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SUPPLYING ENERGY THROUGH GREATER EFFICIENCY: THE POTENTIAL FOR CONSERVATION IN CALIFORNIA'S RESIDENTIAL SECTOR

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Contents

	List of Illustrations	ix
	List of Tables	xi
	Preface	xv
	Acknowledgements	xvii
I	DEVELOPING SUPPLY CURVES OF CONSERVED ENERGY	3
	Defining Conservation	3
	A Supply Curve of Conserved Energy	3
	The Cost of Conserved Energy	5
	Estimating the Cost of a Conservation Measure	7
	Estimating Annual Energy Savings	8
	Choosing Amortization Periods	10
	Choosing the Discount Rate	11
	Aggregating Energy Savings	13
	Interpreting Supply Curves of Conserved Energy	15
II	END-USE STUDIES	19
	A Guide to the Supply Curves of Conserved Energy	21
	Space Heating	
	The Supply Curves	23
	Gas Space Heating	23
	Electric Space Heating	27
	Conservation Measures	28
	Introduction	28
	Gas Space Heating	31
	Electric Space Heating	38
	Statewide Savings	40
	Introduction	40
	Gas Space Heating	44
	Electric Space Heating	50
	References and Notes	53

Water Heating

The Supply Curves	57
Gas Water Heating	57
Electric Water Heating	59
Conservation Measures	61
Introduction	61
Gas Water Heating	62
Electric Water Heating	67
Statewide Savings	69
Gas Water Heating	69
Electric Water Heating	71
References and Notes	73

Refrigerators and Freezers

The Supply Curve	77
Refrigerators	80
Conservation Measures	80
Statewide Savings	82
Freezers	83
Conservation Measures	83
Statewide Savings	85
References and Notes	86

Lighting

The Supply Curve	89
Conservation Measures	91
Statewide Savings	94
References and Notes	95

Air Conditioners

The Supply Curve	97
Room Air Conditioners	99
Conservation Measures	99
Statewide Savings	100

Central Air Conditioners 101
Conservation Measures 101
Statewide Savings 104
References and Notes 105
<u>Electric Appliances</u>
The Supply Curve 109
Electric Clothes Dryers 111
Conservation Measures 111
Statewide Savings 112
Electric Ranges 112
Conservation Measures 112
Statewide Savings 113
Televisions 114
Conservation Measures 114
Statewide Savings 115
Miscellaneous Electric Appliances 116
Conservation Measures 116
Statewide Savings 116
References and Notes 117
<u>Gas Appliances</u>
Gas Clothes Dryers 119
Conservation Measures 119
Statewide Savings 120
Gas Ranges 120
Conservation Measures 120
Statewide Savings 122
Miscellaneous Gas Appliances 122
References and Notes 123
<u>Swimming Pools</u>
The Supply Curve 125
Conservation Measures 127
Statewide Savings 129
References and Notes 130

III GRAND SUPPLY CURVES OF NATURAL GAS AND ELECTRICITY 135

Appendixes

A. Conservation Will Always Be With Us 147

B. Data Tables 153

Bibliography 163

List of Illustrations

1-1 The tradeoff between energy use and efficiency. (p.4)

1-2 The relation between price and energy use for a refrigerator. (p.4)

1-3 Supply curves for two grades of coal. (p.5)

1-4 A schematic supply curve of conserved energy. (p.6)

1-5 The capital recovery factor as a function of amortization period for four discount rates. (p.12)

1-6 Comparison of two conservation measures, showing the effect of roll-in time. (p.15)

2-1 Supply curve of conserved gas: space heating. (p.24)

2-2 Supply curve of conserved electricity: space heating. (p. 26)

2-3 The effect of changes in occupant behavior on the amount of gas needed to heat a typical home in Fresno. (p.29)

2-4 Distribution of gas use among 250 single-family homes in Berkeley, California during a summer and winter month. (p.31)

2-5 Monthly average gas use per residential customer in Northern California during 1978. (p.33)

2-6 Monthly average electricity use per residential customer in Northern California during 1978. (p.39)

2-7 Monthly average gas use in single-family homes in Northern and Southern California during 1978. (p.42)

2-8 Supply curve of conserved gas: water heating. (p.58)

2-9 Supply curve of conserved electricity: water heating. (p.60)

2-10 Conservation options for an electric water heater. (p.62)

2-11 Supply curve of conserved electricity: refrigerators and freezers. (p.78)

2-12 Supply curve of conserved electricity: lighting. (p.90)

2-13 The load curve for lighting in a typical house. (p.91)

2-14 Supply curve of conserved electricity: air conditioning. (p.98)

2-15 Supply curve of conserved electricity: appliances. (p.110)

2-16 Suppply curve of conserved gas: swimming pools. (p.126)

3-1 Grand conservation supply curve for natural gas. (p.136)

3-2 Grand conservation supply curve for electricity. (p.139)

3-3 Residential energy by end use in California in 1978 and the potential energy savings for a 10-year time horizon. (p.143)

List of Tables

Space Heating

2-1 Data for the supply curve of conserved gas: space heating. (p.24)

2-2 Data for the supply curve of conserved electricity: space heating. (p.27)

2-3 Saturations for gas and electric space heating by housing type. (p.41)

2-4 Gas consumption of furnaces in typical single-family homes kept at 70°F in three climatte zones. (p.43)

2-5 Heating degree-days for population centers in Northern California. (p.44)

2-6 Number of homes heated with gas in 1978. (p.45)

2-7 Average annual household consumption of gas for space heating. (p.46)

2-8 Average annual regional consumption of gas for space heating. (p.46)

2-9 Average annual statewide consumption of gas for space heating. (p.46)

2-10 Assumed consumer practices with respect to pilot lights, 1978 and future. (p.47)

2-11 Assumed thermostat settings in different climates. (p.48)

2-12 Estimates of insulation in gas-heated single-family homes. (p.49)

2-13 Number of electrically heated homes. (p.50)

2-14 Average annual household use of electricity for space heating. (p.50)

2-15 Annual regional use of electricity for space heating. (p.51)

2-16 Average annual statewide use of electricity for space heating. (p.52)

2-17 Assumed insulation levels in electrically heated homes. (p.53)

Water Heating

2-18 Data for the supply curve of conserved gas: water heating. (p.58)

2-19 Data for the supply curve of conserved electricity: water heating. (p.60)

2-20 Characteristics of a typical gas water heater. (p.63)

2-21 Typical household use of gas for water heating. (p.63)

2-22 Energy savings in a typical water heater when an insulation blanket is installed. (p.65)

2-23 Characteristics of a typical electric water heater. (p.67)

2-24 Typical household use of electricity for water heating. (p.68)

2-25 Gas water heater saturation and stock. (p.69)

2-26 Characteristics of the average gas water heater. (p.70)

2-27 Electric water heater saturation and stock. (p.72)

2-28 Characteristics of the average electric water heater. (p.72)

Refrigerators and Freezers

2-29 Data for the supply curve of conserved electricity: refrigerators and freezers. (p.78)

2-30 Saturation and energy use of refrigerators. (p.83)

2-31 Saturation and energy use of freezers. (p.85)

Lighting

2-32 Data for the supply curve of conserved electricity: lighting. (p.90)

Air Conditioning

2-33 Data for the supply curve of conserved electricity: air conditioning. (p.98)

2-34 Typical 10,000 Btu/hour room air conditioner energy use. (p.100)

2-35 Average annual energy used by air conditioners. (p.101)

2-36 Conservation options for typical central air-conditioning unit in the Central Valley. (p.103)

2-37 Conservation options for the average central air conditioner. (p.105)

Electrical Appliances

2-38 Data for the supply curve of conserved electricity: miscellaneous appliances. (p.110)

2-39 Savings from replacing electric clothes dryers with gas clothes dryers. (p.111)

2-40 Savings from replacing electric ranges with gas ranges. (p.113)

2-41 Annual electricity use of televisions in California. (p.115)

2-42 Characteristics of the television stock in California. (p.115)

Gas Appliances

2-43 Annual energy use of the typical gas clothes dryer. (p.120)

2-44 Typical gas use in ranges with and without spark ignition. (p.121)

2-45 Average gas use in ranges with and without spark ignition. (p.122)

Swimming Pools

2-46 Data for the supply curve of conserved gas: swimming pools. (p.126)

2-47 Characteristics of a typical swimming pool in California. (p.127)

2-48 Annual heating needs of a typical pool. (p.128)

2-49 Annual energy savings from tune-up of pool heater. (p.129)

Grand Supply Curves

3-1 Data for the grand supply curve of conserved natural gas. (p.137)

3-2 Data for the grand supply curve of conserved electricity. (p.140)

Preface

The role of conservation in alleviating our energy dilemmma is controversial. Most views rest on rhetoric. To some, conservation conjures up images of "freezing in the dark." But the need for energy can be reduced without sacrifice; however, like the development of more tangible energy resources, it requires investment.

This study treats conserved energy as if it were a new source of energy, like shale oil or alcohol. Conservation can reduce our reliance on expensive and limited conventional fuels. Two questions need immediate answering: how large are the reserves of energy created by improving efficiency of use, and how much will it cost to "extract" them?

Precisely because conserved energy is a novel source, the techniques of estimating its reserves are almost as important as the the estimates themselves. While geologists have fairly accepted procedures for characterizing tangible energy reserves, no analagous procedure exists for future conserved energy. By presenting the energy available through conservation on a supply curve, we ensure that conservation is truly comparable to other energy sources.

Reserves of energy created through conservation do not lie in the ground; rather, they lie in the <u>end uses</u> of energy. Therefore, one must ask how and <u>why</u> energy is used. The demand for energy is not fixed; it will fall as conserved energy is extracted.

The reserves of conserved energy are highly dispersed. They are "located" in inefficient refrigerators, poorly insulated homes, and gas guzzling cars. It may be simple enough to identify a reserve of conserved energy, that is, the potential energy savings, in a single refrigerator, home, or car. However, the scale of these savings is dwarfed by the size of conventional energy reserves. Comparing 10 MBtu saved by home insulation to the millions of MBtu in an oil field seems inappropriate. In this report, we have tried to bridge the gap between the known savings in a single home, and the unknown savings in the entire sector.

We have examined only a limited portion of California's reserves of conserved energy, namely, that found in the existing residential sector. For a first attempt at developing conservation supply curves, this sector is probably the easiest to analyse. The data on energy use in California's residential sector are probably better than that found in any other sector. One simplification is that only two fuels, electricity and natural gas, are used in California's homes. Further, the number of end uses within the residential sector is limited and they are well understood. Nevertheless, the information needed to construct supply curves of conserved energy is awesome. With it, though, one has an extraordinarily detailed understanding of how energy demand could be cut through improved efficiency instead of sacrifice.

Acknowledgments

Only our co-workers and reviewers can truly appreciate the magnificent efforts of our editor, Howard Beckman. He has transformed a virtually unreadable draft into a report that, we believe, is both highly intelligible and useful as a reference document.

There are many others without whose contributions this report would be thinner.

The initial development of the computer program, CPS 1.0, that generates the supply curves was done by Haldun Arin and Ric Steinberger. Leonard Wall spent a summer running DOE-2 to provide a basis for our estimates of space heating savings. Later, Brian O'Regan assisted in the same way when we finally discovered the questions we wanted to ask. Jeana McCreary, a virtuoso performer on the word processor, competently assisted in the final preparation of the manuscript.

We drew upon the resources of the major utility companies in California--Pacific Gas & Electric, Southern California Gas, San Diego Gas & Electric, and Southern California Edison. Many staff members in the California Energy Commission and the California Public Utilities Commission provided information at critical times.

Of course, this project would not have been possible without the financial assistance of the California Legislature through the California Policy Seminar program.

Part 1

Developing Supply Curves of Conserved Energy

Developing Supply Curves of Conserved Energy

DEFINING CONSERVATION

Consumers demand the services that energy provides, not energy itself. Furnaces burn gas to provide heat; air conditioners use electricity to cool the air; and motors use electricity to provide mechanical drive. The amount of energy used for a particular service depends on the efficiency of the service mechanisms and the level of service demanded. Figure 1-1 illustrates this relationship. If, for example, Figure 1-1 represented energy used for space heating in a house, each service curve would represent a different thermostat setting, say 60°F for the lower curve and 70°F for the upper. One approach to energy conservation is to accept lower levels of service (turning down the thermostat in our example). This is not our approach because, as we will show, large amounts of energy can be saved by simple, economic measures that improve efficiency without changing the level of service.

Tradeoffs between energy and efficiency exist for most devices. Figure 1-2 summarizes one study of refrigerators.

A SUPPLY CURVE OF CONSERVED ENERGY

A supply curve for any energy source ranks the various reserves of that energy in order of increasing cost and shows how large each reserve is. Figure 1-3 depicts supply curves for two grades of coal.

A supply curve of <u>conserved</u> energy is the same as a supply curve for reserves of gas, coal, or other tangible energy resources--the curve slopes upward since more conserved energy becomes available at increasing costs. The reserves of conserved energy can be tapped by a sequence of conservation measures, each with its own size and cost.

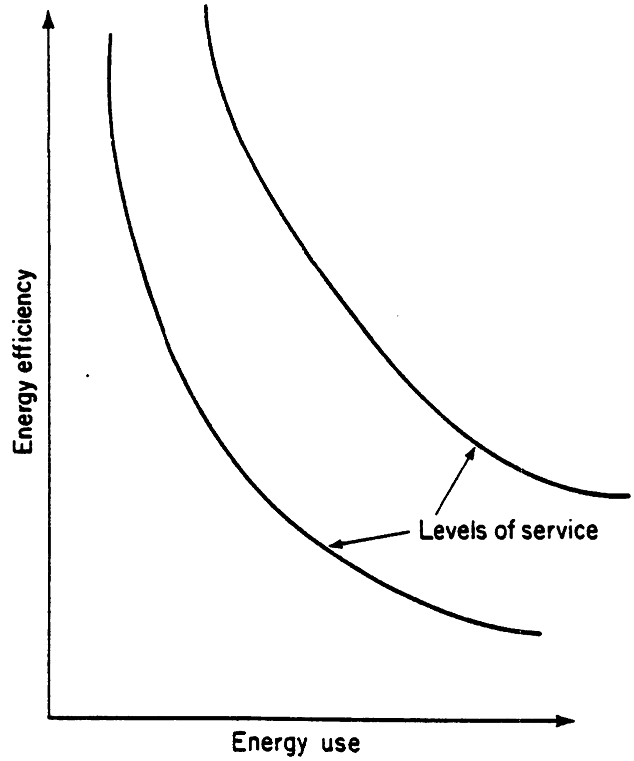

Figure 1-1. A schematic representation of the tradeoff between energy use and efficiency. Each curve represents a constant level of service.

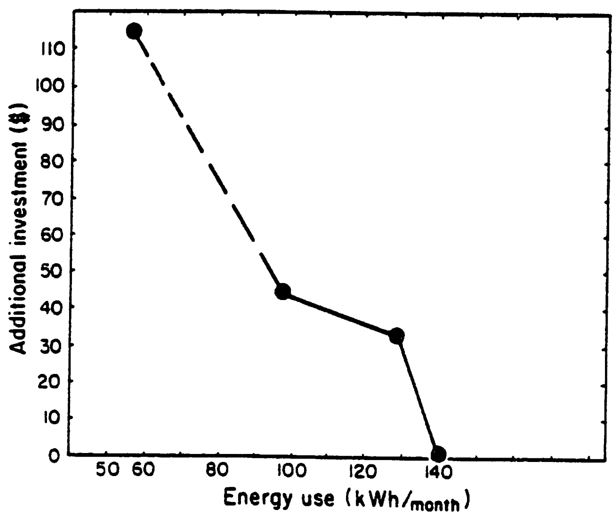

Figure 1-2. The relation between price and energy use for a 17-cubic-foot, frost-free refrigerator. The points connected by solid lines represent actual models on the market. The point on the left is an estimate from an engineering- economic analysis. (A.D. Little, 1977).

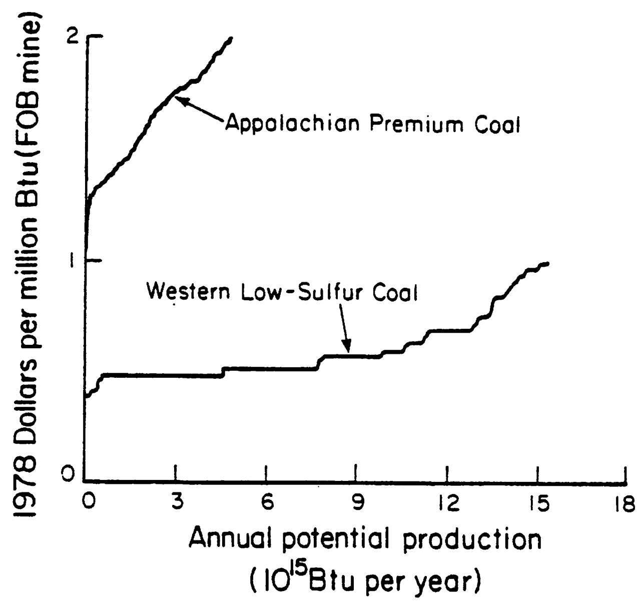

Figure 1-3. Supply curves for two grades of coal. The reserves of Western coal are cheaper and three times as large as the reserves of Appalachian coal. (Source: EIA, 1978.)

To develop a regional supply curve of conserved energy, two coordinates must be found for each measure. The vertical coordinate (y-value) of a conservation measure is the cost of the energy conserved by that measure; the horizontal coordinate (x-value) is the cumulative energy saved annually by that measure and all measures preceding it in the supply curve. Figure 1-4 shows this scheme. Determining the y-value requires engineering and economic data; determining the x-value requires research into the characteristics of the energy-using stock. We discuss these two types of investigations in detail in the next two sections.

The Cost of Conserved Energy

To establish the unit cost of the conserved energy, such as cents per kWh, the annual investment in conservation (for materials and labor) is divided by the annual energy savings:

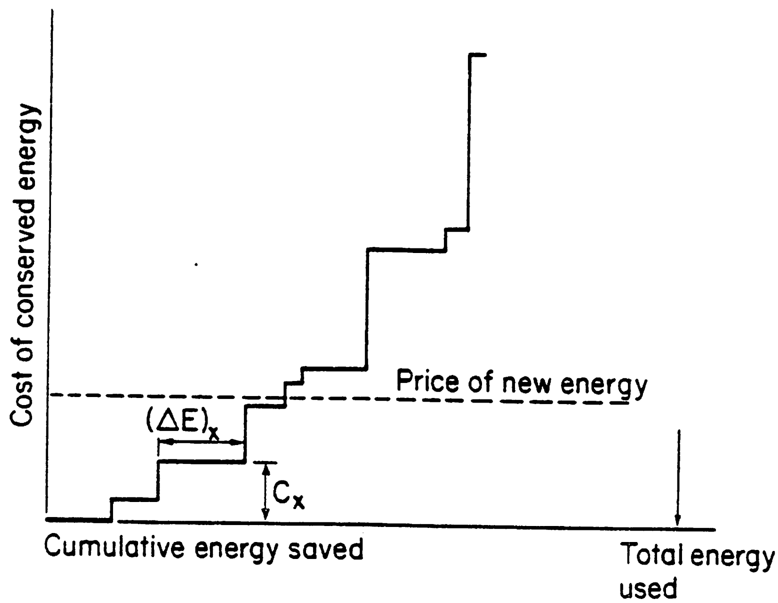

Figure 1-4. A schematic supply curve of conserved energy. Implementation of "measure x" will save energy, $(\Delta E)_x$, at a cost per unit of conserved energy, C_x.

$$\text{cost of conserved energy} = \frac{\text{annual investment (\$ per year)}}{\text{annual energy saved (kWh per year)}}$$

Since investment actually occurs just once, it must be annualized by multiplying it by the capital recovery factor,

$$\frac{d}{1 - (1 + d)^{-n}},$$

where n is the time over which the investment is written off, or amortized, and d is the discount rate. The unit cost is thus determined by the formula.

$$\text{cost of conserved energy} = \frac{\text{(capital recovery factor) X (investment)}}{\text{annual energy saved}}.$$

Let us take an example. A consumer wishes to buy a new refrigerator. The high-efficiency model (offering identical services to the standard model) costs $60 more but uses 400 kWh per year less electricity. The consumer wants to recover his investment in 10 years. The consumer has a real discount rate of 5% (at an inflation rate of 10%, this would be equivalent to borrowing at 15%). The cost of conserved energy in this case is

$$= \frac{\left[\frac{.05}{1 - (1 + .05)^{-10}}\right] (\$60)}{400 \text{ kWh per year}}$$

$$= \frac{(0.13)\ (\$60)}{400 \text{ kWh}}$$

$$= \$0.02 \text{ per kWh} .$$

Is the high-efficiency model a profitable investment? Here the cost of conserved electricity is less than half the current average California rate of 5 cents per kWh. Furthermore, the cost of the conserved electricity will stay the same for 10 years (after that it will be free). In contrast, the real price of electricity will most likely rise, that is, exceed general inflation. Note that the cost of the conserved electricity is independent of the price of electricity.

As the above shows, calculating the cost of the energy supplied by a conservation measure involves four variables:

1. Investment or initial cost of the conservation measure.
2. Annual energy savings expected from the measure.
3. Amortization period of the investment.
4. Discount rate of the investor.

These variables are analogous to the criteria for investment in the supply sector.

1. Cost of extraction facility.
2. Rate of extraction.
3. Depreciation of facility (and possibly depletion of the reserve).
4. Discount rate of the firm.

We now turn to a discussion of each of these four variables in turn.

Estimating the Cost of a Conservation Measure

Investment costs in conservation typically have two components: materials and labor. Where no labor is involved, such as in the purchase of an efficient refrigerator, we have chosen to use the additional retail cost of products. Wherever possible, these costs are taken from major national retailers, such as Sears. A policymaker might prefer to use other costs. For example, the state or utilities could decide to distribute fluorescent lights at a reduced price to encourage replacement of less efficient incandescents. But although large purchases would mean substantial discounts, this savings could be offset by the administrative cost of such a program.

Installation labor could be provided free in some (simple) cases by the occupants rather than by a contractor. However, in order to standardize costs, we assume that all labor is performed by a contractor. Certainly, contractor charges vary widely, but not as widely as the value people place on their own time. Wherever possible, we present labor and materials costs separately. Thus a "do-it-yourself" reader may recalculate costs of conserved energy based on materials alone.

Assigning an investment cost to measures that replace appliances with models meeting the energy efficiency standards of the California Energy Commission presents a unique problem. Since all new appliances sold in California must meet CEC standards, the average costs of appliances should rise. Nevertheless, we have given such measures a zero cost since the consumer does not have the option of buying a less expensive (less efficient) model (save ordering the appliance from a nearby state).*

We have ignored the numerous secondary costs and benefits of energy conservation. Increases in property taxes resulting from conservation measures that upgrade a house are not added to the measures' costs. Likewise, income tax credits are not deducted. (They can be significant; California has a 40% conservation tax credit.) Including such secondary factors would be an awesome task since it would require many new assumptions about income, tax rates, and the real estate market.

In addition, there are externalities we have not included. Investments in energy conservation will probably have few if any negative effects on the environment. Also, many measures provide increased comfort. For example, reducing the leakage of cold air into a home will not only save energy but eliminate the discomfort of drafts. Such "belt-loosening" consequences of conservation are often overlooked. We mention them wherever appropriate but do not include them in our calculations.

Estimating Annual Energy Savings

Our estimates of energy savings from conservation measures come from two sources. First, wherever possible, we have used actual meas-

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* This zero-cost assignment affects the cost of conserved energy only for that measure. The remainder of the supply curve will be unchanged in either event.

urements of the savings. For example, the electricity used by each refrigerator model on the market has been determined according to a standard procedure; the amount will be little affected by individual consumer behavior.

