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ENERGY UTILIZATION IN THE U. S. A.

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Abstract

The use of energy in households is tabulated by use and by fuel. Trends in electrical energy consumption by use are given for the period 1960-1970. Comparison of energy use for households employing various appliances are made. Projections of the use of electrical appliances are made to the year 2000. These projections are used to project the total residential use of electricity to the year 2000. The results are found to be a factor of 4 below the straight line (exponential) predictions usually found in the literature. Electricity and total energy fuel savings, primarily through the use of better insulation and the partial employment of solar energy, are calculated. Approximately a thirty percent reduction of electricity and total energy consumption, over the projection without conservation measures, can be achieved.

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I. Introduction

In a previous article, we presented an overall analysis of energy utilization in the U.S.A.[1] Various methods of decreasing per capita energy consumption without affecting the standard of living were outlined. Here, we analyze in depth the direct consumption of energy in the residential sector, and make projections for this sector, to the year 2000 for both electricity and total energy consumption. We exclude from the present analysis the transportation sector and the energy required for the manufacture of household goods.

Residential energy consumption in 1970 amounted to 20% of the total energy consumption in the U.S.A., the other 80% being taken up by transportation, industry, commercial enterprises, public works and agriculture.[1,2] The residential sector is important because (i) the quantity of energy involved is large (the per capita household energy consumption in the U.S. is larger than the per capita total energy consumption in the rest of the world), (ii) the use of energy in the home makes itself immediately manifest in terms of household needs and comforts such as heating and cooling, lighting, appliances, etc., (iii) the environmental effects of household energy use tend to be ignored since

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the deleterous consequences are generally not apparent at the point of use and (iv) predictions of large increases in electricity consumption are predicated in large measure on large increases in household electricity consumption.

The major uses of energy in the household are shown in Table I. In this table we have included the efficiency of supply of energy to the household so that 1 kwht (kilowatt-hour thermal) of fossil fuel at the mine or well site corresponds to 0.9 kwht available at the housing unit and 1 kwhe (kilowatt-hour electrical) at the housing unit corresponds to 3.7 kwht of fuel heat value. We note from Table I that 70% of the energy used in the household is for space and water heat. This portion of the household energy use has not changed significantly in the past decade. The remainder (30%) is taken up by cooling, washing and drying, lighting, kitchen facilities and various household electrical appliances. It is this part of household energy use (usually in the form of electricity) that has grown significantly in the past decade. Therefore, the consumption of electricity in the household has increased much more rapidly than the total household energy use. Since the net production and supply efficiency of electricity is rather low (about 27% on the average), rapid increases in the use of electricity tend to have an even more pronounced effect on the consumption of energy. For these reasons, we shall devote considerable attention to household electricity use, saturation levels of appliances, growth rates of appliances and substitutability of other forms of energy for some major uses of household electricity.

TABLE I

MAJOR USES OF ENERGY IN THE HOUSEHOLD - 1970.[4]

		Kwht/yr.	Kwt/capita
1.	Space Heat: TOTAL	35,060	1.22
	(a) Electric[1]	2,260	
	(b) Fossil Fuel[2]	32,800	
2.	Cooling[1]	2,240	.075
3.	Water Heat[1]	10,800	.38
	(a) Electric	4,950	
	(b) Fossil	5,850	
4.	Other Elec.[1]	16,710	.57
5.	Other Heat[3]	≈1,000	.035
	TOTAL	65,810	2.28

1. See Table III. Overall electricity supply efficiency = 27% including transmission and distribution losses.
2. On the basis of (i) 90% fossil fuel supply efficiency, 70% utilization efficiency and annual average heat loss = 75×10^6 Btu/yr. See Appendix for calculational procedure.
3. Gas stove and household gas dryers.
4. General accuracy limits are ± 20 % throughout this paper.

II. Electrical Appliances

The average annual consumption of electricity by various household appliances is shown in Table II. We note immediately that the appliances that use the largest quantity of electricity are electric space and water heaters. The average overall efficiency of electric space and water heat is about 27% whereas the respective average efficiencies of gas or oil units are 60-65% for space heat and 50-55% for water heat. These figures include a 90% fossil fuel supply efficiency. The next largest item in Table II is air conditioning. Coefficients of performance (COP) of air-cooled air-conditioners vary between 1.4 and 3.5[7] and the average COP is about 1.75. Lighting is usually by incandescent bulbs which are generally very inefficient sources of light compared to fluorescent lamps. Thus, in all of the items discussed above, substantial improvements in efficiency are indicated and can be implemented with equipment that is commercially available today. In the section on projections, we will return to the question of heating and cooling efficiencies and the energy requirements for different insulation levels.

III. Recent Trends in Residential Electricity and Energy Consumption

We now examine the trends in household electricity and energy use in the decade 1960-1970. Table III shows percent of saturation and total per capita electricity consumption for various electrical appliances. Trends in household per capita and total per capita electricity use are shown in Fig. 1. An approximately exponential increase in the percent of saturation for many appliances is evident, with particularly rapid doubling times for space heating and cooling and portable appliances. The increase in population is responsible for only a small

TABLE II

CONSUMPTION OF ELECTRICITY BY MAJOR HOUSEHOLD APPLIANCES

Item #	Appliance	Average Elec. Cons. kwhe/yr.
1.	Elec. Space Heat	8,000-20,000[2]
2.	Elec. Water Heater	4,500
3.(a)	Room Air Conditioner	1,350
(b)	Central Air Conditioner[3]	~2,000
4.	Elec. Range	1,200
5.	Freezer	1,000
6.	Refrigerator	1,000
7.	Washer	90
8.	Dryer	900
9.	Lighting	1,000
10.	B & W TV	300-400
11.	Color TV	500
12.	Dishwasher[4]	360

1. Sources: References 3, 4 and 5.
2. Depending on climate, insulation and desired indoor temperature National average ~ 10,000 kwhe.
3. Assumed. Published estimates (references 6,7,8) vary considerably and no average use figures have been compiled. Range of variation: ≈ 1000 kwhe/yr to 3600 kwhe/yr.
4. Excluding hot water requirements which are approximately 500 kwht/yr.

TABLE III

TRENDS IN HOUSEHOLD ELECTRICITY CONSUMPTION

1960 - 1970

YEAR	1960			1965			1969 (Jan. 1, 1970)		
# of WIRED HOMES (10^6)	50.6			56.4			62.7		
POPULATION (10^6)	183.3			193.5			201.3		
ITEM	Saturation %	Total kwhe/yr (10^9)	kwhe/yr cap.	Saturation %	Total kwhe/yr (10^9)	kwhe/yr cap.	Saturation %	Total kwhe/yr (10^9)	kwhe/yr cap.
1. Elec. Resistance Heat	1.5	7.6	41	3.5	19.7	102	6.1	38.2	190
2. Elec. Water Heat	18.6	42.5	232	23.2	59	304	29.6	83.6	416
3. Elec. Ranges	35.6	21.6	118	41.4	27.2	144	52.7	39.5	197
4. A/C TOTAL	14.8	10.8	59	23.7	19.5	100	42.6	38.4	191
(a) Central	2.0	2	11	≈ 3.5[2]	4	20	5.9	7.4	37
(b) Room[3]	12.8	8.8	48	20.2	15.5	80	36.7	31	154
5. Freezers	22.1	10.8	59	26.7	15.1	78	29.6	18.6	92
6. Dishwashers	6.3	1.2	7	11.8	2.6	13	23.7	5.4	27
7. Portable Appliances	-	19	104	-	32	165	-	≈45	223
8. Refrigerators[4]	98	29.8	163	99.3	44.3	229		62.5	310

NOTES FOR TABLE III

1. Sources: references 2, 5 and Table II.
2. Assumed = 3.5 %
3. Percent saturation represents total number of room air-conditioners divided by total number of houses.
4. The electricity consumption per refrigerator was assumed as follows: 1960: 600 kwhe/yr; 1965: 800 kwhe/yr; 1970: 1000 kwhe/yr. Increases are due to (i) refrigerators with larger freezers (ii) frostless refrigerators.

portion of the total electric energy increase per appliance. However, from Table III, we also see that the percent of saturation for most electrical appliances (with the major exception of electrical space heat) were fairly high in 1970, so that there is no longer the possibility for many more doublings in the number of appliances. Table IV shows the trends in household energy consumption by fuel. The only item that has been increasing rapidly is the electrical energy. Gas has been replacing oil as the preferred heating fuel.

