation as a whole. We also ran additional cases for the nation only to test the effects on solar water heater benefits of:

1. much higher fuel prices from 1980 through 2000
2. changes in daily hot water consumption.

These runs show the sensitivity of our solar results to changes in these variables.

Tables 1 and 2 summarize the major energy and economic results for each region and the nation. Heat pump water heaters are expected to provide larger energy and economic benefits in each region (and in the nation as a whole) than do solar systems. This is generally true even

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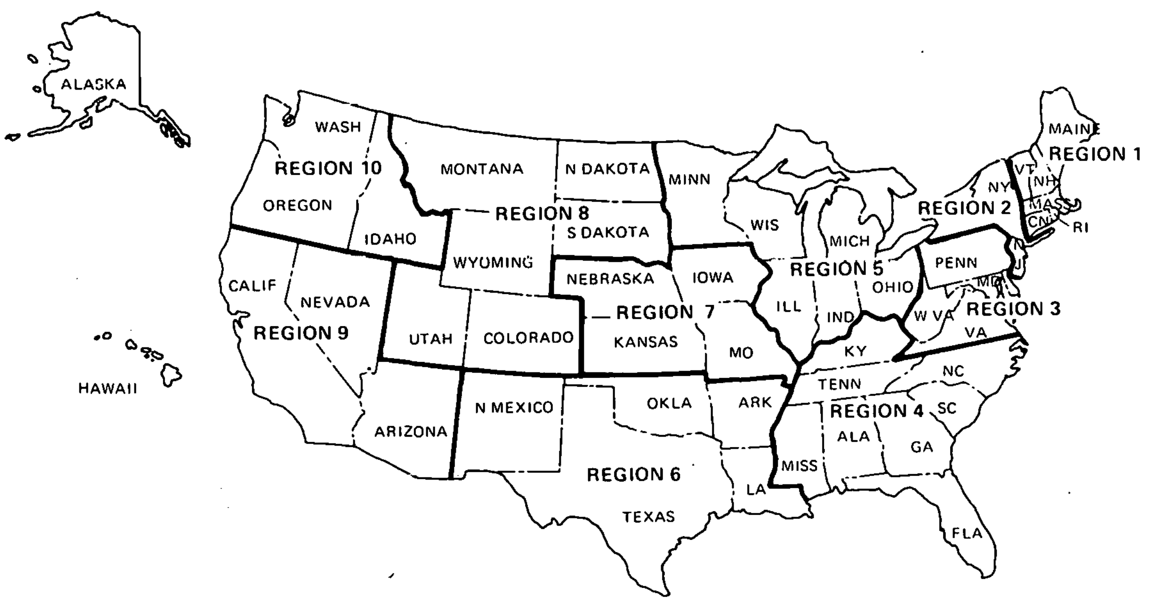

Fig. 1. Map of the United States showing the ten Federal regions.

Table 1. Cumulative (1977-2000) primary energy savings due to adoption of improved electric water heating systems

Federal region	Energy savings (trillion Btu)		
	Heat pumps	Solar	Solar with tax incentives
1	124	28	51
2	98	16	33
3	160	58	96
4	505	313	448
5	246	76	124
6	68	63	82
7	37	16	24
8	33	25	36
9	119	66	136
10	64	0	10
U. S.	1453	661	1041

Table 2. Cumulative (1977-2000) net economic benefits due to adoption of improved electric water heating systems[a]

Federal region	Net economic benefit (million 1975-$)		
	Heat pumps	Solar	Solar with tax incentives
1	99	23	45
2	77	14	30
3	89	30	55
4	183	92	144
5	122	38	66
6	20	16	22
7	12	5	8
8	14	11	17
9	2	-12	-10
10	23	1	5
U. S.	640	217	383[b]

[a]Net economic benefits represent the present worth (at a real interest rate of 8%) of the difference between fuel bill reductions and the extra capital cost of more efficient water heaters.

[b]The present worth of government expenditures (tax credits) on solar systems is $345 million. Thus, the net economic benefit to society is reduced from $383 to $38 million.

if tax credits are provided for purchase of solar water heaters, except for regions 6, 8, and 9. Our national runs show that much higher fuel prices during the 1980s and 1990s increase the energy and economic benefits of solar water heaters; benefits would also increase for heat pumps with higher fuel prices. Variations in daily hot water use have only small effects on the benefits of solar water heaters.

The next section discusses the water heating technologies considered in this analysis: conventional electric water heaters, electric heat pump water heaters, and solar water heaters. The energy use/capital cost characteristics of each system are defined to show how investment in more efficient equipment reduces fuel use and operating costs. Because of large regional variations in insolation, solar water heater relationships are developed for specific cities in each of the ten Federal regions.

Section 3 briefly describes the major features of the ORNL residential energy use model, especially those characteristics of the model that strongly influence the present results. Section 4 presents our findings concerning the energy and economic benefits of heat pump and solar water heaters. The final section summarizes our findings and interprets these results in light of the assumptions and limitations in our energy use model.

2. WATER HEATING SYSTEMS

This section examines the costs and energy use of systems that presently compete (or will soon compete) for the electric water heating market. These include: conventional electric, heat pump, and solar water heating systems.

Conventional Water Heaters

The relationship between annual energy use and initial cost for conventional electric water heaters was examined at both ORNL and A. D. Little, Inc.[2] Detailed computer programs were developed to calculate energy flows in water heaters. The assumed characteristics for conventional systems are shown in Table 3.*

Table 3. Characteristics of conventional electric water heaters

Daily water usage	72 gal/day	Initial cost	$157
Storage tank size	50 gallons	Annual energy use	6600 kWhr
Hot water temp.	140°F	Tank insulation	2" fiberglass
Distribution pipe	25' long, uninsulated	Lifetime	10 years

Source: ref. 2.

Several design changes can be made to reduce energy use: increase jacket insulation, reduce jacket insulation thermal conductivity, and add insulation to the distribution pipe. The maximum energy reduction for a typical electric water heater with these options is 14%. The extra cost of this more efficient unit is $37.

The energy savings, extra cost, and simple (undiscounted) payback periods for several design changes to conventional water heaters are shown in Table 4.† Results are given for units in Portland, OR; Kansas City, MO; and New York, NY. These cities provide a representative range in residential electricity prices; see footnote c of Table 4. Even in

*All prices and incomes in this report are given in 1975-$.

†Electricity use figures in this section are given in kWhr. In the rest of the report, electricity is given in primary energy (at 11,500 Btu/kWhr) to include losses in generation, transmission, and distribution.

Table 4. Conventional electric water heater design changes, energy savings, and payback periods

Design option	% energy saving[a]	% cost increase[b]	Payback period (years)[c,d] Portland	Kansas City	New York City
1. Increase jacket insulation to					
a. 3" fiberglass	4	4	1.5	0.9	0.5
b. 4" fiberglass	7	8	2.0	1.2	0.6
2. Reduce jacket insulation thermal conductivity					
a. 2" urethane	8	6	0.8	0.5	0.2
b. 3" urethane	10	11	1.5	0.8	0.4
c. 4" urethane	11	14	1.7	1.0	0.5
3. Add 1" fiberglass insulation to 25' of distribution pipe	3	9	3.6	2.0	1.1
4. 2c, 3	14	24	1.9	1.1	0.6

[a] Baseline energy use is 6950, 6510, and 7120 kWhr in Portland, Kansas City, and New York, respectively.

[b] Baseline capital cost for the 50 gallon water heater is $157.

[c] Electricity prices were (1975-$) 2.08, 3.66, and 6.64 ¢/kWhr in Portland, Kansas City, and New York respectively, in January 1978.

[d] The simple payback periods given in Tables 4, 5, and 7 do not include increases in fuel prices, maintenance costs, and the time value of money (interest rate).

Portland, where electricity prices are quite low, the payback period for these improvements is less than two years (compared with the ten year lifetime for the water heater itself). These results suggest that improvements to conventional water heaters are quite cost-effective. As electricity prices increase in the future (see Appendix Tables A1-A10 for estimates of regional fuel prices to 2000), payback periods for these improvements will become even shorter.

Heat Pump Water Heaters

Heat pump water heaters are not new. Several hundred were manufactured and sold in the late 1950s. Because of low and declining electricity prices and the state-of-the-art of heat pumps at the time, they did not compete effectively against conventional water heating systems. As a result, they were withdrawn from the market.[3]

With recent and projected increases in fuel prices and advances in heat pump technology, there is new interest in applying heat pumps to domestic water heating. There are two heat pump designs being developed with funding from the Department of Energy. Both involve small heat pump units installed with a conventional hot water tank, used only for heating water (not for space heating). One uses a standard Rankine cycle and the other a Brayton cycle. Details on the hardware, energy use, and capital costs of these systems are given in references 3 and 4. The two systems are briefly described below.

The general principle of both heat pump systems is similar to that of heat pumps used in space heating. Heat is extracted from cool ambient air and "pumped" into a medium at a higher temperature. For a heat pump used in space heating, this medium is the conditioned air inside a structure. For a heat pump water heater, this medium is water.

Energy Utilization Systems, Inc. (EUS) is developing a Rankine cycle heat pump water heater for DOE. It uses a motor-compressor, evaporator, expansion valve, refrigerant, and control system similar to those space heating heat pumps use. The condenser is the only component of this system that is not an "off-the-shelf" item. It consists of a double-wall tube wound in a helical coil. The heat pump cabinet is built as part of the water heater. The heat pump water heater fits into the same floor space a conventional water heater does. A project to field test 100 water heaters is planned to start by the end of 1978. Marketing of the units should begin in 1980 and each should cost about $400.[3,5]

Preliminary results show that the Rankine cycle heat pump has a seasonal performance factor (SPF)* of at least two and, under certain conditions, as high as three. The performance of this heat pump water

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*Seasonal performance factor is defined as:

$$\text{SPF} = \frac{\text{Total annual heat energy provided by the water heater}}{\text{Total annual electricity used by the water heater}}$$

heater varies with the source (ambient) air and water supply temperature, and hot water temperature. The performance improves as the source air temperature increases and decreases as the water supply or hot water temperature increases. If the source air temperature goes below 45^{o}F, electric resistance heaters must be used to supplement the heat pump.

The system under development by Foster Miller Associates (FMA) is a Brayton cycle heat pump.[4] The Brayton cycle has been used for refrigeration applications in the past, but not for water heating.[6] The hardware consists of a reciprocating compressor/expander, air-to-water heat exchanger, electric motor, water circulation pump, and controls. With the exception of the compressor/expander and the air-to-water heat exchanger, all of the items are commercially available. The compressor/expander consists of a single piston that both compresses and expands the refrigerant. For this system, air is the refigerant.

The system fits into a cyclindrical package under the water tank. The estimated SPF and initial cost of this heat pump is expected to be 1.7 and $430, respectively.[5] Like the EUS system, performance improves as the source air temperature increases and decreases as the water supply or hot water temperature increases. FMA is currently assembling a prototype unit. They will conduct tests in 1978 to compare actual and expected performance of the unit.

Table 5 shows the expected payback periods for the two heat pump water heaters compared to a conventional electric water heater in three cities. Even in Portland where electricity prices are low, the heat pumps have short payback periods. For both Kansas City and New York, the paybacks are very short. Because of the fast paybacks, heat pumps should provide an attractive alternative to conventional electric water heaters.

Table 5. Expected energy savings and economics for heat pump water heaters[a]

Heat pump	% energy saving	% cost increase	Payback period (years)		
			Portland	Kansas City	New York
EUS	50	157	3.4	2.1	1.0
FMA	41	173	4.5	2.7	1.4

Sources: refs. 3-5.

[a]The baseline system energy use and capital cost, and electricity prices are the same as those in Table 4.

Solar Water Heaters

Solar water heating is the most popular form of solar energy utilization in the residential sector in the United States. By the end of 1977, an estimated 63 thousand homes had installed solar water heaters (new and retrofit), compared to 3 thousand solar space or combined solar space and water heaters.[7]

Figure 2 shows a schematic of a representative residential solar water heating system.[8-11] Flat plate collectors are used to entrap energy from the sun and heat a liquid (either water or an ethylene glycol/water solution) flowing through the collectors. Heat in the liquid is transferred to the preheat tank using a heat exchanger in the tank. When the temperatures are not high enough in the collectors to add heat to the preheat tank (e.g., at night or during overcast days), automatic controls terminate flow of the liquid through the collectors.

The preheat tank stores useful heat from the solar collectors. The water in the preheat tank is moved to the hot water tank by pressure from the water main. If pressure is insufficient, an auxiliary pump would be needed.

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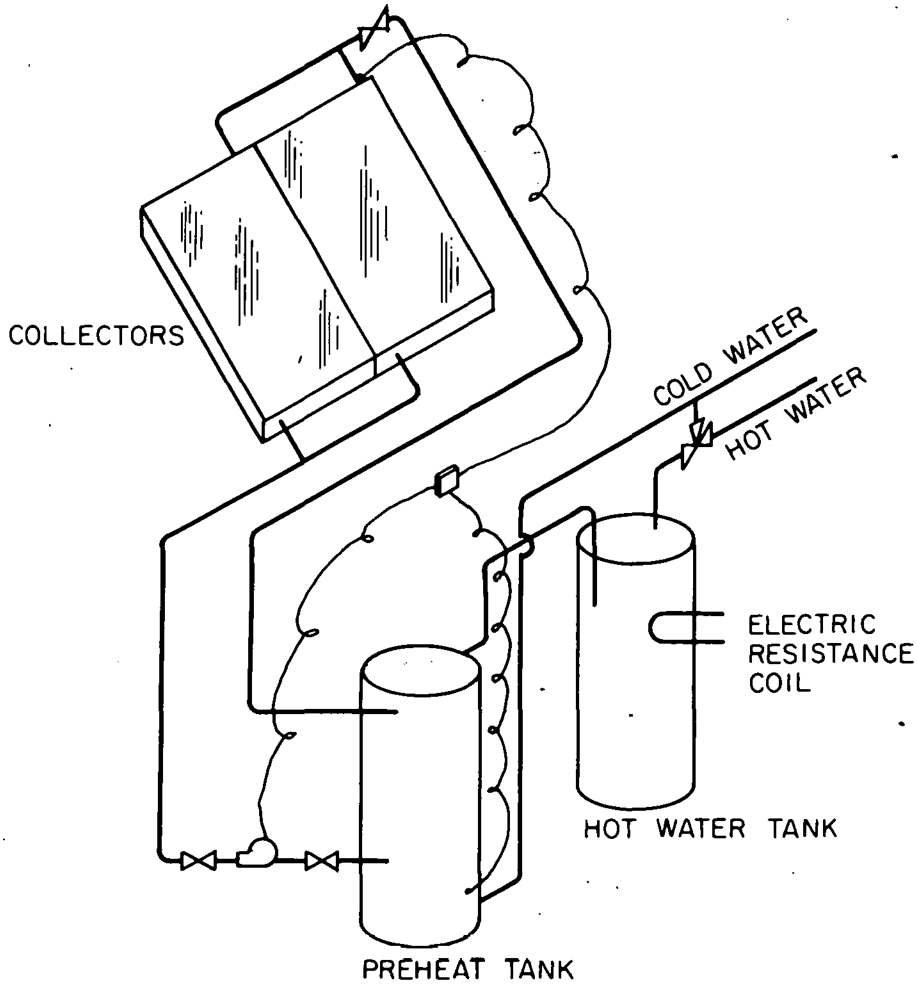

Fig. 2. Schematic of a typical residential solar water heating system.

The hot water tank is a conventional water heater. When the solar collectors cannot provide the needed energy for hot water, electric resistance coils in the tank are used.

Individual systems may vary from the one shown in Fig. 2. For instance, in warmer climates where freezing temperatures are infrequent, water is often used instead of an ethylene glycol/water solution. In a residence where hot water demand is low, the preheat tank can be eliminated, making the system less expensive but less effective. Another modification is to use either gas or oil as the backup fuel. For this study, the system in Fig. 2 is used.

To determine the performance of a solar water heating system, characteristics of the collectors, heat exchanger, weather, water temperatures, and water usage must be known or assumed. The computer program FCHART, developed at the University of Wisconsin, estimates the yearly performance of solar systems based on the above parameters.[11,12] The user specifies system parameters and the city in which the system is located. The program provides month-by-month and yearly estimates of the energy provided by the solar system.