Second, when empirical data are not available, we have relied on engineering calculations to estimate energy savings. These calculations range in complexity from simple reductions in heat loss to sophisticated computer simulations. One drawback of such calculations is that many devices fall short of performance specifications. For example, R-19 insulation may only be equivalent to R-14 when installed. Nevertheless, we assume that devices perform to their nameplate specification and have reduced the estimated savings only when especially suspicious.

How accurate can estimates of aggregated energy savings be? In principle, accurate estimates should be based on very specific conservation measures. For example, to estimate the statewide savings from installing attic insulation, one should estimate the savings for many variants of the measure, such as "Add R-19 insulation to the attics of 1,500 square-foot, uninsulated, gas-heated, single-family houses kept at 70°F and located in Los Angeles." In practice, however, it is virtually impossible to get an accurate count of the number of homes that fit such narrow specifications. Thus, our accuracy in estimating the energy saved by a conservation measure is constrained by our knowledge of the stock to which the measure applies. We have formulated our own uncertainty principle: "The more accurately one specifies the conservation measure, the less accurately does one know the stock to which it applies." Accordingly, we have adopted such "general" measures as "Add R-19 insulation to the attics of uninsulated, gas-heated, single-family houses in Southern California".

In Part 2 of this report, the impact of each measure is analyzed at two levels. First, we present information on the typical energy savings for individual consumers; this data may serve as the basis for other studies. Second, we present the average savings along with the stock data used to obtain this average. This average savings is used to calculate the cost of conserved energy. In some cases our ignorance about the stock eligible for a conservation measure is so great that we cannot estimate aggregate savings. In such cases only the typical savings are presented.

Much useful information is lost in the averaging process necessary for aggregation. For example, the most common size of gas water heater is 40 gallons, whereas the average size is only 35 gallons. Thus, for some water heating conservation measures, the average energy savings will be lower than the actual savings for the typical (40-gallon) water heater. Further, gas water heaters do not come in 35-gallon sizes, so the weighted average savings are not applicable to any actual water heater. Because of this, we discuss in abundant detail the typical savings that provide the basis for estimating average savings.

The sequence in which measures are assumed to be implemented is important. Since conservation measures can be anti-synergistic, the energy savings from a particular measure depend on what measures have already been implemented. For example, if wall insulation is installed after attic insulation, the energy savings will be less than without attic insulation. An insulating blanket on a water heater saves more energy when the water is heated to 140°F than when it is heated to 120°F. Thus, the order in which tank insulation and thermostat setback are done influences the energy savings of these measures. We assume that all measures are implemented in the optimal economic sequence, that is the measure with the lowest cost of conserved energy is done first. For this reason, the energy savings from some measures may be underestimated.

We have calculated only the energy saved by the consumer. Savings that would concern a utility planner, such as decreased transmission loss or variations in efficiencies of conversion, are not included. The ultimate energy savings from our conservation measures are thus even greater than we have shown.

Choosing Amortization Periods

The amortization period for a conservation investment is the time over which the investment is spread in order to annualize the investment (see p.6). Spreading an investment over a larger number of years gives a lower annualized investment, and consequently, a lower cost of conserved energy.

An obvious amortization period is the lifetime of the appliance or materials in the conservation measure. For example, a new refrigerator typically lasts 20 years, and weatherstripping probably needs replacing about every 5 years. However, this approach has its complications.

One complication arises when an energy-saving device is attached to an appliance. The remaining life expectancy of the appliance may be shorter than that of the device. In that case the effective lifetime of the retrofit is the remaining lifetime of the appliance. For example, the effective lifetime of a spark ignition system retrofitted to a gas furnace is only the remaining expected lifetime of the furnace (provided the ignition system is not transferred to another furnace).

The amortization period for a conservation investment may also be defined in accounting terms. Suppose a homeowner borrows money to finance attic insulation. Then the amortization period becomes the period in which the loan is to be repaid. However, this accounting approach is misleading because it ignores the energy savings after the loan is paid off.

A "first-owner" amortization period is appropriate when the consumer does not expect to recover his conservation investment on resale. When the original owner of a car with high gas mileage wants to sell the car, he will be able to charge a premium for fuel economy because the buyer will recognize the benefits to him of fuel economy. In contrast, the buyer of a second-hand refrigerator will probably not be willing to pay extra for high efficiency because the great variation in operating costs of refrigerators is not well known. Thus the conservation investment may not be recovered on resale. Differences between first-owner and physical lifetimes can be enormous. For example, the first-owner lifetime for a house is less than 10 years.

Whichever lifetime is selected--physical, accounting, or first owner--a problem arises when the effectiveness of a conservation device deteriorates with age. For example, insulation lasts about 30 years, but there is evidence that its thermal resistance falls with time. This can be resolved in two ways. One could calculate the energy savings due to R-19 insulation as if the thermal resistance were only, say, R-14. Alternatively, one could assign a shorter effective lifetime, say 20 years. We opted for the second approach.

We assume that consumers will amortize investments in short-lived conservation measures over their normal physical lifetimes. For longer-lived measures, e.g., purchasing appliances, whose lifetimes exceed 10 years, we arbitrarily assume that investments are amortized over 10 years. The exception is insulation. Home buyers (and even appraisers) now recognize that insulation adds to the value of a home. Accordingly, we have amortized these measures over 20 years.

Choosing the Discount Rate

The discount rate affects the cost of conserved energy through the capital recovery factor. Figure 1-5 shows the sensitivity of the capital recovery factor to both the discount rate and amortization period. Note that the choice of discount rate is more crucial for long-lived than for short-lived measures.

Discount rates can be expressed in two ways, as nominal or real. The nominal discount rate is the sum of the real discount rate and the inflation rate. If a nominal discount rate is used, then the cost of conserved energy is in nominal (inflated) dollars. If a real discount rate is used, then the cost of conserved energy is expressed in real or constant dollars (in our case, 1979). We elected to use a <u>real</u> discount rate. We thus avoid assumptions about inflation, in line with our policy of minimizing guessing.

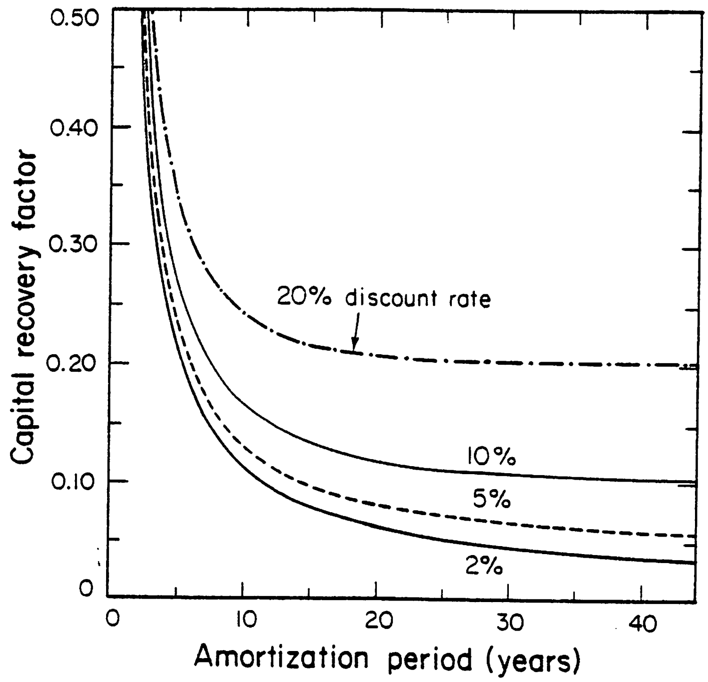

Figure 1-5. Capital recovery factor as a function of amortization period for four discount rates.

We have also chosen to use a consumer discount rate since we prefer to be economically conservative. For government conservation programs, a social discount rate would be appropriate. Social discount rates are low since externalities such as pollution and employment can be entered into the accounting. Utilities can borrow at lower interest rates than consumers so a utility discount rate will be lower than a consumer discount rate, but higher than a social discount rate.

What is an appropriate consumer discount rate? Discount rates vary widely with income level (low discount rates are a luxury only the rich can afford).

Analysts for the proposed federal Building Energy Performance Standards (BEPS) employed a 3% real discount rate when calculating optimal insulation levels in new houses. They chose this rate as roughly equivalent to the real mortgage rate. Another approach is based on interest rates for home improvement loans; subtraction of the inflation rate could indicate a real discount rate. Alternatively, the consumer with money to invest might take the average rate of return available to him on the market as a nominal discount rate.

High-risk investments have higher expected rates of return. The other three variables used in calculating the cost of conserved energy--investment cost, annual energy saving, and amortization period--are all uncertain. Should the discount rate for conservation investment reflect this risk? In a large conservation program involving thousands of individuals, the probability of achieving the expected savings is greater because the individual results are averaged. The individual consumer, however, faces only one outcome--either the expected savings are realized or they are not. Thus, if the discount rate is to reflect uncertainty, it should be higher for the individual than for a large program. Of course, government programs that encourage conservation, such as appliance labeling and low-cost energy audits, may lower the consumer's perceived risk. In contrast, direct government intervention in the form of tax incentives, rebates, and low-interest loans will lower the cost of conserved energy by subsidizing investment costs without changing the discount rate.

We have selected a real discount rate of 5%. Currently, this corresponds roughly to a nominal rate of 18%.

Aggregating Energy Savings

Supply curves of conserved energy demonstrate the potential energy savings for whole regions and thus permit comparison between the costs of conserved energy and new energy supplies. Furthermore, they show the relative cost and energy savings of different conservation measures. In this study we have developed two types of supply curves of conserved energy. In the first type we aggregate the savings from all conservation measures for a single end use of one type of energy, e.g., gas water heating. In the second type, which we call a "grand curve," we aggregate the potential savings in all end uses of a particular energy type. For California's residential sector there are only two grand supply curves, one each for natural gas and electricity.

To aggregate, one must know the stock eligible for a conservation measure. We estimated the eligible stock in two stages. First, we estimated the total stock to which a measure could conceivably apply. For attic insulation, for example, this meant all houses in California. Next, we estimated the fraction of the total stock eligible for the measure. For insulation, we eliminated those homes whose attics were already insulated or could not be insulated.

Our study is limited to estimating conservation potentials in the 1978 stock of California homes and appliances, including replacements. Thus, the size of the stock remains constant in our calculations, while the make-up changes through retirement and replacement. By ignoring growth, we consistently <u>underestimate</u> the conservation potential in the future. At the same time, we avoid many complications, such as the problem of estimating energy savings in homes not yet built. In any event, the size of growth in energy use is small compared to the 612 teraBtu of natural gas and 49.6 terawatt-hours of electricity that constituted California's residential energy use in 1978.

How long will it take to realize the potential savings we have identified? Even under ideal conditions, conservation measures will take years to implement statewide. ("Crash" programs are unlikely, and are vulnerable to administrative and supply bottlenecks.) The roll-in time is the time we believe necessary to achieve 100% implementation without seriously upsetting or straining normal supply schedules. For example, we believe it would take five years to insulate all of the eligible water heaters in California, even though a single water heater can be insulated in 30 minutes. We have assigned roll-in times of less than 10 years to almost all retrofit measures.

We assume that the more efficient appliances will be introduced at the normal turnover rate of stock. The fraction of stock that will be replaced with high-efficiency models in any given year is thus determined by the average lifetime of all models in the stock. For example, water heaters have an average lifetime of 10 years, so roughly one-tenth of the stock will be replaced annually.*

The roll-in time and turnover rate constrain the rate at which the reserves of conserved energy from any given end use can be tapped. In this sense, the reserves are a function of time--the longer one waits, the larger will be the reserves. (This is especially true for long-lived electrical appliances, such as refrigerators.) We have arbitrarily chosen a waiting period or time horizon of 10 years. The aggregate energy savings shown on a supply curve are for the final year of the time horizon. Supply curves for coal, oil, and other conventional energy sources also have time horizons, although they are rarely specified. Figure 1-6 shows the implementation rates of two conservation measures.

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* We have used a linear decay model. An exponential decay model might be more realistic; however, given the uncertainties in the data, use of an exponential model would add little accuracy.

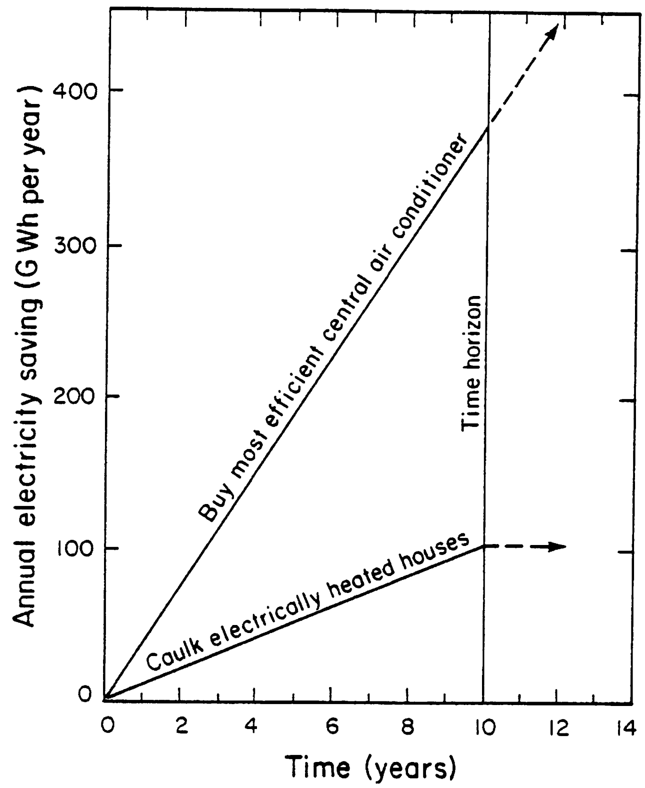

Figure 1-6. Annual energy savings for two conservation measures. The retrofit measure, caulking, is fully rolled in and thus achieves the full conservation potential at the end of the time horizon (10 years). The appliance-replacement measure achieves its full potential only after 15 years, when the entire 1978 stock has been replaced.

INTERPRETING SUPPLY CURVES OF CONSERVED ENERGY

A major advantage of supply curves of conserved energy is that changes in the price of energy will not alter the costs of conserved energy. A supply curve of conserved energy would be completely unaffected by a doubling of energy prices. The price of energy does, however, determine which conservation measures on a supply curve are economic. Any measure having a cost of conserved energy less than the price of the energy it saves is economic. Since all measures on a supply curve appear in order of increasing cost, the measure with a cost of conserved energy equaling the price of the displaced energy serves as the <u>cut-off point</u>. Measures below it are economic; measures above it are not. Unfortunately, establishing the cut-off point has complications. Some of these are due to the methodology of constructing supply curves of conserved energy, while others are due to California's complex rate structure, which penalizes profligacy.

The fact that a conservation measure cannot be implemented in many homes at once means that today's energy prices should not be the basis for the cut-off point. One must compare the costs of conserved energy to the expected energy prices during the time horizon.* In our study, this means using a 10-year weighted-average energy price.

The supply curves can be constructed using either a nominal or constant dollar basis. Once the basis is chosen, however, it must be used for both the cost of conserved energy and the price of the replaced energy. Our study used constant dollar, or real, discount rates, so our costs of conserved energy must be compared to the expected prices of energy in constant (1979) dollars.

We assume that energy prices will rise at the same rate as inflation. Using constant dollars, this means that future energy prices will be the same as current prices. But which of today's prices? The rate structure for California's residential customers is graduated and varies with season.† As a consequence, the consumer faces several energy prices that differ by as much as 100%. For some uses, such as swimming pools, all the potential energy savings will be from the most expensive rate block (the "tailblock"). Rather than using several rates, we arbitrarily chose <u>reference energy prices of six dollars per MBtu and eight cents per kWh</u> (these are close to the tailblock rates for California utilities). Generally, we consider measures with a cost of conserved energy below six dollars per MBtu or eight cents per KWh to be economic.

Readers who disagree with our cut-off prices may choose other prices. For example, a utility may use their production costs as a reference price. Others may argue for using so-called social costs of energy for comparison. In any case, all comparison costs must be in real terms.

Throughout this report we sometimes describe statewide electricity savings in terms of "typical power plants." This is to provide the reader with some sense of the magnitude of the savings. "Saving the equivalent of a typical power plant" means saving the annual delivered

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* The precise scheme for weighting the price depends on the specific conservation measures involved and the rates at which they are implemented. It is difficult to apply and in any case too complicated to discuss here. (See Meier, 1981 for details.)

† In the San Francisco Bay Area in a summer month, for example, Pacific Gas and Electric charges 29 cents per therm for the first 26 therms of gas used (the lifeline block), 57 cents per therm for the second 26 therms used, and 67 cents per therm for the excess (the tailblock).

electricity generated by a 1 GW plant with a 65% capacity factor, that is, 5,700 GWh generated and 5,100 GWh delivered. (Approximately 10% of generated electricity is lost in transmission and distribution.) "Saving the equivalent of a typical power plant" does not mean avoiding the need to build a new plant or replacing an old one; for that, 1 GW of power would have to be saved as well as 5,100 GWh per year of electricity.

Part 2
End Use Studies

In this part we examine the existing potential for energy conservation in California in terms of different end uses. The analysis of each end use comprises four parts:

1. Supply curve of conserved energy with table of data
2. Discussion of the supply curve
3. Technical discussion of individual conservation measures
4. Estimate of the aggregate (statewide) savings

The supply curve summarizes the potentials for conservation in the end use considered. We examine the implications of the curve and discuss in general the conservation measures included in the curve, focusing on ways to implement the measures and technical or institutional barriers. We then examine the measures in detail from two perspectives. First, the costs and energy savings for typical, or representative, cases are described; any unusual features of the measure are also mentioned. Next, the representative cases are aggregated to arrive at an estimate of statewide savings. Here entirely different assumptions are applied, such as how many units of each representative case actually exist, how many units are eligible for the measure, and how rapidly the stock turns over.

A Guide to the Supply Curves of Conserved Energy

The supply curve consists of a series of steps, each of which represents a conservation measure. The width of each step is the annual energy that could be saved in California by the implementation of the measure within the time horizon specified (10 years in our study). The height of the step is the cost at which a unit of that energy can be saved. For example, in Figure 2-1 (p. 24) measure 18 would save about three times as much energy annually as measure 10 but at more than twice the cost per unit of saved energy. Thus the supply curve ranks conservation measures in terms of their economic attractiveness. Clearly, those measures that are on the low part of the curve should receive higher priority, since they supply energy most cheaply.

To decide which conservation measures are economic, one must compare their costs of conserved energy to the price of new energy supplies during the time horizon. Since the cost of conserved energy is an average over the time horizon, one must choose a representative energy price over that same time period. Also, we have calculated costs of conserved energy in real (constant) dollar terms, so energy prices must also be expressed in real terms. The tailblock rate is a reasonable guide to the price of new energy.*

A table accompanying each supply curve provides the data used to construct the supply curve. It includes the following information:

* The tailblock rate is the highest rate consumers now pay. It is about $6 per MBtu for gas and 8 cents per kWh for electricity. (See Part 1.)

Marginal Cost of Conserved Energy. This is calculated using the average energy saved each year, the cost of the conservation investment, the discount rate, and the amortization period. The details of this calculation are given in Part 1 (pp. 5 - 7).

Average Cost of Conserved Energy. This is the cost if the measure is implemented together with all preceding measures in the sequence.

Energy Supplied per Measure. This is the annual energy that could be saved statewide. For most measures, this savings would not be fully realized until the last year of the time horizon.

Total Energy Supplied. This is a running total (in round numbers) of the savings in the previous column.

Total Dollars Invested. This is a running total of the investments required to save the energy in the previous column.

It is important to understand the distinction between the representative and aggregate estimates in each end-use analysis. Estimates of representative savings (discussed under the heading "Conservation Measures") are the energy savings for a typical household, which we presume actually exists. Aggregate estimates (discussed under the heading "Statewide Savings") use average energy savings. These average savings are not typical of any group of houses or appliances, but are used only as an accounting convenience. For example, most water heaters are in single-family homes with perhaps three occupants. However, the average home has only 2.7 occupants, so less hot water is used on average. Thus, a low-flow showerhead will save 36 therms in a typical home but only 31 therms on the average.

Space Heating

THE SUPPLY CURVES

Gas Space Heating

The supply curve for gas space heating (Figure 2-1) begins with some low-cost measures, gradually climbs while making steady inroads into total consumption, then rises steeply after measure 27. The total savings if all measures were adopted amounts to over 60% of all the natural gas used for space heating.

The cost of conserved energy climbs above current prices midway through the sequence of measures. There are several reasons why some popular space heating measures have surprisingly high costs of conserved energy. Our approach has been conservative; estimating low energy savings and high investment costs results in high costs of conserved energy.

Space heating is the end-use that offers the greatest conservation challenge to the "do-it-yourself" homeowner. Although some measures can be done by homeowners for a fraction of a contractor's cost, nevertheless we consistently used contractor costs. Furthermore, we did not include the recently passed 40% California conservation tax credit.

Because many Californians, especially in the north, have already performed the cheapest conservation measure, namely thermostat setback, energy savings from subsequent measures are lower than might be anticipated. For example, the energy savings from adding insulation are less when the thermostat is at 65°F than when it is at 70°F.

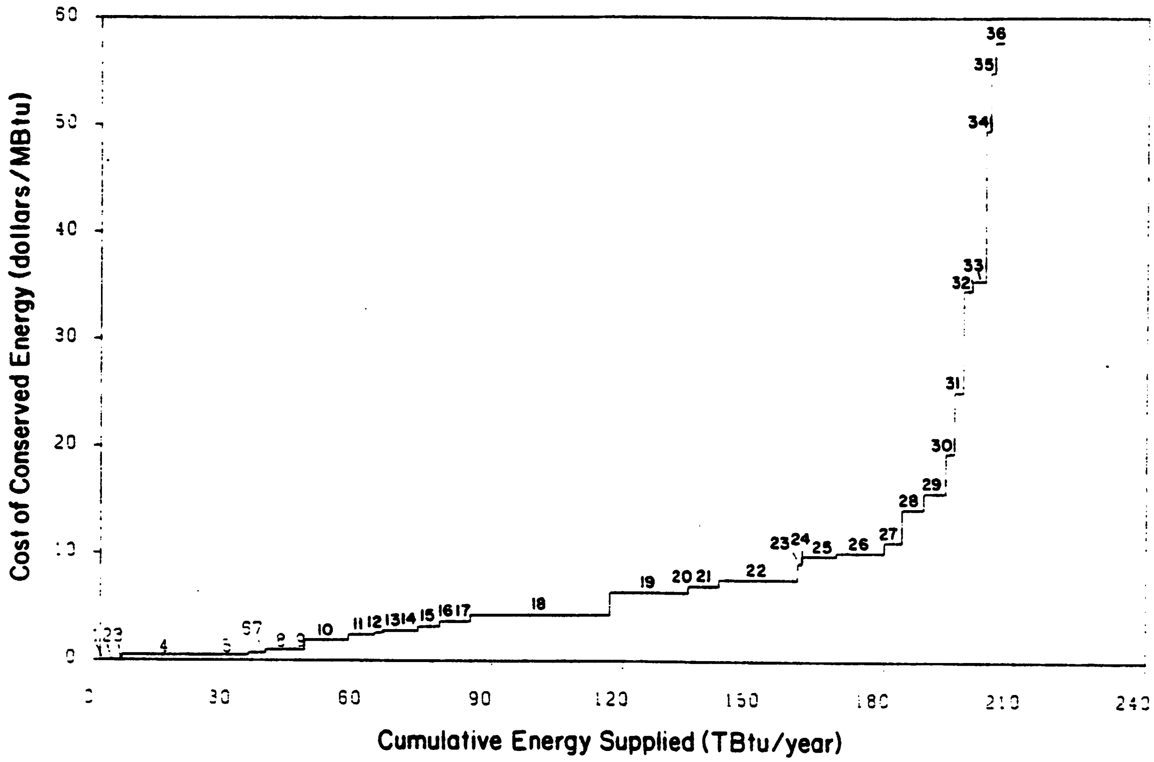

Figure 2-1. Supply curve of conserved gas: space heating. Total gas used for residential space heating in California in 1978 was 325 TBtu.