In Fig. 1 the per capita residential electric energy consumption is compared with the total per capita electricity use over the period from 1950-1970. The exponential increase in appliances is reflected in a less than ten year doubling time for residential electricity use, a rate slightly faster than that for total energy use over the same period.

IV. Comparison of Energy Use in Various Households.

Having made some broad observations regarding the efficiencies of supplying the various forms of residential energy we turn to a more detailed analysis of the energy consumption per household, by the comparison of energy consumption in four households, each equipped with the basic modern amenities. Table V shows the electricity and energy consumption comparison between these four households. The differences in appliances are the presence or absence of freezers, air-conditioners and dishwashers which are the major appliances for which the present day saturation level is less than 50 percent.

TABLE IV

TRENDS IN HOUSEHOLD ENERGY USE

BY FUEL[4]

FUEL	ENERGY CONSUMPTION PER HOUSEHOLD Kwht/yr. 1960	ENERGY CONSUMPTION PER HOUSEHOLD Kwht/yr. 1970	% GROWTH/Yr.
Electricity[2]	13,700 (3,700)	26,200 (7,050)	6.5
Gas[3]	19,600	25,200	2.5
Oil[4]	13,300	10,700	- 2.2
Coal & Wood[4]	1,900	2,200	1.6
TOTAL without electricity	34,800	38,100	0.86
TOTAL	48,500	64,300	2.8

NOTES FOR TABLE IV

1. Sources. References 2, 11.
2. An overall efficiency of 27 % from fuel to electricity at the point of use has been assumed. Numbers in parentheses are kwhe/yr.
3. Includes bottled, manufactured, mixed and liquid petroleum gas and a 90 % supply efficiency.
4. Efficiency of supply assumed 90 %.

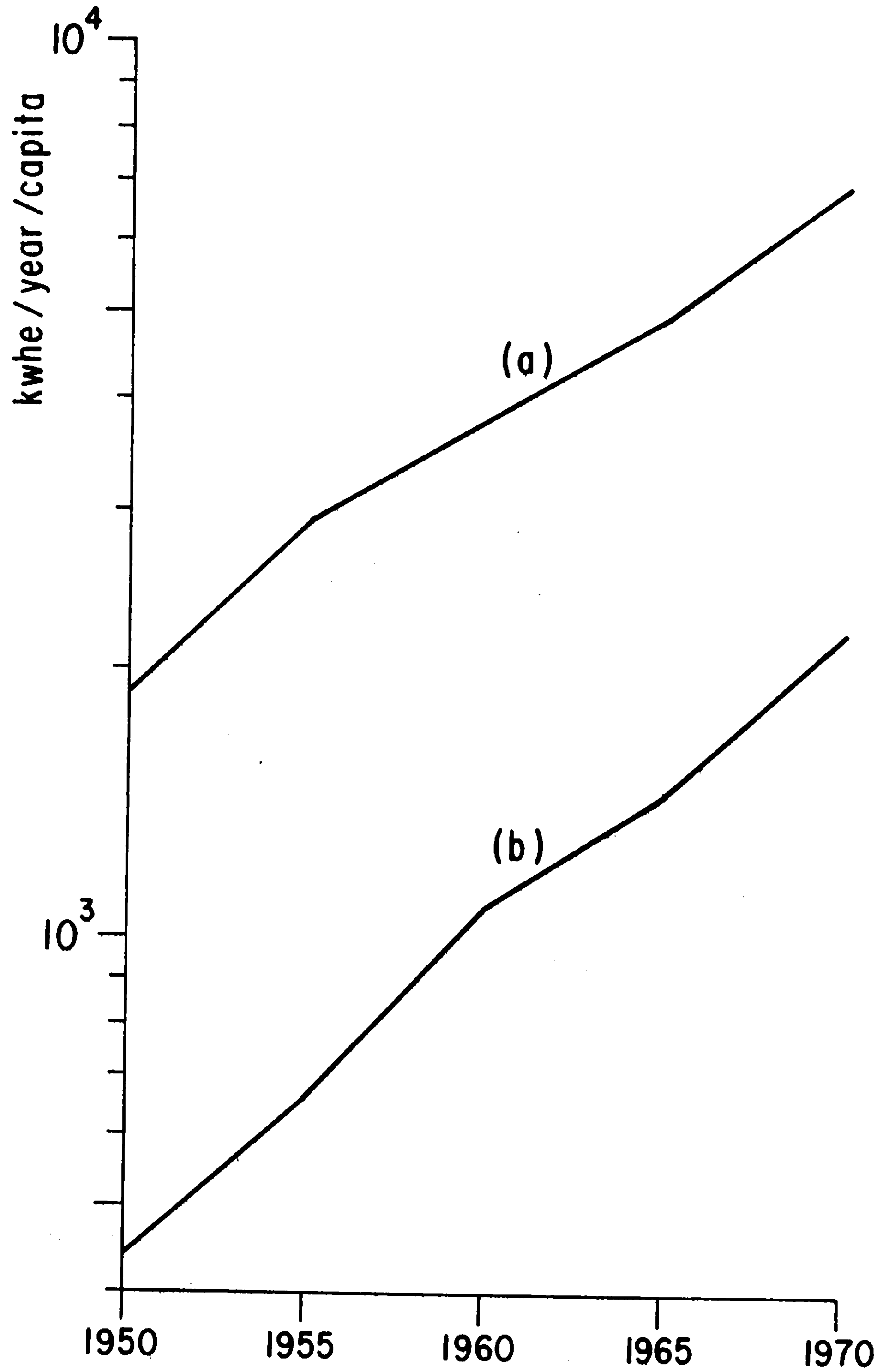

FIGURE 1. TRENDS IN PER CAPITA ELECTRICITY USE

(a) Total electricity consumption

(b) Household electricity consumption

TABLE V

COMPARISON OF ELECTRICITY & ENERGY USE

IN VARIOUS HOUSEHOLDS

		ELECTRICITY kwhe/yr			
ITEM #	ITEM	(1)	(2)	(3)	(4)
1.	Space Heat	-	-	-	17,000[2]
2.	Water Heat	-	-	4,500	5,000
3.	Air Conditioning	-	-	1,350	1,350
4.	Refrigerator	1,000	1,000	1,000	1,000
5.	Freezer	-	-	1,000	1,000
6.	Elec. Stove	-	1,200	1,200	1,200
7.	Dishwasher	-	-	-	360
8.	Clothes Washer	90	90	90	90
9.	Elec. Clothes Dryer	-	-	900	900
10.	Lighting	1,000	1,000	1,000	1,000
11.	Misc.[3]	≈1,000	≈1,200	≈1,400	≈1,600
	TOTAL ELECTRICITY kwhe/yr	3,090	4,490	12,440	30,500
	TOTAL ENERGY[4] kwht/yr. including space, water, cooking & clothes drying heat	58,920	61,640	80,520	112,620

NOTES FOR TABLE V

1. Assumed area of house = 1000 sq. ft., 3.2 occupants; average climate i.e., heat load per year = 75 x 10^6 Btu. Electrically operated devices in the various households were allocated as follows:

household #1: All major appliances with saturation levels of 75% or greater

household #2: All major appliances with saturation levels of 50% or greater

household #3: All major appliances with saturation levels of 25% or greater

household #4: All major appliances with saturation levels of 0% or greater

2. This is about a factor of two larger than the present national average since the electric resistance heat is utilized primarily in the Southern U.S. where the annual heat load for a given insulation level approximately half of that assumed here.

3. The average use of electricity by portable appliances (excluding washers and dryers) is about 1200-1400 kwhe/yr. Since not all portable appliances are equally saturated a ± 20% spread about the average was assumed.

4. The various efficiencies used to calculate the numbers in this row were: electricity supply 27%; gas/oil supply 90%; gas/oil space heat 70%; gas/oil water heat and dryers 60%; gas stove 30%. The C factor for electrically heated homes was taken at 18.5 to take into account the better insulation of electrically heated homes.