Because the performance of solar systems is strongly dependent on climatic conditions, ten cities (one in each Federal region) are used to provide estimates of regional variations. These include:

Boston, MA - region 1	Ft. Worth, TX - region 6
New York, NY - region 2	Kansas City, MO - region 7
Washington, DC - region 3	Denver, CO - region 8
Atlanta, GA - region 4	Los Angeles, CA - region 9
Madison, WI - region 5	Portland, OR - region 10

Table 6 lists the characteristics of the solar system. Four collector areas are used: 36, 72, 90, and 108 ft^2. Two performance parameters of the system change with collector area: total storage volume and collector fluid flowrate. The values, $F_R(\tau\alpha)_n$ and F_RU_L, are unique characteristics of a collector* determined from measurements of collector efficiency.[13]

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*F_R is the collector heat removal efficiency factor, τ is the solar transmittance of the transparent covers, α is the solar absorptance of the collector plate, and n indicates that τ and α are at an angle of normal incidence. The quantity, $F_R(\tau\alpha)_n$ is the vertical axis intercept of the collector efficiency curves. U_L is the collector overall energy loss coefficient. The product F_RU_L is the slope of the collector efficiency curve.

Table 6. Characteristics of the solar water heating system

Total storage volume	1.84 gal/ft_c^2
Collector parameters	
Tilt	Latitude + 10^o
Glazing	1 (single)
$F_R U_L$	0.75
$F_R(\tau\alpha)_n$	1.00
Area	36, 72, 90 and 108 ft^2
Liquid	1/2 ethylene glycol - 1/2 water
Flowrate	0.022 gpm/ft_c^2
System cost	
Fixed	$434
Variable (per ft_c^2)	$18.3 plus labor
System life	10 years

Sources: refs. 13 and 14.

The values in Table 6 are for a single glazed, selective surface collector.[14]

Solar systems costs are developed from estimates published by the Mitre Corporation and the Dodge manual.[14,15] Mitre provides costs for all components (collector, heat exchanger, controls, etc.), and estimated labor time for installation. Costs are divided into "fixed" and "area dependent" components. Fixed costs are independent of collector size while area dependent costs vary with collector size.[14] The Dodge manual is used with the Mitre estimates of labor time to determine the labor cost of installing systems in each city. In Table 6, labor costs are included in variable costs. Labor costs range from $2.00 per ft_c^2* (Fort Worth) to $3.10 per ft_c^2 (New York).†

*The term ft_c^2 signifies collector area in square feet.

†For example, the cost of a 50 ft^2 solar system in Fort Worth would be: $434 + ($18.3 + $2.0)· 50 = $1449.

Figures 3 and 4 show energy use versus capital cost curves for conventional, heat pump, and solar water heating systems. The solar systems perform poorly in the Northeast (region 1 and 2) and Northwest (region 10) where yearly solar insolation is small compared to other regions. For instance, in regions 1, 2, and 10, the 36 ft_c^2 system provides only 30% of the hot water load compared to 50% in regions 8 and 9.

Each point on the solar technology curve represents a different size system. The size increases as one moves down and to the right (i.e., larger energy savings and higher capital costs). The small difference in capital costs for the same system in different cities is due to variations in labor costs. We assume that the cost of a solar water heating system is the same for a new house as for a retrofit installation.

The solar system costs in Figs. 3 and 4 do not include any possible Federal or State tax credits. The April 1977 *National Energy Plan*[16] proposed a 40% Federal income tax credit on the first $1000 spent for residential solar equipment and a 25% credit for the next $6400. This would yield a maximum tax credit of $2000 for a system costing $7400 or more. The credits would be retroactive to April 1977 and be removed in steps, to be phased out by 1985. An alternative set of incentives was passed by the House of Representatives in their version of the National Energy Act (HR 8444). This proposal provides a 30% tax credit on the first $1500 and a 20% credit on the next $8500. The maximum credit would be $2150 on a system costing more than $10,000. These credits would remain in force unchanged from April 1977 through December 1984. The House system of credits is evaluated in this report; existing and possible state tax incentives are ignored.

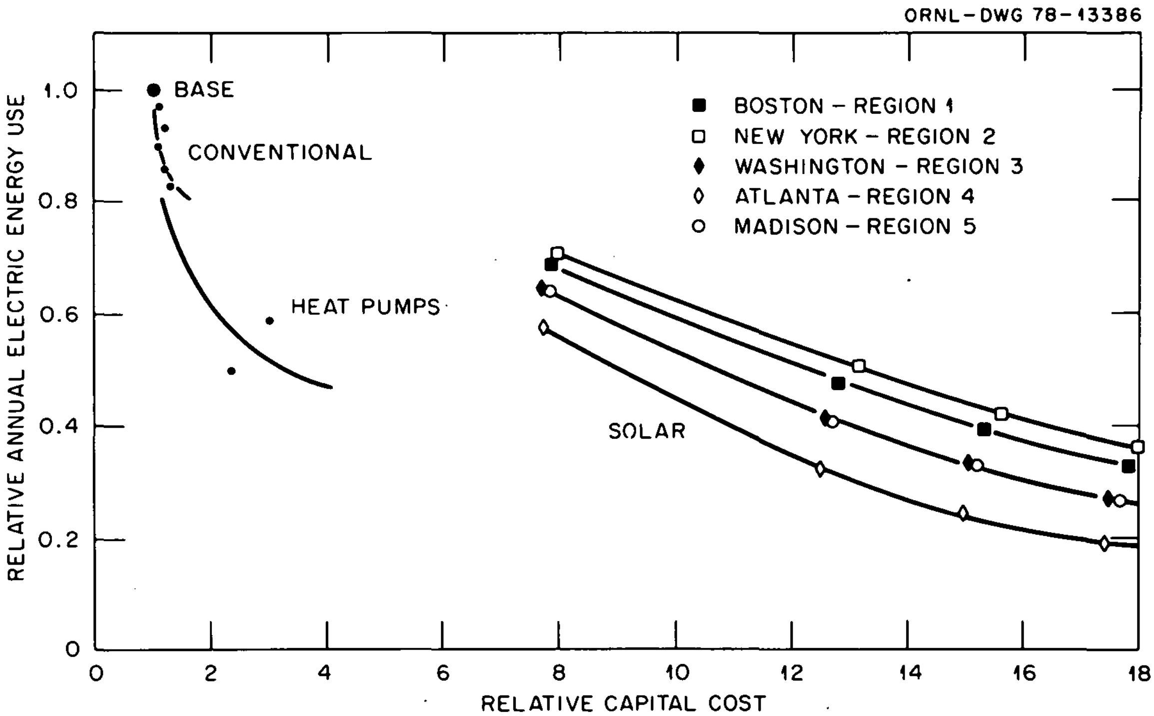

Fig. 3. Energy use versus capital cost for conventional, heat pump, and solar water heaters: Federal regions 1-5. Baseline system energy use and capital cost are 6600 kWhr and $157.

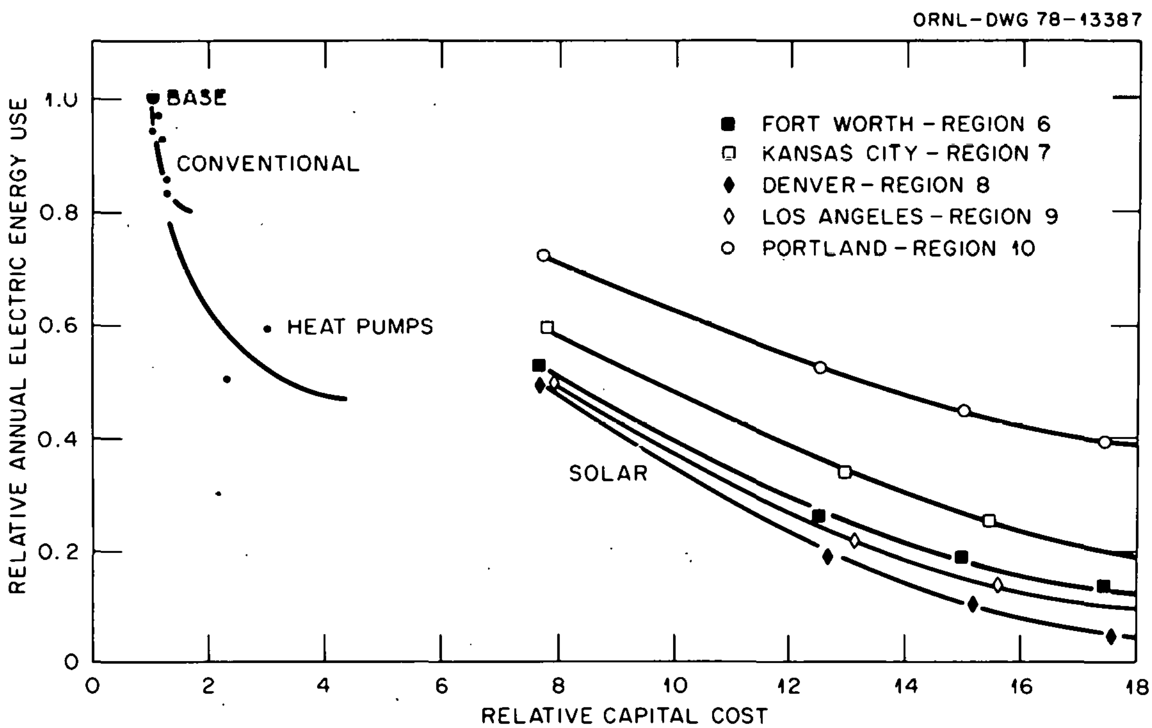

Fig. 4. Energy use versus capital cost for conventional, heat pump, and solar water heaters: Federal regions 6-10. Baseline system energy use and capital cost are 6600 kWhr and $157.

Table 7 shows the effect of the tax credits on the payback period for solar systems compared to conventional electric water heaters in Portland, Kansas City and New York. Even with tax credits, solar systems in Portland never pay for themselves over their assumed lifetime (10 years). Because electricity prices are high in New York, solar systems are economically attractive in that city - both with and without tax credits. In Kansas City, tax credits make the smaller systems competitive with conventional electric water heating.* As electricity prices rise in the future (Tables A1-A10), solar system paybacks will improve (i.e., decrease).

Table 7. Energy savings and economics for solar water heating systems[a]

City	System size (ft^2)	% energy saving	% cost increase		Payback period (years)[b]	
			W/O incentives	With incentives	W/O incentives	With incentives
Portland	36	28	670	420	NP	NP
	72	47	1150	810	NP	NP
	90	55	1400	1010	NP	NP
	108	61	1640	1200	NP	NP
Kansas City	36	41	680	440	NP	8.7
	72	66	1190	840	NP	9.4
	90	74	1440	1030	NP	10.0
	108	80	1690	1240	NP	NP
New York	36	29	690	440	9.1	6.2
	72	50	1210	850	8.7	6.3
	90	58	1460	1050	8.9	6.6
	108	65	1720	1260	9.3	6.9

[a]The baseline system energy use and capital cost, and electricity prices are the same as those in Table 4.

[b]NP means there is no payout on the system because the payback period is greater than 10 years, the assumed life of the system.

We consider solar systems only with electricity as a backup fuel because the economics of solar relative to gas water heating are very poor. Even in New York, where natural gas prices are quite high, solar

*Even in Fort Worth and Denver (regions 6 and 8), which have very high levels of solar insolation, payback periods are longer than those shown for New York in Table 7. This is because the improved performance of solar systems in regions 6 and 8 is not sufficient to offset the much higher electricity price in region 2.

water heaters have payback periods of 25-27 years compared with conventional gas units. In Kansas City, where gas prices are much lower, payback periods are 65-74 years. Clearly, these payback periods - all of which are longer than the assumed water heater lifetime - are economically unacceptable.

All of the previous analysis assumes a particular collector (single glazed selective surface). Three other collectors are examined to determine the possible effects on the energy use versus capital cost curves of Figs. 3 and 4. These three collectors include: a trickle collector, a different single glazed selective surface collector, and a double glazed flat black collector. The characteristics of these three plus the reference collector used in Figs. 3 and 4 are listed in Table 8.[14,17]

Figure 5 shows the energy use versus capital cost curves in Denver for solar systems with these four collectors. For solar systems costing about six times the conventional system, the range in energy provided by solar systems varied from 41% (trickle collectors) to 29% (different selective surface). From the wide variation shown in Fig. 5, it is apparent that one must be careful in selecting a "typical" collector.

Table 8. Characteristics of solar systems using different collectors: Denver

Collector	Cost: Fixed	Cost: Variable[a]	F_RU_L	$F_R(\tau\alpha)_n$	Glazing
Reference	\$434	\$20.6	1.00	0.75	1
Trickle	\$434	\$15.2	2.45	0.85	1
Different selective surface	\$434	\$26.1	0.67	0.70	1
Flat black	\$434	\$19.3	0.81	0.67	2

Sources: refs. 14 and 17.

[a]Cost per ft_c^2 plus labor costs.

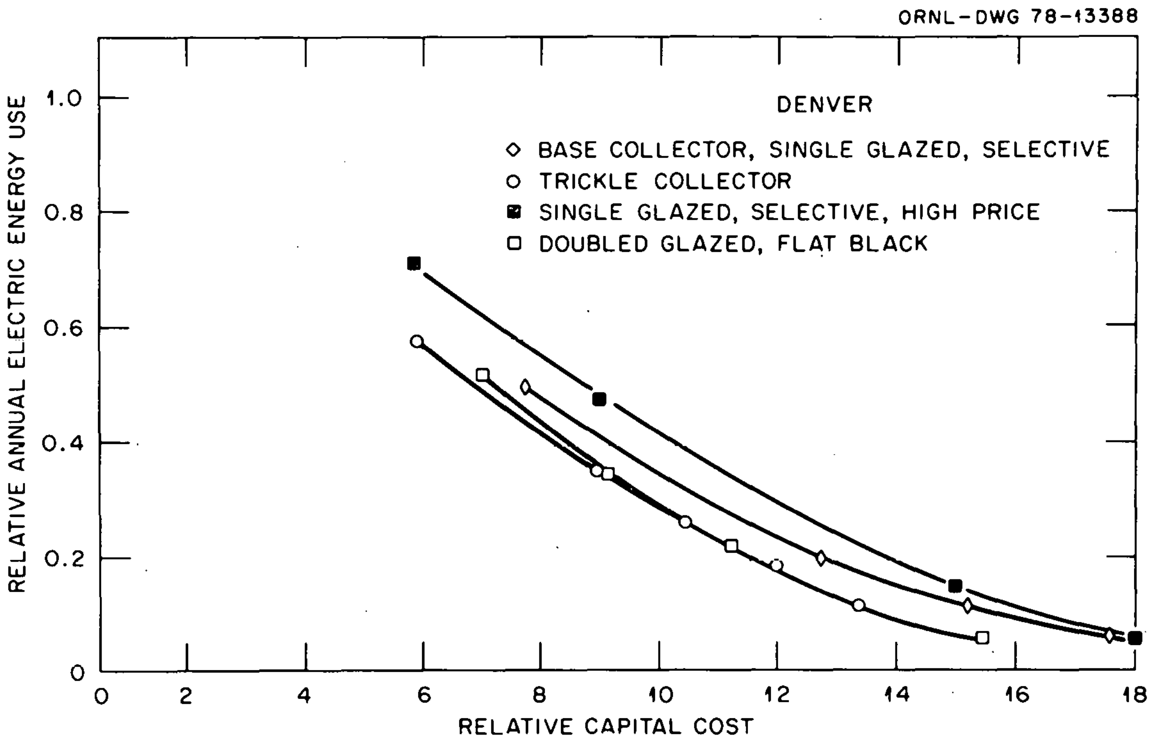

Fig. 5. Energy use versus capital cost for solar water heaters using different collectors. Baseline system energy use and capital cost are 6600 kWhr and $157.