Table 2-1. Table of data for the supply curve in Figure 2-1. The time horizon is 10 years; the discount rate is five percent. Costs of conserved energy are in 1979 dollars. In the description of the measures (first column), N = Northern California, single family; S = Southern California, single family; MF = multifamily.

Measure*	Cost of Conserved Energy ($/MBtu)		Energy Supplied (TBtu/y)		Total Dollars Invested (millions)	Meas. No.
	Marginal	Average	Per Meas.	Total		
1 Pilot off in summer (MF)	0	0	1.3	1	0	28
2 Pilot off in summer (S)	0	0	3.0	4	0	19
3 Pilot off in summer (N)	0	0	1.0	5	0	1
4 Night setback of 10°F (S)	.5	.4	18.5	24	112	20
5 Night setback of 10°F (N)	.5	.4	10.7	34	177	2
6 New furnace w/spark ignit. (S)	.7	.4	2.0	36	194	102
7 New furnace w/spark ignit. (N)	.7	.4	2.0	38	212	100
8 Night setback of 10°F (MF)	1.0	.5	6.8	45	294	29

Table continued

Table 2-1 continued

Measure*	Cost of Conserved Energy ($/MBtu) Marginal	Average	Energy Supplied (TBtu/y) Per Meas.	Total	Total Dollars Invested (millions)	Meas. No.
9 New furn. w/spark ignit. (MF)	1.0	.5	1.5	47	311	104
10 Install R-19 in ceiling (N)	1.9	.8	10.0	57	545	4
11 Seal attic bypasses (N)	2.4	.9	6.2	63	732	3
12 Install R-19 in ceiling (MF)	2.6	1.0	2.1	65	800	30
13 Retrofit spark ignition (S)	2.8	1.1	4.0	69	885	101
14 Retrofit spark ignition (N)	2.8	1.2	4.0	73	969	99
15 Seal attic bypasses (S)	3.2	1.3	4.7	78	1155	21
16 Install R-19 in ceiling (S)	3.7	1.4	5.1	83	1388	22
17 Retrofit spark ignition (MF)	3.7	1.5	2.6	85	1463	103
18 Install R-11 in walls (N)	4.3	2.3	31.3	117	3156	5
19 Storm windows (N)	6.4	2.8	18.2	135	4601	7
20 Seal attic bypasses (MF)	6.9	2.8	.5	135	4640	105
21 Install R-11 in walls (MF)	7.0	3.0	6.7	142	5221	106
22 Install R-11 in walls (S)	7.6	3.5	17.9	160	6,907	23
23 Fireplace damper (S)	9.1	3.6	.7	161	6,960	13
24 Fireplace damper (N)	9.1	3.6	.7	161	7,012	11
25 Caulking (N)	9.8	3.9	7.2	169	7,560	6
26 Storm windows (S)	10.1	4.3	11.4	180	8,998	25
27 Storm windows (MF)	11.1	4.4	4.0	184	9,548	32
28 Caulking (S)	14.2	4.7	5.0	189	10,094	24
29 Additional R-19 in ceiling (N)	15.7	4.9	4.8	194	11,030	8
30 Caulking (MF)	19.4	5.1	1.8	196	11,294	31
31 Additional R-19 in ceilings (S)	25.1	5.4	3.0	198	12,226	26
32 Seal ducts (N)	34.6	5.6	1.5	200	12,450	15
33 Weatherstrip (N)	35.5	6.1	3.2	203	12,948	9
34 Seal ducts (S)	49.5	6.3	1.0	204	13,172	17
35 Weatherstrip (MF)	54.9	6.5	.9	205	13,381	33
36 Weatherstrip (S)	57.7	7.0	2.0	207	13,877	27

*The conservation measures are listed in the order they appear in the supply curve, i.e., according to cost of conserved energy. The measure number (last column) is the number used throughout the report to identify the measure.

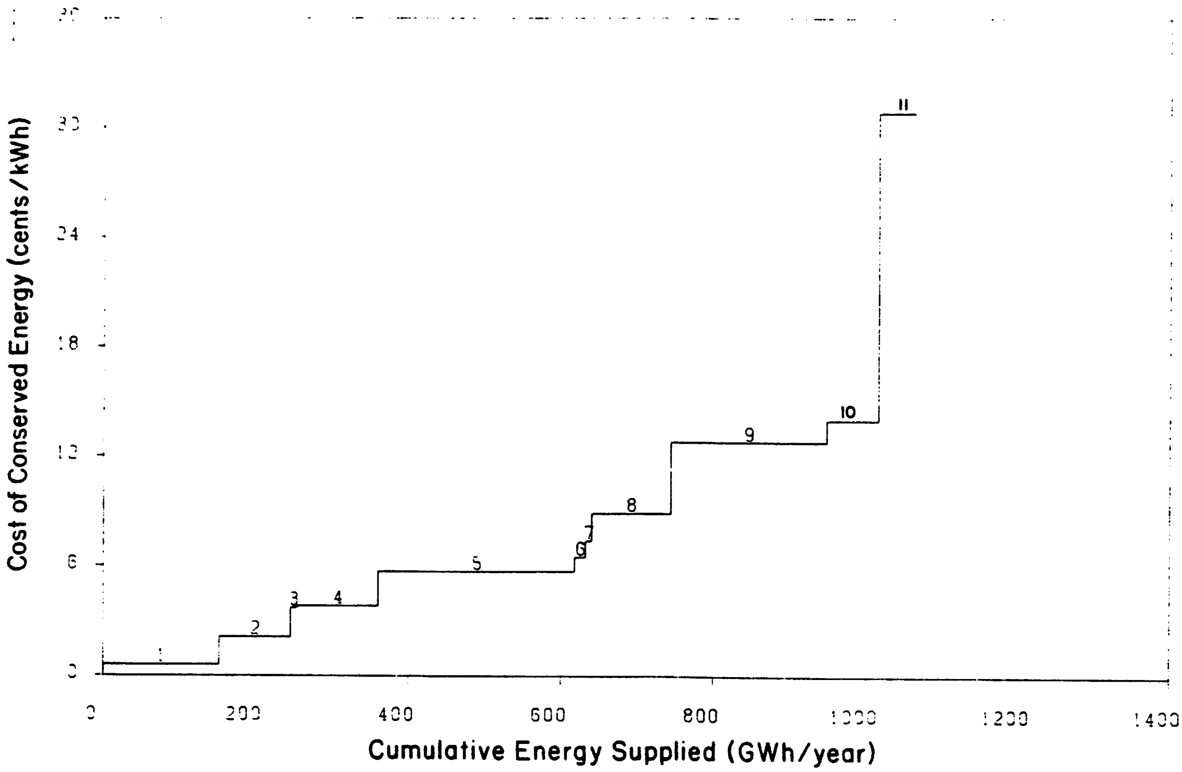

Figure 2-2. Supply curve of conserved electricity: space heating. Total electricity used for residential space heating in California in 1978 was 3,600 GWh.

We suspect that many gas furnaces are being supplemented with portable resistance heaters. Since we have not included this electricity saving for measures that improve the building shell (such as insulation), the energy savings from these measures are conservative.

Finally, space heating is the end-use most sensitive to the behavior of the occupants; consequently, it is where the estimate of average energy savings is most inadequate. Our analysis is too coarse to show that parts of the reserve created by a single conservation measure are cheaper to tap than others. Since energy savings are greatest when consumption is high initially, a more precise analysis would have specified measures such as "add wall insulation to high users," where "high users" might be leaky old houses with the thermostat kept at 70°F. However, such distinctions require detailed information, such as histograms of the distribution of energy use among residential customers, both by

Table 2-2. Table of data for the supply curve in Figure 2-2. The time horizon is 10 years; the discount rate is five percent. Costs of conserved energy are in 1979 dollars.

Measure*	Cost of Conserved Energy (cents/kWh)		Energy Supplied (GWh/y)		Total Dollars Invested (millions)	Meas. No.
	Marginal	Average	Per Meas.	Total		
1 Night setback of 10°F	.6	.6	153.1	153	12	46
2 Seal attic bypasses	2.1	1.2	92.5	246	36	47
3 Install R-19 in ceiling	3.7	1.3	9.9	255	40	48
4 Divert elec. clothes dryer vent	3.8	2.0	105.4	361	71	18
5 Storm windows	5.7	3.6	258.4	619	256	51
6 Fireplace damper	6.5	3.6	13.4	633	263	14
7 Install R-11 in walls	7.4	3.7	8.8	641	271	49
8 Caulking	8.9	4.4	102.1	744	341	50
9 Weatherize apartments	12.8	6.2	204.0	948	613	10
10 Additional R-19 in ceiling	14.0	6.7	68.9	1,016	733	52
11 Weatherstrip	30.8	7.8	47.9	1,064	797	53

*The conservation measures are listed in the order they appear in the supply curve, i.e., according to cost of conserved energy. The measure number (last column) is the number used throughout the report to identify the measure.

month and by year. Directives to utilities might be more profitable if phrased in terms of "conservation measures for the top 10% or 20% of users (for now)," rather than as blanket directives covering all consumers. If the energy available from space heating conservation is viewed as analogous to a coal mine, then the high users represent the "rich ore." As the price of new energy rises, the "lower-grade ore" of medium and low users can be mined for additional reserves of conserved energy.

Electric Space-Heating

The supply curve for electric space-heating (Figure 2-2) climbs gradually through the first eight measures and then climbs rather steeply. The cumulative savings after the final measure amounts to about 30% of the 3,600 GWh per year now used for electric space-heating.

The first seven measures all provide energy at a cost cheaper than present tailblock rates (the highest rates consumers pay). Residential tailblock rates in California are about 8 cents per kWh. Using 10 cents per kWh for comparison (probably close to marginal electricity prices), all but the final three measures are cheaper. As in our analysis of gas space heating, our use of contractor costs tends to inflate the cost of conserved energy. Moreover, we again suspect that focusing on high users, rather than all resistance-heated homes, would lower the cost of conserved energy enormously while still saving most of the electricity.

CONSERVATION MEASURES

Introduction

The demand for space heating depends on three factors: climate, physical characteristics of the building, and occupant behavior. Research has focused on the first two factors because they are easier to quantify. However, one cannot estimate energy savings due to conservation measures without assuming something about occupant behavior.

Most models of building energy use (computer and degree-day) assume the house temperature is maintained at 70°F. (More sophisticated models can include thermostat setbacks.) Such behavior probably occurs mostly in houses where there are elderly people or pre-school children. Some behavioral actions we suspect are significant in reducing the energy used in space heating are:

Maintaining the thermostat lower than 70°F

Lowering the thermostat or turning it off at night

Zone heating

A shorter heating season, e.g., not using the furnace in seasonal transition months

Turning the heat down or off during the day if the house is unoccupied

Turning the heating off if no one is at home over the weekend (and Christmas)

Extra motivation for these actions would come from the rapidly rising cost of energy and a "raised consciousness" about energy conservation. We suspect that in recent years occupant behavior, more than technical retrofits, has reduced the energy used for space heating.

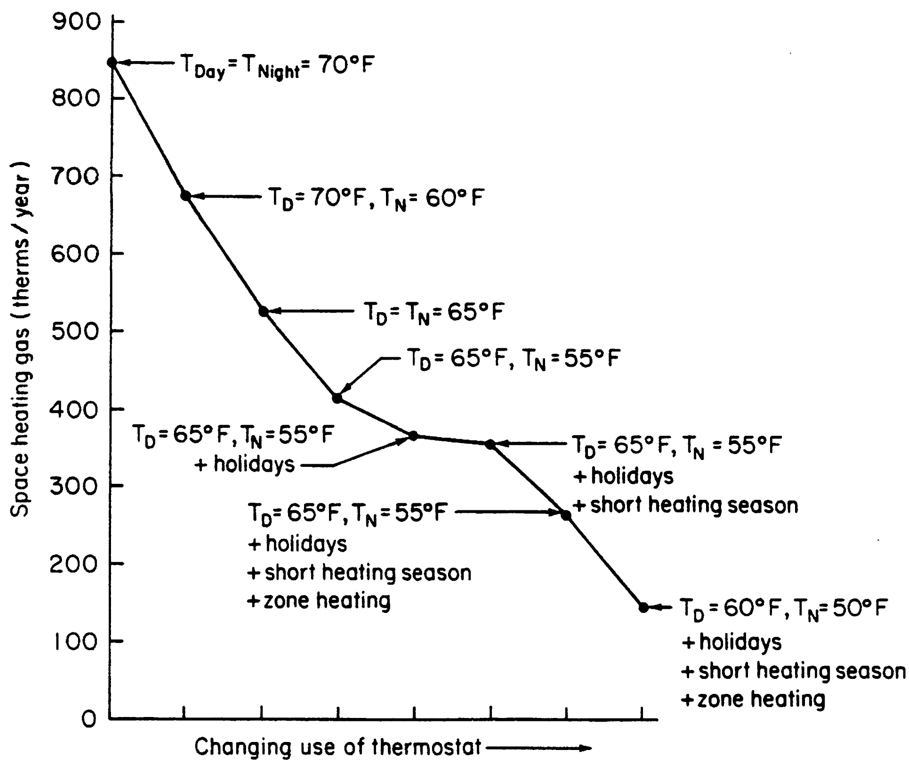

Figure 2-3. The effect of changes in occupant behavior on the amount of gas needed to heat a typical home in Fresno (1,300 sq. ft., R-11 insulation in the attic).

To test the effect of various behaviors on space heating energy requirements, we used a building energy modeling program (DOE-2) developed at Lawrence Berkeley Laboratory. Figure 2-3 shows the dramatic effect that reasonable changes in occupant behavior (listed above) can have on space heating requirements.[1] The last behavior may seem rather extreme, but a night-time temperature of 50°F roughly corresponds to turning the furnace off at night, an action that 27% of single-family homeowners in Northern California claim to do already.[2] An average daytime setting of 60°F may seem low, but many houses are unoccupied during the day and a daytime average of 60°F would roughly correspond to 70°F mornings and evenings with the furnace off during the day. The milder the climate, the more sensitive are space heating energy requirements to thermostat settings.

To bear out our contention that the amount of energy used for space heating varies widely in similar houses in the same climate, we present two histograms based on findings of the Energy Inspection Conservation Service in Berkeley (Figure 2-4).[3] About 25% of the houses had insulation and all were heated with gas. The distribution of energy use is far wider in the winter month than in the summer month. Clearly, behavioral differences in space heating are the main cause of this spread.

A study of winter gas consumption in 205 townhouses in Twin Rivers, New Jersey, found that only about half of the variation in use could be explained by "obvious" physical features.[4]

Our study is not concerned with behavior modification,* but with how a series of technical improvements can reduce the heating load of different houses. We consider a series of retrofits that slow down the heat loss from a house to near the point where free heat from internal sources, such as lights, appliances, and occupants, is supplied at a rate equaling the rate at which heat is lost from the house.

The major factor affecting the thermal performance of a house is the thermal conductivity of its roof, walls, windows, and floor. Several retrofits are aimed at lowering thermal conductivity by increasing R-values.† Insulation is added to both the ceiling and the walls; heat loss through windows is cut in half by the addition of storm windows. For homes with a crawl space, it would be possible to add floor insulation (unfortunately, our computer model, DOE-2, could not accommodate this measure, so we did not include it).

About one-third of the heat lost from buildings in California is due to cold air leaking in as a result of pressure differences between the inside and outside of the house (due to the wind and the indoor-outdoor temperature gradient).[5] We selected an infiltration rate of about one air change per hour (1 ach) as being typical; this can be reduced by four measures--sealing attic bypasses, caulking, weatherstripping, and installation of fireplace dampers.

The remaining target of attack is the heating system itself. Pilot lights are a wasteful ignition system. The efficiency of a furnace may be improved by tuning it or cleaning the filter. The efficiency of the whole heating system may be raised by sealing leaks in ducts and then

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*A possible exception is setback of the thermostat at night, but this action need not decrease comfort.

†R-value is the commonly used measure of thermal resistance in building materials. For example, six inches of fiberglass has a thermal resistance of R-19, i.e., R = 19 (hr ft^2 ^oF)/Btu.

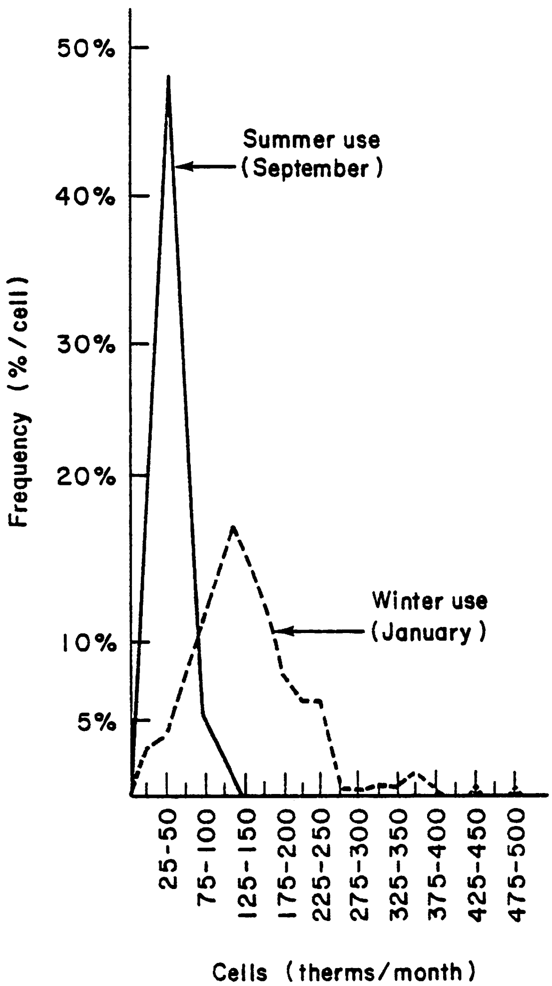

Figure 2-4. The summer use histogram shows that virtually all the houses used 25-75 therms per month for uses other than space heating, i.e., water heating, cooking, and clothes drying. The winter use histogram shows that about 15% of the houses continue to use less than 75 therms, suggesting that they used essentially no space heat during January.

insulating the ducts. The fuel used is tremendously important. Resistance heating uses twice as much primary energy as heating with natural gas.[6]

Gas Space Heating

As a base case, a single-family house with the following characteristics was modeled on DOE-2:

Floor area = 1,300 sq. ft.[7]

Windows are single-glazed, and total window area equals 15% of the floor area. The windows are distributed evenly around the four walls.

No insulation in ceiling or walls; floor is a concrete slab on grade.

Air infiltration rate = 1.07 ach.

Gas furnace, rated at 50,000 Btu per hour, with a system efficiency of 60%. (Gas furnaces have a nameplate efficiency of about 75%, but duct losses reduce the efficiency of the whole heating system.)

It is impossible to generalize about multifamily residences.* The number and orientation of exterior walls and, if in a high rise, the height of the building all have a large effect on internal temperature.

From a close examination of the average gas sold per month to both single-family and multifamily residences in Northern California, we believe that a multifamily residence uses about half as much gas as a single-family home for space heating (Figure 2-5).[8] Based on this, we estimate the energy savings in an apartment to be half that in a single-family home for same conservation measure. The margin of error will thus be greater in the estimates for multifamily residences. At the same time, the costs of retrofits for multifamily residences have been scaled from those for single-family homes, assuming that each dwelling unit has an average area of 850 sq. ft. and two exterior walls.

Hourly weather tapes for two climate zones were used--Fresno, as being typical of North California, and CTZ 9 (L.A. Basin), as being typical of Southern California. A San Francisco climate tape was used early in our study but later discarded because we found that the undefined seasons led DOE-2 to overestimate space heating requirements.

The extent of the savings in space heating due to a particular retrofit will depend on what other conservation measures have been adopted previously. For example, increasing the thermal resistance of a house decreases the furnace operating hours. The higher the thermostat is set, the more energy will be saved by insulation. The more insulation there is in the attic, the less energy will be saved by wall insulation. The energy savings of each conservation measure was calculated

*The term "multifamily residence" as used here means a single self-contained living unit within a larger building, e.g., apartment building or duplex.

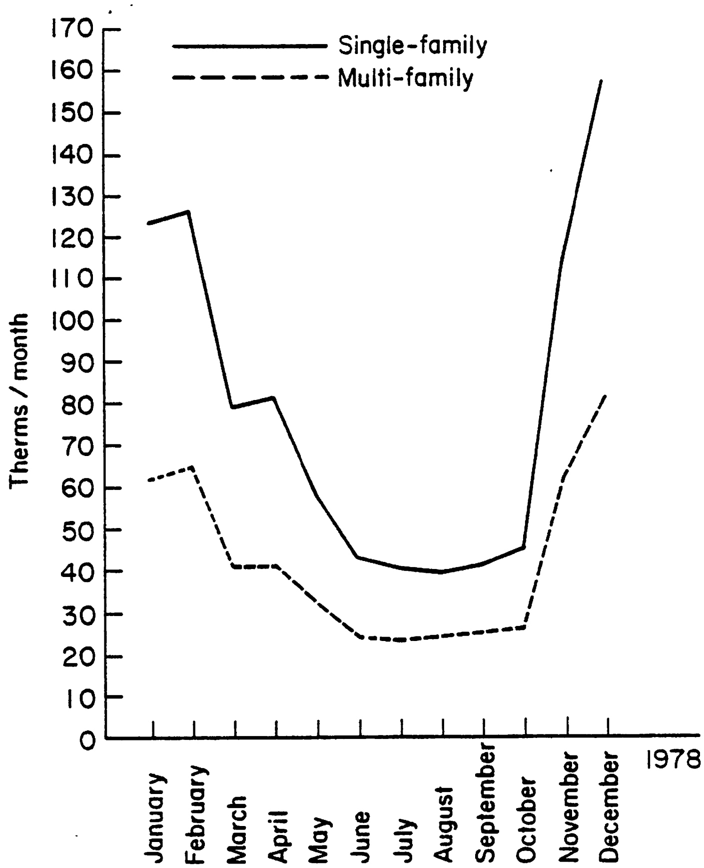

Figure 2-5. Monthly average gas use per residential customer in Northern California during 1978. (Source: Betsy Krieg, Conservation Planner, PG&E.)

on the assumption that all the measures are implemented in the order of increasing cost of conserved energy (or decreasing return on investment). We used the DOE-2 model to determine the optimal sequence of the measures.[9]

Measures 1, 19, 28: Turn the Pilot Light Off in Summer. The majority of single-family homes have a central furnace with one pilot light. Houses heated by wall or floor units usually have two or three units, each with one pilot light. Each apartment in California usually has its own furnace.

There is a wide range in the gas consumption rate of furnace pilot lights; a large furnace may have a pilot light burning 1,600 Btu per hour.[10] We assumed that the typical gas furnace pilot light consumes 80 therms per year in a single-family house and 60 therms per year in a multifamily residence. The gas consumed by the pilot light is entirely wasted, even in winter, when its contribution to heating the house is negligible. Turning off the pilot light in the summer is the simplest way of reducing pilot light energy consumption. The homeowner can do this or the utility will do it for free. In most areas of California the pilot light can be turned off for at least six months.

Measures 99, 101, 103: Retrofit Spark Ignition. In this case the entire pilot consumption is saved. In the foggy areas of San Francisco, where turning off a pilot light in summer is not a viable option, PG&E is subsidizing a program of retrofitting spark ignitions. The bulk-order cost to the utility is $170, whereas the price on the open market ranges from $180 to $200. A small amount of electricity is used in saving this gas, but only about 12 kWh annually.[11] The installation takes 1-2 hours and must be done by a licensed contractor.