In the first 3 households, some functions are provided by the use of fossil fuels in the home (e.g., a gas stove, gas water heater, oil heat, etc.) whereas the fourth represents an all electric home. The space heating requirements in all four correspond to average U.S. climate (represented typically by New York). The all electric home was assumed to have higher than average insulation.[6] Table V demonstrates that the household in which all heat (space and water heat, stove, dryer) is supplied by gas or oil the energy consumption is only about 50% of the all electric home. The primary cause is the inefficiency of electric heat sources. For example, the only differences between households number 3 and number 4 are (i) a dishwasher in the latter (which accounts for about 3200 kwht difference between the two - including the hot water which must be supplied to the dishwasher from the electric water heater in the all electric home) and (ii) electric heat and better insulation in the latter and fossil fuel heat in the former. Yet the difference in total energy consumption between the two households is 32,100 kwht/yr. Only about 10% of the difference is due to the dishwasher. The rest or 29,000 kwht is attributable to the lower efficiency of electric heat than fossil fuel heat.

V. Insulation

Residential space heat is the largest single user of energy in the household and accounts for more than half of the household energy budget (Table I). Economies in this area can therefore lower household energy consumption significantly. In a detailed study on the value of residential thermal insulation, J. Moyers[6] showed that substantial savings in both energy and money can be achieved by increasing the insulation levels above those required by the pre-June 1971 Federal Housing Administration's Minimum Property Standards (FHA-MPS). In fact, the level of insulation which would produce the largest monetary savings at current prices of energy would approximately halve the household space heat requirements. Higher insulation levels also reduce air conditioning cooling loads.[6] The procedure for calculating heating and cooling loads is fully described in references 6 and 7 and briefly explained in Appendix 1 of this study.

We illustrate the energy savings possible by examining the heat losses from a 1000 square foot residence for 2 insulation levels in 3 climates. The regions chosen were Atlanta (mild winters), New York (moderate) and Minneapolis (extreme). These regions are the ones used by J. Moyers (reference 6) and are representative of the average climatic conditions found in the Southern, northern coastal and northern central regions of the U.S. respectively. The annual residential heat loads are shown in Table VI. (In June 1971, the FHA upgraded the insulation requirements in its Minimum Property Standards, but these are still well below the economically optimum insulation at 1970 fuel prices.[6]) Thus, using insulation corresponding to an economic optimum, the space heating requirements for an average residence, can on the average be halved from the 1970 values. Since the price of energy, and especially that of natural gas, is expected to rise(assumed faster than insulation costs) the economically optimum amount of residential thermal insulation will increase. For optimizing the total cost in the case of electric heating even larger energy savings would be made, since, on the average, electric heat costs 2 to 3.5 times as much as gas heat.

TABLE VI

ANNUAL HEAT LOADS FOR A 1000 SQ. FT. RESIDENCE[1]

	WINTER CLIMATE			
	MILD (Atlanta)	MODERATE (New York)	EXTREME (Minneapolis)	U. S. Average
% of U.S. Population in the climatic region	21%	47%	32%	100%
Annual heat loss: approximate present average in 10^6 Btu.	40.7	75.5	95	75
Annual heat loss with economically optimum insulation,[2,3] in 10^6 Btu.	21.4	35	54.5	38.4

NOTES FOR TABLE VI

1. The approximate area of an average U.S. residence is 1000 sq. ft. General accuracy for this table: ± 20%.
2. The calculational procedure is shown in the Appendix.
3. The optimum insulation was found from reference 6, using current insulation prices and a $\$1.33/10^6$ Btu price for natural gas. The current (1972) average price for residential natural gas is about $\$1.20/10^6$ Btu and is rising (1970 price: $\$1.06/10^6$ Btu).For the mild climate (Atlanta) it was assumed that air conditioning was installed.

The value of insulation for cooling purposes is also substantial, but not as large as that for space heating. The main reason for the difference appears to be the residual heat infiltration via windows in the cooling period. In general, insulation levels approximately equal to those for an economically optimum space heating installation corresponding to a reduction of 25-30% in the energy requirements for cooling.

VI. Solar Energy

Solar heat is a widely available, well distributed but little used form of energy. The relatively dilute nature of solar energy and its interruptability have been the major reasons why it has not been extensively employed so far. However, it possesses an important advantage of being essentially pollution free. A number of schemes for generating electricity in central station power plants have been proposed, but none of these are presently economically feasible. On the other hand, the use of solar energy for household space and water heat using roof top collectors is economically competitive and, in most areas of the country, cheaper than electric heat.[10] In some cases, the costs are similar to those of gas or oil heating.

Solar space heating should become increasingly more attractive with respect to gas heating since gas prices are expected to rise rapidly in the next decade. The economics of solar space and water heating are fully discussed in reference 10 (Tybout and Löf) which we summarize in Appendix II. It should be pointed out that the economic analysis of Tybout and Löf is pessimistic, particularly for the Southern regions of the U.S. since they assume that a full capacity supplementary source of heat would be necessary in all cases. This would not be necessary for the Southern regions, since the amount of supplementary heat is not large and supplementary electric heating of the storage medium (water) could be accomplished for a small fraction of the cost of an entire furnace. Similar combination heating systems with gas or oil may also be practical in the North, at substantial savings.

Solar heat can also be used for summer cooling if absorption cycle air-conditioners are used. The factory cost of central electric and water-lithium bromide absorption cycle air-conditioners* are comparable.[11] Since an absorption cycle air-conditioner employing solar heat has no associated fuel costs, the effect of its installation is to reduce the overall cost of the solar space heating and cooling system.

Figure 2 shows monthly electricity consumption in an average New York residence under various assumptions. The basic consumption of 400 kwhe/mo. is the average electricity use including an electric stove but excluding air conditioning and water and space heating. We note from Fig. 2 that the use of electric heat in every household would create a peak in electricity demand which would pale the present air conditioning summer peaks into insignificance. (The present pattern in New York is rather that of summer peaks because of the small percentage of residences now having electric resistance heat.) The winter peak would persist if electric heat were used in a well insulated home or

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* At present only water-lithium bromide absorption cycle air-conditioners seem feasible in conjunction with solar heat. Even in that case, the water heat by solar energy should be at about 200° F. and detailed feasibility studies are needed.