In the analysis of Section 4, we assume that heat pump and solar water heating systems can be installed in both new housing units and in existing housing units to replace worn-out systems at the same initial cost. We only consider electricity as a backup fuel for the solar systems because gas is always so much less expensive than electricity (Tables A1-A10). Maintenance and repair costs are ignored because we have no data or estimates on these costs. Finally, we remind the reader that the energy use/capital cost estimates for these systems are highly uncertain.*

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*Some of our reviewers felt that actual costs for solar systems installed today are higher than our estimates; other reviewers felt the opposite. Others suggested that solar system costs are likely to decline substantially in the future. Similar uncertainties surround the heat pump cost estimates.

3. RESIDENTIAL ENERGY USE SIMULATION MODEL

The ORNL residential energy model is an analytical tool used to evaluate a variety of energy conservation policies, programs, and technologies for their effects on energy use, energy costs, and capital costs over time.[1]

The model deals with annual energy use for four fuels* (electricity, gas, oil, other); eight end uses (space heating, air conditioning, water heating, refrigeration, food freezing, cooking, lighting, other); three housing types (single-family, multi-family, mobile homes); and two housing states (new, existing). Household energy use for each component is computed in response to changes in: stocks of occupied housing units and new residential construction, equipment ownership by fuel and end use, size and thermal performance of housing units, average unit energy requirements for each type of equipment, and usage factors that reflect household behavior.

The model simulates annual energy use for each year from 1970 through 2000. Thus, a simulation involves the calculation of 5,760 (30 years x 192) fuel use components. The model also calculates, at the same level of detail, information on new equipment installations, equipment ownership, new and average equipment efficiencies, new and average structure thermal performance, usage factors; and annual expenditures on fuels, improved equipment, and thermal improvements to new and existing structures.

Figure 6 is a schematic diagram of the energy model. The demographics submodel calculates stocks of occupied housing units by type for each

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*Electricity use figures are in primary energy (11,500 Btu/kWhr from 1970-2000); that is they include losses in generation, transmission, and distribution. Figures for gas and oil, however, do not include losses associated with refining and transportation.

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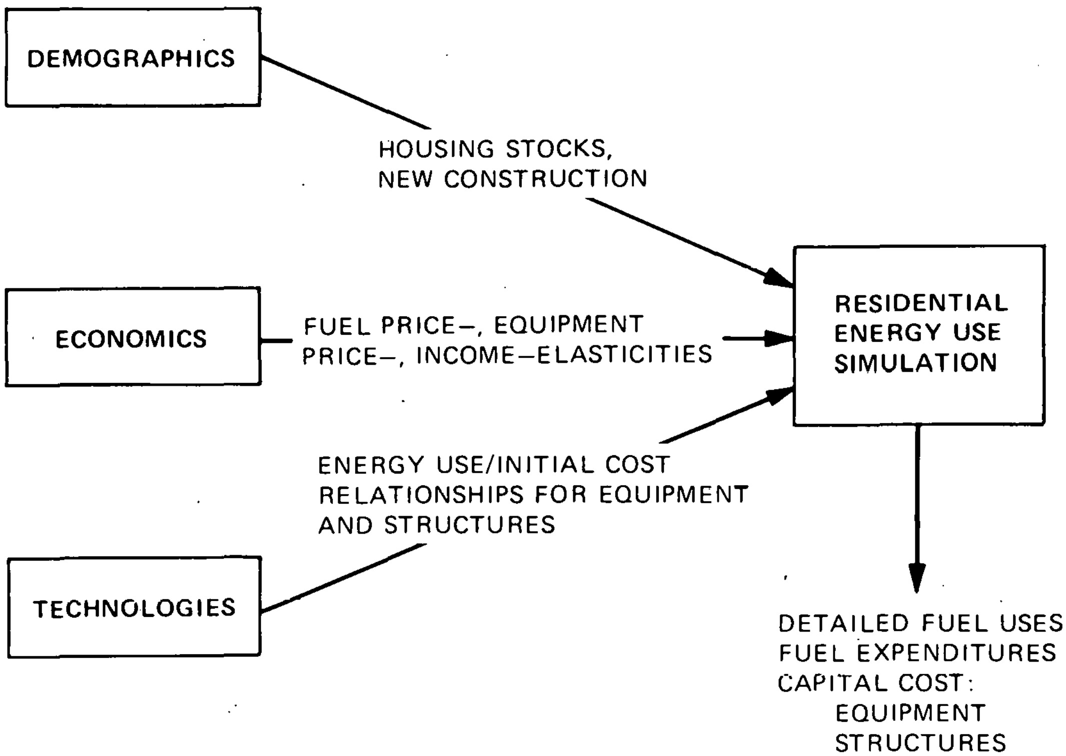

Fig. 6. Schematic of the ORNL residential energy use model.

year of the simulation. Based on calculations of household formation and retirements from the existing stock of occupied housing units, new construction requirements are calculated for each year to ensure that the stock of occupied housing units matches demand (the number of households that year).

The technologies submodels relate changes in equipment energy requirements to purchase price for alternative designs. Detailed engineering submodels were constructed for electric, gas, and oil space heating systems; gas and electric water heaters; refrigerators; and gas and electric ranges. Figures 3 and 4 (for electric water heaters) are typical of the outputs from our engineering submodels. We synthesized data from a number of sources to infer relationships between equipment energy use and initial cost for the other end uses. In a similar fashion, we evaluated changes in thermal performance for new and existing structures as functions of increased capital cost for each housing type.

The economic submodels calculate elasticities that determine the responsiveness of households to changes in economic variables: incomes, fuel prices, equipment prices. Elasticities are calculated for each of the three major household fuels for each of the eight end uses. Each fuel price and income elasticity is composed of three components: equipment ownership, equipment and structure efficiencies, and equipment usage. The first gives changes in equipment fuel choice (market share) in response to changes in fuel prices, equipment prices, and incomes. The second gives changes in equipment and structure efficiencies, and the third gives changes in household usage of equipment (holding ownership and efficiencies constant).

The simulation model combines outputs from the various submodels (Fig. 6) with appropriate initial conditions for 1970 and boundary conditions (policy variables) for the 1970-2000 period. Outputs from the simulation model include 192 fuel use components for each year. Each fuel use component is determined in the simulation program as the product of six factors: housing stock, housing size, equipment fuel choice (market share), equipment energy requirement, structure thermal performance, and usage.

The market penetration part of the model calculates changes in new equipment efficiencies and new structure thermal performance over time. These changes are functions of consumer behavior, available technologies, and time.

Each submodel and the simulation model influence our results with respect to water heating energy use and economics. Some of the major factors include:

1. Demographics. Different regions of the country are expected to grow at different rates. For example, Regions 4, 6, 8, and 9 are all expected to have average population growth rates of about 1.2%/year between 1975 and 2000, compared with the national average of 0.8%/year. Regions 2, 3, 5, and 7, on the other hand, are expected to have growth rates less than or equal to 0.5%/year during this period; see Appendix Tables A1-A10.[18,19] Regions with high population (and household) growth will purchase more new water heaters per household than will regions with slow growth. Thus, high growth regions have larger potential benefits from new water heating systems than do low growth regions.

2. Technologies. Our model treats all water heaters as one of four types: electric, gas, oil, other/none. The characteristics of different systems within each of these four types are assumed identical, except for annual energy use and captial cost.* Thus the model results assume that household perceptions of the safety, reliability, noise, maintenance cost, and other characteristics of all electric water heaters (conventional, heat pumps, solar) will be the same. Only the energy use and capital cost characteristics are allowed to vary.

This is probably a reasonable assumption for electric heat pump water heaters, except for maintenance costs. Their characteristics, from the standpoint of the homeowner, are very much like those of a conven-

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*Because very few new water heaters fall in the category "other/none," we do not consider design changes for other/none units that would reduce energy use and increase initial cost.

tional electric water heater. This assumption may be less valid with respect to solar water heaters. Household perceptions of solar systems may be very different from those of conventional electric systems. If these solar perceptions are more favorable than those for conventional systems (e.g., cleaner, environmentally more benign), then our results underestimate the market penetration and benefits of solar systems. If, on the other hand, consumer perceptions of solar are less favorable (e.g., high cost, unreliable), then we overestimate the benefits of solar water heating systems.

Our energy use/capital cost characterization for residential technologies is represented in the simulation model by a simple three-parameter curve.[1] This curve does a good job of fitting both conventional and heat pump water heaters. However, we were unable to find values for the three parameters to accurately fit both conventional and solar water heaters. The technology characterizations input to our energy model understate the cost of small solar systems and overstate the cost of large systems. The major consequence with respect to results presented in the next section is that estimated energy and economic benefits of solar systems are too high (because the model predicts adoption of primarily small solar systems).

3. Market penetration. Our energy model contains a simple algorithm that estimates changes in new equipment efficiencies over time as functions of consumer interest rates, fuel prices, fuel price trends, and available technologies. However, our methodology is ad hoc; it lacks a theroetical basis and empirical validation. We are presently developing a theoretically-sound model of market penetration that deals with both the equilibrium shares of different systems and the dynamics of approach

to equilibrium. We hope to have an improved operating market penetration model in 1979.

Our present market penetration algorithm proceeds in two steps. First, the model calculates the location on the energy use/captial cost curve for new electric water heaters sold in a particular year. That is, the model selects an average new electric water heater (average of the technologies incorporated into the technology curve) on the basis of present and past electricity prices and the average performance (energy use/capital cost) of electric water heaters sold during the preceding year. (This procedure is repeated for each type of water heater: electric, gas, oil.)

Second, the model calculates market shares for each type of water heater (electric, gas, etc.) on the basis of fuel prices, average characteristics of the units calculated in the first step, and market share elasticities.

4. Baseline market shares for new electric water heaters. The number of heat pump or solar systems sold in a particular year depends on the characteristics of the competing systems and on the baseline market share of new electric water heaters. In regions that have large baseline market shares for electric water heating (e.g., region 4), the benefits of heat pump and solar systems are relatively high, in part because the potential market is so large. On the other hand, the benefits of heat pumps and solar systems are low in regions 7 and 9 because their baseline market shares for electric water heating are so low.

Also, shifts from gas and oil to electricity (because of the improved average efficiency of new electric systems) tend to reduce the energy and economic benefits because gas and oil are less expensive and (in terms of primary energy) relatively efficient. So regions with high electric market shares in the baseline tend to show much less fuel switching and higher energy and dollar benefits than do regions with low electric market shares.

5. Market share elasticities. Market shares (equipment choices) are determined in the model by a logistic equation of the form:

$$ln\left(\frac{MS_i}{1 + MS_i}\right) = f_i\left[\sum_{j=1}^{3} \text{(operating and capital costs)}_j\right]$$

where MS is market share, i is the fuel choice being considered, and j is an index of choices (electric, gas, oil). The coefficients on the right hand side are determined from our national analysis of residential fuel choices; the market share elasticities are obtained from a cross-sectional analysis using 1970 state-level data.[20] Because we have no regional estimates of these market share elasticities, we ran the regional models using these national elasticities. This gave ridiculous results in some regions. To improve our regional results, we multiplied each coefficient on the right hand side by the ratio:

$$\left[MS_j(r)_{1970}/MS_j(US)_{1970}\right]^{0.5}$$

where r refers to a particular region and US refers to the nation as a whole. Although this is ad hoc, it eliminated the problems we encountered with the direct use of national market share elasticities.*

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*The national elasticities, when used in the regional models, predicted shifts from gas/oil water heating to electricity (because of heat pumps or solar systems) that exceeded the number of new heat pumps or solar systems being installed. This excess market share shift occurred only in regions where the baseline electric water heating market share was low. In regions where the baseline electric market share was high, there was very little fuel switching. Adjusting the equipment choice elasticities as shown above eliminated this large disparity in fuel switching among regions.

An alternative approach to analysis of solar systems is to calculate the payback period for a solar system relative to its competitors, as was done in the preceding section. In this micro-approach, solar energy savings depend only on system costs and efficiencies, and local fuel prices and insolation. The structure of our model is such that these factors only partly determine market penetration and regional benefits. As discussed above, regional population and household growth, trends in fuel prices (as well as absolute values), and baseline projections of electric water heating market shares also influence results. Also, changes in relative prices between competing fuels will change market shares. Thus, even if a gas water heater is less expensive than an electric water heater, an increase in gas price will induce some households to switch from gas to electricity as a water heating fuel (because of the change in relative prices). This is because households do not minimize lifecycle costs when making purchase decisions, at least not only with respect to the capital and energy operating costs of the alternatives.

4. RESULTS

We assume that national population grows according to the Bureau of the Census Series II projection.[21] National per capita income is derived from a projection prepared for the Department of Energy and the population projection.[22] These projections show population growing at an average rate of 0.8%/year and real per capita income growing at 2.4%/year between 1977 and 2000.

Projections of household formation, stocks of occupied housing units, and new construction are from our housing model using the per capita income and population estimates noted above. The ORNL housing model produces estimates for each region as well as for the nation. The nation's households are distributed among regions on the basis of recent projections of population distribution.[19]

The regional variation in per capita income is derived from the national projection using a projection of state income growth.[23]

National fuel price trajectories are from the Department of Energy and the Brookhaven National Laboratory.[22] The DOE energy model also produces estimates of regional fuel prices for 1980, 1985, and 1990. For the 1991-2000 period, we assumed the same regional variation in fuel prices as for 1990.

Appendix Tables A1-A10 show the values used for population, households, per capita income, and fuel prices for each region from 1970 through 2000. These inputs remain constant for all the scenarios.

Baseline

Our baseline case assumes that no new water heating technologies (heat pumps, solar) are available to consumers between now and the year 2000. We also assume that no government programs exist to encourage or require improvements in water heating energy efficiency. Thus the baseline includes only voluntary (free-market) responses to rising fuel prices with present-day well-established technologies.

Table 9 shows the baseline projection of water heating energy use for 1975 and 2000 for each region and the nation. National residential energy use for water heating grows at an average rate of 1.1%/year. Regions 1, 4, 8, and 9 show more rapid growth; these regions also show more rapid growth in population and households (Tables A1 through A10).

Table 9. Baseline primary energy use for water heating (trillion Btu)

Federal region	1975				2000			
	Elec.	Gas	Oil	Total[a]	Elec.	Gas	Oil	Total[a]
1	54	32	41	130	121	55	18	195
2	44	102	79	230	92	136	30	260
3	105	109	25	248	175	119	15	311
4	338	83	3	445	525	129	0	658
5	177	266	7	463	305	246	1	554
6	39	136	2	205	82	172	0	261
7	31	67	0	109	55	68	0	126
8	26	38	0	67	60	43	0	104
9	53	197	1	255	182	201	0	385
10	105	7	1	114	111	28	0	140
U. S.	972	1037	159	2266	1708	1197	64	2994

[a]The totals include use of other fuels (coal, liquified gases) not included elsewhere.

Water heating primary energy use in the year 2000 ranges from a high of 39 MBtu/household in region 10 to a low of 22 MBtu in region 6; the national average is 28 MBtu. This large regional variation is due to differences among regions in fuel prices, income growth, and water heater fuel choices (Table 10). Between 1975 and 2000, per household use of energy for water heating declines at an average rate of 0.5%/year for the nation. This decline is due to recent and projected increases in fuel prices and the consequent improvement in equipment energy efficiencies.

Table 10 shows the percentage of water heaters in use that are electric in each region for 1970, 1975, 1980, 1990, and 2000. Electricity's share of the water heaters in use is always highest in regions 4 and 10 and lowest in regions 2, 6, 7, and 9. Electricity captures such a large share of the market in regions 4 and 10 because of their low electricity prices (due to the presence of the Tennessee Valley Authority in region 4 and the Bonneville Power Administration in region 10).

Table 10. Baseline market shares for electric water heating[a]

Federal region	Ownership market share (%) 1970	1975	1980	1990	2000
1	21	25	30	36	39
2	9	10	12	15	18
3	24	26	28	32	34
4	55	61	62	63	62
5	24	23	24	27	31
6	9	10	10	12	15
7	17	16	16	18	22
8	24	21	22	24	29
9	12	12	12	25	27
10	82	84	85	78	66
U. S.	25	29	32	36	40

[a]Figures for 1970 are from the 1970 Census of Housing, U. S. Bureau of the Census; other figures are from energy model baseline projections.

Electricity's share of the water heating market increases over time in every region, except 10 (the region that always has the highest electricity market share).