Measures 100, 102, 104: Buy a New Furnace with Spark Ignition. Upon the demise of an old furnace, the homeowner may buy a new furnace with spark ignition. The extra cost of a furnace with spark ignition rather than a pilot light is about $70.[12] This is far cheaper than retrofitting.

Measures 2, 20, 29, 46: Automatic Night Setback of 10°F A tremendous amount of energy is wasted because many houses are kept at unnecessarily high temperatures while the occupants are in bed, at work, or away for the weekend. There are advantages to having the thermostat automatically controlled. A clock thermostat allows the occupants to go to sleep and wake up in a warm house, to breakfast in comfort, and to return to a warm house in the evening. Under these conditions, a thermostat setback is not a lifestyle change since no hardship is involved. A clock thermostat will pay for itself in a few years in any California climate.

Existing thermostats can be converted to automatic control or replaced by clock thermostats. The latter are generally more expensive and take longer to install. Prices for clock thermostats range from about $10 to $100. Most can be installed simply in a few minutes by the homeowner. We allowed a price of $65 for the device and added on $10 to cover the cost of installation. Sears sells an easily installed clock thermostat for $60.[13] It can be programmed to change temperature four times in 24 hours and can therefore be used for both day and night setback. In addition, it can control a central air conditioning system, raising air conditioning temperature both at night and when the house is unoccupied during the day. Most clock thermostats qualify for an energy conservation credit on income taxes (though we did not include it).

Measures 3, 21, 105, 47: Seal Attic Bypasses. A recent study of the winter energy use of houses in New Jersey revealed a previously unknown source of heat loss from buildings.[14] Attic heat loss was found to be far greater than expected. The researchers believe that the difference is due to heat loss paths that bypass the attic insulation (e.g., an open shaft around the furnace flue). Hence, the effective thermal resistance of the attic is not that obtained by summing up the nominal resistances in the attic. An attic with R-19 insulation may well have an effective thermal resistance lower than 19. The presence of bypass paths can be confirmed by comparing indoor, outdoor, and attic temperatures. If the attic insulation is doing its job, the attic temperature should be close to the outdoor temperature. Bypass paths can be quickly identified using an infrared scanner.

Identification and elimination of bypasses in a house is expected to take only two man-hours of labor and $30 or $40 of materials.[15] We estimate an average cost of $70. The homeowner can probably fix some of the bypasses himself after carefully inspecting the attic.

Because savings from this measure are so house-specific, it was difficult to model this heat-loss mechanism. We assumed that, for a typical house, sealing attic bypasses would reduce the infiltration rate from 1.07 to 0.87 air changes per hour.

Measures 4, 22, 30, 48: Add R-19 Insulation to the Attic. A contractor can install R-19 insulation in less than a day in most homes. Besides cutting heat loss through the attic, the insulation raises the radiant temperature of the ceiling. The living space below then feels more comfortable. During the summer the insulation lowers cooling loads by reducing heat flow from outside. In some climates, though probably in only a small part of California, insulation will save more cooling energy than heating energy.

Contractors typically charge 36 cents per sq. ft. to install R-19 in a ceiling, i.e., $470 for a 1,300 sq. ft. house.[16] Six-inch-thick fiberglass retails at 25 cents per sq. ft., so the "do-it-yourself" homeowner need only pay $325.[17] Blow-in insulation costs less, only 30 cents per sq. ft.[18]

Measures 5, 23, 106, 49: Add R-11 Insulation to the Walls. Adding R-11 insulation to the walls requires professional labor and is expensive. Nevertheless, it will save both heating and cooling energy, as well as make the house more comfortable in both winter and summer. (Insulation raises the radiant temperature of the walls during winter.) The cost of retrofitting wall insulation is highly variable. Factors influencing it are the type of insulation (foam or cellulose), the accessibility of the wall cavities, and the profit margin of the contractor; 75 cents per sq. ft. seems to be typical.[19] Therefore, insulating the walls of a 1,300 sq. ft. house would cost $900.

Measures 6, 24, 31, 50: Reduce Infiltration by Caulking Leaks. Most homes have literally dozens of small leaks that can be filled with a caulking gun. Each house has its own peculiar leaks, which can easily be found by using smokesticks as tracers. But certain areas are common places for leaks: around the sill plate (the joint between wall and floor), window frames, exterior door frames, power outlets, plumbing penetrations, wall corners and broken windows.

Eliminating leaks will increase the comfort of the occupants. Reducing air infiltration will also have a marked effect on the cooling load of a house in a hot, humid climate because the latent heat load will be reduced. The effect will be smaller in a dry climate.

There is concern that reducing air infiltration rates leads to health risks for the occupants. Indoor pollutants such as radon, formaldehyde, and nitrogen oxides may reach higher concentrations in a "tight" house. However, retrofits will not make a house as tight as newer houses that have been designed for low infiltration, so the likelihood of significant health risk from reducing infiltration in an old house is small.

In our building energy model, we assumed that caulking would reduce the infiltration rate by 0.2 ach. This conservation measure is very labor-intensive; the home handyman can do the job for a fraction of the contractor cost. We assumed that the best-quality caulking (silicone based) would be used. This would last 10 to 20 years and costs $4 per 25 lineal feet.[20] We allowed a materials cost of $60 per house. It is difficult to estimate the time this retrofit would take since few old houses have been thoroughly caulked. Experience in Denver indicates that the process takes about one man-day of labor, including sealing joints between wall gypsum board and the floor and pressurizing the house to check the effectiveness of the sealing.[21] At $20 an hour, we allowed a labor cost of $160, giving a total contractor cost of $220.

Measures 7, 25, 32, 51: Add Storm Windows. Single-pane windows have a thermal resistance of R-1.1. This means heat is lost about three times faster than through an uninsulated wall and about 12 times faster than through an insulated wall. The difference is probably even greater because of infiltration around the frames and sashes.

In a new house, in most climates, it is cost-effective to use double-glazed instead of single-glazed windows, more than doubling the thermal resistance (the dead air space between the panes is significant).[22] The extra cost is $2-$3 more per sq. ft.[23] A second pane will somewhat reduce free heat from the sun, but this is more than compensated for by savings in heat loss.

A well-sealed storm window has a weatherstripping effect. However, if the frame of a storm window is sealed tightly and the original window is not, condensation can be a problem. Storm windows vary in quality and price. Cheap sheets of translucent flexible plastic that fit tightly on the inside of windows are available. We assumed a cost of $2.50 per sq. ft. and $80 for measurement and fitting.[24]

Measures 8, 26, 52: Add Additional R-19 Insulation to the Attic. The energy savings from adding a layer of R-19 insulation to an attic depend on how much insulation is there already. Adding R-19 to existing R-11 (giving R-30) will save a little more energy than adding it to existing R-19 (giving R-38). We took the lower saving. The cost of this measure is much lower if it is done when the first layer of insulation is installed. We allowed a cost of $470, the same as for installing a first layer of R-19 insulation. There may be a space problem with this retrofit; some attics may not be able to accommodate such a thickness of insulation.

Measures 9, 27, 33, 53: Weatherstrip Around Doors and Windows. Weather-stripping creates a tight seal around the opening edges of doors and windows, and thereby reduces infiltration. Like caulking, it is a labor-intensive measure. Our model shows weatherstripping reduces infiltration by 0.2 ach. However, it must be remembered that this estimate is an average. In a home where an exterior door has a half-inch gap below it, sealing this "scandal" is a very cost-effective retrofit. Also, one cannot quantify the benefit of the increased comfort due to the reduction of drafts.

Costs for weatherstripping materials vary widely. Weatherstripping for one door can cost as little as $2 or as much as $20, but $5 is enough for a good job.[25] We allowed a materials cost of $40, assuming that only the worst leaks will be weatherstripped. Contractor costs vary even more widely, from $15 to $120 for one door.[26] We allowed a labor cost of one man-day at $20 an hour, giving $160. Thus, our total contractor weatherstripping cost is $200.

California homes are notorious for their settling and shifting, which results in sagging windows and doors, especially in older houses. As a result, we assumed that the weatherstripping would remain effective only five years.

Measures 11, 13, 14: Install Fireplace Damper. In terms of infiltration, an open flue is similar to a hole in the roof. A top-sealing damper that can easily be operated from inside the house is available for $40.[27] Allowing further costs for a cable extension for tall chimneys and one hour labor for installation, we estimate this retrofit will cost $70. (Alternatively, one can make a wooden hatch for the chimney for just a few dollars.)

The energy savings will depend on the extent of heating in the home and how often the fireplace is used. Sherman and Rosenfeld have made a theoretical estimate, based on a Northern California climate, of 20 therms per year.[28] This corresponds to a very high user. Average Northern California savings would probably be lower, perhaps half.

Measures 15, 17: Seal Ducts. Although most ducts in forced-air heating systems are insulated, they usually leak at the joints. This measure involves stripping off the insulation, taping the joints, and replacing the insulation. We assumed an average improvement of 10% in the efficiency of the heating system.

Costs are extremely variable among houses. We assumed an average duct length of 150 feet, and that one hour of labor was required to seal 10 feet of duct. The old insulation can generally be reused and enough duct tape would cost about $10. A big problem is accessibility; in some homes as little as three feet can be sealed in an hour, while in others as much as 20 feet per hour can be done. Thus, costs could range from $150 to $1,000.[29] Duct tape lasts at least 10 years, but we amortized it over five because of uncertain deterioration in performance.

Sealing ducts is an efficiency improvement measure; hence the energy savings are proportional to the energy used at the time of application. If duct sealing is done as the first measure in the space heating conservation sequence, it could save well over 100 therms per year. However, because of its relatively high cost ($300 is typical), we assume this measure would be done after several cheaper measures. In this case, the savings would be small, about 16 therms.

Electric Space Heating

Most resistance-heated homes in California have some insulation. We selected as a typical house, one with R-11 in the ceiling and R-7 in the walls.[30] Because so few homes are electrically heated, we did not feel division into two climatic regions was warranted. The typical savings are based on a Fresno climate.

Figure 2-6 shows the average amount of electricity sold per month to both single-family and multifamily residences in Northern California.[31] We estimated the amount used for heating in each case by "scooping off the winter peak" and adjusting for the fraction of electrically heated homes.[32] This approach is complicated by the electricity used by lights; more electricity is used for lighting in winter months than in summer months. A further complication is the electricity used by furnace fans in homes with forced-air gas heating. We estimate that 70% of the gas-heated single-family and 40% of the gas-heated multifamily residences have forced-air systems.[33] Assuming an average furnace fan consumption of 250 and 120 kWh per year in single-family and multifamily residences, respectively,[34] we subtracted out that part of the winter electrical peak due to furnace fans.

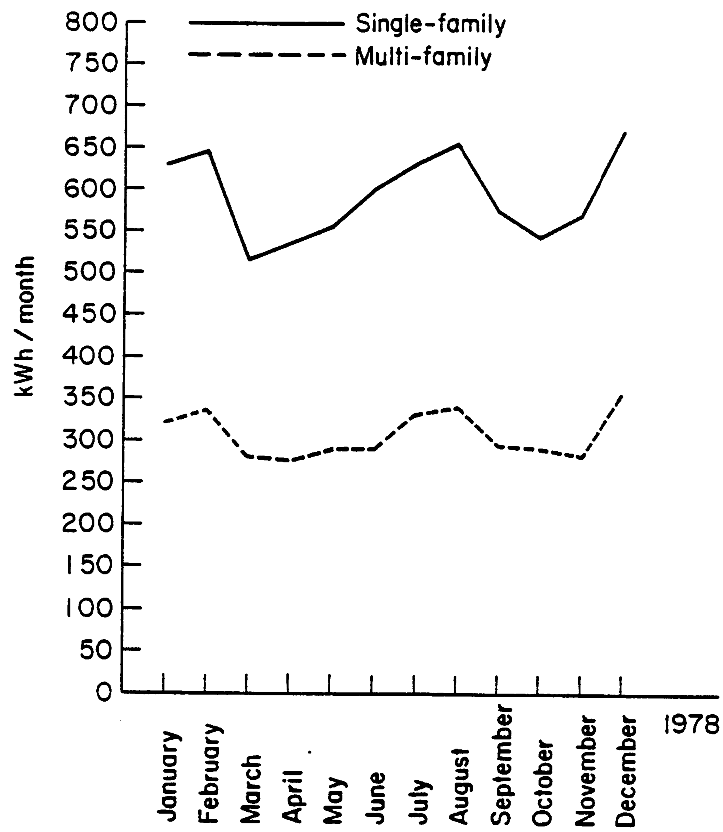

Figure 2-6. Monthly average electricity use per residential customer in Northern California during 1978.

We concluded that an electrically heated multifamily residence uses only about 30% of the electricity that single-family homes do for heating. We suspect most electrically heated apartments are newer, and in large high-rise buildings. Consequently, they would be somewhat smaller than average, better insulated, and many would have three internal walls, so much of the heat will be "free."

The electricity savings due to retrofits in resistance-heated single-family homes were estimated from the DOE-2 model in the same way as for gas-heated homes. The same typical house used in our analysis of gas space heating was used to analyze electric space heating, except the efficiency of an electric heating system is 100%. The same series of retrofits as for gas-heated homes applies, except, of course, those related to the furnace. For electrically heated multifamily residences, we considered only one measure, measure 10, namely the reduction of infiltration and the addition of storm windows.

Measure 18: Divert Electric Clothes Dryer Vent. If the vent from an electric clothes dryer is diverted to a living space, essentially all the exhaust heat, both latent and sensible, can be used for space heating. Since many dryers are in areas distant from living areas, extra exhaust ducting will no doubt be needed. Homeowners can make diverters themselves or buy them. A typical diverter retails for $9.[35] With a $20 allowance for flexible plastic ducting and an hour of labor, the total cost would be $50.

Since the high humidity of the exhausted air may be excessive during milder winter months, we assumed that the diverter would be used only during the coldest two months each year. Under these conditions, a diverter could provide about 170 kWh per year of useful heat.

STATEWIDE SAVINGS

Introduction

In 1978 there were 8.85 million houses in California. Of these, 62% were single-family homes, 34% were multifamily residences, and 4% were mobile homes.[36] The saturations of gas and electric heating are shown in Table 2-3.

In order to estimate energy savings, one must first know how much is used. This is especially difficult for space heating because there is so much variation in the physical characteristics of buildings and in occupant behavior.

We have approached the problem from two angles. First, we subtracted our best estimates of the quantities of gas and electricity used for other end uses in the residential sector from the total amount of gas (570 trillion Btu) and the total amount of electricity (49.1 TWh) used by the residential sector during 1978.[37] Assuming that the remainder was used for space heating, we estimate that 283 trillion Btu of gas (50% of the total) and 3.1 TWh of electricity (6% of the total) was used for heating homes in 1978.

Table 2-3. Saturations for gas and electric space heating by housing type.[a]

	Gas Heating	Electric Heating
Single family	88%	7%
Multifamily	71	25
Mobile homes	64	10

[a]Estimated by weighting saturations reported by the major California utilities (CEC, 1978c, p.III-43).

Second, we used utility billing data. From Pacific Gas and Electric Company (PG&E), Southern California Gas Company (SCG), Southern California Edison (SCE), and San Diego Gas and Electric Company (SDG&E) we obtained the average monthly gas and electricity sales per home for several recent years.[38] Much information can be gleaned from an examination of graphs of this data. Winter peaks in both gas and electricity are due to space heating, while summer peaks in gas are due to swimming pool heating, and summer peaks in electricity are due to air conditioning. But the data cannot be simply interpreted. For example, in the same month, San Francisco houses may be heating, while Walnut Creek houses may be air conditioning. Swimming pool filters consume a considerable amount of electricity (we estimate 1 to 2% of the total), and so air conditioners are not the only cause of the summer peak.[39] Some appliances use more energy in winter; there is definitely more lighting during long winter evenings.

Figure 2-7 shows average monthly gas use in single-family homes in Northern and Southern California.[40] The two curves are surprisingly similar. The Southern California curve shows a higher use in summer due to the larger number of heated swimming pools. Southern California also has a slightly higher saturation of gas ranges and gas clothes dryers than does Northern California[41], further raising the base consumption. There is no way to correct the data for the few houses that have gas connections but use electric heating. Taking all these factors into account, we conclude that houses in North California use, on the average, only 30% more gas for space heating than do houses in Southern California.[42] On the basis of the degree-day difference in the severity of the winter, one would expect a 60% difference. In 1978, the average gas-heated single-family home in California used about 460 therms for space heating; the average electrically heated single-family home used

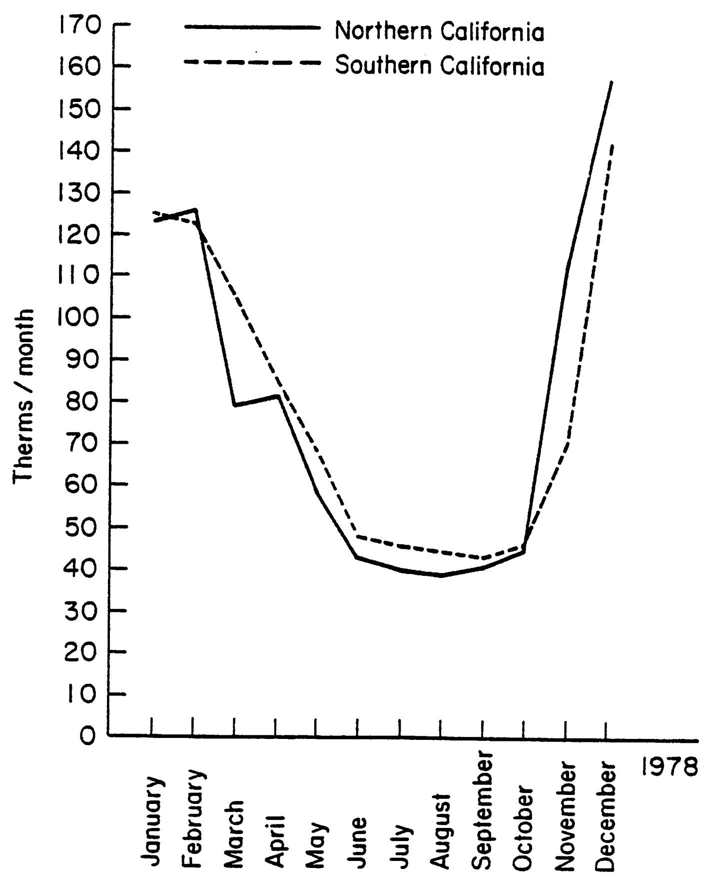

Figure 2-7. Monthly average gas use in single-family homes in Northern and Southern California during 1978.

3,500 kWh for space heating. The averages for multifamily residences were 240 therms and 1,000 kWh.[43]

Before the DOE-2 model can accurately predict savings from a given conservation measure, the heating loads must be calibrated with actual use. In a first attempt do this, we grouped the 15 National Oceanographic and Atmospheric Administration (NOAA) climate zones[44] into three climate regions. These were represented by weather tapes for San Francisco, Fresno, and Los Angeles. Table 2-4 shows DOE-2's predicted energy use for the standard house in each of the climates.[45]

A comparison of the predicted consumptions in Table 2-4 with actual use (Figures 2-5, 2-6, and 2-7) gives some indication of how the model

Table 2-4. Gas consumption (therms/year) of furnaces in typical single-family houses kept at 70°F in three climate zones, as predicted by the DOE-2 model.

Ceiling Insulation	Wall Insulation	San Francisco	Fresno	Los Angeles
R-0	R-0	1520	1160	750
R-11	R-0	1130	850	380
R-19	R-11	670	520	340

is to be reconciled with reality. First, close attention to variation in climate is not warranted. Second, people in Northern California probably set their thermostats lower and live in better-insulated houses than people in Southern California.[46] Third, the 1978 winter was milder than usual.

Two climate zones were finally chosen. The Southern Region comprises the Los Angeles area, San Diego, and the desert inland at the same latitude. The Northern Region comprises the rest of the state, i.e., the populated centers of inland California and the coast as far south as Santa Maria. All population centers in the Northern Region have more than 2,000 heating degree-days; all in the Southern Region have fewer.*

Because of our suspicion that thermostat settings are generally lower in Northern California, we believe that degree-days to base 60°F are a better indication of heating load in this region than a 65°F base.† Degree-days to both base temperatures for different cities in Northern California are shown in Table 2-5. Using base 60°F degree-days, Fresno appears colder than the Bay Area. Because few people in California live in places colder than those appearing in Table 2-5, we feel that Fresno is probably representative of the Northern Region.

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*Heating degree days are a measure of the severity of the winter. They are usually based on 65°F. On a day when the average temperature is 60°F, there are 5 degree-days.

† Free heat raises indoor temperatures roughly 5°F. Thus, degree-days to base 65°F are a good indication of heating load if the house is maintained at 70°F. However, if a house is kept at 65°F, degree-days to base 60°F are appropriate.

Table 2-5. Heating degree-days for population centers in the Northern Region.

	Base 65°F	Base 60°F
Fresno	2,650	1,724
Oakland	2,909	1,570
Sacramento	2,843	1,837
San Francisco	3,068	1,668

The winter of 1977-78 was exceptionally mild; there were about 15% fewer heating degree-days than average during that winter. The average for Fresno is 2,650 degree-days. The Fresno climate tape is for a TRY (Test Reference Year) year and has 2,778 degree-days. We scaled the 1978 data to give results for an average year, that is, 2,650 degree-days.

The NOAA climate tape used to represent the Southern Region was CTZ 9, the Los Angeles Basin. This climate tape had 1,878 degree days; since this is high for Southern California, we selected 1,600 degree-days to represent the Southern Region in an average year.

To reconcile the model with the average energy actually used for space heating, a matrix of "typical houses" was established. The dimensions of the matrix were climate zone, day and night thermostat settings, insulation levels in both attic and walls, and whether the pilot light burned all year or not. In the following pages, these dimensions are discussed instead of the individual conservation measures.

Gas Space Heating

Table 2-6 shows the number of gas-heated homes in the two climate regions. Tables 2-7 and 2-8 show how much gas was used for space heating. These estimates were made using the assumptions discussed in the preceding pages.

Table 2-6. Number of homes heated with gas in California in 1978. (These figures do not include the approximately 254,000 gas-heated mobile homes; they are difficult to retrofit and are unlikely candidates for long-term investments.)

	Single Family	Multi-family
North	2,490,000	955,000
South	2,480,000	1,240,000

Assuming that the amount of gas used for space heating in mobile homes is between that used in single-family and multifamily residences, we deduce that in 1978 mobile homes used about 7 trillion Btu for space heating. Table 2-9 shows the total regional use by housing type. Because the winter of 1978 was exceptionally mild, space heating demand in 1978 was less than average. Therefore, we calculated energy savings based on demand in an average year.

Pilot Lights. In a 1979 survey of single-family homeowners, 50% claimed they turned off their pilot lights in summer.[47] The real percentage in 1978 was probably somewhat less than this, because the survey did not verify respondents' claims and also because homeowners are more likely to turn off the pilot (because they know how). We assume that in 1978 in Northern California 40% of the pilot lights were turned off for six months. In view of the unexpectedly high amount of gas used for space heating in Southern California, we assume that fewer pilot lights are turned off in summer in that region.

Gas furnaces with a spark ignition have not been on the market long and are more expensive than conventional furnaces. We assume that 10% of gas furnaces in 1978 had spark ignitions (this estimate includes those that have retrofits).

Estimates for the lifetimes of gas furnaces vary. We used 20 years for a furnace in a single-family home and 18 years for one in a multifamily residence.[48]

We estimate that pilot lights consume about 40 TBtu annually, or 12% of the total gas used for space heating. Turning the pilot off in summer is obviously the cheapest way to reduce the gas wasted by pilot

Table 2-7. Average annual household consumption of gas (therms per year) for space heating, by climate and housing type. (Actual consumption for the milder 1978 year is in parentheses.)