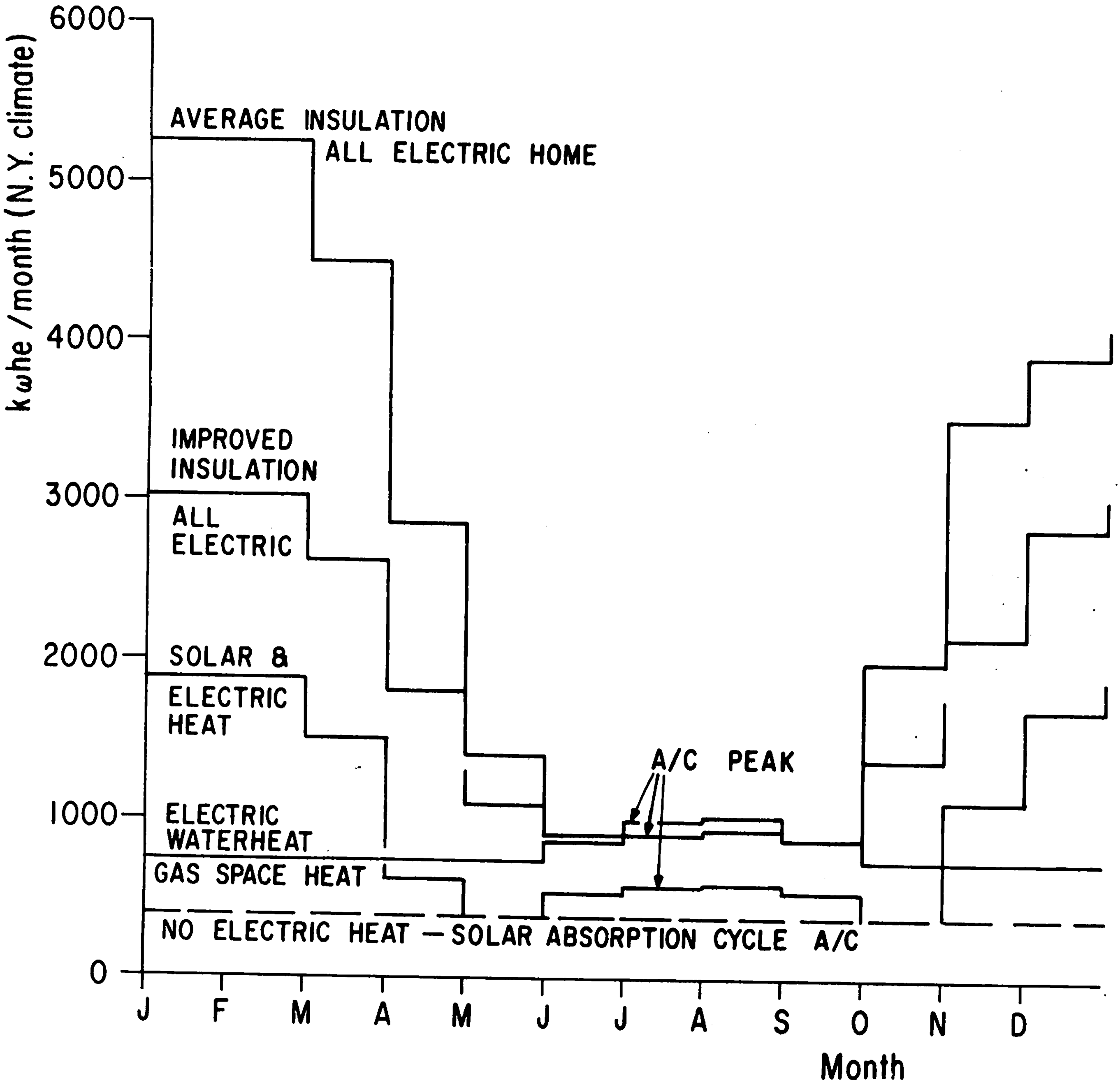

FIGURE 2. MONTHLY ELECTRICITY USE IN A NEW YORK HOME: SOME ALTERNATE SYSTEMS

as a supplement to solar heat. We note also that the use of solar heat with gas or oil as the supplemental heat source and solar absorption cycle air conditioning eliminates seasonal variations in electricity demand. Monthly household electricity use curves for Phoenix are shown in Fig. 3. Here the air conditioning loads (central air conditioning) are much larger and the winter heat requirements smaller than those of New York. Electric resistance heating still creates a winter peak, whereas with solar heat using electric resistance heat as a supplement gives a summer peak. If absorption cycle air conditioning is used, increased economically optimum size of the solar heat collector and heat storage system obviates the need for any significant amount of regular supplemental heat, although a small amount of resistance heating is still required for prolonged cold spells, cloudy weather, etc. However, the detailed economics of a combined solar heating and cooling system have not been studied so that, although the situation seems favorable on the surface, no final conclusions can be drawn at this time. We note that in Phoenix the central air conditioning costs for electricity alone (at 1.5 ¢/kwhe) for a system with a coefficient of performance (CP) equal to 2, are about $100/yr. This would seem to indicate that considerable economic incentive exists for the installation of a solar heating and cooling system.

For a solar heating system in a Northern climate, about half of the heating load must be supplied by the supplemental heat source for a system that is optimized with respect to solar heating costs. Since this amount of energy is very large, it appears desirable from the

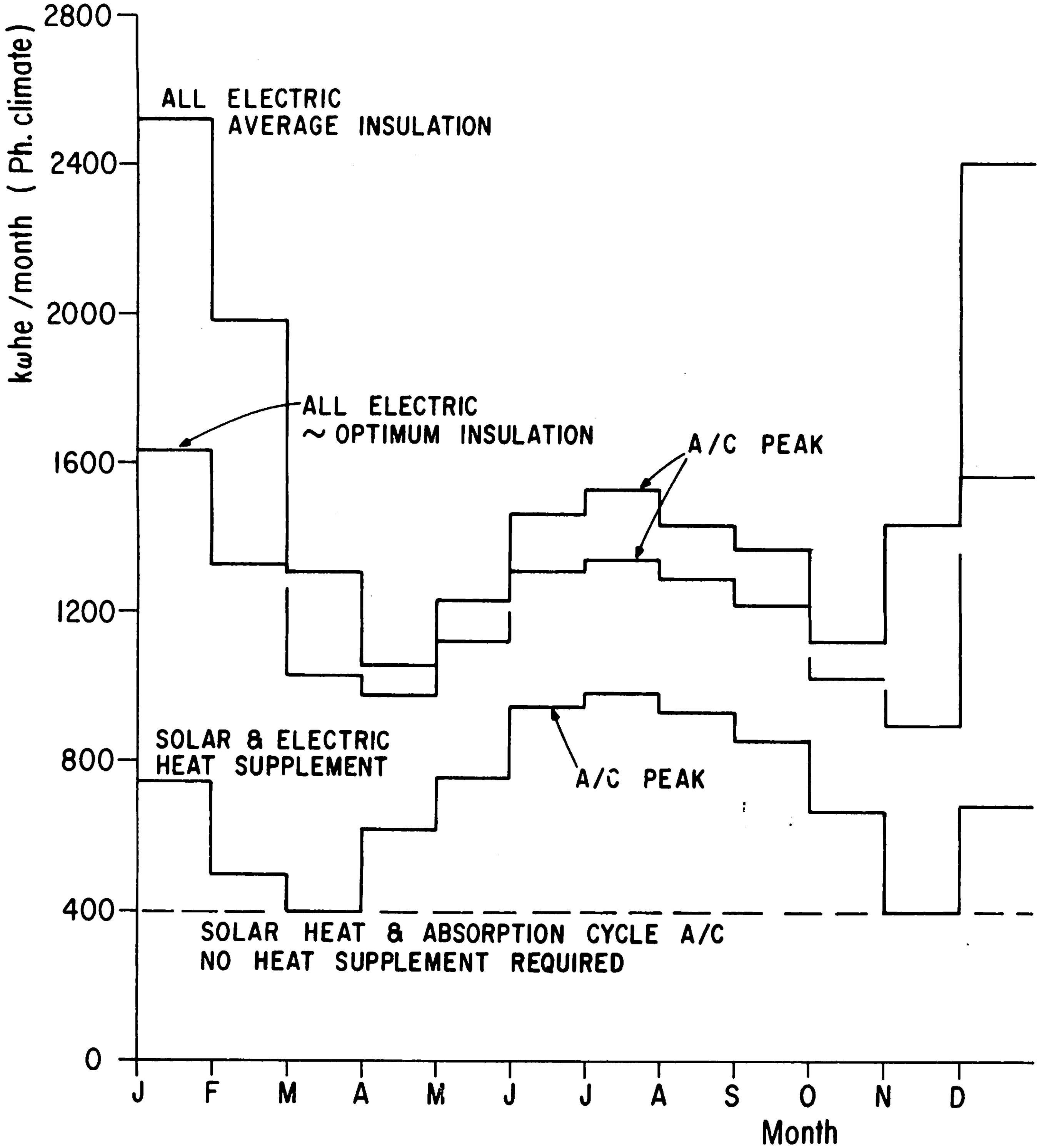

FIGURE 3: MONTHLY ELECTRICITY USE IN A PHOENIX HOME:

SOME ALTERNATE SYSTEMS

efficiency and fuel cost viewpoints to use gas or oil as the supplemental heat source. On the other hand, solar heating systems in the South require a comparatively small amount of supplemental heat (≈ 1000 kwht/yr/household net). This heat can therefore easily be supplied at a small extra cost by the installation of resistive heating of the water used to store the solar heat.

VII. Projections for Residential Electricity and Total Energy Use.

In this section, we make projections for residential electricity and energy use to the year 2000. Each projection corresponds to a certain set of assumptions regarding appliance saturation levels, use of insulation, use of solar space heat, efficiencies of air-conditioners, etc. Common to all the projections are the assumptions of population and number of households. Since the final graphs are in terms of electricity and energy use per household, the projections are not sensitive to assumpsions in regard to population.

A population of 250 million was assumed for the year 2000. This is somewhat lower than the Series E projection in the U.S. Statistical Abstract of 1971.[2] The number of people per household was taken as 3 (the 1960 and 1970 figures were 3.46 and 3.2 respectively), and the retirement rate of residential housing units at 1% per year (approximately equal to the 1960-1970 average). These assumptions give the housing figures shown in Table VII.