Heat Pump Water Heaters

In the next scenario we introduce electric heat pump water heaters in 1981. The model then estimates the number of heat pump units installed each year in each region and the consequent energy and economic effects of this market penetration.

Table 11 and the maps of Fig. 7 show the energy and economic effects of introducing these heat pump water heaters.* The national energy saving increases from 0.004 QBtu in 1981 to 0.13 QBtu in 2000. The cumulative national energy saving (to 2000) amounts to 1.5 QBtu. About

*The "normalized savings" in Table 11 (and also Tables 12 and 13) refer to the per household energy (or economic) benefit in the region divided by the national per household energy (or economic) benefit. These ratios are shown graphically in the maps of Figs. 7, 8, and 9.

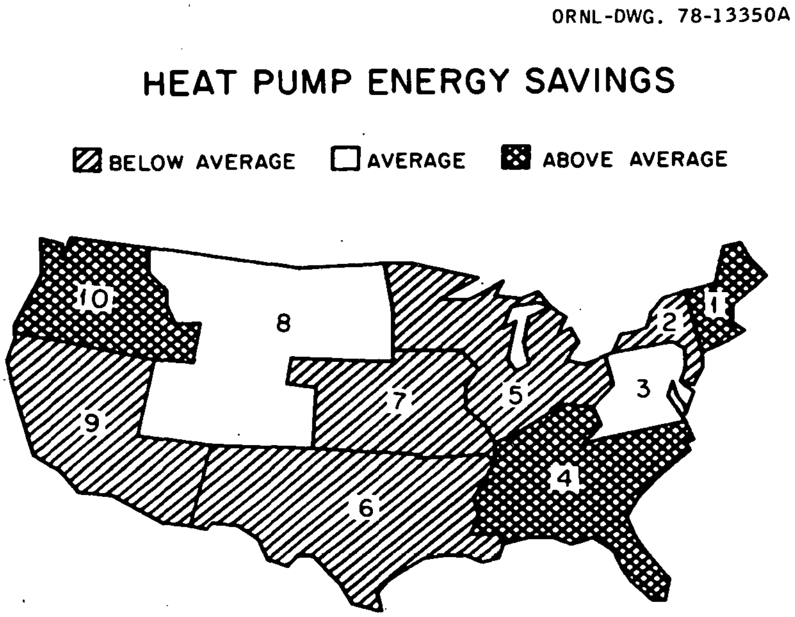
Table 11. Cumulative (1977-2000) energy and economic effects of heat pumps

	ENERGY SAVINGS				ECONOMIC BENEFITS		
FEDERAL REGION	TRILLION BTU	PERCENT OF BASELINE	PERCENT OF NATIONAL SAVINGS	NORMALIZED SAVINGS	NET SAVING 1975 DOLLARS (IN BILLIONS)	PERCENT OF NATIONAL SAVINGS	NORMALIZED SAVINGS
1	124.	3.04	8.5	1.5	0.10	15.6	2.7
2	98.	1.62	6.7	0.6	0.08	12.0	1.0
3	160.	2.30	11.0	1.0	0.09	13.8	1.2
4	504.	3.68	34.7	2.0	0.18	28.6	1.7
5	246.	1.98	16.9	0.8	0.12	19.0	0.9
6	68.	1.20	4.7	0.5	0.02	3.1	0.3
7	37.	1.29	2.5	0.5	0.01	1.9	0.4
8	33.	1.58	2.3	0.9	0.01	2.2	0.8
9	119.	1.54	8.2	0.7	0.00	0.3	0.0
10	64.	1.98	4.4	1.5	0.02	3.5	1.2
US	1453.	2.24	100.0	1.0	0.64	100.0	1.0

half the energy saving is gas and oil, due to shifts in water heating fuel choice from gas and oil to electricity. Electricity accounts for the other half.

The net economic benefit to the nation's households due to commercialization of heat pumps is $640 million. This represents the present worth (at a real interest rate of 8%) of the stream of fuel bill reductions less the extra capital costs of the heat pumps relative to conventional water heaters. As shown in Table 11, the energy and economic benefits are positive in every region.

The first map of Fig. 7 shows the distribution of energy benefits among regions, on a per household basis relative to the national per household energy saving. Regions labeled "average" have a cumulative energy savings of about 15 MBtu/household between 1981 and 2000. Savings are higher than average in regions 1, 4, and 10; and lower than average in regions 2, 5, 6, 7, and 9. Regions 4 and 10 show large savings because of their very high baseline electric market shares (Table 10). Also, both regions have above average population growth during this period. Region 1 has large energy benefits because of its very high gas prices throughout the projection period. The high gas prices induce a



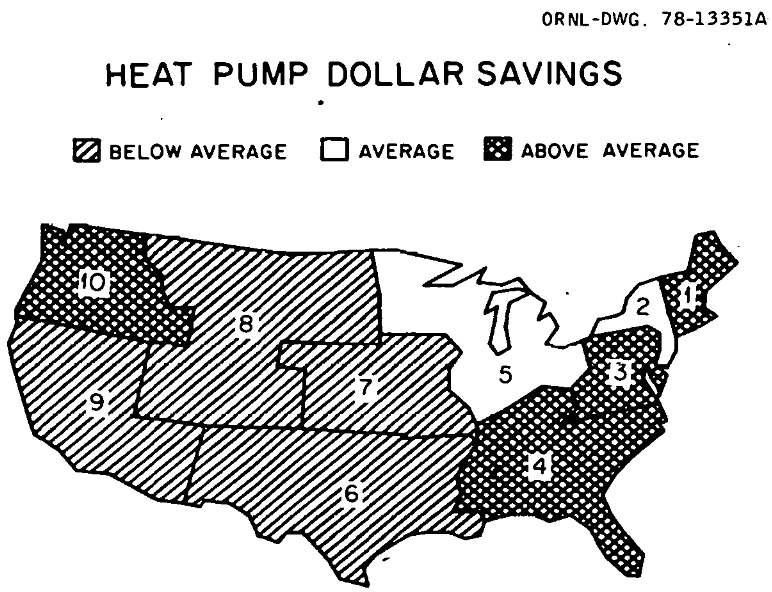


Fig. 7. Regional variation in cumulative per household energy and economic benefits of introducing heat pump water heaters in 1981. Regions labeled "average" have a per household energy or economic benefit in the range of 90–110% of the national per household benefit.

large increase in electric water heating market shares, as shown in Table 10.

The second map of Fig. 7 shows the regional distribution of the net economic benefits, again on a per household basis compared with the national average. Regions 1, 3, 4, and 10 show larger than average dollar benefits. Benefits are high in regions 1, 4, and 10 because of the previously-discussed large energy benefits. Benefits are slightly above average in region 3 because of the region's high electricity prices. On the other hand, economic benefits are below average in regions 6, 7, 8, and 9. Regions 6, 7, and 9 also had lower than average energy savings, probably because of low baseline electricity market shares (Table 10). Regions 7 and 8 also have very low growth in electricity prices.

Note that each region shows positive energy and positive economic benefits due to commercialization of electric heat pump water heaters. Appendix Table All provides additional detail on energy savings over time by type of fuel and number of heat pumps installed each year for each region and for the nation.*

Solar Water Heaters

In our third scenario, we allow introduction of solar water heaters (with electricity as the backup fuel) in 1977. We assume that these systems can be installed in both new and existing housing units at the same cost (Figs. 3 and 4) and that solar systems have the same average lifetime as do conventional and heat pump water heaters - 10 years.

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*Table All shows two sets of national results. The first is obtained by summing results for the ten regions. The second is obtained by running our national energy model. Results are similar although those obtained with the national model show larger energy and economic benefits; this is also true for our solar water heater analyses (Tables A12 and A13).

Again, the energy model estimates the number of solar systems installed each year in each region and the consequent energy and direct economic effects.

Table 12 and the maps of Fig. 8 show the energy and economic effects for each region and for the nation due to commercialization of solar water heaters. The cumulative national energy saving is 0.7 QBtu, less than half the energy saving due to commercialization of heat pump water heaters. The energy savings increase over time, from 0.001 QBtu in 1977 to 0.05 QBtu in 2000. The energy savings due to solar systems are less in every region than those due to heat pumps.

The net economic benefit to the nation's households due to adoption of solar water heaters is almost $220 million. This is one-third the national economic benefit due to commercialization of heat pumps. As with the energy savings, heat pumps provide larger economic benefits in each region than do solar systems.

The first map of Fig. 8 shows the cumulative solar energy saving per household for each region relative to the national saving. Regions 4 and 8 have larger than average energy savings, while regions 1, 2, 5, 7, 9,

Table 12. Cumulative (1977-2000) energy and economic effects of solar water heaters without incentives

	ENERGY SAVINGS				ECONOMIC BENEFITS		
FEDERAL REGION	TRILLION BTU	PERCENT OF BASELINE	PERCENT OF NATIONAL SAVINGS	NORMALIZED SAVINGS	NET SAVING 1975 DOLLARS (IN BILLIONS)	PERCENT OF NATIONAL SAVINGS	NORMALIZED SAVINGS
1	28.	0.69	4.3	0.7	0.02	10.7	1.9
2	16.	0.26	2.4	0.2	0.01	6.3	0.5
3	58.	0.84	8.8	0.8	0.03	13.9	1.2
4	313.	2.28	47.4	2.8	0.09	42.2	2.5
5	76.	0.61	11.5	0.5	0.04	17.4	0.8
6	63.	1.11	9.6	1.0	0.02	7.2	0.7
7	16.	0.56	2.4	0.5	0.00	2.3	0.5
8	25.	1.17	3.7	1.4	0.01	5.2	2.0
9	66.	0.85	9.9	0.8	-0.01	-5.7	-0.5
10	0.	0.00	0.0	0.0	0.00	0.6	0.2
US	661.	1.02	100.0	1.0	0.22	100.0	1.0

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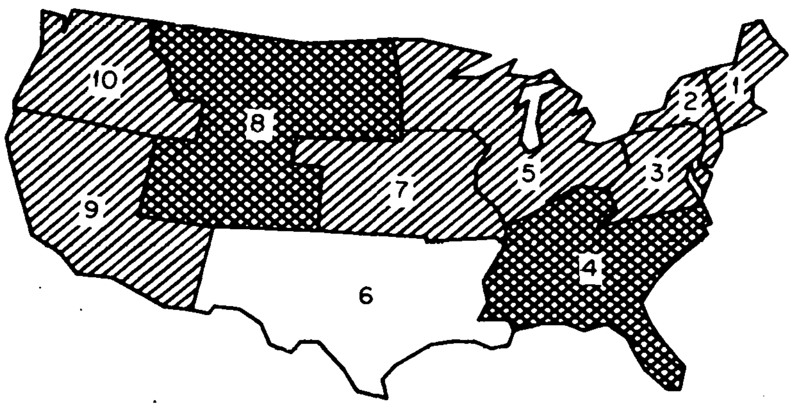
SOLAR ENERGY SAVINGS

BELOW AVERAGE AVERAGE ABOVE AVERAGE



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SOLAR DOLLAR SAVINGS

BELOW AVERAGE AVERAGE ABOVE AVERAGE

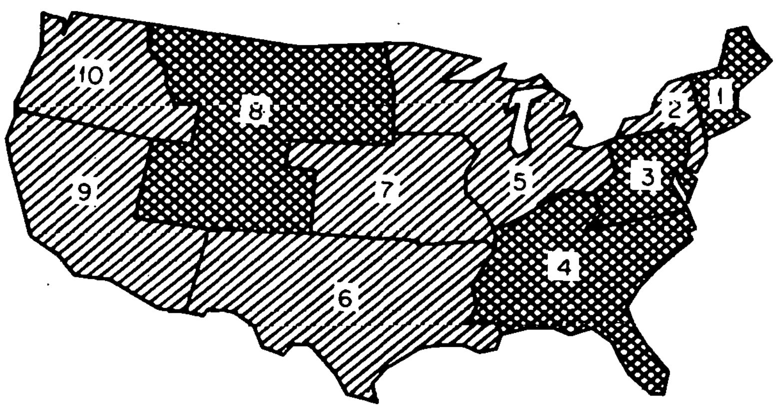


Fig. 8. Regional variation in cumulative per household energy and economic benefits of introducing solar water heaters in 1977.

and 10 have lower than average savings. Each region, however, shows positive energy savings. Region 4 shows large benefits because of its large electric market share and because insolation in region 4 is higher than average. Region 8 has large benefits because it receives more insolation than any other region in the country. (Region 10, which did well with respect to heat pumps, does poorly here because it has the least insolation of all regions.)

It is surprising that regions 6 and 9, both of which have much higher than average insolation, show average and lower than average energy savings, respectively. Regions 6 and 9 have two of the lowest electric water heating market shares (9 and 12% in 1970, compared with the national average of 25%; see Table 10). This low electric market share has two adverse effects with respect to solar systems. First, the potential market (electric water heaters) is smaller than in most regions. Second, the shift in fuel choice from gas to electric does not save much energy because the baseline gas system uses only half as much primary energy per unit as does the baseline (conventional) electric water heater. Thus, a shift from conventional gas to solar-with-electric-backup may save very little energy. (The same is true with respect to reductions in fuel bills because gas is a much cheaper fuel per Btu.)

Regions 1, 2, 3, and 10 show below average energy savings because of their very low levels of insolation. Regions 5 and 7 have below average energy savings because of a combination of factors: average insolation, slow population growth, low growth in electricity prices, and low market shares for electricity.

The second map of Fig. 8 shows the relative economic benefits due to commercialization of solar water heaters in 1977. Regions 4 and 8 show larger than average economic benefits, consistent with their larger than average energy benefits. Regions 1 and 3 also show large economic benefits, presumably because their electricity prices are quite high. The economic benefits are positive in each region except region 9. The slightly negative impact in region 9 is due to the shift in fuel choice from inexpensive gas systems to solar systems using electricity as a backup.

The relationship between energy and dollar savings due to solar systems and that due to heat pumps is closely related to solar insolation; see Tables 1 and 2. Solar systems perform better than average relative to heat pumps in regions that have high insolation (regions 4, 6, 8, and 9). In these four regions, the cumulative energy savings due to solar is greater than half that due to heat pumps. In the other six regions (which have less than average insolation), the solar energy benefits are less than half the heat pump benefits. The same pattern holds for the net economic benefits of solar versus heat pump water heaters.

Appendix Table A12 provides additional detail on the energy savings, units installed, and economic effects in each region.

Solar Water Heaters With Tax Incentives

In this case, we consider the same water heaters discussed in the previous scenario. Here, however, we provide a tax credit for purchase of these systems. The tax credit is that passed by the U. S. House of Representatives in 1977 (as part of the National Energy Act, HR 8444). It provides for 30% of the first $1500 and 20% of the next $8500 for residential solar systems; these credits are assumed to apply from 1977 through 1984.*

*For a typical solar system that provides 55% of the energy needed for water heating, the government tax credit is $425.

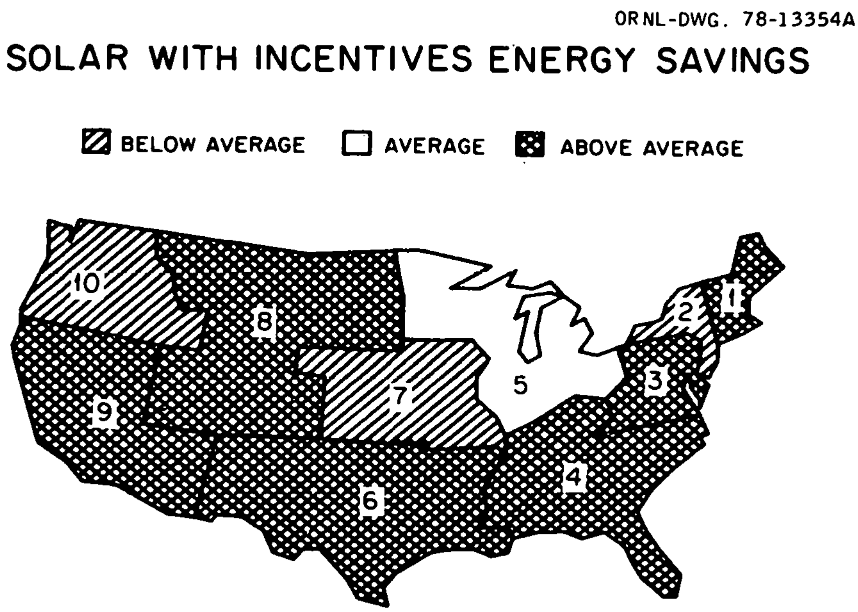
Table 13 and the maps of Fig. 9 show the energy and economic effects in each region of offering solar water heaters with the tax credit. The cumulative national energy saving is 1.0 QBtu, 50% more than the saving due to solar water heaters without a tax credit. The energy saving increases over time, from 0.002 QBtu in 1977 to 0.06 QBtu in 2000. However, even with the tax credit, solar energy savings are still less than those due to commercialization of heat pump water heaters. The national economic benefit of the solar systems with the tax credit (ignoring the cost of government credits) amounts to $383 million, 70% more than the saving without the tax credit. Again, the solar economic benefits are less than those due to heat pumps.