	Single Family	Multi-family
North	595 (513)	310 (270)
South	443 (386)	237 (209)

Table 2-8. Average annual regional consumption of gas (TBtu per year) for space heating, by climate and housing type. (Actual consumption for the milder 1978 year is in parentheses.)

	Single Family	Multi-family
North	148 (128)	30 (26)
South	110 (96)	29 (26)

Table 2-9. Average annual gas consumption (in TBtu) for space heating in the residential sector of California. (Actual consumption for the milder 1978 year is in parentheses.)

Single-family	258 (224)
Multifamily	59 (52)
Mobile homes	8 (7)
Total	325 (283)
Fraction of total gas residential use:	53% (50%)

Table 2-10. Assumed consumer practices with respect to pilot lights, 1978 and future.

	North	South
1978:		
Turned off pilot in summer	40%	20%
Had spark ignition	10	10
Left pilot on all year	50	70
	100	100
Future:		
Will turn off pilot in summer	10	30
Will retrofit spark ignition	20	20
Will buy new furnaces with spark ignition	20	20
Already turn off pilot	40	20
Already have spark ignition	10	10
	100	100

lights, but not everyone can or will do it. It is not likely to be done in San Francisco, where the fog in summer makes heating desirable throughout the year. Table 2-10 summarizes our assumptions.

Thermostat Settings. To estimate savings from thermostat setback (as well as from subsequent energy-conserving measures), it is necessary to have some idea about average thermostat settings in both the daytime and night-time.

In a 1979 survey of single-family homeowners, 41% of the respondents claimed they set their thermostats at 65°F or lower in winter in the daytime; 42% claimed their thermostats were set at 55°F or lower at night; and another 27% (not additive) claimed they turned the furnace off at night. Only 9% claimed to have automatic thermostats.[49]

We have no information about thermostat settings in Southern California except for the indirect evidence from the utility data already discussed (pp. 41-43). We suspect that thermostat settings are perhaps 5F higher in the south than in the north.

Table 2-11. Assumed thermostat settings in different California climates.

Day/Night (°F)	North	South
70/70	10%	40%
70/60	25	40
65/65	25	20
65/55	40	0

Table 2-11 shows our assumptions for thermostat settings. These settings may appear low, but we chose to model constant indoor winter temperatures rather than reflect real-life behaviors, e.g., turning off the heat while away over weekends.

Energy savings from a setback of 70°F to 60°F are greater than those from a setback of 65°F to 55°F. Therefore, energy savings due to night setback are weighted averages of savings from the two setbacks at insulation levels discussed below. For example, the average saving of 123 therms from a 10°F night setback in the Northern Region is a weighted average of savings that vary from 243 therms for a 70°-60° setback in an entirely uninsulated house to 56 therms for a 65°-55° setback in a house with R-19 in the attic and R-11 in the walls.

Insulation. To determine the savings from installing insulation and the percentage of stock eligible for such retrofitting, one must know how many houses in the state are insulated and to what degree. Table 2-12 illustrates differences in estimates of the extent of insulation in California single-family homes. The only number known with any degree of certainty is the 10% of the 1978 housing stock built since 1975 that should have R-19 and R-11.

We have made the same assumptions about insulation in multifamily residences. Apartments that are not at the top of a building will have greater thermal resistance than the insulation in the roof. Thus, in a high-rise building with R-11 in the roof, all apartments in the building will have the equivalent of at least R-11 in their ceilings.

Although we estimate that 30% of single-family homes have no attic insulation, we took 20% as the eligible fraction.[53] We have no reason to believe that there is more insulation in the North; growth has been much faster in the South and houses built since 1975 are well insulated, but

Table 2-12. Estimates of insulation in gas-heated single-family homes in California.

Ceiling/Wall Insulation	PG&E[50] (1978)	CEC[51] (1975)	Goldstein[52] (1976)	CPS[a] (1978)
R-19/R-11	20%	40%	10%	20%
R-11/R-0	55	25	50	50
R-0/R-0	25	35	40	30

[a]Our study.

presumably the motivation for retrofit is much stronger in the colder North. Again, estimates of energy savings are based on weighted averages. Those houses with the thermostat at 70°F/60°F (day/night) will save more gas from ceiling insulation than those with the thermostat at 65°F/55°F.

We estimate that 10% of the multifamily residences are eligible. Only about 50% have ceilings adjacent to the roof; of these, most will already have ceiling insulation and some will be uninsulatable.[54] Our estimates of energy savings are thus conservative since some of this insulation will benefit apartments on lower floors.

To calculate the savings from adding another layer of R-19 insulation in single-family homes, we assume that all insulatable homes (90% of the stock) already have R-19. We then assume that additional insulation would not fit in 10% of the homes, leaving roughly 80% of all homes eligible for a second layer of R-19.

We estimate that 80% of California homes have no insulation in the walls and can be retrofitted with R-11. Estimated energy savings are again weighted averages.

Other Measures. Nonmasonry fireplaces already have workable dampers fitted in their flues. Nationally, more than half of single-family homes have fireplaces.[55] Allowing for bricked-up and other unused fireplaces, we estimated that 30% of single-family homes might be eligible for this measure. Clearly, there is great uncertainty both in the energy savings and in the number of homes in which the measure might be adopted.

We made the following assumptions in estimating the fraction of gas-heated, single-family houses eligible for the duct sealing measure:

70% have forced-air systems

80% of these have untaped ducts

60% of the ducts are reasonably accessible

Electric Space Heating

Energy savings for electric space heating were estimated in the same way as for gas space heating. Although the heating reduction due to each retrofit was calculated for both climate regions, in the end we did not feel such a breakdown was warranted and, consequently, weighted the North and South savings.

Table 2-13 shows the number of electrically heated homes in the two climate regions. Table 2-14 shows the average annual household use of electricity for space heating. Because the records of Southern California Edison (SCE) do not distinguish between single-family and multifamily accounts for electricity, while those of PG&E (in the North) do, we could not use utility records to compare electricity use for space heating in single-family homes in the two regions. "Scooping the winter peak" to estimate electricity used for space heating (as was done for natural gas) gives misleading information. Electric appliances, such as additional lights and gas furnace fans, operate more often in the winter, thus distorting the winter heating peak. Because air conditioning and swimming pool filter pumps operate during the summer, we do not have a summer base consumption level. Lacking data to the contrary, we assume the North-South ratio for electric space heating was the same as for natural gas space heating, that is, 30% more in the South (Table 2-15).

Table 2-13. Number of electrically heated homes in California (1978) by climate and housing type.

	Single Family	Multi-family
North	239,000	255,000
South	80,000	425,000

Table 2-14. Average annual household use of electricity (kWh/year) for space heating in California by climate and and housing type. (Actual consumption for the milder 1978 year is in parentheses.)

	Single Family	Multi-family
North	4330 (3680)	1340 (1140)
South	3240 (2750)	1060 (900)

Table 2-15. Annual regional use of electricity (TWh/year) for residential space heating in California by climate and housing type.[a] (Actual consumption for the milder 1978 year is in parentheses.)

	Single Family	Multi-family
North	1.03 (0.88)	0.35 (0.29)
South	0.27 (0.22)	0.44 (0.38)

[a] Assuming that mobile homes use an amount of electricity for space heating between that used by single-family and multifamily residences, we deduce that in 1978 approximately 40,000 mobile homes used about 0.1 TWh for space heating.

The estimates in Tables 2-14 and 2-15 apply only to those houses that have all-electric space heating. From our examination of monthly utility data for electricity, we estimate that a further 0.9 TWh per year is used by furnace fans and 0.5 TWh by portable resistance heaters in gas-heated homes. This brings the percentage of residential electricity used for space heating to 7% (Table 2-16).

Table 2-16. Total annual use of electricity (TWh/year) for space heating in California residences. (Actual use during the milder 1978 year is in parentheses.)

Single family	1.3 (1.1)
Multifamily	0.8 (0.7)
Mobile homes	0.1 (0.1)
Furnace fans	0.9 (0.8)
Small portable resistance heaters	0.5 (0.4)
Total	3.6 (3.1)
Fraction of total residential elect.	7% (6%)

Thermostat Settings. We assume that thermostat settings in electrically heated single-family homes are the same as for gas-heated homes. Since electrically heated homes are generally better insulated, their energy use is lower than comparable gas-heated homes.

Insulation. For electrically heated houses, Goldstein found that it had been common practice for many years to insulate to R-11 in the ceiling and R-7 in the walls. Again, we assume that all houses built since 1975 have R-19 in the ceiling and R-11 in the walls. Presumably, a small percentage of electrically heated homes have no insulation. We assumed that this is only true in the Southern Region. Table 2-17 shows our assumptions about the extent of insulation in electrically heated homes in California.

Houses With Electric Clothes Dryers. There are 3.1 million electric clothes dryers in California. Because we assume that 70% of these can switch to gas (see p.112), only 30% of the original stock of electric dryers can be used to supplement space heating.

Table 2-17. Assumed insulation levels in electrically heated homes.

Ceiling/Wall Insulation	North	South
R-19/R-11	30%	20%
R-11/R-7	70	70
None/none	0	10

REFERENCES AND NOTES

1. These DOE-2 runs were done by Brian O'Regan.

2. Result of PACE V survey in January, 1979. Information from Daniel J. Fitzgerald, PG&E.

3. Meier, 1980.

4. R.C. Sonderegger, in Socolow, 1978, Chapter 9.

5. Routes of infiltration are extremely building specific. Information about infiltration given by David Grimsrud, Energy-Efficient Buildings Program, Lawrence Berkeley Laboratory.

6. Heat pumps can be twice as efficient as resistance heating in a California climate.

7. We believe this is close to the average single-family house size in California.

8. Data supplied by Betsy Krieg, Conservation Planner, PG&E.

9. DOE-2 runs modeling the effects of retrofits were done by Leonard Wall.

10. Arthur D. Little, Inc. 1977a.

11. Ibid.

12. Sears, 1979.

13. Ibid.

14. Dutt and Beyea, 1979.

15. Estimate by G. Dutt, August, 1979.

16. Information from Conservation Division, PG&E.

17. See note 12.

18. See note 16.

19. Local insulation contractors quoted prices for wall insulation ranging from 50 cents to $1 per square foot. The R-value obtained from retrofitting wall insulation is uncertain; it is difficult to ensure the cavities are completely filled.

20. Sears, 1979.

21. See note 5.

22. Series V results of the Residential Building Energy Performance Standards (BEPS) project conducted by the Energy-Efficient Buildings Program, Lawrence Berkeley Laboratory, 1979.

23. Information about windows from Stephen Selkowitz, Windows and Lighting Group, Energy-Efficient Buildings Program, Lawrence Berkeley Laboratory. August, 1979.

24. Based on prices in Sears and Montgomery Wards catalogs, 1979.

25. Information from local building materials outlets.

26. Information from local weatherstripping contractors.

27. See note 12.

28. Max Sherman and A.H. Rosenfeld, unpublished technical note, 1979.

29. Information on sealing ducts from David Krinkel and Jim Adams, Energy-Efficient Buildings Program, Lawrence Berkeley Laboratory, June 1980.

30. It was common building practice for many years to insulate electrically heated homes to this level.

31. See note 8.

32. About 10% of single-family homes and 20% of multifamily residences in the PG&E service area are electrically heated. (CEC, 1978c, p.III-43).

33. The PG&E Residential Appliance Saturation Study found that 55% of single-family homes and 30% of multifamily residences had central forced-air heating. These percentages correspond to 65% and 38%, respectively, for gas-heated homes. Since there are more older, gas-heated homes with gravity-feed systems in the PG&E service area than elsewhere, we raised the percentages (65 and 38) to reflect statewide conditions. The CEC assumes 80% and 50%, respectively. (CEC, 1979c, p.5-58)

34. Based on the assumptions that a single-family home has a 75,000 Btu/hour furnace and a 400 W (input) furnace fan (see also CEC, 1979c, p.5-62).

35. Consumer Reports, January 1979.

36. Population Research Unit, 1979.

37. CEC, 1978d.

38. Comparisons must be made carefully since some utilities record this data for all homes, some for individually metered homes, and some for single-family and multifamily residences separately. Cooperation from the utilities was much appreciated throughout this study.

39. One reference gives an estimate of 3,440 kWh per year as the average electricity used per pool for running filters and sweeps (CEC, 1979c, p.5-119). With 410,000 residential pools, this gives a total of 1.4 TWh in 1978.

40. Information from Pacific Gas And Electric and Southern California Gas Company.

41. CEC, 1978c, p.III-43.

42. If there are many swimming pools in the Los Angeles area heated with gas through the winter, there would be considerable error in this interpretation of the data.

43. Estimates based on data in Figures 2-5, 2-6, and 2-7.

44. Crow and Holladay, 1976.

45. These DOE-2 runs were done by Leonard Wall.

46. A check of census data did not reveal any difference in average house size between Los Angeles and the San Francisco Bay Area.

47. Haug Associates, PACE V, 1979.

48. CEC, 1978c, Table III-3.

49. See note 47.

50. PG&E has conducted a series of surveys of owner-occupied single-family homes (Haug Associates, 1978). Owner-occupied single-family homes would be the houses most likely to have been retrofitted with insulation. Therefore, the percentages of those with insulation is probably a little high. In the survey it was found that, of the uninsulated houses, seven out of 10 were insulatable in the ceiling, i.e., had a suitable attic or crawl space.

51. In 1975 the CEC estimated there were two million single-family homes in California without ceiling insulation and 1.3 million with inadequate ceiling insulation, presumably R-11 (CEC, Biennial Report, 1977, p.54). This translates to 35% and 25%, respectively, of the 1978 housing stock. Clearly, a proportion of these houses have been retrofitted since 1975. However, the inferred figure of 40% with adequate insulation (presumably R-19 and R-11) seems high.

52. In 1976, Goldstein estimated the extent of insulation in California houses based on HUD "Minimum Property Standards" and information on housing starts. (Private communication from David Goldstein, Lawrence Berkeley Laboratory, August 1979.)

53. Only seven out of 10 uninsulated houses inspected in the PG&E survey could be insulated. (Haug Associates, 1978).

54. In 1978, 30% of multifamily units were in duplexes, triplexes, and four-plexes. (Population Research Unit, 1979). Most of these have ceilings adjacent to the roof.

55. Information about fireplaces from Rick Diamond, Energy-Efficient Buildings Program, Lawrence Berkeley Laboratory, June, 1980.

THE SUPPLY CURVES

Gas Water Heating

The supply curve for gas water heating (Figure 2-8) begins with two no-cost measures, gradually climbs for two more measures, and then rises steeply for the final measure. The cumulative savings after the last measure is about 37% of the estimated 205 TBtu presently used by gas water heaters.

The most remarkable aspect of the supply curve for gas water heating is the low cost of conservation available with existing water heaters. About one-third of all the energy used for water heating could be saved at costs below what consumers now pay for lifeline allocations. The final measure, the flue damper retrofit, is not yet on the residential market, but adds about $40 to the cost of a new water heater.

The chief obstacle to even greater savings with the thermostat set-back is the automatic dishwasher. Virtually all dishwashers require 140°F washing water. As a result, the water heater must heat and maintain 40 gallons of 140°F water, even though the dishwasher will only need a fraction of it. It would be better to provide a resistance heater in the dishwasher to boost the water to its required temperature. This is one case where the lower overall efficiency of resistance heating is offset by its high precision of application.

Dishwashers are not presently covered by any CEC energy efficiency standards, but there appears to be a good justification for their inclusion. A standard might require every dishwasher to have a wash-water booster (at least one such model exists; other models have a booster for the rinse cycle). Then, however, dishwashers would become even greater sources of power demand.

At the same time, research should be directed to development of lower-temperature detergents for dishwashers. Dishwasher detergents have remained virtually unchanged for 20 years (whereas the mechanical actions of dishwashers have improved). One solution, probably

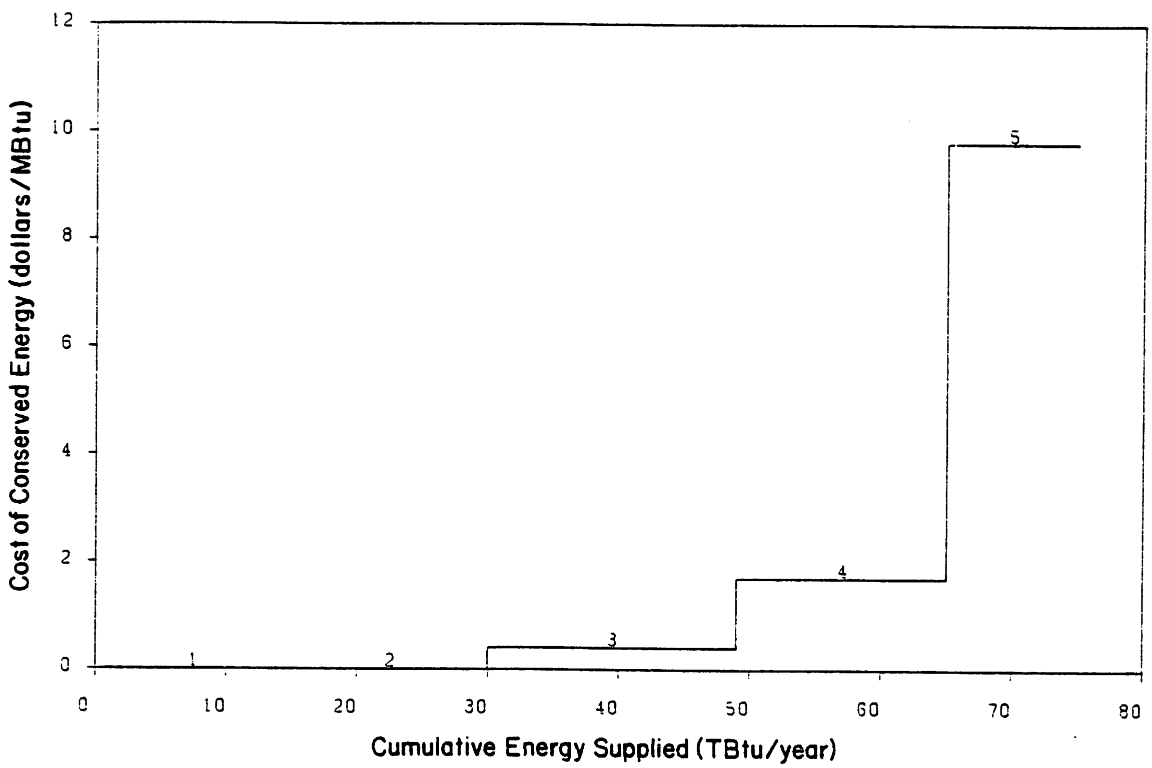

Figure 2-8. Supply curve of conserved gas: water heating. Total gas used for residential water heating in California in 1978 was 205 TBtu.

Table 2-18. Table of data for the supply curve in Figure 2-8. The time horizon is 10 years; the discount rate is five percent. Costs of conserved energy are in 1979 dollars.

	Measure*	Cost of Conserved Energy ($/MBtu)		Energy Supplied (TBtu/y)		Total Dollars Invested (millions)	Meas. No.
		Marginal	Average	Per Meas.	Total		
1	Water heater temp. setback	0	0	14.7	15	0	35
2	Cold water laundry	0	0	15.6	30	0	34
3	Low-flow showerhead	.4	.2	18.5	49	60	36
4	Water heater insul. blanket	1.7	.5	16.1	65	179	37
5	Water heater flue damper	9.8	1.7	9.7	75	588	75

*The conservation measures are listed in the order they appear in the supply curve, i.e., according to cost of conserved energy. The measure number (last column) is the number used throughout the report to identify the measure.

environmentally unacceptable, would be to increase the phosphate content of the detergent. Some improvement might be made if detergent manufacturers were given sufficient encouragement.

The less successful thermostat setback programs are, the greater the amount of energy that an insulation blanket will save. In other words, the estimated cost of conserved energy for the blankets may be lower than we have shown because we have assumed a certain sequence of adoption of the measures. Every effort should be made to ensure that all water heaters are retrofitted with additional insulation. The savings are virtually independent of the level of hot water use.

The flue damper is an expensive retrofit ($9.80 per MBtu). But as a feature of a new water heater, the cost of conserved energy is lower. Our estimate of the energy savings is conservative since we assume people set back their thermostats and insulate their water heaters prior to implementing this measure. Although flue dampers are common in Europe, licensing and safety questions have prevented their introduction in the United States. New standards for water heaters should be developed to encourage flue dampers, i.e., to further lower the standby loss. First, however, certain safety questions need to be resolved. The utility companies could play an important role in the introduction of the cheaper type of flue damper. New efficient commercial water heaters are now equipped with flue dampers.

Solar water heating systems can be installed in many California homes. It is therefore useful to compare the cost of providing solar energy with that of conservation. Our estimates for the cost of solar energy for domestic water heating range from $6 to $10 per MBtu.[1]

Electric Water Heating

Every comment about the supply curve for gas water heating applies equally to the curve for electric water heating (Figure 2-9), only here the economics are even more persuasive. The total energy savings after the last measure is implemented is 36% of the estimated 3.7 TWh presently used by California's electric water heaters. (This savings is approximately equal to a quarter of the output of a typical power plant.) Every one of the measures yields costs of conserved energy at a fraction of what consumers are now paying for electricity.

These extraordinarily low costs of conserved energy surprised us. Other conservation measures may also prove economic in specific situations. These include insulation of water pipes, more insulation around the tank, special booster systems, and heat pumps.

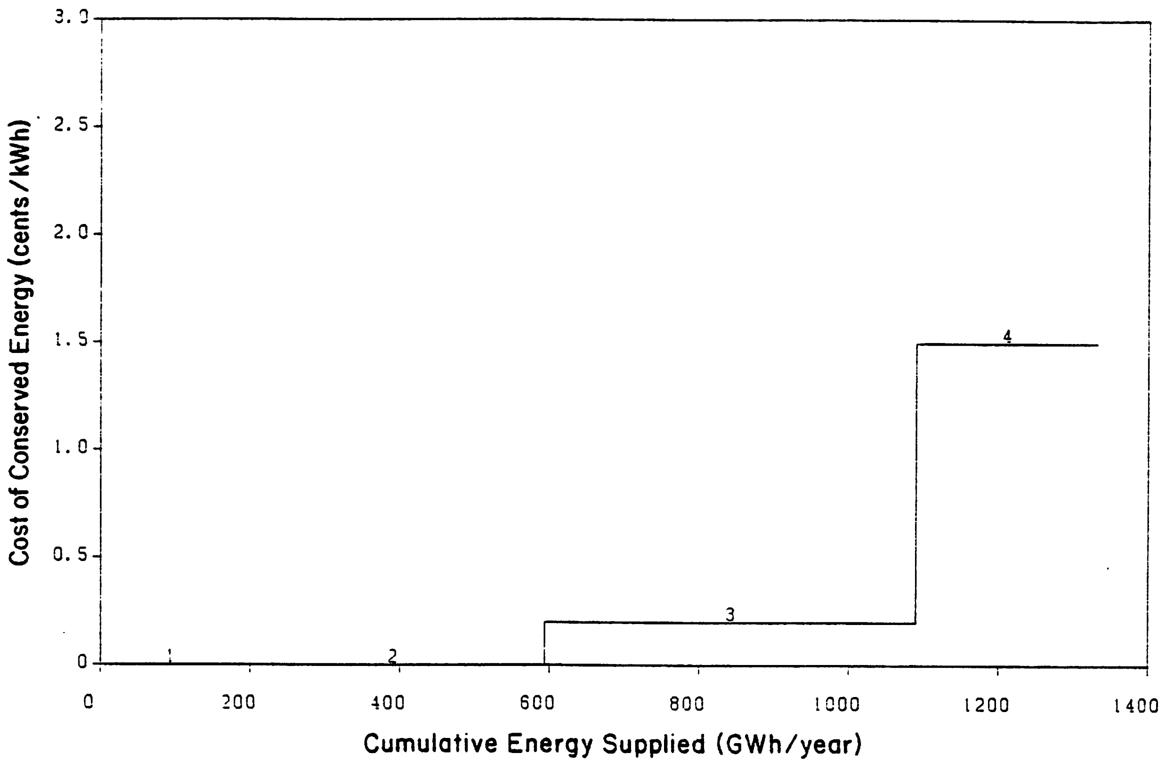

Figure 2-9. Supply curve of conserved electricity: water heating. Total electricity used for residential water heating in California in 1978 was 3,700 GWh.