Current growth rates per electrical appliances are generally in the 5-10% per year range. Because most appliances already are at a significant percentage of saturation (see Table III), these rapid growth rates cannot persist for any length of time, before 100 percent saturation would be attained. We make the following assumptions for approach to saturation of the various electrical appliances. For dishwashers and air-conditioners a percent saturation of 70% for the year 2000, is considered appropriate in that factors such as life-style, climate and income level are expected to inhibit the growth of nonessential appliances beyond this level. For electric water heaters and electric clothes dryers, saturation was taken at 50% and 60% respectively since both these appliances are available with gas heat and these latter are both more efficient and less expensive to operate. For electric resistance heating, we selected a 20% saturation since (i) use of resistance heating is much more expensive than gas or oil heating especially in the northern climates and (ii) a percent saturation significantly higher than 20% would produce winter peaks in electric utility loads (as is illustrated by Fig. 2) which would be more severe than present air conditioning summer peaks, and will therefore be unacceptable to the utilities themselves. These projections, to the year 2000, are compared with the standard constant growth rate projections in Fig. 4.

Based on the rates of saturation of appliances given in Fig. 4 and the possible energy saving innovations, described in Sections V and VI, three sets of projections are made for residential energy consumption. The assumptions for the projections (explained in more detail in the tables) are listed below:

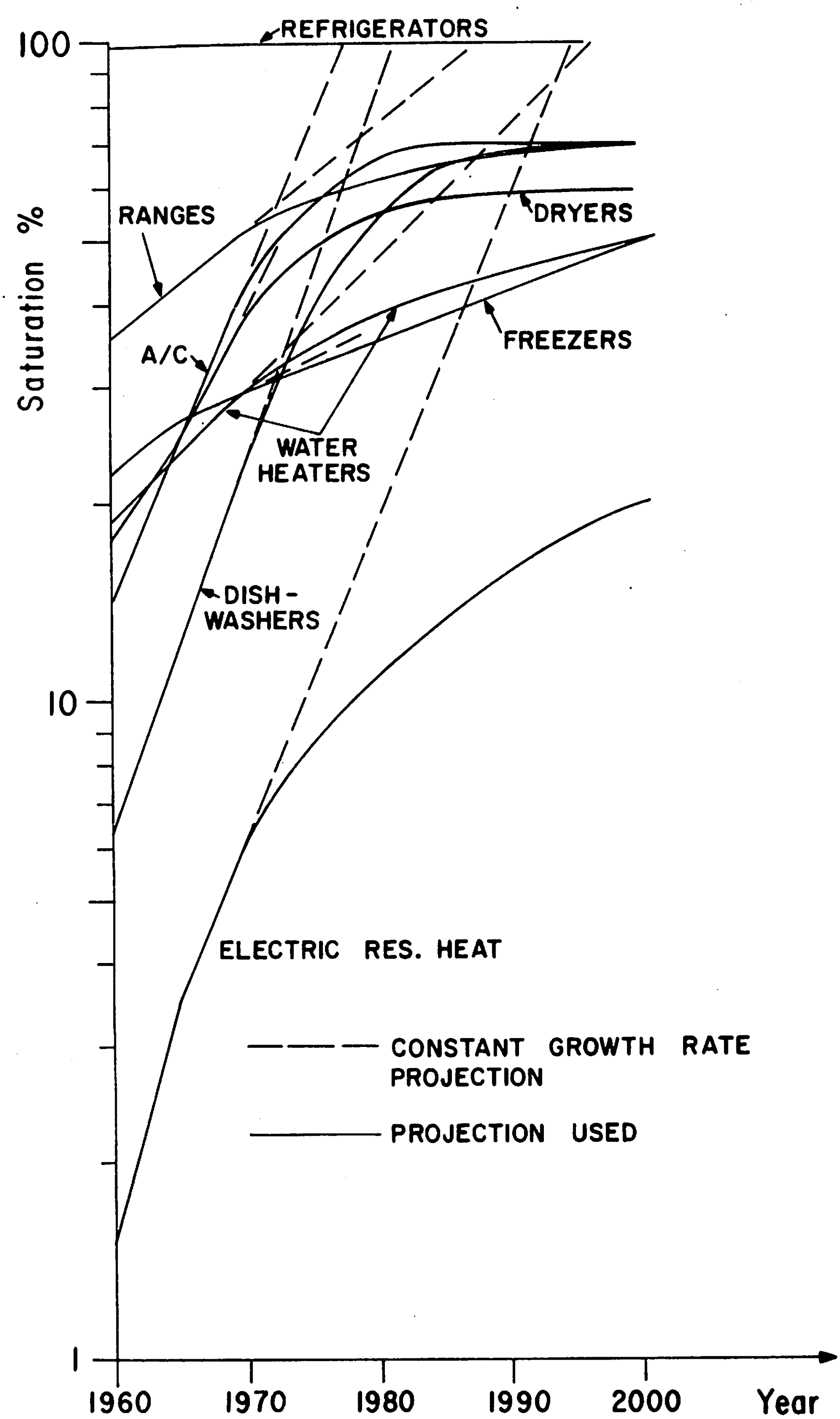

FIGURE 4: SATURATION OF HOUSEHOLD ELECTRICAL APPLIANCES: 1960-2000

TABLE VII

PROJECTION FOR NUMBER OF RESIDENTIAL HOUSING UNITS[1]

	1970	1980	1990	2000
TOTAL # of occupied housing units (millions)	63.4	69.5	76.2	83.3
# of housing units built in 1970 or earlier (millions)	63.4	56.8	49.6	41.7
# of housing units built after 1970 (millions)	-	12.7	26.6	41.6
% of occupied units with electricity	98	100	100	100

1. On the basis of a population of $250x10^6$ (3 people/housing unit in the year 2000 and a 1 %/yr. retirement rate for housing.)

(1) Rapid-Growth-No-Innovations projection:

Growth in electrical appliances following our saturation curves, new housing units use of insulation approximately in accordance with the FHA standards of June 1971 and a moderate improvement in air-conditioners coefficient of performance.

(2) Rapid growth with partial use of solar energy projection:

Growth in electrical appliances as in (1) except space and water heat, the partial use of solar heat on new housing starts and the use of approximately economically optimum insulation on all new housing.

(3) Constant standard of living projection

Constant standard of living as typified by electrical appliances at today's percentages of saturation, replacement of resistance space heat by solar or fossil fuel heat on new housing starts, partial use of solar heat on new housing starts and the use of insulation as in projection 2 above.

(1) Rapid-Growth-No-Innovations projection.

The detailed breakdown of electricity use and the calculational assumptions are listed in Table VIII and in the notes for Table VIII. Total energy use is shown in Table IX. This projection indicates an increase in per capita electricity use by 50% and total household electricity (including the population factor) by 80%.

TABLE VIII

CALCULATION OF ELECTRICITY DEMAND

1970-2000

RAPID-GROWTH-NO INNOVATIONS PROJECTION

ITEM #	APPLIANCE	1970		1980		1990		2000	
		Saturation %	10^9 kwhe/yr	Saturation %	10^9 kwhe/yr	Saturation %	10^9 kwhe/yr	Saturation %	10^9 kwhe/yr
1.	Elec. Space Heat[2]	6.1	38.2	11	66.9	16	102.5	20	134.7
2.	Elec. Water Heat[6]	29.6	83.6	39	127	45	161	50	196
3.	Elec. Ranges	52.7	39.5	62	51.8	67	61	70	70
4.	Total A/C[3]	42.6	38.4	66	69	70	79.5	70	87
5.	Freezers	29.6	18.6	35	24.3	42	32	50	41.7
6.	Refrigerators[4]	99.8	62.5	100	83	100	99	100	108
7.	Dishwashers	23.7	5.4	54	13.5	65	17.8	70	21
8.	Portable Appliances[5] (including TV)	variable	70	variable	88	variable	111	variable	140
9.	Lighting	100	62.8	100	70	100	76.5	100	83.5
10.	Washers	90.8	5.4	95	5.9	95	6.5	95	7.1
11.	Dryers	38.8	22	55	35.3	59	40.5	60	45
12.	Other	-	negligible	?	5	?	10	?	20
	TOTAL		446.4		639.7		797.3		954
	Total per household in kwhe/yr		7,050		9,200		10,500		11,470

NOTES FOR TABLE VIII

1. The electricity consumption per appliance is taken from Table II Saturation figures are % of wired homes, assumed 100% after 1970 (98% for 1970). No. of homes, 1980: 69.5 x 10^6; 1990: 76.2 x 10^6; 2000: 83.3 x 10^6 ; population, 2000: 250 x 10^6.

2. The present average consumption is 10,000 kwhe/yr. Assumptions are that electric heat will be employed predominantly in the South and that the units added after 1970 will have an electricity demand of 7,500 kwhe/yr, due to improved insulation.