Table 13. Cumulative (1977-2000) energy and economic effects of solar water heaters with tax incentives

	ENERGY SAVINGS				ECONOMIC BENEFITS		
FEDERAL REGION	TRILLION BTU	PERCENT OF BASELINE	PERCENT OF NATIONAL SAVINGS	NORMALIZED SAVINGS	NET SAVING 1975 DOLLARS (IN BILLIONS)	PERCENT OF NATIONAL SAVINGS	NORMALIZED SAVINGS
1	51.	1.24	4.9	0.9	0.04	11.7	2.1
2	33.	0.55	3.2	0.3	0.03	7.9	0.7
3	96.	1.39	9.3	0.8	0.05	14.3	1.3
4	448.	3.27	43.1	2.5	0.14	37.6	2.2
5	124.	1.00	11.9	0.6	0.07	17.2	0.8
6	82.	1.45	7.9	0.8	0.02	5.8	0.6
7	24.	0.85	2.3	0.5	0.01	2.1	0.4
8	36.	1.69	3.4	1.3	0.02	4.5	1.7
9	136.	1.75	13.0	1.1	-0.01	-2.6	-0.2
10	10.	0.32	1.0	0.3	0.01	1.4	0.5
US	1041.	1.61	100.0	1.0	0.39	100.0	1.0

Because of the tax credit, 1.15 million solar systems are installed between 1977 and 1984. (Without the tax credit, only 288 thousand are installed during this eight year period.) The undiscounted cost to the Federal government is $490 million. The present worth (in 1977 at a real interest rate of 8%) of this government outlay is $345 million.* This

*This government subsidy should be compared with past and present subsidies for use of electricity (e.g., lack of complete internalization of costs associated with environmental protection).



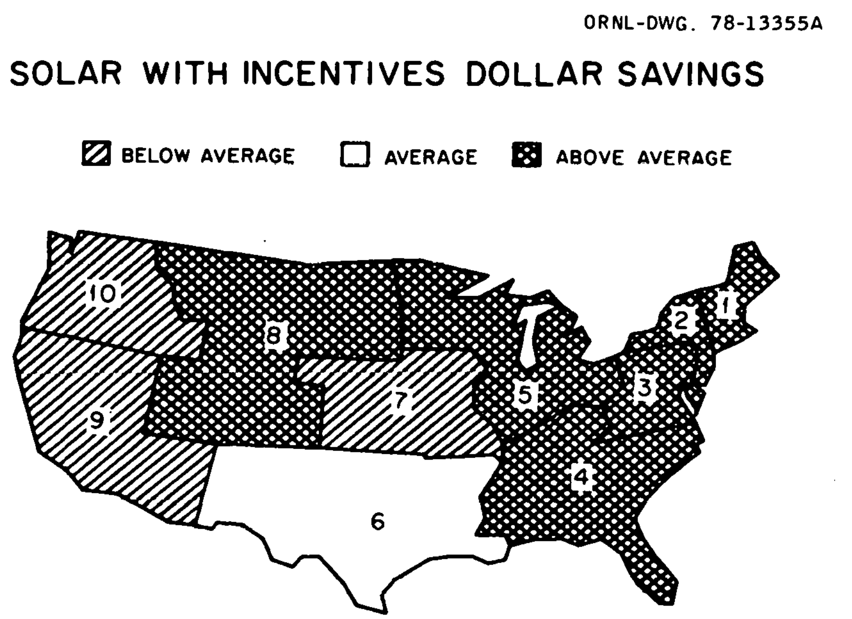


Fig. 9. Regional variation in cumulative per household energy and economic benefits of introducing solar water heaters in 1977, with a Federal tax credit in effect from 1977 through 1984. "Average" refers to the national per household benefit without tax credits, shown in Fig. 8.

reduces the net economic benefit from the $383 million shown in Table 13 to $38 million, considerably less than the net economic benefit of solar systems without government tax credits.

The solar-related energy benefits are positive in each region. They are less than the energy savings due to heat pumps in each region, except for regions 6, 8, and 9 (which have high insolation levels). Similarly, the economic benefits of solar systems with the tax credit are positive in each region except 9; the dollar benefits are higher for heat pumps than for solar systems with tax credits in each region except 6 and 8. (These economic comparisons do not include the government cost of the tax credits.)

The two maps of Fig. 9 show the regional variations in per household energy and economic benefits of solar systems with tax credits, relative to the national per household savings for solar systems <u>without</u> tax credits. The regional energy savings are higher in every region with the tax credits than without. Regions 1, 3, 6, and 9 all show increases in energy savings sufficient to bring them above the national average per household savings without tax credit (6.8 MBtu/household). Only regions 2, 7, and 10 show energy savings with tax credits lower than the national average without tax credits.

Similarly, regions 2 and 5 show higher than average economic benefits because of the tax credit. However, regions 7, 9, and 10, even with the tax credit, continue to show economic benefits lower than the national average without thc tax credit.

Appendix Table A13 gives additional regional detail for this scenario.

Sensitivity Analysis

We ran two additional sets of cases with the national model to evaluate the effects on solar system energy and economic benefits of much higher fuel prices and variations in daily hot water use.

For the high price case, we assume that oil and gas prices are 50% higher than in the previous cases for the 1980-2000 period. Electricity prices are assumed to be 25% higher. These price changes reflect, in a crude way, the kinds of oil price projections prepared by the CIA and the Workshop on Alernative Energy Strategies.[24]

Solar benefits increase because of these higher fuel prices. Energy savings are higher than those due to solar systems with the baseline prices by 6% in 1980, 50% in 1990, and nearly 70% in 2000. Similarly, the net economic benefits are higher by 80% because of higher fuel prices. These results suggest that solar systems can provide a valuable "hedge" against the possible (but uncertain) effects of very much higher fuel prices in the 1980s and 1990s. Electric heat pump water heaters offer the same type of hedge. In fact, the value of a "heat pump hedge" is likely to be greater than that of the solar hedge because the energy and economic benefits of heat pumps are larger than the benefits of solar.

We also used our national model to evaluate the effects of differences in daily hot water consumption on the estimated benefits due to solar hot water heating. We ran cases with daily hot water use increased by 20% and decreased by 20%. Reducing daily hot water use improves the relative performance of solar systems. That is, a given solar system will provide a larger fraction of houshold hot water energy use with smaller hot water use. Offsetting this <u>relative</u> improvement is a reduction in absolute energy requirement for heating less water. Results show that decreasing (or increasing) hot water use reduces (or increases) the energy and economic benefits of solar systems. However, the effect is nonlinear: a 20% change in hot water use causes a 10% change in energy and economic benfits.

Comparison With Other Studies

We compared our results for solar water heating with those from the Los Alamos Scientific Laboratory (LASL),[25] A. D. Little, Inc., (ADL),[26] and the Mitre Corp.[27] It is difficult to perform a meaningful comparison because the assumptions used in these studies on fuel prices, regional migration, income growth, availability of natural gas, solar system costs and performance, and other factors are often different, unstated, or both.

The most striking feature of the results obtained in these four studies is the variation in estimated energy savings. For example, ADL estimates a baseline energy saving of less than 2 trillion Btu in 1990 for residential solar water heating. Our estimated saving is 32 trillion Btu and Mitre's is 74 trillion Btu.* The LASL analysis gave results only for the 1977-1985 period; their results are much higher than ADL's, slightly higher than ours, and lower than Mitre's.

Estimates of actual solar water heating installations range from 20-45 thousand for 1977. Our model results show 8 thousand without federal tax credits and 31 thousand with tax credits. Our results would have

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*According to Peter C. Spewak of Mitre, their "analysis reflects cost decreases which are spurred on by a much larger market penetration that includes heating, heating and hot water, heating, cooling and hot water in both residential and commercial sectors." Our analysis assumes that solar system costs do not change over time. We were unable to reach analysts at A. D. Little to discuss their results.

yielded higher estimates had we assumed that solar systems were commercially available before 1977. We present results with tax credits because many states offered tax credits in 1977.

5. CONCLUSIONS

We examined the regional energy and economic effects of introducing improved electric water heating systems to the residential market: electric heat pump water heaters in 1981 and solar water heaters in 1977. We also examined the regional effects of offering tax credits for the purchase of solar water heaters from 1977 through 1984. Finally, we evaluated the sensitivity of our solar results to changes in residential fuel prices and changes in daily household hot water use. These analyses were conducted with the ORNL engineering-economic model of residential energy use.

Water heating is the second most important use of energy in homes (space heating is the first), accounting for about 15% of total residential fuel use. Commercialization of heat pump water heaters might save 1.5 QBtu between now and the year 2000, 2-3% of baseline cumulative water heating energy use. The estimated savings in the year 2000 - 0.13 QBtu - is 5% of water heating energy use for that year. These seem like small savings. They are less than might be expected for several reasons:

1. New heat pump water heaters provide a unit energy savings of 40-50% relative to baseline electric water heaters (which are themselves likely to improve in efficiency over time as electricity prices rise).

2. The share of water heaters in use that is electricity grows from 25% in 1970 to 32% in 1980 and 40% in 2000. Thus a majority of the water heaters in use are not electric.

3. Introduction of heat pump water heaters induces some switching from gas and oil water heaters to electric units. For example, the

percentage of homes with electric heaters is 43% in 2000 with electric heat pumps, compared with 40% in the baseline. Even though heat pumps are relatively energy efficient, they consume more primary energy than do conventional gas and oil water heaters.*

4. New systems penetrate the market slowly. That is, a new technology such as heat pumps cannot capture 100% of electric water heater sales immediately. Even in 2000, electric heat pump water heaters capture only 25% of the new electric water heater market according to our model estimates.

Nevertheless, these improved systems offer significant energy and economic benefits in each region and for the nation. Savings due to heat pumps amount to 1.5 QBtu between now and 2000; the net present worth of the cumulative benefits (fuel bill reductions less increases in capital costs) to the nation's households amounts to $640 million. The benefits due to solar water heaters without tax credits are 30-40% of those due to heat pumps, and 50-60% with tax credits.

The energy and economic benefits of heat pumps are greater than those due to solar in every region (Tables 1 and 2). This is true even though solar systems have a four year head start in terms of commercial availability (1977 versus 1981) and generally true even if tax credits are available for purchase of solar systems between 1977 and 1984. Figures 3 and 4 show why heat pumps yield much larger benefits. They provide roughly the same unit energy benefit (50% reduction in unit electricity use) at a capital cost lower than solar systems by $700 - $2,000.

The national effects of heat pumps and solar systems (both with and without tax credits) are summarized in Figs. 10-12. Figure 10 shows installations of improved electric water heater units over time. The two

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*Conventional water heaters improve over time because of increases in fuel prices. These improvements reduce unit energy use 5, 13, and 15% for electric, gas, and oil units in 1985. These energy use reductions are due to additional jacket insulation, insulation of distribution pipes; and for gas and oil units, improvements in the combustion system.

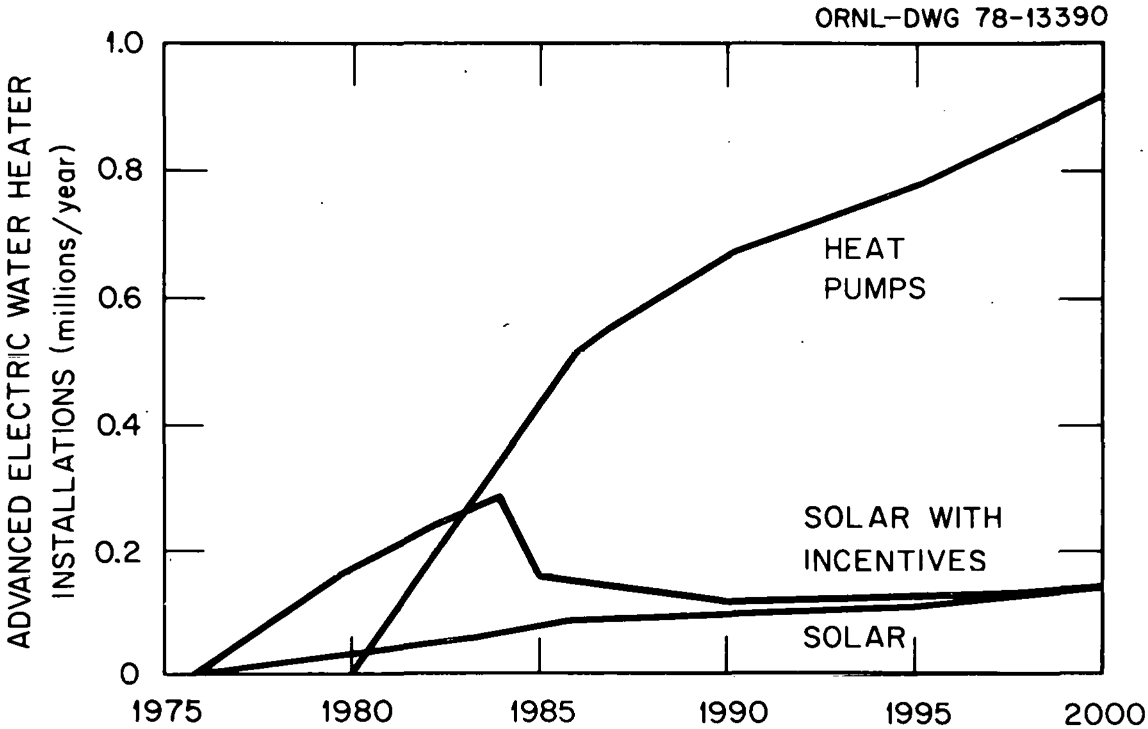

Fig. 10. Installation of improved electric water heaters, 1977–2000.

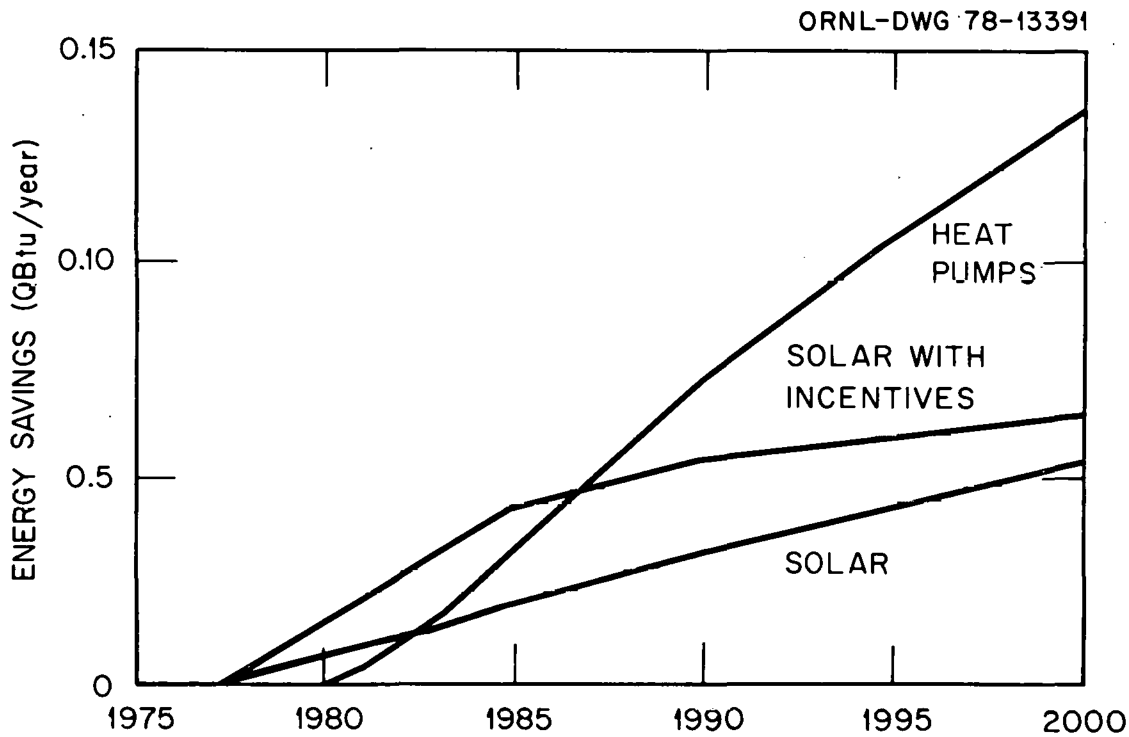

Fig. 11. National energy savings due to improved electric water heaters, 1977–2000.