Table 2-19. Table of data for the supply curve in Figure 2-9. The time horizon is 10 years; the discount rate is five percent. Costs of conserved energy are in 1979 dollars.

	Cost of Conserved Energy (cents/kWh)		Energy Supplied (GWh/y)		Total Dollars Invested	Meas.
Measure*	Marginal	Average	Per Meas.	Total	(millions)	No.
1 Water heater temp. setback	0	0	186.2	186	0	62
2 Cold water laundry	0	0	407.4	594	0	61
3 Low-flow showerhead	.2	.1	496.6	1,090	8	63
4 Water heater insul. blanket	1.5	.3	240.6	1,331	23	64

*The conservation measures are listed in the order they appear in the supply curve, i.e., according to cost of conserved energy. The measure number (last column) is the number used throughout the report to identify the measure.

Even the short-run economics of using electricity for water heating are poor; every effort should be made to discourage its use.* County governments have taking the initiative by requiring solar water heating for regions not served by gas. Solar water heating is far more economic when it replaces electric water heating than when it replaces gas. In competition with electric water heating, solar energy costs 3-5 cents per kWh.[2]

CONSERVATION MEASURES

Introduction

There are three general techniques for conserving energy in water heaters: (1) reducing hot water demand; (2) reducing standby loss+; and (3) improving the efficiency of the heating process. These techniques are illustrated in Figure 2-10. In Figure 2-10, step B (thermostat setback) also allows an energy saving from temperature-independent uses, e.g., rinsing dishes. When rinsing dishes by hand, most people simply turn on the hot water and rinse immediately. The exact temperature is not critical--the water only needs to be "hot." In this case, a thermostat setback from 140°F to 120°F saves energy because the replacement water need not be heated to such a high temperature.

Gas and electric water heaters differ in several respects. Since electric resistance heat is much more expensive than gas heat, electric water heaters are better insulated. They are generally larger than gas heaters in order to offset slower recovery times. (A five-gallon per minute shower equals a 33 kW energy flow!) Electric heaters convert electricity to heat at essentially 100% efficiency, while gas heaters typically operate at 70%. Although heat from the pilot light partly offsets standby loss in gas water heaters, losses are greater than for electric heaters due to convection up the flue.[3]

The following formula[4] can be used to estimate the hot water requirements in a house:

$$HW = (10.5 + 5.25\ CW + 3.5\ DW)\ P,$$

*If heat pumps for water heating can be marketed with COP = 2, then electric water heating will be as efficient as gas water heating.

+ Standby loss is the heat lost through the walls of the tank during storage.

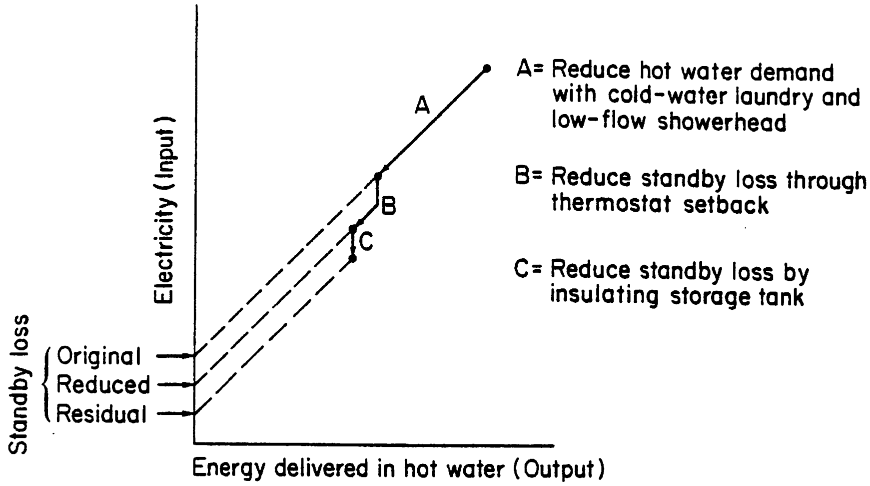

Figure 2-10. Conservation options for an electric water heater. (See text for an explanation of the second energy saving in step B.) A similar schematic diagram would apply to gas water heaters.

where HW = number of gallons of 140°F water per day; CW = number of clotheswashers; DW = number of dishwashers; and P = number of persons in the household. Thus, a typical household having three occupants and both a dishwasher and a clotheswasher uses roughly 60 gallons of 140°F hot water per day.

Gas Water Heating

We assumed the typical single-family home has a 40-gallon water heater that consumes 325 therms per year. Of this, 130 therms goes to standby losses, 25 therms for the dishwasher, 40 therms for the washing machine, and the remaining 130 therms for personal uses, such as bathing. Multifamily residences generally have smaller water heaters and fewer dishwashers and clothes washers. Table 2-20 lists the characteristics of the typical gas water heater. Table 2-21 shows gas consumption for water heating in typical single-family and multifamily residences.

Table 2-20. Characteristics of a typical gas water heater.

Capacity[a]	40 gal	Annual gas use	325 therms/yr
Jacket insulation[b]	R-3.6	Standby loss[d]	130 therms/yr
Incoming water temp.	60°F	Efficiency[e]	70%
Ambient air temp.	70°F	Lifetime[f]	10 years
Heated water temp.[c]	140°F	Initial use	60 gal/day at 140°F

[a]Gas water heaters typically come in 30, 40, and 50-gallon sizes.

[b]T. Rosenfeld, 1976, p.4.

[c]The "medium" setting on a gas water heater is 140°-145°F.

[d]Standby loss in two new 40-gallon gas water heaters with one inch of insulation was measured at 96 therms and 111 therms (Booth and Hansen, 1979, pp.25-26). But many gas water heaters have insulation only 3/4 inch thick. The average standby loss (which will be lower than for our typical case) for gas water heaters in 1975 was 110 therms/year (CEC Biennial Report, 1977, p.155).

[e]Burner efficiency in two new gas water heaters was measured at 77% for one and 68% for the other (Booth and Hansen), 1979, p.19).

[f]CEC, 1978c, Appendix A, p.III-53.

Table 2-21. Typical household use of gas (therms/year) for water heating.

	Single Family	Multi-family
Basic	260	200
Basic + clotheswasher	300	225
Basic + dishwasher	285	220
Basic + clotheswasher and dishwasher	325	245

Measure 34: Cold-Water Laundry. This conservation measure is a "reduce demand" type and costs nothing. Many detergents now effectively clean clothes with cold water. Especially greasy or dirty clothes, however, might still require a hot-water wash. In a typical household, laundering with cold water 80% of the time will save 13 gallons of 140°F water per day, which corresponds to a savings of 32 therms of gas per year.

Measure 35: Turn Down Water Heater Thermostat. This measure costs nothing, and can be done in a couple of minutes. Virtually every use of hot water in the home is at a temperature well below the water heater storage temperature. Lowering the storage temperature reduces standby losses and the amount of energy used to heat each gallon of water. Booth and Hansen found that standby losses in gas water heaters could be estimated as follows:

$$\text{standby loss} = \text{constant} \times [7.0\,(T_w - T_a) + 1.3\,(T_w - T_a)^{1.3}] \;,$$

where T_w is the temperature of stored hot water and T_a is the temperature of the ambient air.[5] Therefore, a 20°F setback (from 140° to 120°) should reduce standby losses by 41 therms per year. Some additional electricity (about 50 kWh per year) will be used by the dishwasher booster. This reduces the energy savings to 36 therms per year. Households with dishwashers lacking boosters cannot set back thermostats since lower temperatures impair the machines' cleaning ability.

One incidental advantage of lower thermostat settings is the lessened danger of scalding to children. For families with small children, this alone might justify lowering the temperature of hot water.

Measure 36: Low-Flow Showerheads and Aerators. This conservation measure is also a "reduce demand" type. A good low-flow showerhead can substantially reduce the flow without affecting the quality of the spray. Similarly, aerators in faucets provide equivalent, or even better, quality spray but with less water. (Where water pressure is low, a low-flow showerhead or faucet raises the pressure of the spray.)

A high-quality low-flow showerhead costs $10 and can be installed with common tools in a few minutes. We assume that the typical home has two showers and that the heavily used shower will receive an expensive showerhead while the less frequently used shower will be fitted with a cheaper unit.

Not every showerhead can be easily retrofitted. Some showers have "theft-proof" showerheads, where the "gooseneck" must also be changed. This probably should be done by a plumber since there is a chance for invisible internal damage.

A low-flow showerhead will typically reduce the flow by 1.75 gallons per minute (say, from 4.5 to 2.75 gallons per minute).[6] A Southern California Gas Company survey of 500 households indicated 1.5 showers per household every day, where the average shower lasted 7.5 minutes.[7] (The normal bathing temperature is about 40°C or 105°F.) This corresponds to savings of 36 therms per year in a typical house. Aerators on faucets will certainly save hot water, but we have not estimated the savings from this retrofit.

Measure 37: Insulating Blanket on Water Heater. Additional insulation can appreciably reduce heat loss through water heater walls. Most hardware stores sell kits (R-6 insulation) for $20, which residents can install in less than half an hour.[8] Alternatively, foil-backed fiberglass R-11 batts can be taped on at half the cost.

Booth and Hansen found a 30% reduction in standby loss after installation of an insulation blanket.[9] Installation of a two-inch blanket on one of the water heaters tested reduced standby loss enough so that the pilot light alone was able to offset standby loss.[10] Obviously, the savings depend on the level of the original insulation, the thermostat setting, and the ambient temperature (Table 2-22).

Table 2-22. Energy savings (therms/year) in a typical water heater (Table 2-20) when an insulation blanket is installed.

	Standby Loss			
	Original	After Temp. Setback	With Blanket	Savings from Blanket
Setback possible[a]	130	96	72	24
Setback not possible[a]	130	-	91	39

[a]The typical water heater is maintained at 140°F, which can be set back to 120°F without affecting household use of hot water. However, if the household includes a dishwasher, setback is not possible, since dishwashers require 140°F water.

Measure 75: Flue Damper on Water Heater. A flue damper reduces convective standby losses by closing the flue when the main burner is off. It also limits the amount of room air drawn into the flue. Thus, if the water heater is located in a conditioned space, then the damper also reduces space heating and cooling demands by reducing air infiltration. Because water heaters last only about 10 years, it is probably not worthwhile to pay for the professional labor required to retrofit a flue damper. However, the extra cost for a damper in a new heater is economically justified. Dampers are available in only a few models of new residential water heaters, although they are becoming increasingly popular in the commercial sector.

Booth and Hansen tested two flue dampers. The first, a thermally operated flue damper, saved 20% of the standby loss. The second, a gas-pressure operated combination flue and vent damper, saved 25% of the standby loss.[11] We selected the first model. It costs $20 and we allowed $35 for installation, for a total cost of $55. Of course, the gas savings will be much larger if not all of the lower-cost conservation measures in our sequence have been done. We assume, however, that all have been done.

Safety is an important consideration. If the damper fails to open when the burner ignites, flames could shoot out of the bottom of the water heater. Also, overheating of the water, and subsequent damage to the tank, could occur if the pilot light is oversized, that is, if it provides more heat than is lost by the tank. (This could conceivably happen after "super-insulation" of the tank.)

<u>Measure 119: Buy New Gas Water Heater Complying with CEC Standard.</u> The CEC standard for gas water heaters calls for a reduction in standby loss and an increase in efficiency. A new water heater must have a standby loss below 4.5% an hour (down from 6.5% in the past)[12] and a minimum burner efficiency of 74% (up from 60-70% in the past).[13] The standby loss standard should save 40 therms per year on a typical 40-gallon water heater; the efficiency improvement should save another 13 therms. Since this measure is required by law, the consumer does not pay extra for these savings.[14]

<u>Other Conservation Measures in Gas Water Heating.</u> Further savings can be achieved in new water heaters by reducing the size of the pilot light and increasing flue baffling. One source estimated that a reduced pilot could save 6% of the total gas, and improved baffling 3% (at a cost of only $1.50).[15]

High-efficiency commercial water heaters have a spark ignition coupled to the flue damper, so the damper can be closed when the main burner is off. This feature reduces standby losses. These water-heaters also have multiple flues to enhance heat transfer.

Insulating hot water pipes may be cost effective in certain circumstances. The heat lost in the pipes depends both on the pattern of water use and the location of the pipes. Apartment buildings, which have one large boiler for circulating hot water, may benefit from pipe insulation. At this time, however, we have not attempted to estimate an energy savings for this measure.

Electric Water Heating

Electric resistance water heaters tend to be larger and set at a higher temperature than gas heaters because they have a longer recovery time (Table 2-23). They also have better insulation owing to the higher price of electric heat. Most of the conservation measures applicable to gas water heaters also apply to electric units. However, since electric resistance heat involves no combustion, there are no flue losses. Table 2-24 shows our assumptions about energy use of electric water heaters.

Table 2-23. Characteristics of a typical electric water heater.

Capacity[a]	52 gal	Annual elec. use	4,700 kWh/yr
Jacket insulation[b]	R-5.8	Standby loss[d]	1,100 kWh/yr
Incoming water temp.	60°F	Efficiency	100%
Ambient air temp.	70°F	Lifetime[e]	10 years
Heated water temp.[c]	150°F	Initial use	60 gal/day at 140°F

[a]Electric water heaters typically come in sizes of 30, 42, 52, and 82 gallons.

[b]T. Rosenfeld, 1976, p. 4.

[c]The thermostat on an electric water heater is usually preset at the factory at 150°F.

[d]The average standby loss for electric water heaters in 1975 has been estimated at 900 kWh/year (CEC, 1977. p.155). This is lower than our typical case.

[e]CEC, 1977, p.133.

Measure 61: Cold-Water Laundry. Similar assumptions to those used for gas water heaters were used here. We estimate that this measure will save 640 kWh per year.

Measure 62: Turn Down Thermostat. The standby loss for an electric heater is simpler than for a gas heater because there are no convection flue losses. The standby loss is simply a function of the temperature difference between the heated water and the ambient air:[16]

$$\text{standby loss} = \text{constant} \times (T_w - T_a).$$

Table 2-24. Typical household use of electricity (kWh/year) for water heating.

	Single Family	Multi-family
Basic	3330	2630
Basic + clotheswasher	4130	3180
Basic + dishwasher	3860	3000
Basic + clotheswasher and dishwasher	4660	3550

We estimate this measure will save 410 kWh per year if the thermostat is lowered to 120°F. However, dishwashers may not clean efficiently at this temperature, that is, watermarks may be left on glassware and the dirtiest dishes may not be completely cleaned. Many dishwashers have a built-in "sanitemp" cycle that boosts the incoming water temperature to 155°F for the final rinse. In most cases, this will be sufficient to properly clean the dishes. However, it does require additional electric energy. We estimate that such a feature uses an extra 80 kWh per year, so that the net savings of the thermostat setback would be 330 kWh per year.

Measure 63: Low-Flow Showerheads and Aerators. Based on assumptions identical to those for gas water heaters, we estimate this measure will save 790 kWh per year.

Measure 64: Insulating Blanket on Water Heater. Booth and Hansen showed that the addition of an insulating blanket to an electric water heater saves 45% of the standby loss, or 310 kWh per year.[17] (These savings are proportionately higher than for a gas water heater because essentially all the heat loss in an electric water heater is through the shell.)

Measure 120: Buy New Electric Water Heater Complying with CEC Standard. The CEC estimates that the average heat transfer coefficient for existing water heaters is 6.45 Btu per hour-degree (Btu/h-°F) and that implementation of the new standard will lower this to 3.3 Btu/hr-°F.[18] Since standby loss in an electric water heater occurs only through the shell, the electricity saved by a typical water heater meeting the standard should be 530 kWh per year.[19]

Other Conservation Measures. Water heaters powered by a heat pump have just entered the market. At this time, however, we do not have adequate performance and cost data to estimate the energy savings. Smaller, demand-controlled water heaters located at the point of use might also save electricity. There would be less standby loss in the tank (because it would be smaller) and in the pipes. There may be plumbing savings, too, because only a cold-water feed line need be installed to the point of use.

STATEWIDE SAVINGS

The quantity of hot water used in the average home is somewhat less than that estimated for the typical single-family home. The formula (p.62) for estimating hot water demand in a typical home can also be used to give average hot water use. For California, P = 2.7 (persons per household); CW = 0.69 (clotheswasher saturation)[20]; and DW = 0.52 (dishwasher saturation)[21]. Thus the average California home uses 40-45 gallons per day of 140°F hot water.

Gas Water Heating

Table 2-25 gives data on the stock of gas water heaters in California. A single-family home in 1978 was roughly three times as likely to have a clotheswasher and one and a half times as likely to have a dishwasher as a multifamily residence.[22]

Table 2-25 Saturation and stock of gas water heaters in California.

	Single Family	Multi-family	Total
Saturation	87%	79%	84%
Stock	4,780,000	2,660,000	7,440,000

Using the information in Table 2-25, we concluded that the average gas water heater uses 275 therms per year. Table 2-26 gives the characteristics of the "average" gas water heater where they differ from the typical characteristics given in Table 2-20 (p.63).

Table 2-26. Characteristics of the average gas water heater.

Size[a]	35 gal
Annual gas use[b]	275 therms
Standby loss[b]	110 therms/year
Initial use	40-45 gal/day at 140°F

[a]T. Rosenfeld, 1976, p.22.

[b]CEC, 1977, pp.154,155.

Measure 34: Cold-Water Laundry. Roughly 69% of California households had clotheswashers in 1978. While the typical single-family house would save about 32 therms per year with cold-water laundry, inclusion of multifamily residences lowers the average saving to 30 therms per year.

Measure 35: Turn Down Water Heater Thermostat. Practically all homes without automatic dishwashers can turn down the water heater thermostat. A few might run out of hot water, but after instituting other hot water conservation measures, such as low-flow showerheads, capacity should not be a problem. Roughly 52% of all California households have dishwashers. One reference estimated in 1975 that 15-20% of the dishwashers had boosters.[23] However, over half of the dishwasher models currently for sale have this feature, so we assumed 30% of homes with dishwashers can turn down the thermostat to 120°F. Thus, about 60% of all California homes can turn down their thermostats to 120°F.

Turning down the thermostat to 120°F would lower the standby loss of the average gas water heater from 110 therms to 76 therms, saving 34 therms. However, in those homes with booster-equipped dishwashers--about one quarter of the cases--the savings will be less since there is additional electric heating done by the booster. After adjusting for the booster electricity use, the average savings falls slightly to 33 therms.

Measure 36: Low-Flow Showerheads and Aerators. Not all homes can be retrofitted with low-flow showerheads. In a small proportion, the existing showerheads are "theft-proof" and cannot be removed without changing the "gooseneck." One energy auditor estimated that 5-10% of all homes in Santa Cruz and Santa Clara counties could not be easily converted to low-flow showerheads.[24] In addition, some homes installed low-flow showerheads during the 1976 drought. Therefore, we estimate that low-flow showerheads can be installed in only 80% of all homes.

Furthermore, we assume that only one shower per household--the one most often used--will be converted. The cost is only $10. (A small in-line flow restrictor costs less than a dollar.) We estimate that the average gas savings will be 31 therms per year, based on the average California household of 2.7 occupants.

Measure 37: Insulating Blanket on Water Heater. Energy savings from these blankets depend on both hot water temperature and the size of the storage tank. We estimate the average savings to be 23 therms per year for thermostats set at 120°F and 33 therms per year for thermostats set at 140°F. If 60% of the water heaters are set at 120°, then the average saving is 27 therms. Since this is a "do-it-yourself" measure, not every resident can be expected to install a blanket. Thus, we assume that blankets will be installed in 80% of the homes.

Measure 75: Flue Damper on Water Heater. Although flue dampers can technically be retrofitted, institutional barriers lie in the way. The cheaper flue damper tested by Booth and Hansen has not been approved by the American Gas Association.[25] Assuming that all lower-cost measures have been done, the average energy savings will be 13 therms.

Measure 119: Buy New Water Heater Complying with CEC Standard. Savings from this "replacement measure" cannot be added to the savings from the "retrofit measures" above. In the next 10 years some water heaters will gain thicker insulation by retrofit; others will be replaced with more efficient new water heaters. Average gas savings from this standard will be about 44 therms. Assuming that 10% of the water heaters already have blankets or meet the standard, statewide savings in 10 years through stock turnover will be 29 TBtu, or 14% of the gas used in 1978 for water heating.

Electric Water Heating

Roughly 10% of California's homes have electric water heaters. Nevertheless, water heating accounts for about 7% of all electricity used in the residential sector, or 3.7 TWh. Table 2-27 gives data on electric water heater stocks in the state.

The average electric water heater in California uses 3,800 kWh per year, of which 900 kWh is standby loss.[26] Table 2-28 gives the characteristics of the "average" electric water heater where it differs from the typical characteristics given in Table 2-23 (p.67).

Measure 61: Cold-Water Laundry. By using the same assumptions discussed for gas water heaters, we estimate that this measure will save 600 kWh per year.

Table 2-27. Electric water heater saturation and stock.

	Single Family	Multi-family	Total
Saturation	10%	13%	11%
Stock	550,000	420,000	970,000

Table 2-28. Characteristics of the average electric water heater.

Size[a]	40 gal
Total electricity use	3,800 kWh/yr
Standby loss	900 kWh/yr
Initial use	40-45 gal/day at 140°F

[a]T. Rosenfeld, 1976, p.22.

Measure 62: Turn Down Thermostat. By using the same assumptions discussed for gas water heaters, we estimate that this measure will save 340 kWh per year. In those homes with booster-equipped dishwashers, the savings will be lower, about 260 kWh. On the average, the saving will be 320 kWh per year.

Measure 63: Low-Flow Showerhead and Aerators. By using the same assumptions discussed for gas water heaters, we estimate that this measure will save 640 kWh per year.

Measure 64: Insulating Blanket on Water Heater. With the thermostat set at 120°F, the saving will be about 250 kWh per year. With the thermostat set at 140°F, the saving will be about 400 kWh per year. We estimate the average saving is 310 kWh per year.

Measure 120: Buy New Electric Water Heater Complying with CEC Standard. The same comments apply to this "replacement measure" as for gas water heaters. Average electricity savings from this standard will be about 440 kWh per year. Hence, statewide savings in 1990 through natural turnover of the stock will be 0.4 TWh per year, or 11% of the electricity used for water heating in 1978.

REFERENCES AND NOTES

1. In comparing the economics of solar heating and conservation, the chief complication is the high fixed cost of solar heating systems. A system sized to meet hot water demand after conservation will not cost much less than one sized to meet the original demand. Plumbing requirements are the same, for example. The table below gives the costs of two representative solar water heating systems.

	Conventional Two-Panel System	Small System
Contractor cost	\$2,500[a]	\$1,900[b]
Contractor cost with tax credit[c]	\$1,130	\$860
Delivered energy[d]	12 MBtu/yr	6 MBtu/yr
Gas replaced[e]	17.1 MBtu/yr	8.6 MBtu/yr
Cost of replaced gas without tax credit[f]	\$14.00/MBtu	\$21.30/MBtu
Cost of replaced gas with tax credit[f]	\$6.40/MBtu	\$9.60/MBtu

[a]The following materials costs were used in this estimate:

two panels	\$520	storage tank	\$400	pump	\$100
controller	\$100	framing	\$70	pipes	\$100

Labor charges will double this total. The \$2,500 estimate was confirmed by the Berkeley Solar Group, who quoted a range of \$2,000 to \$3,000 for a standard solar water heater (August 1979).