3. Average air-conditioner electricity was assumed to be from 1980-2000, 1500 kwhe/yr. A transition to central systems with higher capacities is expected. This is partly offset by higher coefficient of performance of central A/C systems. The rest of the decrease is due to improved insulation. 1970 average electricity use per installed unit ≈ 1450 kwhe/yr (average of central and room A/C in 1970).

4. Average energy consumption: 1970: 1000 kwhe/yr; 1980: 1200 kwhe/yr; 1990: 1300 kwhe/yr, 2000: 1300 kwhe/yr. Increase is due to larger freezers in refrigerators and increase of frostless refrigerators.

5. Electricity consumption by portable appliances assumed to double by the year 2000 due to changes to color TV, electric cooking appliances and miscellaneous other gadgets.

6. The 1970 electric water heater requirement are 4500 kwhe/yr. After 1980 4700 kwhe/yr was assumed due to partial supply of dishwashing hotwater by electric water heaters.

TABLE IX

HOUSEHOLD ENERGY PROJECTION 1970 - 2000

RAPID GROWTH - NO INNOVATIONS

Units of 10^9 kwht/yr.	1970	1980	1990	2000
Electricity[3]	1,650	2,380	2,960	3,530
Fossil fuel space heat	1,950	1,930	1,890	1,860
Fossil fuel water heat(including dishwashers)	360	370	380	380
Gas stoves	120	110	100	100
Clothes drying (gas)	20	20	20	30
TOTAL	4,100	4,810	5,350	5,900
Per household Kwht/yr.	64,900	69,400	70,000	70,800

NOTES FOR TABLE IX

1. The average yearly heat loss for pre 1970 homes was taken as 75×10^6 Btu (see Table I and Appendix I) and for post 1970 homes as 50×10^6 Btu due to the higher insulation levels recommended by the FHA-MPS.
2. An allowance of 500 Kwht (net) was made for dishwasher hot water. In 20 % of the occupied units in the year 2000, the dishwasher hot water was assumed to come from an electric water heater.
3. Efficiency of electricity and fossil fuel production and supply were taken as 27 % and 90 % respectively.

(2) Rapid Growth with Partial Use of Solar Energy Projection:

Here we make what may be termed as a national combination of rapid growth and energy conservation policies. Table X shows electricity use and the assumptions for the electricity calculations. We see that the electric space and water heating are gradually replaced (at the retirement rate of houses with these appliances) either with the more efficient fossil fuel heat or with solar heat. Other appliances are assumed to grow at the rates shown in Fig. 4. Table XI shows the heat and air conditioning sources for households as used in this projection and Table XII shows the total household energy consumption figures. With the use of solar heat as assumed in this projection, the electricity use per household levels off and the per household energy use falls. We do not include the solar energy used since (i) this does not contribute to the depletion of fuel resources and (ii) is available in any case. From Tables X and XII we may therefore draw the conclusion that if energy is used efficiently and if presently available solar energy technology for household use is implemented, the fuel energy consumption per household can be reduced despite increasing use of appliances.

(3) Constant Standard of Living with Partial Solar Energy Use Projection.

To make contact with the estimates of possible decrease in per capita household energy made in reference 1, we make a calculation for household energy needs for a constant material standard of living. The use of solar energy is assumed as in the previous section (Table XI) and electric space and water heat are assumed to be phased

TABLE X

RAPID GROWTH - PARTIAL SOLAR HEAT USE PROJECTION FOR RESIDENTIAL ELECTRICITY

ITEM #	APPLIANCE	1980		1990		2000	
		Saturation %	10^9kwhe/yr	Saturation %	10^9kwhe/yr	Saturation %	10^9kwhe/yr
1.	Elec. Space Heat[1]	4.9	34	3.9	30	3	25
2.	Elec. Water Heat[1]	24	74.5	19	65.2	15	55
3.	Air conditioning[2]	66	57	70	52.5	70	42.7
4.	All other (as in Table VIII)		370		454		536
5.	Supplemental[3] Resistance heat		3		6.2		9.7
6.	Pumping Power for Solar[4] Heating/Cooling Systems		8.9		18.6		29.2
	TOTAL		547.4		625.5		697.6
	Per household(kwht/yr)		7,850		8,200		8,350

NOTES FOR TABLE X

1. Houses with electric space or water heat that are retired in the interval 1970-2000 are assumed to be replaced by either fossil fuel or solar heating systems.
2. 70% of the new housing starts assumed to have solar heat and absorption cycle air conditioning. Total air conditioning saturation was assumed to be 70%, all central units, by the year 2000. The average coefficient of performance (CP) of electric air conditioners was assumed to rise from 1.75 in 1970 to 2.6 in 2000. The current range of CP's in commercially available units is 1.5 - 3.5.
3. The allocation of homes using supplemental resistance heat is shown in Table XI.
4. The pumping and blower power for each of two solar heated houses in the Washington D.C. area is about 500 kwhe/yr. Assuming an equal amount for solar cooling systems, we have a total pumping power of approximately 1000 kwhe/yr for each solar heating/cooling installation.

TABLE XI

HEATING AND COOLING SOURCES USED IN

PARTIAL SOLAR HEAT USE PROJECTIONS

(in Millions of Housing Units)

	1980	1990	2000
1. Elec. Resistance heat (old units)	3.4	3	2.5
2. Elec. waterheat	16.6	14.5	12.2
3. Solar heat[1] + elec. supplement for space heat	3	6.2	9.7
4. Solar heat and gas/oil supplement for space heat	5.9	12.4	18.5
5. Fossil fuel (old units)	53.8	46.6	39.2
6. Fossil fuel (new units)	3.8	8.0	13.4
7. Central absorption a/c	8.9	18.6	29.2
8. Electric a/c	22.4	15.7	8.3

NOTES FOR TABLE XI

1. Resistance supplemental heat is assumed used in southern climates, only,where 1/3 of the solar heating units are assumed to be located. The other 2/3 of the solar units (installed in 70% of new housing starts - see Table VII) are in the north.

TABLE XII

RAPID GROWTH - PARTIAL USE OF SOLAR ENERGY PROJECTION
TOTAL ENERGY

		1980 10^9 Kwht/yr.	1990 10^9 Kwht/yr.	2000 10^9 Kwht/hr.
Electricity		2,030	2,320	2,580
Waterheat		390	410	380
Fossil Fuel	Direct	1,840	1,660	1,530
	Supplement	70	140	200
Gas Dryers		20	20	30
Gas Stoves		110	100	100
		4,460	4,650	4,820
Per household		64,100	60,600	57,800

out at the rate shown in Table X. The percent of saturation for the other appliances are essentially held constant as shown in Table XIII. In this case, we see that both electricity and total energy use (Table XIV) per household are reduced. Per capita energy consumption in the year 2000 would then be 1.86 kwt (continuous) which is 0.42 kwt less than the 2.28 kwt per capita used in 1970. The difference between this figure and the value of 1.19 kwt per capita found in the study in reference 1 is attributable to (i) the wider use of solar energy assumed in reference 1, (ii) the more detailed nature of the present calculations (iii) the number of people/household assumed in the present study is smaller whereas the total number of new houses assumed is about the same and (iv) energy data in reference 1 are for 1968. In addition, the electricity transmission and distribution losses, and the fossil fuel efficiencies are not directly attributed to the residential sector in reference 1.