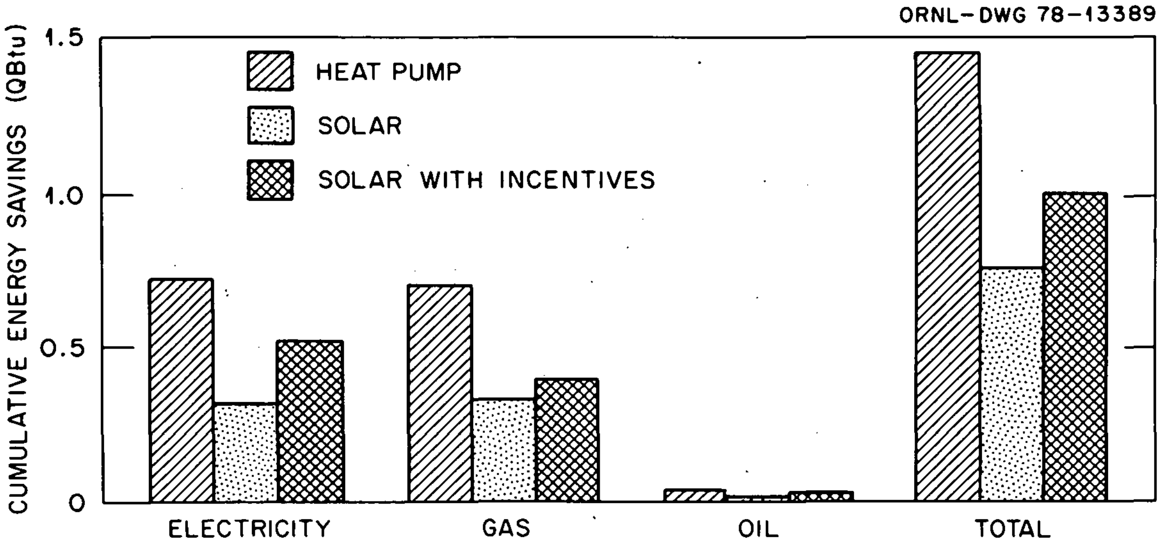

Fig. 12. National cumulative (1977-2000) energy savings by fuel for improved electric water heating systems.

lower curves provide dramatic evidence on the effectiveness of the tax credit for solar installations. The number of new solar systems installed each year increases much more rapidly with the incentive than without. In 1984 (the last year of the credit), almost 350 thousand solar water heaters are installed with the tax credit, compared with 75 thousand without the tax credit. Even though heat pumps are not introduced until 1981, their sales exceed those of solar systems immediately without the tax credit and within two years with the tax credit.

Figure 11 shows the national energy savings due to adoption of either heat pump or solar water heaters. Because heat pumps are introduced four years later than are solar systems, heat pump energy savings do not exceed those of solar systems until 1983 without solar tax credits or 1986 with solar tax credits. In either case, heat pump energy savings increase much more rapidly than do solar energy savings.

Figure 12 shows the cumulative energy savings by fuel for the three systems considered. Heat pumps provide larger cumulative energy savings than do solar systems, even if tax credits for solar systems are available. This is true for each fuel - electricity, gas, oil - as well as for overall energy use.

Our results show large regional variation in the energy and economic benefits for these systems. Regions 1, 3, 4, and 10 show relatively large benefits due to commercialization of heat pumps; regions 6, 7, and 9 show low benefits. Regions 1, 3, 4, and 8 show relatively large solar benefits, while regions 2, 7, and 10 show low benefits. These benefits differ from region to region because of baseline growth in electric water heating market shares, increases and absolute levels of electricity prices, growth in population and households, and solar insolation (for solar systems only).

Two policy conclusions emerge from this analysis. First, tax credits that favor one type of energy-saving investment over another (e.g., present proposals to give larger subsidies for solar systems than for conventional conservation measures) lead to investments that are inefficient with respect to both economics and energy use. To the extent that reduced energy use is an important social goal, incentives should be neutral with respect to mechanisms used to save energy. In other words, two investments that save the same amount of a particular fuel should be subsidized equally.

Second, the tax credit analyzed here appears to be an effective instrument for encouraging purchase of solar water heaters. As shown in Figs. 10 and 11, the tax credit not only increases solar installations and energy savings while in force, but also has positive effects after the tax credit stops. A similar tax credit for heat pump water heaters would probably yield even larger energy benefits.

We conclude with a final caveat about our model results. As discussed in Section 3, the model contains several limitations and assumptions that should be kept in mind while interpreting these results. The most important with respect to the present study are: 1. Lack of a theoretically-sound and empirically-validated model of market penetration to show how new technologies enter the market and increase or decrease their market share over time. 2. Lack of sufficient time series/cross-section data to develop econometric models of regional equipment ownership market shares. 3. Lack of good information about the performance and costs of heat pump and solar water heating systems.

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REFERENCES

1. E. Hirst, and J. Carney, *The ORNL Engineering-Economic Model of Residential Energy Use*, Oak Ridge National Laboratory, ORNL/CON-24, July 1978.

2. R. A. Hoskins and E. Hirst, "Residential Water Heaters: Energy and Cost Analysis," *Energy and Buildings* 1(4), 1978. Also R. P. Wilson, Jr., "Energy Conservation Options for Residential Water Heaters," *Energy* 3(2), April 1978.

3. R. L. Dunning, "The Time for a Heat Pump Water Heater," *Proceedings of the Conference on Major Home Appliance Technology for Energy Conservation*, Paper D-3, Purdue University, West Lafayette, IN, February 1978.

4. A. C. Harvey, J. T. Diertmann, and W. M. Toscano, "High Efficiency Brayton Cycle Water Heater," *Proceedings of the Conference on Major Home Appliance Technology for Energy Conservation*, Paper D-5, Purdue University, West Lafayette, IN, February 1978.

5. R. Eckstrom, personal communication, Oak Ridge National Laboratory, May 1977.

6. V. M. Faires, *Thermodynamics*, Fifth edition, The McMillan Company, Toronto, 1970. Also B. D. Wood, *Applications of Thermodynamics*, Addison-Wesley Publishing Company, Reading, MA, 1969.

7. S. H. Butt, "The Solar Future - 1978," *Solar Engineering*, 3(3), March 1978.

8. National Bureau of Standards, *Intermediate Standards for Solar Domestic Hot Water Systems/HUD Initiative*, U. S. Department of Commerce, NBSIR 77-1272, July 1977.

9. Los Alamos Scientific Laboratory, *ERDA's Pacific Regional Solar Heating Handbook*, LA-6242-MS, 2nd edition, November 1976.

10. Sheet Metal and Air Conditioning Contractors National Association, *Fundamentals of Solar Heating*, HCP/M4038-01, January 1978.

11. W. A. Beckman, S. A. Klein, and J. A. Duffie, *Solar Heating Design*, John Wiley & Sons, New York, 1977.

12. S. A. Klein, W. A. Beckman, and J. A. Duffie, "A Design Procedure for Solar Heating Systems," *Solar Energy*, 18(2), 1976.

13. J. E. Hill, et al., *Development of Proposed Standards for Testing Solar Collectors and Thermal Storage Devices*, National Bureau of Standards, Technical Note 899, February 1976.

14. R. Hewett and P. Spewak, *Systems Descriptions and Engineering Costs for Solar-Related Technologies*, Vol. II, Mitre Corp., MTR-7485, June 1977.

15. Dodge Building Cost Services, *1977 Dodge Manual for Building Construction Pricing and Scheduling*, 12th edition, McGraw-Hill Information Systems Company, New York, 1977.

16. The White House, *The President's Energy Program*, April 20, 1977. Also Executive Office of the President, *The National Energy Plan*, April 29, 1977. Also, *National Energy Act*, 95th Congress, House Document No. 95-138, April 29, 1977.

17. Office of Technology Assessment, *Applications of Solar Technology to Today's Energy Needs*, U. S. Congress, June 1977.

18. Bureau of the Census, *Statistical Abstract of the United States: 1977*, 98 edition, U. S. Department of Commerce, 1977.

19. D. Bjornstad, personal communication, "Multiregion Series TOPS.R1. OBERS," Oak Ridge National Laboratory, June 1978.

20. W. Lin, E. Hirst, and S. Cohn, *Fuel Choices in the Household Sector*, Oak Ridge National Laboratory, ORNL/CON-3, October 1976. Also R. S. Hartman, *A Critical Review of Single Fuel and Interfuel Substitution Residential Energy Demand Models*, MIT Energy Laboratory, MIT-EL-78-003, March 1978.

21. Bureau of the Census, "Projections of the Population of the United States: 1975-2050," *Current Population Reports*, Series P-25, No. 704, U. S. Department of Commerce, July 1977.

22. R. Sastry, personal communication, U. S. Department of Energy, January 27, 1978. Also S. Carhart, personal communication, Brookhaven National Laboratory, January 17, 1978.

23. U. S. Water Resources Council, *1972 OBERS Projections*, "Regional Activity in the U. S., Volume 4, States," U. S. Department of Commerce and U. S. Department of Agriculture, April 1974.

24. Central Intelligence Agency, *The International Energy Situation: Outlook for 1985*, ER 77-10240U, April 1977. Also, C. L. Wilson, *Energy: Global Prospects, 1985-2000*, Report of the Workshop on Alternative Energy Strategies, McGraw-Hill, New York, 1977.

25. F. Roach, et al., *Prospects for Solar Energy: The Impact of the National Energy Plan*, Los Alamos Scientific Laboratory, LA-7064-MS, December 1977.

26. A. D. Little, Inc., *Solar Heating and Cooling of Buildings (SHACOB) Commercialization Report*, Volumes I, II, and III, C-80440, September 1977.

27. G. Bennington, et al., *Solar Energy - A Comparative Analysis to the Year 2020*, Mitre Corp., MTR-7579, March 1978.

Table A1. Assumed inputs for all projections of residential energy use: region 1

	POPULATION (10**6)	HOUSEHOLDS (10**6)	FCI (1975-$)	FUEL PRICES (1975-$/MBTU) ELEC.	GAS	OIL
1970	11.9	3.7	5958.	10.55	2.57	1.83
1975	12.2	4.1	6077.	13.19	3.06	3.13
1980	12.6	4.5	7805.	12.35	3.19	3.17
1985	13.3	5.0	8639.	12.88	3.83	3.39
1990	14.0	5.4	9652.	13.83	4.37	3.66
2000	15.1	6.2	11439.	14.88	5.68	4.15

Table A2. Assumed inputs for all projections of residential energy use: region 2

	POPULATION (10**6)	HOUSEHOLDS (10**6)	FCI (1975-$)	FUEL PRICES (1975-$/MBTU) ELEC.	GAS	OIL
1970	25.6	7.9	6520.	11.22	2.07	1.85
1975	25.6	8.5	6585.	14.81	2.50	2.87
1980	25.4	9.1	8541.	13.35	2.96	3.21
1985	25.8	9.8	9519.	13.58	3.48	3.50
1990	26.3	10.3	10497.	13.92	3.87	3.75
2000	26.3	10.8	12258.	15.04	5.01	4.25

Table A3. Assumed inputs for all projections of residential energy use: region 3

	POPULATION (10**6)	HOUSEHOLDS (10**6)	FCI (1975-$)	FUEL FRICES (1975-$/MBTU) ELEC.	GAS	OIL
1970	23.6	7.3	5480.	9.01	1.70	1.77
1975	24.2	8.1	5973.	11.08	1.92	2.78
1980	24.8	8.9	7288.	10.36	2.55	3.36
1985	25.6	9.6	8056.	11.17	3.03	3.63
1990	26.3	10.3	9042.	11.99	3.31	3.87
2000	27.3	11.2	10790.	12.89	4.30	4.10

Table A4. Assumed inputs for all projections of residential energy use: region 4

	POPULATION (10**6)	HOUSEHOLDS (10**6)	FCI (1975-$)	FUEL FRICES (1975-$/MBTU) ELEC.	GAS	OIL
1970	32.2	10.0	4494.	6.72	1.43	1.75
1975	34.9	11.6	4988.	8.19	1.49	2.80
1980	37.7	13.5	5977.	9.07	2.10	3.41
1985	40.4	15.2	6741.	9.60	2.58	3.70
1990	43.2	16.9	7595.	9.94	3.03	3.95
2000	48.2	19.7	9213.	10.75	3.92	4.49

Table A5. Assumed inputs for all projections of residential energy use: region 5

	POPULATION (10**6)	HOUSEHOLDS (10**6)	PCI (1975-$)	FUEL PRICES (1975-$/MBTU) ELEC.	GAS	OIL
1970	44.5	13.8	5682.	9.45	1.36	1.70
1975	45.2	15.1	6080.	9.73	1.53	2.65
1980	45.9	16.5	7557.	9.54	2.09	2.97
1985	47.3	17.8	8409.	10.58	2.50	3.31
1990	48.7	19.0	9375.	11.15	3.16	3.55
2000	50.3	20.5	11137.	12.00	4.09	4.03

Table A6. Assumed inputs for all projections of residential energy use: region 6

	POPULATION (10**6)	HOUSEHOLDS (10**6)	PCI (1975-$)	FUEL PRICES (1975-$/MBTU) ELEC.	GAS	OIL
1970	20.5	6.3	4693.	8.68	1.16	1.72
1975	21.9	7.3	5303.	7.90	1.34	2.73
1980	23.4	8.4	6242.	11.90	1.67	3.12
1985	25.0	9.4	6993.	12.07	1.92	3.42
1990	26.6	10.4	7837.	12.85	2.43	3.66
2000	29.4	12.0	9480.	13.81	3.15	4.14

Table A7. Assumed inputs for all projections of residential energy use: region 7

	POPULATION (10**6)	HOUSEHOLDS (10**6)	PCI (1975-$)	FUEL PRICES (1975-$/MBTU) ELEC.	GAS	OIL
1970	11.3	3.5	5244.	9.83	1.18	1.70
1975	11.5	3.8	5821.	8.95	1.29	2.69
1980	11.7	4.2	6922.	10.13	1.58	2.88
1985	12.0	4.5	7814.	10.52	1.78	3.22
1990	12.3	4.8	8705.	10.42	2.48	3.48
2000	12.5	5.1	10436.	11.21	3.20	3.95

Table A8. Assumed inputs for all projections of residential energy use: region 8

	POPULATION (10**6)	HOUSEHOLDS (10**6)	PCI (1975-$)	FUEL PRICES (1975-$/MBTU) ELEC.	GAS	OIL
1970	5.7	1.8	4878.	9.75	1.08	1.83
1975	6.2	2.1	5561.	8.19	1.17	2.78
1980	6.7	2.4	6585.	7.89	1.59	3.07
1985	7.1	2.7	7415.	8.19	1.78	3.38
1990	7.6	2.9	8244.	8.97	2.42	3.62
2000	8.3	3.4	9854.	9.65	3.12	4.11

Table A9. Assumed inputs for all projections of residential energy use: region 9

	POPULATION (10**6)	HOUSEHOLDS (10**6)	PCI (1975-$)	FUEL PRICES (1975-$/MBTU) ELEC.	GAS	OIL
1970	23.2	7.2	6143.	8.62	1.35	2.03
1975	24.9	8.3	6450.	9.83	1.54	2.98
1980	26.8	9.6	7863.	11.72	2.28	3.13
1985	28.7	10.8	8723.	11.81	3.30	3.39
1990	30.6	12.0	9706.	12.15	3.37	3.65
2000	34.1	13.9	11365.	13.10	3.81	4.16