[b]Based on a "one-panel system" with other components scaled appropriately. Other systems may be used for a small load.

[c]California has a tax credit for solar installations of 55%.

[d]We assume that a conventional system can supply 60% of the demand.

[e]Assumed efficiency of gas water heaters is 70%.

[f]Based on a real discount rate of 5% and a lifetime for the solar system of 15 years.

The cost of the replaced gas, even after including the tax credit, is quite high. Moreover, the energy supplied by the small system costs 50% more (per MBtu) than the conventional unit, reflecting the high fixed cost of solar water heating units. So, in one sense, extensive conservation raises the cost of solar energy. On the other hand, hot water conservation measures reduce peak demand and therefore may lower the cost of a solar system. (Solar heating systems are generally sized to meet a portion of peak demand.)

2. The following table parallels the one in note 1. The costs are the same as in note 1 and are therefore omitted. The replaced electricity is equal to the energy delivered by the solar system since electric water heaters have an efficiency of 100% (1 kWh = 3,413 Btu).

	Conventional Two-Panel System	Small System
Delivered energy	12 MBtu/yr	6 MBtu/yr
Electricity replaced	3,520 kWh/yr	1,760 kWh/yr
Cost of replaced electricity without tax credit	6.8 ¢/kWh	10.4 ¢/kWh
Cost of replaced electricity with tax credit	3.1 ¢/kWh	4.7 ¢/kWh

3. Booth and Hansen (1979) found that the efficiency of the pilot light was virtually the same as the burner efficiency (p.19) and concluded that "pilot removal would not save energy" (p.7).

4. R.D. Clear and D.B. Goldstein, in Berman et al, 1976, Appendix 6.

5. Booth and Hansen, 1979, p.21.

6. The CEC assumes that the average flow rate for showers before implementation of the 1978 standards was 4.5 gallons per minute. According to the standards, flow rates of new showers and faucets must not exceed 2.75 gallons per minute. (CEC, 1979c, p.5-83)

7. Southern California Gas Co., 1977, p.13.

8. Sears, 1979.

9. Booth and Hansen, 1979, pp.25, 26.

10. Booth and Hansen, 1979, p.20.

11. Booth and Hansen, 1979, pp.3, 35.

12. CEC, 1979c, p.5-88.

13. CEC, 1978e.

14. Water heaters that exceed the standard are available at an extra cost. T. Rosenfeld (1976, p.12) estimates that consumers can save up to 71 therms by the careful choice of brand and model of gas water heater. This gives an extra saving of 20 therms per year beyond the standard.

15. Hirst and Hoskins, 1977, p.399.

16. Booth and Hansen, 1979, p.21.

17. Booth and Hansen, 1979, pp.27, 28. 310 kWh per year is 45% of the remaining standby loss after thermostat setback.

18. CEC, 1979c, p.5-85.

19. Electric water heaters that exceed the standard are available for an additional cost. T Rosenfeld (1976, p.12) estimates a total saving of 718 kWh per year, which, for our typical case, is a saving of 190 kWh per year beyond the standard.

20. Estimated by weighting the saturations of appliances as reported by the major Californian utilities (CEC, 1978c, Appendix A, p.III-43).

21. Ibid.

22. Saturations of these two appliances were forecasted for PG&E in 1978 (CEC, 1979a, Table D-4):

	Single Family	Multi-family
Clotheswasher	92%	30%
Dishwasher	61	39

Refrigerators and Freezers

THE SUPPLY CURVE

The supply curve for refrigerators and freezers (Figure 2-11) begins with several low-cost measures, gradually rises, and then goes up sharply with relatively small amounts saved. The cumulative savings after the final measure amounts to 29% of the estimated 15.7 TWh of electricity used by refrigerators and freezers.

This curve shows that considerable conserved electricity can be supplied at costs below that now paid for electricity. Even the final measure on the curve is cheaper than peak electricity. A study by Arthur D. Little, Inc. (1977b) revealed other, mostly simple technical changes that would dramatically reduce refrigerator electricity use. No manufacturers have, to our knowledge, taken all the steps recommended by this study.* Variations in efficiency among existing refrigerators are mostly due to different thicknesses of insulation. Since the potential savings in electricity are so great, at what appear to be costs barely above those needed to buy the most efficient model, we believe that the California Energy Commission should move to establish even stricter standards. There is a sharp increase in the cost of conserved energy at

*We understand that Amana Co. has built several prototype refrigerators that have incorporated most of the features recommended by ADL. These models use about half as much electricity as models now meeting the CEC standard. Amana hopes to be offering these refrigerators in two years. The federal government has also proposed appliance efficiency standards. The 1981 standards refrigerators are generally weaker than the 1979 CEC standards (and may actually preempt them). The 1986 standards, however, are much tighter, although the Amana unit discussed above will meet them with no difficulty.

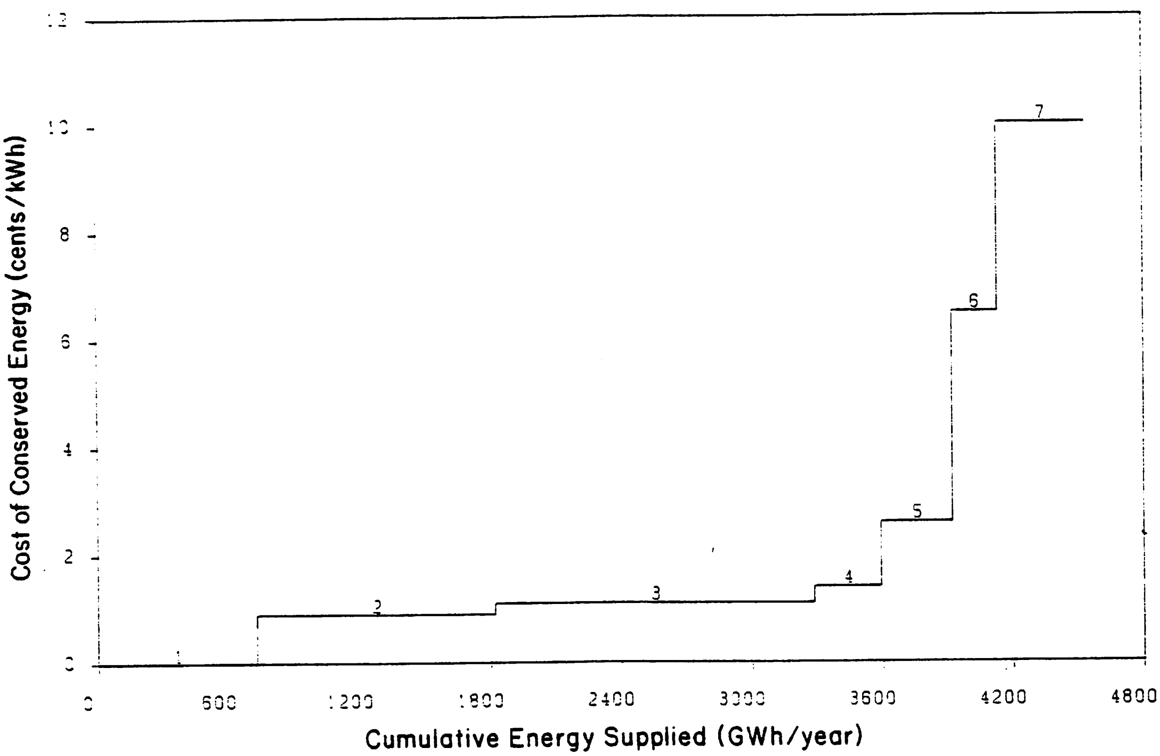

Figure 2-11. Supply curve of conserved electricity: refrigerators and freezers. Total electricity used for refrigerators and freezers in California in 1978 was 15,700 GWh.

Table 2-29. Table of data for the supply curve in Figure 2-11. The time horizon is 10 years; the discount rate is five percent. Costs of conserved energy are in 1979 dollars.

	Cost of Conserved Energy (cents/kWh)		Energy Supplied (GWh/y)		Total Dollars Invested (millions)	Meas. No.
Measure*	Marginal	Average	Per Meas.	Total		
1 CEC standard refrigerator	0	0	728.0	728	0	78
2 Buy most eff. refrigerator	.9	.6	1092.0	1,820	78	65
3 Refrigerator package "A"	1.1	.8	1466.4	3,286	203	79
4 Buy most efficient freezer	1.4	.8	305.8	3,592	236	66
5 Freezer package	2.6	1.0	327.6	3,920	301	85
6 Manual refrig. improvement	6.5	1.3	208.0	4,128	405	81
7 Refrigerator package "B"	10.0	2.0	405.6	4,533	717	80

*The conservation measures are listed in the order they appear in the supply curve, i.e., according to cost of conserved energy. The measure number (last column) is the number used throughout the report to identify the measure.

4.1 TWh, about one-fourth the total refrigerator and freezer energy use, or slightly less than one power plant's output.

The potential energy savings from refrigerators and freezers are extremely reliable and translate directly into baseload power plants. That is, once old appliances have been replaced by new high-efficiency appliances, (and the old ones scrapped) the utility can plan with confidence on lower demand.

This supply curve illustrates one of the great energy conservation bargains available. We could gain the equivalent of 9/10 of the output of a typical power plant in 10 years by investing in efficient refrigerators and freezers. Furthermore, the electricity from this supply would have an average cost of 2 cents per kWh.

Unfortunately, utility campaigns to encourage the purchase of efficient refrigerators have backfired to some extent. Many buyers have kept their old units in use ("in the garage for the beer") after buying the new efficient model for their kitchen. A utility "bounty" on refrigerators of perhaps $50 might help to remove these second refrigerators.* Removing a "guzzler" (200 kWh per month) will result in a considerable saving to the utility (280 W, all baseload).† On the other hand, a customer might claim the $50 bounty for a 50 kWh per month manual refrigerator; once off the grid, that refrigerator saves only 70 watts. Under conservative assumptions, this results in a cost of conserved energy <u>to the utility</u> of roughly 5 cents per kWh. Even the modest success of such a program might result in substantial electricity savings, since 18% of California's homes have two refrigerators. This measure is not on the supply curve because it relies on a utility decision rather than a consumer decision.

Since refrigerators typically last 20 years and freezers even longer, the choice of time horizon will greatly affect the amount of conserved energy available from this end use. In this study we used a linear decay model, which predicts that half of the refrigerators will be replaced in 10 years and all of them in 20 years. As a consequence, the energy conserved in refrigerators over a 20-year time horizon will be twice as large as that over the 10-year time horizon we used. Thus, for refrigerators it is crucial to introduce high-efficiency models as soon as possible; an inefficient refrigerator bought today will very likely still be operating in 2000.

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* Presently, PG&E has an experimental $25 "bounty" program in Santa Clara County that appears to be a success. With practically no advertising, about 60 refrigerators a week are being turned in. This corresponds to a 200 kW drop in demand each year. This program is now being expanded to the entire service district.

† In contrast, most new power plants cost $2 per watt to build.

REFRIGERATORS

Conservation Measures

Refrigerators are the largest users of electricity in most California homes. Moreover, refrigerator energy use is growing rapidly because people are replacing their small manual defrost models with larger, automatic defrost models. Also, old refrigerators are frequently not junked; instead, they are moved into garages and basements for extra refrigerated storage.[1]

Only a few energy conservation measures are available once a refrigerator is purchased. Changes in use patterns will save little electricity. Heat gains from opening and closing the door account for only 2% of total electricity use.[2] The efficiency loss from dirty coils, poor ventilation, and sunlight shining on coils is difficult to estimate but is generally small. Additional insulation (like on a water heater), which might save 10-15%, is theoretically possible but is unlikely due to both practical and aesthetic considerations. Thus, the greatest potential for energy savings occurs at the time of purchase.

The most popular model of refrigerator sold today is a 17-17.5 cubic-foot unit with automatic defrost. There is quite a range in electricity use among models even within this class: from 1,200 to nearly 2,000 kWh per year, with an average of about 1,700 kWh per year.[3]

<u>Measure 77: Turn Off Anti-Sweat Switch.</u> Many refrigerators have anti-sweat heaters to prevent condensation build-up around door openings. However, this is only a problem in humid climates. Few households in California need this option, and then only for brief periods. Switching the anti-sweat heater off is a simple task. There is a great range in energy use of the anti-sweat heaters, even among similar 17-cubic-foot models, from 140 to 430 kWh per year.[4] A typical saving would be 200 kWh per year.

<u>Measure 78: Replace Old Refrigerator with One Meeting CEC Standards.</u>[5] CEC standards require new refrigerators to use significantly less energy than those in the past. Replacing an old unit with a new one (with similar features) will result in substantial energy savings. In some cases, it may be economic to junk an especially inefficient refrigerator prematurely.

A 17.3-cubic-foot automatic defrost refrigerator typically uses 1,500 kWh per year (with the anti-sweat switch off). The 1979 CEC standard is 1,340 kWh per year (with anti-sweat switch turned off all year).[6] Thus, electricity savings for this most popular model will be about 160 kWh per year. The consumer need not make a special investment since models that just meet the standard should be among the cheapest on the market.

Measure 65: Replace Old Refrigerator with the Most Efficient Available. Many refrigerators surpass CEC energy standards. An alert consumer can save much more if he buys the most efficient model available rather than one just meeting the standard. Within the 17-17.5 cubic-foot frost-free class, it is possible to buy models using 1,070 kWh per year, or 270 kWh per year less than the CEC standard.[7] We allow an extra $20 for the additional cost of such an efficient model.[8]

Measure 79: Improvement Package "A" for Frost-free Refrigerators. An A.D. Little study predicted that with only a small increase in retail cost, even more efficient refrigerators could be built.[9] The lower energy use would be a result of increasing the insulation, modifying the motor, improving the evaporator, and reducing compressor losses. These measures would not affect the services of the refrigerator, only the energy it uses. They would save another 480 kWh per year (beyond the most efficient model currently available) on a 17-cubic-foot frost-free refrigerator (with the anti-sweat switch turned off). After adjusting the ADL estimates for inflation, the additional retail cost would be about $40.

Measure 80: Improvement Package "B" for Frost-free Refrigerators. The same ADL study found that further modifications could reduce electricity use below the Package A level, although at a higher cost. These modifications include a hot-gas defrost system, defrost on demand, and a thermostat-controlled expansion valve. Package B modifications would typically reduce electricity use by further 130 kWh per year but increase the retail cost by $100 beyond package A.

Measure 118: Buy Most Efficient Manual or Partial Refrigerator. Most manual and partial defrost refrigerators comply with the 1979 CEC standard. However, considerable variation in energy use still exists within a given size and type. A typical 12-cubic-foot manual defrost refrigerator uses 790 kWh per year, but a 550 kWh per year model is also available.[10] A similar variation in energy use exists among partial defrost models.

Measure 81: Improvement Package for Manual and Partial Defrost Refrigerators. The ADL study examined the energy savings potential in a 12-cubic-foot, partial defrost refrigerator. They found that by improving closure area, modifying the motor, reducing suction gas heating, improving the evaporator, and adding insulation, they could lower energy use to 57% of the baseline. These modifications could also be made to a manual defrost refrigerator. These technical improvements could save 80 kWh per year at an increase in retail cost of $50.

Measure 82: Junk Second Refrigerator. Many people keep their old refrigerator after they buy a new one. It typically sits in the garage, cooling beer, soft drinks, and perhaps some perishables. In some cases it operates virtually empty. Since the refrigerator costs roughly $40 per year to operate, residents should ensure they receive at least that value from its service, i.e., discounts from bulk purchases, special sales, fewer shopping trips, etc. In some cases it will be worthwhile to junk the second refrigerator. Old refrigerators are usually manual defrost, using about 650 kWh per year. This measure costs nothing and, of course, saves the entire 650 kWh per year.

Statewide Savings

There are about 10.4 million refrigerators in California; together they use 25% of the total residential electricity.[11] The shift towards a different kind of refrigerator, i.e., one providing more services (frost-free, ice maker, etc.) complicates the estimate of conservation potentials in this sector. The state's stock of refrigerators comprises 40% manual defrost and 60% frost-free.[12] (The distinction between manual and frost-free accounts for a greater difference in energy use among refrigerators than any other factor.) On the other hand, frost-free models account for 74% of current sales.[13]

Since we have chosen to base potential savings on current stock rather than purchasing patterns, we make no adjustments for changes in stock mix. In other words, owners of manual defrost refrigerators will replace them with manuals, and owners of frost-free with frost-free models. This results in a low estimate of potential savings because the possible savings from a manual defrost refrigerator are lower than from a frost-free. One can be confident that these potentials exist because only existing stock is considered.

Measure 78: Replace Old Refrigerator with One Meeting CEC Standard. Table 2-30 shows the average electricity use of frost-free and manual refrigerators complying with the CEC standard, as well as their combined weighted average. The average savings per refrigerator replaced will be 140 kWh per year. This is a no-cost measure since the consumer has no choice but to pay for the increased efficiency.

Measure 65: Buy Most Efficient Refrigerator. Many refrigerators are significantly more efficient than required by the CEC standard. The weighted electricity use of the most efficient models is shown in Table 2-30. This will lead to an average saving of 210 kWh per year per refrigerator. Buying the most efficient refrigerator will cost about $15 more.

Measure 79: Improvement Package "A" for Frost-free Refrigerators. We applied the savings for the typical 17-cubic-foot refrigerator proportionately to the average frost-free model.[14] The average energy savings is 470 kWh per year and the extra cost $40. Sixty percent of the refrigerator stock are frost-free, and all are eligible for this measure.

Measure 80: Improvement Package "B" for Frost-free Refrigerators. Using similar logic as for Package A, we estimate that the average energy savings will be 130 kWh per year at an average cost of $100. Again, 60% of the entire refrigerator stock would be eligible for this measure.

Measure 81: Improvement Package for Manual and Partial Defrost Refrigerators. We applied the proportionate savings for the 12-cubic-foot partial defrost refrigerator to all manual and partial defrost models. We estimate an average energy savings savings of 100 kWh per year at an extra cost of $50. Forty percent of the refrigerator stock are manual defrost refrigerators, and all are eligible for this measure.

Table 2-30. Saturation and energy use of refrigerators in California in 1978. (Source: CEC 1979c, p.5-99 and pp.E37-39.)

	Frost-free	Manual	All Refrigerators
Saturation	70%	48%	118%
Stock average (kWh/yr)	1600	650	1210
Weighted mode meeting CEC standards (kWh/yr)	1400	590	1070
Weighted minimum available (kWh/yr)	1180	400	860

FREEZERS

Conservation Measures

Estimating conservation potentials in freezers presents some problems. Three significantly different types are sold (manual-defrost chest, manual-defrost upright, and frost-free upright). The three most popular sizes are 10, 16, and 21 cubic feet.[15] Unlike refrigerators, no single type and size dominates either the stock or current sales.

A freezer may be the largest electricity user in a home or require only half the electricity use of the refrigerator. As with refrigerators, it is difficult to reduce a freezer's energy use once it is purchased. Some models have an anti-sweat switch that can be turned off. In theory, one could add a layer of insulation and save as much as 15%, but condensation problems are likely to result. Alternatively, the freezer could be kept in an area requiring space heating during the winter (and an unconditioned space during the summer) to exploit its waste heat.

Electrical use depends on the type of freezer. Chest freezers use less than comparably sized upright models, because of lower losses through gaskets and door openings. Virtually all chest freezers, and most manual-defrost upright freezers, meet the 1979 CEC standard. About half of the frost-free models meet the standard.[16] Energy savings from natural turnover of the stock will be small since frost-free freezers are not common.[17] For this reason we have not included a "comply with CEC standard" measure for freezers.

<u>Measure 84: Turn Off Anti-Sweat Switch.</u> A few upright freezers have anti-sweat switches. They are not needed in most California climates. Savings range from 100 to 240 kWh per year, but 180 kWh is typical.[18]

<u>Measure 66: Buy Most Efficient Freezer Available.</u> There is only a weak correlation between purchase price and electricity use of freezers, so comparison shopping will result in some savings. Nevertheless, some manufacturers offer high-efficiency models for a small additional cost. High-efficiency models are generally available only among larger freezers.[19] A popular model is the 22-cubic-foot chest freezer.[20] Simply buying the most efficient model of a 22-cubic-foot chest freezer will cost (if anything) $10 more and save about 160 kWh per year.[21]

<u>Measure 85: Improvement Package for Freezers.</u> In a recent study, A.D. Little, Inc. found that a small additional investment (about $50, after adjusting for inflation) could further reduce freezer energy use.[22] For a 22-cubic-foot chest freezer, these measures were increasing insulation to three inches of polyurethane, substituting back-mounted condensers, modifying the motor, and reducing suction gas heating. ADL estimated that these measures would reduce electricity use by 45%. These technical improvements, applied to a typical 22-cubic-foot freezer, would save 460 kWh per year beyond the previous measure.

For a 17-cubic-foot frost-free upright freezer, the technical improvements include increasing insulation, improving the closure area, insulating the interchanger, modifying the motor, reducing suction gas heating, placing the evaporator motor outside the cold space, shutting the evaporator fan off during door openings, improving the evaporator fan motor, increasing the evaporator area, switching to hot-gas defrost, and using a smaller anti-sweat heater. They projected that these measures would save 47% of the baseline energy and cost $120.

A manual-defrost upright freezer uses about 30% less electricity than a comparable frost-free model.[23] While ADL did not analyze the energy savings potential for this type, we estimate that technical improvements would save about 50% of the base consumption at a cost of

Table 2-31. Saturation and energy use of freezers in California in 1978. (Source: CEC, 1979c, p.5-99 and pp.E-37-39.)

Saturation	31%
Energy use 1978 stock average	1130 kWh/yr
Weighted mode meeting CEC standard	1100 kWh/yr
Weighted minimum available	850 kWh/yr

$80. These improvements are identical to those for the frost-free model, with the exception of those measures directly related to the automatic defrost system.

Statewide Savings

There are about 2.7 million freezers in California using 6% of the total residential electricity.[24] One estimate is that the average freezer uses 1,130 kWh per year.[25]

As discussed earlier, typical freezers are difficult to characterize owing to the wide range in type and size. Little data exists on the current stock of freezers, either for the United States or California. Statistics indicate that manual-defrost chest freezers now comprise 55% of sales, manual uprights 38%, and frost-free uprights, 8%.[26] Roughly 24% are around 10-cubic-foot, 30% around 16-cubic-foot, and 32% around 21-cubic-foot.[27] Information on freezers is given in Table 2-31.

Measure 66: Buy Most Efficient Model Available. High-efficiency models are not available in all sizes and types of freezers. We estimate that, on the average, a $30 investment will save an average 280 kWh per year. Frost-free models offer the greatest savings per unit, but they comprise only a small portion of the total stock. A small part of this savings (30 kWh) will occur necessarily as a consequence of the 1979 CEC standard, but most freezers already comply.

Measure 85: Improvement Package for Freezers. We estimate that the average savings (weighted by market share) from the ADL improvement packages for the three major types of freezers could cut energy use 54% from the base case (the unimproved typical freezer).[28] However, the most efficient models now available use less energy than the ADL base cases. After adjusting for this, the average savings will be about 300 kWh per year at an average increased cost of $60.

REFERENCES AND NOTES

1. About 18% of Californian homes have two refrigerators. This is estimated by weighting saturations of refrigerators as reported by the major California utilities (CEC, 1979c, p.5-99).

2. Hoskins et al., 1978.

3. CEC, 1978b.

4. These numbers are derived from data in the CEC Directory of Refrigerators and Freezers (1978), where the difference between the highest and lowest monthly electrical use is the electricity consumed by the anti-sweat heater when it is on all the time.