The results of the three projections and comparison with constant rate projections are summarized in Fig. 5. It is clear that continued 10-year doubling times of electricity use cannot be accounted for by the presently known appliances. However, although we have made some allowance for new appliances by doubling energy consumed in portable appliances, and allowing one new appliance on the energy scale of a dishwasher (see Fig. 4 and Table VIII) we have not included any large energy increases due to presently unknown residential uses. The rationale behind this omission is that no current major uses of household electricity was completely unknown 20 or 30 years ago. One potentially large residential consumer of energy, which we have not included, due to lack of

TABLE XIII

CONSTANT STANDARD OF LIVING -

PARTIAL SOLAR ENERGY USE PROJECTION

ELECTRIC ENERGY

ITEM #	APPLIANCE	1980		1990		2000	
		Saturation %	10^9 kwhe/yr	Saturation %	10^9 kwhe/yr	Saturation %	10^9 kwhe/yr
1.	Elec. Res. Heat[1]	4.9	34	3.9	30	3	25
2.	Water Heat[2]	24	74.5	19	65.2	15	55
3.	Elec. Ranges	62	51.8	67	61	70	70
4.	A/C[3]	45	26.9	45	16.5	45	7.8
5.	Freezers	30	20.9	30	22.9	30	25.3
6.	Refrigerators[4]	100	69.5	100	76.2	100	83
7.	Dishwashers	25	6.3	25	6.9	25	7.5
8.	Portable Appliances[5]	variable	77.5	variable	85	variable	93
9.	Lighting	100	70	100	76.5	100	83.5
10.	Washers	90	5.6	90	6.2	90	6.7
11.	Dryers (Elec.)	24	15	19	13	15	11.3
12.	Other	-	-	-	-	-	-
13.	Solar Energy Elec. Requirements[6]		11.9		24.8		38.9
	TOTAL		463.9		474.2		507.0
	Per household (kwht/yr)		6,680		6,210		6,100

NOTES FOR TABLE XIII

1. Number of electrical heated homes as in Table XI.
2. Elec. Water Heat replaced by gas, oil and solar.
3. A/C COP assumptions: 1970: 6 Btu/whr, (1400 kwe/yr); 1980: 7 Btu/whr, (1200 kwhe/yr); 1990 8 Btu (1050 kwhe/yr); 2000: 9 Btu/whr, (935 kwhe/yr). Units in new houses with solar heat installations assumed to run on absorption systems with heat provided by water heated by solar heat.
4. Electricity consumption per refrigerator taken as 800 kwhe/yr (average 1970 value).
5. Electricity consumption for portable appliances assumed to increase in proportion to the number of household.
6. See Note 4 in Table X.

TABLE XIV

CONSTANT STANDARD OF LIVING -

PARTIAL SOLAR ENERGY USE PROJECTION
TOTAL ENERGY

		1980 10^9 Kwht/yr.	1990 10^9 Kwht/yr.	2000 10^9 Kwht/yr.
Electricity		1,720	1,760	1,880
Fossil Fuel	Direct	1,840	1,660	1,510
	Solar Supplement	70	140	220
Fossil Fuel Water Heat		370	390	350
Gas Stove		110	100	100
Dryers		20	20	30
TOTAL		4,130	4,070	4,090
Per household (kwht/yr.)		59,500	53,400	49,000

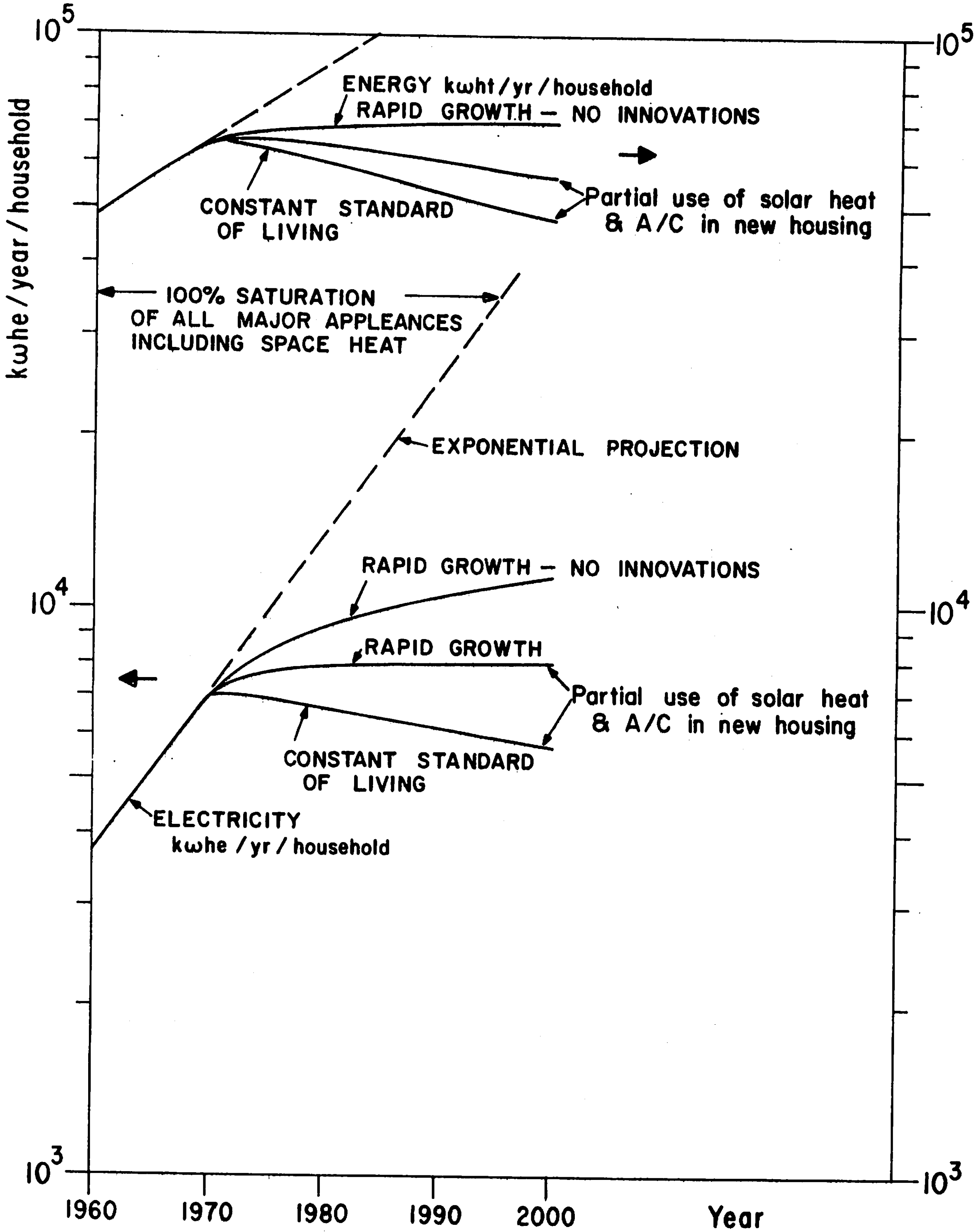

FIGURE 5: SOME PROJECTIONS FOR RESIDENTIAL ELECTRICITY AND ENERGY DEMAND

information, is heated swimming pools. A 500 square foot area swimming pool, heated for 5 months per year to 75° F. would use approximately 50,000 kwht/yr. which is approximately equal to the total residential energy use per household. Thus, in the absence of energy saving technology, if by the year 2000, 20 percent of all household units had heated swimming pools of this size associated with them, this would represent a 20 percent increase of total residential energy consumed. If solar heating technology is applied, on the other hand, swimming pool heating can be essentially accomplished by direct capture of solar heat within the swimming pool, itself. Systems to accomplish this are already commercially available. The possible widespread use of electric cars is not considered here in that the energy use for this category properly belongs to an analysis of the transportation sector.

VIII. Summary and Conclusions.

We have analyzed the present use of electricity and energy in the household. The use of residential electricity has in the past 20 years increased much more rapidly than the total use of energy primarily due to the increase in the use of various kinds of electrical appliances. The major household energy users are space and water heating. Fossil fuel space and water heaters are in general much more efficient than their electric counterparts on the basis of both fuel consumption and cost. We have shown how solar energy may be employed in the household, to reduce the consumption of energy resources. With reasonable assumptions concerning the percent of saturation of various household appliances we have projected an energy increase by the year 2000 which is about a factor of four less than the customary constant growth rate predictions. Conservation of energy by the use of improved insulation and substitution of solar and fossil heat for electric heat have been found to lead to approximately a 30 percent reduction in both electricity and total energy (excluding solar energy), from the projections in the absence of these energy saving innovations.