Table A10. Assumed inputs for all projections of residential energy use: region 10

	POPULATION (10**6)	HOUSEHOLDS (10**6)	PCI (1975-$)	FUEL PRICES (1975-$/MBTU) ELEC.	GAS	OIL
1970	6.6	2.0	5383.	4.67	1.94	2.03
1975	7.0	2.3	6137.	4.25	2.10	2.92
1980	7.4	2.7	7159.	5.75	3.11	3.13
1985	7.8	3.0	7967.	5.93	3.05	3.39
1990	8.2	3.2	8936.	6.59	3.03	3.65
2000	8.9	3.6	10605.	7.05	3.44	4.16

Table A11. Regional and national energy and economic effects of heat pumps

	1977	1978	1979	1980	1981	1983	1985	1990	1995	2000	TOTAL
REGION 1											
ENERGY SAVINGS (TRILLION BTU)	0.0	0.0	0.0	0.0	0.29	1.35	2.68	6.09	9.11	11.78	124.26
SAVINGS (MBTU)/HOUSEHOLD	0.0	0.0	0.0	0.0	0.06	0.28	0.53	1.12	1.57	1.91	21.82
UNITS INSTALLED (THOUSANDS)	0.0	0.0	0.0	0.0	6.80	19.69	29.85	46.15	56.26	63.94	864.61
% ELEC W. HEATERS INSTALLED	0.0	0.0	0.0	0.0	4.27	11.43	16.41	23.61	26.98	28.95	16.72
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 154.17				INCREASED EQUIPMENT = 54.68			NET = 99.49		B/C= 2.82	
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= 78.91		GAS= 32.15		OIL= 13.20		OTHER= 0.0				
REGION 2											
ENERGY SAVINGS (TRILLION BTU)	0.0	0.0	0.0	0.0	0.23	1.08	2.13	4.83	7.16	9.14	97.69
SAVINGS (MBTU)/HOUSEHOLD	0.0	0.0	0.0	0.0	0.02	0.10	0.20	0.42	0.58	0.70	8.12
UNITS INSTALLED (THOUSANDS)	0.0	0.0	0.0	0.0	5.45	15.90	23.92	35.04	41.65	47.27	654.74
% ELEC W. HEATERS INSTALLED	0.0	0.0	0.0	0.0	4.36	11.77	16.71	22.88	25.50	27.28	16.26
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 119.53				INCREASED EQUIPMENT = 42.60			NET = 76.93		B/C= 2.81	
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= 67.75		GAS= 21.26		OIL= 8.68		OTHER= 0.0				
REGION 3											
ENERGY SAVINGS (TRILLION BTU)	0.0	0.0	0.0	0.0	0.43	1.89	3.67	7.98	11.60	14.77	160.07
SAVINGS (MBTU)/HOUSEHOLD	0.0	0.0	0.0	0.0	0.05	0.19	0.36	0.74	1.01	1.22	14.19
UNITS INSTALLED (THOUSANDS)	0.0	0.0	0.0	0.0	10.52	29.77	45.07	66.81	80.04	90.23	1248.08
% ELEC W. HEATERS INSTALLED	0.0	0.0	0.0	0.0	3.99	10.68	15.41	22.32	25.49	27.32	15.25
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 170.21				INCREASED EQUIPMENT = 81.72			NET = 88.50		B/C= 2.08	
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= 93.97		GAS= 57.12		OIL= 8.99		OTHER= 0.0				
REGION 4											
ENERGY SAVINGS (TRILLION BTU)	0.0	0.0	0.0	0.0	1.26	5.71	11.17	25.18	36.89	46.42	504.17
SAVINGS (MBTU)/HOUSEHOLD	0.0	0.0	0.0	0.0	0.09	0.40	0.76	1.55	2.11	2.49	29.60
UNITS INSTALLED (THOUSANDS)	0.0	0.0	0.0	0.0	31.95	96.07	147.34	224.22	264.47	295.96	4120.57
% ELEC W. HEATERS INSTALLED	0.0	0.0	0.0	0.0	3.91	11.06	16.20	22.98	25.84	27.60	15.27
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 456.71				INCREASED EQUIPMENT = 273.66			NET = 183.06		B/C= 1.67	
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= 315.76		GAS= 188.40		OIL= 0.0		OTHER= 0.0				
REGION 5											
ENERGY SAVINGS (TRILLION BTU)	0.0	0.0	0.0	0.0	0.57	2.56	4.96	11.66	18.18	24.40	245.80
SAVINGS (MBTU)/HOUSEHOLD	0.0	0.0	0.0	0.0	0.03	0.14	0.26	0.58	0.85	1.09	11.70
UNITS INSTALLED (THOUSANDS)	0.0	0.0	0.0	0.0	13.20	36.67	56.09	95.46	119.58	140.21	1795.23
% ELEC W. HEATERS INSTALLED	0.0	0.0	0.0	0.0	3.47	9.03	13.13	18.94	21.69	23.36	13.91
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 237.45				INCREASED EQUIPMENT = 115.89			NET = 121.56		B/C= 2.05	
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= 154.33		GAS= 91.47		OIL= 0.0		OTHER= 0.0				
REGION 6											
ENERGY SAVINGS (TRILLION BTU)	0.0	0.0	0.0	0.0	0.14	0.65	1.30	3.19	5.09	6.98	68.34
SAVINGS (MBTU)/HOUSEHOLD	0.0	0.0	0.0	0.0	0.02	0.08	0.15	0.35	0.52	0.68	7.12
UNITS INSTALLED (THOUSANDS)	0.0	0.0	0.0	0.0	3.83	11.83	19.06	37.04	50.54	64.90	727.39
% ELEC W. HEATERS INSTALLED	0.0	0.0	0.0	0.0	4.38	12.04	17.63	25.70	29.16	31.14	19.79
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 62.38				INCREASED EQUIPMENT = 42.75			NET = 19.63		B/C= 1.46	
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= 32.67		GAS= 36.12		OIL= 0.0		OTHER= -0.45				

Table A11 (continued)

	1977	1978	1979	1980	1981	1983	1985	1990	1995	2000	TOTAL
REGION 7											
ENERGY SAVINGS (TRILLION BTU)	0.0	0.0	0.0	0.0	0.08	0.36	0.71	1.74	2.77	3.71	36.96
SAVINGS (MBTU)/HOUSEHOLD	0.0	0.0	0.0	0.0	0.02	0.08	0.16	0.37	0.56	0.73	7.56
UNITS INSTALLED (THOUSANDS)	0.0	0.0	0.0	0.0	2.07	5.71	8.49	15.60	19.20	22.79	287.22
% ELEC W. HEATERS INSTALLED	0.0	0.0	0.0	0.0	3.49	9.01	12.76	16.88	18.51	19.85	12.56
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 30.49 INCREASED EQUIPMENT = 18.52 NET = 11.98 B/C= 1.65										
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= 18.91 GAS= 18.06 OIL= 0.0 OTHER= -0.02										
REGION 8											
ENERGY SAVINGS (TRILLION BTU)	0.0	0.0	0.0	0.0	0.07	0.30	0.60	1.48	2.50	3.58	33.31
SAVINGS (MBTU)/HOUSEHOLD	0.0	0.0	0.0	0.0	0.03	0.13	0.26	0.60	0.97	1.34	13.07
UNITS INSTALLED (THOUSANDS)	0.0	0.0	0.0	0.0	1.04	3.00	4.46	8.94	12.50	15.94	177.94
% ELEC W. HEATERS INSTALLED	0.0	0.0	0.0	0.0	1.98	5.34	7.56	11.39	13.58	15.08	9.09
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 24.67 INCREASED EQUIPMENT = 10.66 NET = 14.02 B/C= 2.32										
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= 19.91 GAS= 13.40 OIL= 0.0 OTHER= 0.01										
REGION 9											
ENERGY SAVINGS (TRILLION BTU)	0.0	0.0	0.0	0.0	0.17	0.94	2.60	6.66	8.55	10.28	119.28
SAVINGS (MBTU)/HOUSEHOLD	0.0	0.0	0.0	0.0	0.02	0.09	0.25	0.58	0.70	0.79	10.02
UNITS INSTALLED (THOUSANDS)	0.0	0.0	0.0	0.0	6.62	31.78	77.87	103.14	92.48	135.36	1748.26
% ELEC W. HEATERS INSTALLED	0.0	0.0	0.0	0.0	4.36	12.22	17.72	24.72	27.71	29.49	20.79
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 116.82 INCREASED EQUIPMENT = 114.86 NET = 1.96 B/C= 1.02										
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= -51.73 GAS= 171.42 OIL= 0.0 OTHER= -0.41										
REGION 10											
ENERGY SAVINGS (TRILLION BTU)	0.0	0.0	0.0	0.0	0.25	1.14	2.19	3.97	4.21	3.65	63.58
SAVINGS (MBTU)/HOUSEHOLD	0.0	0.0	0.0	0.0	0.10	0.44	0.82	1.39	1.39	1.14	21.72
UNITS INSTALLED (THOUSANDS)	0.0	0.0	0.0	0.0	5.70	15.29	22.18	31.75	36.09	38.92	578.17
% ELEC W. HEATERS INSTALLED	0.0	0.0	0.0	0.0	2.95	7.65	10.85	16.01	18.62	20.07	9.87
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 62.82 INCREASED EQUIPMENT = 40.16 NET = 22.65 B/C= 1.56										
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= -9.97 GAS= 73.32 OIL= 0.0 OTHER= 0.24										
NATION											
ENERGY SAVINGS (TRILLION BTU)	0.0	0.0	0.0	0.0	3.50	15.98	32.01	72.77	106.05	134.72	1453.48
SAVINGS (MBTU)/HOUSEHOLD	0.0	0.0	0.0	0.0	0.01	0.02	0.04	0.09	0.13	0.16	14.69
UNITS INSTALLED (THOUSANDS)	0.0	0.0	0.0	0.0	87.17	265.70	434.33	664.14	772.82	915.50	12202.20
% ELEC W. HEATERS INSTALLED	0.0	0.0	0.0	0.0	3.81	10.47	15.34	21.71	24.48	26.32	15.36
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 1435.27 INCREASED EQUIPMENT = 795.49 NET = 639.77 B/C= 1.80										
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= 720.52 GAS= 702.72 OIL= 30.87 OTHER= -0.64										
NATION (USING NATIONAL DATA)											
ENERGY SAVINGS (TRILLION BTU)	0.0	0.0	0.0	0.0	4.31	19.64	38.74	88.43	132.68	172.24	1808.46
SAVINGS (MBTU)/HOUSEHOLD	0.0	0.0	0.0	0.0	0.05	0.23	0.44	0.93	1.31	1.62	18.26
UNITS INSTALLED (THOUSANDS)	0.0	0.0	0.0	0.0	108.26	312.87	477.42	736.66	893.34	1022.63	13776.00
% ELEC W. HEATERS INSTALLED	0.0	0.0	0.0	0.0	4.00	10.67	15.34	21.66	24.47	26.20	15.09
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 1772.22 INCREASED EQUIPMENT = 889.13 NET = 883.09 B/C= 1.99										
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= 1026.79 GAS= 634.97 OIL= 146.27 OTHER= 0.45										

Table A12. Regional and national energy and economic effects of solar water heaters

	1977	1978	1979	1980	1981	1983	1985	1990	1995	2000	TOTAL
REGION 1											
ENERGY SAVINGS (TRILLION BTU)	0.05	0.13	0.22	0.31	0.42	0.63	0.84	1.34	1.82	2.29	28.21
SAVINGS (MBTU)/HOUSEHOLD	0.01	0.03	0.05	0.07	0.09	0.13	0.17	0.25	0.31	0.37	5.05
UNITS INSTALLED (THOUSANDS)	0.16	0.30	0.42	0.50	0.59	0.74	0.86	1.19	1.54	1.88	26.04
% ELEC W. HEATERS INSTALLED	0.11	0.20	0.28	0.33	0.38	0.45	0.50	0.66	0.80	0.93	0.53
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 38.70				INCREASED EQUIPMENT = 15.51			NET = 23.19			B/C= 2.50
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= 16.45		GAS= 8.11		OIL= 3.66		OTHER= 0.0				
REGION 2											
ENERGY SAVINGS (TRILLION BTU)	0.03	0.07	0.13	0.18	0.24	0.37	0.48	0.75	0.99	1.22	15.62
SAVINGS (MBTU)/HOUSEHOLD	0.00	0.01	0.01	0.02	0.02	0.04	0.05	0.07	0.08	0.09	1.33
UNITS INSTALLED (THOUSANDS)	0.07	0.15	0.21	0.25	0.30	0.36	0.41	0.49	0.60	0.75	11.05
% ELEC W. HEATERS INSTALLED	0.06	0.13	0.19	0.21	0.24	0.28	0.30	0.35	0.40	0.47	0.29
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 21.46				INCREASED EQUIPMENT = 7.76			NET = 13.70			B/C= 2.76
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= 10.13		GAS= 3.72		OIL= 1.77		OTHER= 0.0				
REGION 3											
ENERGY SAVINGS (TRILLION BTU)	0.10	0.26	0.47	0.69	0.91	1.36	1.79	2.81	3.71	4.59	58.35
SAVINGS (MBTU)/HOUSEHOLD	0.01	0.03	0.05	0.07	0.10	0.14	0.18	0.26	0.32	0.38	5.28
UNITS INSTALLED (THOUSANDS)	0.56	1.04	1.47	1.79	2.06	2.57	3.05	4.02	4.97	5.90	86.56
% ELEC W. HEATERS INSTALLED	0.25	0.44	0.59	0.70	0.79	0.96	1.10	1.45	1.71	1.93	1.11
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 68.38				INCREASED EQUIPMENT = 38.32			NET = 30.06			B/C= 1.78
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= 33.16		GAS= 21.70		OIL= 3.50		OTHER= 0.0				
REGION 4											
ENERGY SAVINGS (TRILLION BTU)	0.56	1.44	2.52	3.71	4.65	7.25	9.63	15.27	19.97	24.08	313.10
SAVINGS (MBTU)/HOUSEHOLD	0.05	0.12	0.20	0.28	0.36	0.51	0.65	0.94	1.14	1.29	18.87
UNITS INSTALLED (THOUSANDS)	4.76	9.39	13.99	18.14	20.78	27.08	32.27	41.45	48.54	55.90	864.13
% ELEC W. HEATERS INSTALLED	0.61	1.18	1.69	2.16	2.53	3.18	3.67	4.44	4.97	5.47	3.28
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 313.96				INCREASED EQUIPMENT = 222.46			NET = 91.50			B/C= 1.41
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= 191.02		GAS= 122.07		OIL= 0.0		OTHER= 0.0				
REGION 5											
ENERGY SAVINGS (TRILLION BTU)	0.11	0.29	0.51	0.75	1.01	1.53	2.05	3.49	5.02	6.64	75.79
SAVINGS (MBTU)/HOUSEHOLD	0.01	0.02	0.03	0.04	0.06	0.08	0.11	0.17	0.24	0.30	3.67
UNITS INSTALLED (THOUSANDS)	0.48	0.89	1.27	1.56	1.86	2.45	3.05	4.78	6.29	7.80	101.31
% ELEC W. HEATERS INSTALLED	0.15	0.27	0.36	0.43	0.49	0.62	0.75	1.01	1.22	1.39	0.82
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 78.96				INCREASED EQUIPMENT = 41.26			NET = 37.70			B/C= 1.91
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= 44.00		GAS= 31.79		OIL= 0.0		OTHER= 0.0				
REGION 6											
ENERGY SAVINGS (TRILLION BTU)	0.09	0.23	0.40	0.58	0.77	1.19	1.66	2.92	4.24	5.65	63.24
SAVINGS (MBTU)/HOUSEHOLD	0.01	0.03	0.05	0.07	0.10	0.14	0.19	0.32	0.43	0.55	6.69
UNITS INSTALLED (THOUSANDS)	0.78	1.64	2.67	3.77	4.69	6.70	8.42	13.80	18.62	24.36	292.36
% ELEC W. HEATERS INSTALLED	0.92	1.91	2.99	4.18	5.20	5.84	7.94	9.95	11.22	12.24	8.14
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 63.84				INCREASED EQUIPMENT = 48.24			NET = 15.60			B/C= 1.32
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= 33.29		GAS= 30.47		OIL= 0.0		OTHER= -0.51				