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APPENDIX I. Calculational Procedure for Obtaining Heating Requirements

For the purpose of calculating heating requirements, the U.S.A. was directed into three winter climatic regions - mild, as typified by Atlanta, moderate as typified by New York and extreme as typified by Minneapolis. The percentage of the population residing in each climate region was obtained from the Statistical Abstract and is shown in Table VI of the text of this study. The annual heat loss for various levels of insulation for an 1800 sq. ft. house for the above three cities has been calculated by J. Moyers.[6] However the area of an average housing unit is approximately 1000 sq. ft. The annual heat loss for various insulation levels for a 1000 sq. ft. house were calculated from J. Moyers' study by assuming that heat loss is approximately proportional to floor area. While this is not entirely accurate the method yields satisfactory results since a major proportion of the heating load scales roughly as floor area - for example floor, ceiling and window losses and occupancy loads all scale approximately as the floor area. The wall losses scale as the perimeter (for constant height) so that the assumption is not valid for wall losses. For high insulation levels wall losses are small, so that the calculation can be expected to yield better results for these cases. We have also assumed that heat losses calculated on this basis (i.e. on the basis of single family dwellings) may be applied to all dwellings. This tends to overestimate somewhat the actual heat losses since 70% of the housing units are single family dwellings, 85% are located in structures with four housing units or less and 15 % in structures with five or more units.[8]

The effects of the above assumptions are relatively small. Thus, those assumptions yield satisfactory results as demonstrated by the agreement between the fossil fuel numbers in Table I (obtained using the above method) and those in Table IV (obtained from published sources).

APPENDIX II. Solar House Heating

An extensive study of the economics of Solar House Heating has been made by Tybout and Löf.[10] In their study they assigned reasonable costs to the various elements of a solar heating system, such as collectors, energy storage, controls, pipes, and pumps. They also assumed that a complete backup heating system was necessary to supply heat when the solar collection system was inadequate, so that the savings from the solar heating was that of fuel savings, alone, and that this had to be balanced against the amoritization of the capital costs of the solar heating system. They then chose a number of cities to represent various climatic conditions, and programmed the absorption of heat by the collectors and the loss of heat from the house,hour by hour, with the collector plus storage system supplying the necessary heat whenever its temperature was above a critical value. At other times the back-up system supplied the house heating. The solar heating also supplied the hot water. The solar heating system was then optimized with respect to such variables as the type of collector, the collector tilt, the collector size and the heat storage capacity. It was found that for a large house, losing 25,000 BTU/degree day the collector size was optimized when it supplied between 50 % and 75 % of the total heat, depending on whether the city was in a severe or mild climate, respectively. For a smaller house, losing 15,000 BTU/degree day, the collector size was optimized with generally over 70 % of the heat being supplied by the solar collector. They further found that the optimization was rather broad so that up to 80 % of the heat could be supplied by solar radiation within a 10 % variation of costs. The size of heat storage was optimized with from one to three days of average radiated heat stored depending on whether the climate was mild or severe, respectively, but the optimization was not a very strong function of the energy storage.

The above study led to a comparison of optimized solar heat costs with that of conventional sources of heat as given in Table AII-1. The high and low costs in $\$/10^6$ BTU are, respectively, with the assumption that solar collectors will remain at current prices for solar hot water systems, and with the assumption that solar collector prices will be halved when mass production techniques are employed. We note that at the lower price the solar heating systems are well below the price of electrical heat in almost all cities and is competitive with oil heat in the sunny milder west and southwest climates. The artifically low current gas prices are not representative for planning future developments, as they are due to rise rapidly in the near future, probably going beyond oil prices, which are also expected to rise.

There are a number of reasons why the above comparisons of prices of solar heating systems with conventional heating may be pessimistic. In addition the above reason that conventional fuel costs are due to rise sharply, considerable possibilities exist for reducing the solar heating costs. The very high cost of solar heat in Miami, for instance, is due to the large fixed costs coupled with low demand. One of the largest fixed costs for Miami is that of the backup heating system which costs in the neighborhood of $200. For areas such as this, in which the heat demand is small, it appears that simple resistance supplemental heating could be applied directly to the energy storage system eliminating most of the cost of the backup heating system. This would reduce the solar heating costs by approximately $\$1.7/10^6$ BTU for the 15,000 BTU/deg.day house, and $\$1/10^6$ BTU for the 25,000 BTU/deg.day house, reducing the low cost estimate of solar heating to $ $4.15/10^6$ BTU and $\$3.05/10^6$ BTU, respectively, well below the electric heat costs as given in Table AII-1. Another saving can be made for those areas in which electricity is supplied more cheaply for off-peak service. In these places part of the cost of the energy storage can be assigned to savings in the supplemental electric heat costs.

A potentially much larger saving than those mentioned above would accrue by the development of an absorption air conditioning cycle employing the relatively low temperature solar heated water. A number of investigations of this problem are already underway and there is every reason to believe that a satisfactory solution can be found. Such a system would very significantly reduce the effective costs of the combined solar heating and cooling system. For example, in Phoenix, where approximately an equal quantity of heat is expelled for summer cooling as is required for winter heating, and assuming that an equal percentage of summer cooling as winter heating can be handled with the same size solar collecting system, the low cost of solar heat-cooling is reduced to $\$1.25/10^6$ BTU in the 15,000 BTU/deg. day house, well below the price of oil heat,alone. If we compare this solar combined system with the current electrical powered air conditioning at a COP of 1.5, the the combined oil heating, electrical cooling system would cost approximately $\$2.3/10^6$ BTU. In a cold climate, such as Boston, the

the advantages of combining air conditioning are not as great, but are still significant. Taking the air conditioning load to be 10 % of the heating load and that it can be completely satisfied with the solar collector, then for the low cost 15,000 BTU/deg.day house the solar heating-cooling system would cost approximately $\$2.3/10^6$ BTU as compared with $\$2.1/10^6$ BTU for the combined oil heating and electrical cooling used today and at today 's fuel costs. The results are summarized in Table AII-2. These figures indicate the potential importance of solar heating systems even in northern climates, and justify our inclusion of a substantial percentage of solar heated and cooled homes in northern climates for our low fuel use projections in Fig.5. We should repeat, however, that solar cooling using an absorption cycle is not a proven system (unlike solar house heating) and the economics as given here are tentative in nature.

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TABLE AII-1 (After Tybot and Löf[10])

COSTS OF SPACE HEAT (UNITED STATES)

	Least Cost Solar Heat, $\$/10^6$ BTU (1961)				Electric Heat, Electricity Cost Only, $\$/10^6$ BTU (1967)			Conventional Heat, Fuel Cost Only, $\$/10^6$ BTU (1962)	
	15,000 BTU/ DD House		25,000 BTU/ DD House						
	Low	High	Low	High	20,000 kwhr/yr	30,000 kwhr/yr		Gas	Oil
Santa Maria	1.35	1.84	1.10	1.59	4.51[a]	4.36[a]	California	1.42	1.62
Albuquerque	1.70	2.31	1.60	2.32	4.89	4.62	New Mexico	0.89	2.07
Phoenix	2.55	3.55	2.05	3.09	4.56	4.25	Arizona	0.79	1.60
Omaha	2.65	3.16	2.45	2.98	3.30	3.24	Nebraska	1.05	1.32
Boston	2.70	3.15	2.50	3.02	5.49	5.25	Massachusetts	1.73	1.76
Charleston	3.15	4.16	2.55	3.56	4.50	4.22	South Carolina	0.96	1.55
Seattle-Tacoma	2.85	4.05	2.60	3.82	2.26[b]	2.31[b]	Washington	1.83	2.00
Miami	5.85	6.48	4.05	4.64	5.16	4.90	Florida	2.81	1.73

NOTES FOR TABLE AII-1

(a) Electric power costs are for Santa Barbara. Electric power data for Santa Mara were not available.

(b) Electric power costs are for Seattle.

Source: Solar heat costs are from optimal design systems by interpolation of Figures 10-13 in ref. 10. Electric power heat costs are from U.S. Power Commission, All Electric Homes, Table 1 (1967). Conventional heat fuel costs are derived from prices per million BTU reported in P. Balestra, The Demand for Natural Gas in the United States, Tables 1.2 and 1.3 (North Holland Publishing Co., 1967). Fuel prices were converted to fuel costs by dividing by the following national average heat (combustion) efficiencies: gas, 75 %; oil, 75 %. Heat efficiencies are from American Society of Heating, Refrigerating and Air Conditioning Engineers, Guide and Data Book 692-694 (1963-ed.)

TABLE AII-2

COST OF COMBINED HEATING AND COOLING $ /10^6 BTU

	15,000 BTU/ DD house[a]	25,000 BTU/ DD house[a]	ALL ELECTRIC HEATING & COOLING[b]	OIL HEATING & ELECTRIC COOLING[b]
Phoenix	1.25	1.0	3.8	2.3
Boston	2.3	2.2	5.2	2.1

Notes for TABLE AII-2

(a) Sizes of solar collectors that are optimum for heating, alone, were taken from Tybout and Lðf.[10]

(b) COP of 1.5 assumed for standard air conditiong.