Table A12 (continued)

	1977	1978	1979	1980	1981	1983	1985	1990	1995	2000	TOTAL
REGION 7											
ENERGY SAVINGS (TRILLION BTU)	0.03	0.07	0.12	0.17	0.22	0.33	0.44	0.75	1.05	1.35	15.94
SAVINGS (MBTU)/HOUSEHOLD	0.01	0.02	0.03	0.04	0.05	0.08	0.10	0.16	0.21	0.26	3.31
UNITS INSTALLED (THOUSANDS)	0.17	0.32	0.47	0.61	0.73	0.94	1.11	1.70	2.06	2.54	34.75
% ELEC W. HEATERS INSTALLED	0.30	0.57	0.82	1.03	1.22	1.54	1.75	1.95	2.12	2.36	1.58
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 14.16				INCREASED EQUIPMENT = 9.20			NET = 4.96		B/C= 1.54	
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= 7.05		GAS= 8.92		OIL= 0.0		OTHER= -0.02				
REGION 8											
ENERGY SAVINGS (TRILLION BTU)	0.03	0.09	0.16	0.24	0.32	0.49	0.64	1.08	1.64	2.28	24.59
SAVINGS (MBTU)/HOUSEHOLD	0.02	0.04	0.08	0.11	0.15	0.21	0.28	0.44	0.64	0.86	9.78
UNITS INSTALLED (THOUSANDS)	0.30	0.56	0.81	1.00	1.10	1.34	1.54	2.72	3.88	5.14	60.46
% ELEC W. HEATERS INSTALLED	0.67	1.19	1.59	1.95	2.06	2.39	2.66	3.57	4.34	5.01	3.14
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 19.76				INCREASED EQUIPMENT = 8.45			NET = 11.32		B/C= 2.34	
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= 13.49		GAS= 11.09		OIL= 0.0		OTHER= 0.01				
REGION 9											
ENERGY SAVINGS (TRILLION BTU)	0.07	0.19	0.33	0.49	0.66	1.09	1.88	3.58	4.27	4.96	65.58
SAVINGS (MBTU)/HOUSEHOLD	0.01	0.02	0.04	0.05	0.07	0.11	0.18	0.31	0.35	0.38	5.60
UNITS INSTALLED (THOUSANDS)	0.97	2.08	3.42	4.87	6.57	13.19	24.36	25.94	22.82	34.42	481.47
% ELEC W. HEATERS INSTALLED	0.94	1.84	2.73	3.56	4.26	5.33	5.97	6.92	7.72	8.47	6.23
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 68.87				INCREASED EQUIPMENT = 81.23			NET = -12.36		B/C= 0.85	
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= -25.09		GAS= 90.98		OIL= 0.0		OTHER= -0.30				
REGION 10											
ENERGY SAVINGS (TRILLION BTU)	0.01	0.02	0.03	0.04	0.04	0.05	0.06	0.04	-0.03	-0.14	0.13
SAVINGS (MBTU)/HOUSEHOLD	0.00	0.01	0.01	0.01	0.02	0.02	0.02	0.01	-0.01	-0.04	0.08
UNITS INSTALLED (THOUSANDS)	0.03	0.02	0.01	0.01	0.01	0.01	0.02	0.06	0.10	0.13	1.38
% ELEC W. HEATERS INSTALLED	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.04	0.06	0.09	0.03
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 2.00				INCREASED EQUIPMENT = 0.74			NET = 1.26		B/C= 2.71	
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= -4.68		GAS= 4.79		OIL= 0.0		OTHER= 0.02				
NATION											
ENERGY SAVINGS (TRILLION BTU)	1.09	2.79	4.88	7.16	9.44	14.28	19.48	32.04	42.68	52.92	660.57
SAVINGS (MBTU)/HOUSEHOLD	0.00	0.01	0.01	0.01	0.02	0.02	0.03	0.05	0.06	0.07	6.81
UNITS INSTALLED (THOUSANDS)	8.26	16.40	24.75	32.50	38.69	55.39	75.08	96.16	109.42	138.83	1959.50
% ELEC W. HEATERS INSTALLED	0.40	0.77	1.12	1.43	1.69	2.25	2.78	3.37	3.74	4.32	2.58
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 690.10				INCREASED EQUIPMENT = 473.16			NET = 216.93		B/C= 1.46	
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= 318.80		GAS= 333.64		OIL= 8.93		OTHER= -0.81				
NATION (USING NATIONAL DATA)											
ENERGY SAVINGS (TRILLION BTU)	1.59	4.01	6.94	10.10	13.33	20.14	27.05	43.86	59.24	74.24	917.06
SAVINGS (MBTU)/HOUSEHOLD	0.02	0.05	0.09	0.13	0.16	0.24	0.31	0.46	0.59	0.70	9.45
UNITS INSTALLED (THOUSANDS)	11.55	22.15	32.16	40.47	47.68	62.13	74.05	98.16	119.98	142.53	2082.55
% ELEC W. HEATERS INSTALLED	0.45	0.86	1.21	1.50	1.76	2.18	2.49	3.06	3.49	3.88	2.36
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 989.26				INCREASED EQUIPMENT = 570.24			NET = 419.02		B/C= 1.73	
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= 503.73		GAS= 336.94		OIL= 76.18		OTHER= 0.37				

Table A13. Regional and national energy and economic effects of solar water heaters with tax credits

	1977	1978	1979	1980	1981	1983	1985	1990	1995	2000	TOTAL
REGION 1											
ENERGY SAVINGS (TRILLION BTU)	0.14	0.34	0.59	0.86	1.15	1.76	2.25	2.58	2.74	2.96	50.76
SAVINGS (MBTU)/HOUSEHOLD	0.03	0.08	0.13	0.19	0.24	0.36	0.45	0.48	0.47	0.48	9.29
UNITS INSTALLED (THOUSANDS)	1.07	1.99	2.80	3.36	4.05	5.08	2.32	1.56	1.63	1.91	56.34
% ELEC W. HEATERS INSTALLED	0.72	1.33	1.83	2.19	2.52	3.01	1.34	0.86	0.85	0.94	1.14
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 76.61				INCREASED EQUIPMENT = 31.77			NET = 44.84		B/C= 2.41	
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= 30.13		GAS= 13.98		OIL= 6.65		OTHER= 0.0				
REGION 2											
ENERGY SAVINGS (TRILLION BTU)	0.09	0.24	0.42	0.61	0.82	1.25	1.59	1.73	1.71	1.74	33.31
SAVINGS (MBTU)/HOUSEHOLD	0.01	0.03	0.04	0.06	0.08	0.12	0.15	0.15	0.14	0.13	2.89
UNITS INSTALLED (THOUSANDS)	0.66	1.26	1.77	2.13	2.54	3.09	1.43	0.73	0.67	0.77	30.61
% ELEC W. HEATERS INSTALLED	0.61	1.12	1.51	1.78	2.02	2.34	1.05	0.51	0.44	0.48	0.79
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 51.42				INCREASED EQUIPMENT = 21.23			NET = 30.18		B/C= 2.42	
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= 21.83		GAS= 7.62		OIL= 3.85		OTHER= 0.0				
REGION 3											
ENERGY SAVINGS (TRILLION BTU)	0.24	0.62	1.10	1.64	2.19	3.29	4.19	4.90	5.26	5.70	96.50
SAVINGS (MBTU)/HOUSEHOLD	0.03	0.07	0.12	0.18	0.23	0.34	0.42	0.45	0.46	0.47	8.88
UNITS INSTALLED (THOUSANDS)	2.85	5.55	8.10	10.06	11.71	14.71	7.12	5.00	5.23	5.97	170.71
% ELEC W. HEATERS INSTALLED	1.25	2.31	3.18	3.80	4.35	5.31	2.52	1.79	1.80	1.95	2.16
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 122.95				INCREASED EQUIPMENT = 68.36			NET = 54.59		B/C= 1.80	
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= 55.51		GAS= 35.36		OIL= 5.62		OTHER= 0.0				
REGION 4											
ENERGY SAVINGS (TRILLION BTU)	1.05	2.71	4.77	7.02	9.23	13.86	17.91	22.76	25.59	28.11	448.11
SAVINGS (MBTU)/HOUSEHOLD	0.09	0.22	0.37	0.53	0.68	0.98	1.21	1.40	1.46	1.51	27.45
UNITS INSTALLED (THOUSANDS)	15.66	31.34	47.05	61.21	70.39	91.91	60.70	48.58	50.38	56.38	1333.51
% ELEC W. HEATERS INSTALLED	1.99	3.88	5.59	7.13	8.36	10.50	6.79	5.18	5.16	5.52	5.03
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 477.22				INCREASED EQUIPMENT = 333.13			NET = 144.09		B/C= 1.43	
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= 283.56		GAS= 164.54		OIL= 0.0		OTHER= 0.0				
REGION 5											
ENERGY SAVINGS (TRILLION BTU)	0.28	0.73	1.30	1.92	2.60	3.95	5.05	6.11	6.97	8.04	123.54
SAVINGS (MBTU)/HOUSEHOLD	0.02	0.04	0.08	0.11	0.15	0.22	0.27	0.30	0.33	0.36	6.09
UNITS INSTALLED (THOUSANDS)	2.85	5.44	7.90	9.83	11.64	15.41	7.24	5.98	6.62	7.90	190.52
% ELEC W. HEATERS INSTALLED	0.89	1.62	2.22	2.65	3.06	3.82	1.75	1.26	1.28	1.41	1.53
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 140.75				INCREASED EQUIPMENT = 74.80			NET = 65.94		B/C= 1.88	
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= 71.45		GAS= 52.10		OIL= 0.0		OTHER= 0.0				
REGION 6											
ENERGY SAVINGS (TRILLION BTU)	0.15	0.39	0.68	0.99	1.32	2.07	2.81	4.01	5.08	6.26	82.50
SAVINGS (MBTU)/HOUSEHOLD	0.02	0.05	0.09	0.13	0.17	0.25	0.33	0.43	0.52	0.61	8.82
UNITS INSTALLED (THOUSANDS)	2.24	4.73	7.68	10.82	13.47	19.25	14.93	15.88	19.25	24.55	385.91
% ELEC W. HEATERS INSTALLED	2.61	5.39	8.37	11.58	14.33	18.77	13.73	11.38	11.58	12.33	10.64
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 88.60				INCREASED EQUIPMENT = 66.25			NET = 22.35		B/C= 1.34	
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= 45.17		GAS= 38.05		OIL= 0.0		OTHER= -0.72				

Table A13 (continued)

	1977	1978	1979	1980	1981	1983	1985	1990	1995	2000	TOTAL
REGION 7											
ENERGY SAVINGS (TRILLION BTU)	0.06	0.15	0.26	0.38	0.50	0.76	0.97	1.21	1.39	1.60	24.38
SAVINGS (MBTU)/HOUSEHOLD	0.02	0.04	0.06	0.09	0.12	0.17	0.22	0.25	0.28	0.31	5.12
UNITS INSTALLED (THOUSANDS)	0.72	1.40	2.10	2.71	3.24	4.22	2.39	2.08	2.16	2.57	58.16
% ELEC W. HEATERS INSTALLED	1.28	2.44	3.52	4.47	5.29	6.61	3.67	2.38	2.22	2.39	2.62
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 23.58 INCREASED EQUIPMENT = 15.67 NET = 7.92 B/C= 1.51										
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= 11.01 GAS= 13.40 OIL= 0.0 OTHER= -0.03										
REGION 8											
ENERGY SAVINGS (TRILLION BTU)	0.07	0.19	0.34	0.51	0.67	1.03	1.32	1.69	2.10	2.61	35.53
SAVINGS (MBTU)/HOUSEHOLD	0.03	0.09	0.16	0.23	0.31	0.45	0.57	0.68	0.81	0.98	14.30
UNITS INSTALLED (THOUSANDS)	1.02	1.99	2.91	3.65	4.08	5.03	3.05	3.22	4.03	5.18	88.54
% ELEC W. HEATERS INSTALLED	2.28	4.12	5.57	6.59	7.38	8.67	5.11	4.18	4.50	5.05	4.55
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 30.76 INCREASED EQUIPMENT = 13.59 NET = 17.17 B/C= 2.26										
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= 20.15 GAS= 15.37 OIL= 0.0 OTHER= 0.01										
REGION 9											
ENERGY SAVINGS (TRILLION BTU)	0.20	0.53	0.95	1.43	1.95	3.48	6.01	7.93	7.63	7.28	135.65
SAVINGS (MBTU)/HOUSEHOLD	0.02	0.06	0.10	0.15	0.20	0.35	0.58	0.70	0.62	0.56	11.82
UNITS INSTALLED (THOUSANDS)	4.17	9.27	15.64	22.74	31.26	64.34	78.08	35.76	24.69	35.06	896.64
% ELEC W. HEATERS INSTALLED	3.93	7.78	11.52	15.04	18.02	22.61	18.06	9.36	8.31	8.62	11.20
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 159.08 INCREASED EQUIPMENT = 168.90 NET = -9.82 B/C= 0.94										
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= -11.93 GAS= 148.18 OIL= 0.0 OTHER= -0.60										
REGION 10											
ENERGY SAVINGS (TRILLION BTU)	0.05	0.13	0.23	0.34	0.43	0.63	0.76	0.58	0.34	0.12	10.40
SAVINGS (MBTU)/HOUSEHOLD	0.02	0.05	0.10	0.14	0.17	0.24	0.28	0.20	0.11	0.04	3.77
UNITS INSTALLED (THOUSANDS)	0.18	0.37	0.59	0.82	0.96	1.29	0.50	0.17	0.13	0.14	9.93
% ELEC W. HEATERS INSTALLED	0.09	0.18	0.29	0.41	0.50	0.66	0.26	0.10	0.08	0.09	0.19
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 12.90 INCREASED EQUIPMENT = 7.42 NET = 5.48 B/C= 1.74										
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= 0.03 GAS= 10.31 OIL= 0.0 OTHER= 0.06										
NATION											
ENERGY SAVINGS (TRILLION BTU)	2.33	6.02	10.63	15.69	20.87	32.07	42.86	53.50	58.80	64.41	1040.68
SAVINGS (MBTU)/HOUSEHOLD	0.00	0.01	0.02	0.03	0.04	0.05	0.07	0.07	0.08	0.08	10.90
UNITS INSTALLED (THOUSANDS)	31.41	63.33	96.55	127.33	153.55	224.33	177.76	118.95	114.79	140.43	3220.89
% ELEC W. HEATERS INSTALLED	1.50	2.93	4.26	5.47	6.51	8.77	6.43	4.14	3.91	4.37	4.19
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 1183.87 INCREASED EQUIPMENT = 801.13 NET = 382.75 B/C= 1.48										
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= 526.92 GAS= 498.91 OIL= 16.12 OTHER= -1.28										
NATION (USING NATIONAL DATA)											
ENERGY SAVINGS (TRILLION BTU)	3.34	8.52	14.86	21.77	28.87	43.92	57.06	70.80	79.39	88.72	1402.51
SAVINGS (MBTU)/HOUSEHOLD	0.04	0.11	0.19	0.27	0.35	0.52	0.65	0.74	0.79	0.83	14.69
UNITS INSTALLED (THOUSANDS)	45.47	88.85	131.01	166.56	197.55	258.52	158.87	119.39	125.65	144.06	3494.40
% ELEC W. HEATERS INSTALLED	1.76	3.38	4.79	6.00	7.05	8.74	5.22	3.70	3.65	3.92	3.92
EXPENDITURE CHANGES (MILLION $)	DECREASED FUEL = 1630.13 INCREASED EQUIPMENT = 945.82 NET = 684.31 B/C= 1.72										
TOTAL ENERGY SAVING BY FUEL TYPE	ELEC= 783.16 GAS= 506.79 OIL= 111.99 OTHER= 0.63										

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