5. These standards came into effect in November, 1979.

6. The allowed annual electricity consumption for an automatic-defrost top-freezer refrigerator with the antisweat switch on half the time is 487 + 55 V kWh, where V is the volume of the refrigerator in cubic feet. (This is the CEC 1979 standard.)

7. See note 3.

8. A comparison of the energy performance of top-freezer refrigerators in the January, 1978 issue of Consumer Reports shows an average annual reduction of 470 kWh for an extra purchase cost of $35.

9. Arthur D. Little, Inc., 1977b, Vol. 1.

10. See note 3.

11. This estimate is based on refrigerator saturations derived from utility surveys (CEC, 1979c, p.5-99).

12. Ibid.

13. CEC, 1979c, p.5-107.

14. See note 9.

15. CEC, 1979c, p.E-39.

16. See note 3.

17. Less than 10% of freezers sold are frost-free (CEC, 1979c, p.5-108).

18. See note 3.

19. Sears offers a 15-cubic-foot frost-free upright freezer in both regular and high-efficiency models. The high-efficiency model costs about $30 more, but probably saves about 350 kWh per year.

20. 38% of freezers currently sold have a volume greater than 19.5 cubic feet. 55% of freezer sales are chest freezers (CEC, 1979c, p.E-39, p.5-108).

21 See note 3.

22. See note 9.

23. See note 3.

24. CEC, 1979a. In Table D-4 the 1978 saturations of freezers in the area served by PG&E are 46% in single-family and 11% in multifamily residences.

25. CEC, 1979c, p.E-37.

26. CEC, 1979c, p.5-108.

27. See note 25.

28. See note 9.

Lighting

THE SUPPLY CURVE

The supply curve for residential lighting (Figure 2-12) begins climbing immediately and increases steadily with each measure. The cumulative savings after the final measure is 24% of the estimated 9.4 TWh used for lighting in the residential sector.

The first measure, "switch to high-efficiency bulbs," is still hypothetical since the Halarc bulbs we considered are not yet available. The next measure, installation of fluorescent lights in the kitchen, conserves electricity at less than the current price. The cost will be even lower for heavily used kitchens. This measure saves more electricity than any other single lighting conservation measure.

The subsequent measures do not require any new technology; rather, they involve simply switching to fluorescent lights in rooms used less often. The cost of the fluorescent units is the same in measures 73, 97, 98, and 74; however, the cost of conserved energy increases simply because there are fewer operating hours over which one can spread the initial investment. In other words, when operating fewer hours, the lights have less energy to save.

Rooms with high use and high illumination are naturally the first targets for conversion to more efficient lighting systems. As the cost of new electricity continues to rise, it will become economic to convert less intensively used lights to fluorescent.

Silly as it may seem, a statewide scheme to mail a couple of retrofit fluorescent fixtures to each home could save as much as one-sixth the output of a typical power plant. The costs of conserved electricity would be half that from a new power plant.

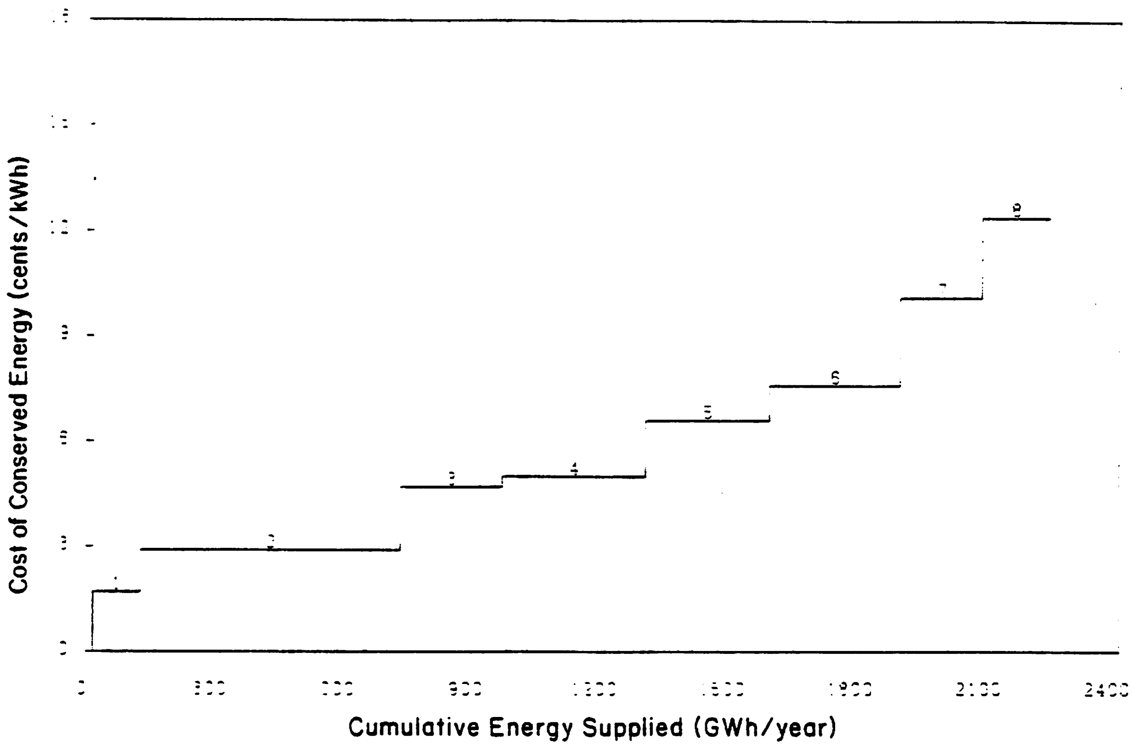

Figure 2-12. Supply curve of conserved electricity: lighting. Total electricity used for residential lighting in California in 1978 was 9,400 GWh.

Table 2-32. Table of data for the supply curve in Figure 2-12. The time horizon is 10 years; the discount rate is five percent. Costs of conserved energy are in 1979 dollars.

	Measure*	Cost of Conserved Energy (cents/kWh)		Energy Supplied (GWh/y)		Total Dollars Invested	Meas.
		Marginal	Average	Per Meas.	Total	(millions)	No.
1	3-way bulb to high-efficiency	1.7	1.7	110.6	111	8	83
2	Kitchen fluorescent	2.9	2.8	608.9	720	146	69
3	Exterior fluorescent	4.7	3.2	239.0	958	234	71
4	100 W bulb to fluorescent (1)	5.0	3.7	334.5	1,293	364	73
5	100 W bulb to fluorescent (2)	6.6	4.2	290.3	1,583	513	97
6	3-way bulb to fluorescent	7.6	4.8	305.3	1,889	692	72
7	100 W bulb to fluorescent (3)	10.1	5.3	191.2	2,080	841	98
8	75 W bulb to fluorescent	12.4	5.8	155.8	2,236	989	74

*The conservation measures are listed in the order they appear in the supply curve, i.e., according to cost of conserved energy. The measure number (last column) is the number used throughout the report to identify the measure.

CONSERVATION MEASURES

The amount of electricity used for lighting depends directly on the number of hours the lights are on. However, the efficiency of the lighting systems will determine how much effective illumination the occupants receive. Such factors as the number of fluorescent bulbs, the fraction of high-wattage incandescent bulbs, and the extent of task-oriented lighting (e.g., reading lamps) determine efficiency. In spite of considerable variation among homes, one can develop reasonably typical load curves. Figure 2-13 is an example. The absolute numbers may differ, but the distribution will probably be fairly close.

Most lighting conservation measures replace an existing bulb with a more efficient one. The energy savings depends on both the reduction in power use and the number of hours the occupants use the light. Thus, frequently used lights have the best payback.

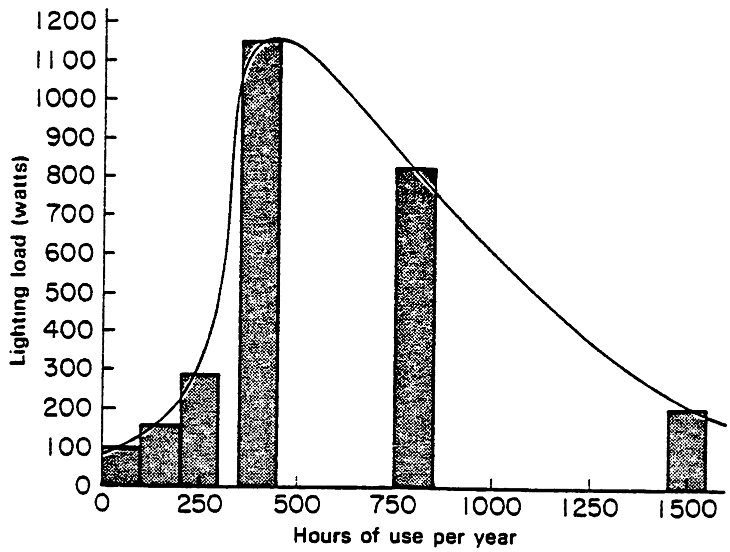

Figure 2-13. The load curve for lighting in a typical house. Frequently used lights occupy the right side of the load curve. In most homes, the kitchen light is the most heavily used light, both in terms of power and number of hours. In some homes, however, a reading light or possibly an exterior light will dominate. We have assigned the different-size lights in the measures to specific rooms. However, the location does not really matter; the crucial variables are how much power the light uses and how many hours it operates.

All fluorescent units require some sort of ballast (transformer), which comes as part of the fixture. The ballast consumes some electricity (lost as heat), typically around 10 watts. So a 22 watt fluorescent bulb installed in a fixture will draw about 32 watts.

Measure 83: Replace Three-Way Incandescent with High-Efficiency Bulbs. Several new types of lights are now being developed for homes. They exploit solid-state controls and new filaments to increase the efficiency of lighting. All of them will cost more than the original incandescent, but this will be offset by lower electricity costs and longer bulb life. The General Electric "Halarc" bulb is one example of this new generation of lights. It is shaped like an incandescent bulb and screws into an ordinary socket, so it can be placed virtually anywhere. GE hopes that it will be available in 1981.[1] We estimate that the "Halarc" will save 50 kWh per year if the light operates 800 hours per year.[2] GE predicts that the "Halarc" will cost $10. The bulb should last five years.

Measure 69: Install Fluorescents in Kitchen. Kitchens are typically brightly lit and intensively used. Most new kitchens already have fluorescents, but many old kitchens still use a 150 watt "kitchen light" or a triple 60 watt unit. Owing to the lower conversion efficiency of the 60 watt bulbs, both provide nearly the same amount of light. Fluorescent bulbs last several times longer than incandescent bulbs.

A 65 watt fluorescent unit (consisting of a 54 watt bulb and an 11 watt ballast) will provide the same illumination as the 180 watts of three 60 watt incandescents.[3] This is a 115 watt power saving. We assume that the light is turned on 1,500 hours a year, so that the annual savings is 172 kWh.

The original bulbs and fixture cost about $22.[4] It takes around an hour to replace the fixture. We chose not to include a contractor cost because installation would probably be done in conjunction with other repairs and renovation, or by the residents. The total cost is somewhat reduced because we have included future savings resulting from lower replacement costs. (Fluorescent bulbs do not have to be replaced as often as incandescents.)

Measure 71: Install Exterior Fluorescent. Some sort of exterior light is often left on all night. This may range from a 40 watt incandescent to a 150 watt floodlight. A 30 watt fluorescent fixture (bulb plus ballast) will provide as much light as a 60 watt incandescent bulb, but with less power.[5] Again, the longer-lived fluorescent bulbs require less frequent replacement. There are several screw-in fluorescent fixtures now available; one simply removes the original incandescent bulb and screws in the fluorescent fixture and bulb. However, we assume that a higher quality unit will be installed because some exterior lights do not have sufficient clearance for a screw-in fluorescent fixture. A wide range of fluorescent lights are available from $10 to $20.[6] We have included half an hour of contractor labor and a credit for bulb savings, for a total cost of $33.

Measure 73: Replace 100 Watt Incandescent with Fluorescent (1). This measure applies to the home's most intensively used lamp (outside the kitchen). Retrofit fluorescents are now available that screw into most lamps. Warm-white fluorescent bulbs provide light with a spectrum virtually identical to incandescent lights. These units are "rapid start," so there is no annoying delay after switching them on. A 22 watt fluorescent circline bulb provides the same light as a 100 watt incandescent bulb.[7] We assume the light is used 800 hours per year. The savings is thus 55 kWh per year. Each unit costs $24.[8] We included a credit for future bulb savings, giving a total cost of $21.

Measure 97: Replace 100 Watt Incandescent with Fluorescent (2). This measure is identical to measure 73 except that it applies to a light used less often, namely 600 hours per year. The power savings are the same, but due to fewer hours of use, the energy savings are smaller (41 kWh). All other assumptions remain unchanged.

Measure 72: Replace Three-Way Incandescent with Fluorescent. Three-way fluorescent light fixtures are now available. These fixtures fit most lamps and simply screw in. A warm-white fluorescent bulb provides light with a spectrum virtually identical to an incandescent bulb. Fluorescents save more money here because three-way incandescent bulbs are especially expensive and need to be replaced three to five times as often as fluorescents. We assume the light being replaced operates at the equivalent of 800 hours of 100 watt light. A 32 watt three-way fluorescent bulb could replace the incandescent, resulting in a 58 watt power reduction and an electricity savings of 46 kWh per year. Typical three-way fluorescent fixtures cost $34.[9] We included a credit for future bulb savings, giving a total cost of $27.

Measure 98: Replace 100 Watt Incandescent with Fluorescent (3). This measure is identical to measures 73 and 97 only it is applied to a less frequently used light (400 hours per year). The payback is naturally slower, though still economic. This measure saves 27 kWh per year. All other assumptions remain unchanged.

Measure 74: Replace 75 Watt Incandescent with Fluorescent. Virtually every home has a 75 watt incandescent bulb, and most have several of them. One of them could be replaced by a 22 watt fluorescent bulb. This unit would actually provide more illumination than the original incandescent and use less power. We assume that the 75 watt incandescent operates 500 hours per year. It would be replaced by a 22 watt fluorescent bulb (32 watt fixture), identical to measure 73. This will save 22 kWh per year.

REFERENCES AND NOTES

1. General Electric press conference announcing the development of the Electronic Halarc bulb (London, June 14, 1979).

2. The Halarc bulb has two settings, low and high, consuming 25 and 55 watts, respectively. We assume that two-thirds of the time the bulb will be used at its lower setting. For power savings at 50 and 95 watts at the low and high settings, respectively, we obtained an average yearly saving of 50 kWh per year.

3. The General Electric Lamp Catalog specifies that a 60 watt incandescent provides between 600 and 850 lumens (a measure of illumination) when new. A 22 watt fluorescent is rated at 1,000 lumens new, while a 32 watt fluorescent has a 1,800 lumen rating.

4. Sears, 1979.

5. A 60 watt incandescent will provide about 850 lumens; a 22 watt fluorescent "Circline" will provide 1,000 lumens (GE Lamp Catalog).

6. Sears, 1979.

7. Sears now sells a 22 watt fluorescent "Circline" lamp (plus 10 watt ballast) that screws easily into a conventional lamp socket. It provides as much light as a 100 watt incandescent because the ballast is a solid-state high-frequency type (Sears, 1979).

8. Sears, 1979.

9. Sears, 1979.

10. In a market research study (probably of single-family homes only) done before 1975, PG&E estimated 1,200 kWh per year as the typical amount of electricity used for lighting. In 1976, R.D. Clear and D.B Goldstein estimated 1,130 kWh per year (in Berman et al., 1976). Because turning off lights is the most obvious way to conserve energy in the home, we suspect that the average electricity used for lighting has fallen in the last few years.

STATEWIDE SAVINGS

About 9.4 TWh (19% of the total residential electricity) is used for lighting in the residential sector. The average household uses 1,070 kWh per year for lighting.[10]

Measure 83: Replace Three-Way Incandescent with High-Efficiency Bulbs. Most three-way bulbs are in table lamps. We assume that 25% of the three-way bulbs could be replaced with high-efficiency bulbs, such as General Electric's "Halarc."

Measure 69: Install Fluorescent in Kitchen. Most new homes already have fluorescent lights in the kitchen, so this measure applies primarily to older houses. We estimate that roughly 40% of the homes are eligible for this conversion. The conversion would occur rather slowly, mainly in the process of renovation rather than retrofitting.

Measure 71: Install Exterior Fluorescent. Not every house consistently uses an exterior light. In addition, fluorescent fixtures cannot fit in every incandescent socket. We believe about 30% of all homes could implement this conservation measure.

Measure 73: Replace 100 Watt Incandescent with Fluorescent (1). Virtually every home has a 100 watt incandescent bulb in use. However, it is possible it could be used less than our assumed 800 hours or be difficult to replace with a fluorescent. We estimate that 70% of all homes are eligible for this measure.

Measure 97: Replace 100 Watt Incandescent with Fluorescent (2). We estimate that 80% of the homes have a 100 watt incandescent light operating 600 hours or more per year that can be converted to fluorescent.

Measure 72: Replace Three-Way Incandescent with Fluorescent. We assume that 75% of the homes are eligible for this measure; the other homes use the high-efficiency bulbs described in measure 83.

Measure 98: Replace 100 Watt Incandescent with Fluorescent (3). We estimate that 80% of the homes have a 100 watt incandescent light operating 400 or more hours per year that can be converted to fluorescent.

Measure 74: Replace 75 Watt Incandescent with Fluorescent. We estimate that 80% of all homes have a 75 watt incandescent suitable for replacement with a fluorescent.

Air Conditioning

THE SUPPLY CURVE

The supply curve for air conditioning (Figure 2-14) begins with two low-cost measures that save relatively large amounts of electricity. It then climbs sharply. The cumulative savings after the last measure amounts to 29% of the estimated 3,500 GWh per year consumed by room and central air conditioners.

The simple turnover of stock (first two measures) will result in a roughly 9% reduction in electricity use due to California Energy Commission standards for air conditioners. The cost of conserved electricity for the third measure (R-11 insulation in walls) is somewhat arbitrary since we apportioned the insulation cost between heating and cooling savings.*

Once the air conditioner meets the CEC standard and the walls are insulated, further measures are significantly more expensive. Nevertheless, residential air conditioning use coincides with the peak demand for electricity. Thus, any reduction in air conditioning demand translates directly into a need for fewer power plants. Furthermore, the energy produced by peak power plants is especially expensive. If consumers paid the real cost of peak electricity, perhaps in the form of a rate schedule based on time of day, further conservation measures would be economic. (Peak electricity should probably cost around 10 cents per kWh.) The great disparity between the costs of conserving and producing a watt of air conditioning demand is a good reason for advocating a standard stricter than conventional life-cycle accounting would justify.

Using 10 cents per kWh as a reference price, nearly one-third of all of the electricity currently used by air conditioners could be conserved economically. On a hot summer day, residential air conditioners use almost a fifth of California's total electrical capacity. Clearly, reduction in air conditioning use could have an enormous impact on the need for power plants.

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*In some climates, insulation saves more air-conditioning energy than space-heating energy.

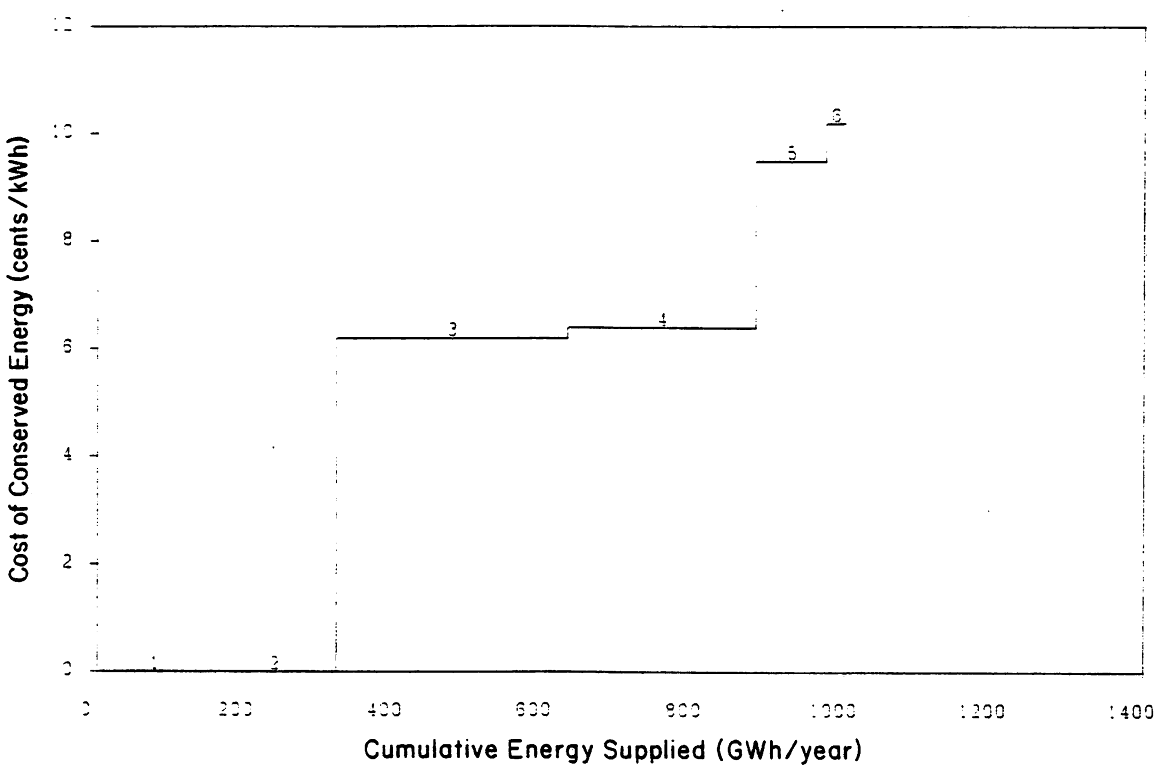

Figure 2-14. Supply curve of conserved electricity: air conditioning. Total electricity used for residential air conditioning in California in 1978 was 3,500 GWh.

Table 2-33. Table of data for the supply curve in Figure 2-14. The time horizon is 10 years; the discount rate is five percent. Costs of conserved energy are in 1979 dollars.

		Cost of Conserved Energy (cents/kWh)		Energy Supplied (GWh/y)		Total Dollars Invested (millions)	Meas. No.
	Measure*	Marginal	Average	Per Meas.	Total		
1	CEC standard room A/C	0	0	152.1	152	0	94
2	CEC standard central A/C	0	0	168.0	320	0	90
3	Central A/C wall insulation	6.2	3.0	308.7	629	238	89
4	Buy most efficient central A/C	6.4	4.0	252.0	881	406	59
5	Window shading for central A/C	9.5	4.5	94.5	975	475	91
6	Buy most efficient room A/C	10.2	4.7	24.3	1,000	497	60

*The conservation measures are listed in the order they appear in the supply curve, i.e., according to cost of conserved energy. The measure number (last column) is the number used throughout the report to identify the measure.

ROOM AIR CONDITIONERS

Conservation Measures

Many homes are only partly air conditioned. They rely on one or more room-size units to keep the most important areas cool. Generally, these units are undersized. As a consequence, measures that reduce cooling loads (e.g., insulation or window shading) will probably not result in less air conditioner operation, but more rooms will be cooled. For this reason, wall and ceiling insulation, shaded windows, and similar measures will more likely simply increase comfort rather than save energy.

As a typical room air conditioner, we selected a 10,000 Btu per hour, 115-volt unit with an energy efficiency ratio (EER) of 6.0 (equal to a coefficient of performance, COP, of 1.76).[1] A 10,000 Btu/hour air conditioner will cool one or two rooms. In inland California (where air conditioners are most common and cooling loads are the greatest), a typical room air conditioner operates 650 hours per year.[2] Under these conditions, the air conditioner would use 1,080 kWh per year.

Measure 94: Replace Unit with One Meeting CEC Standards. New room air conditioners meeting the 1979 CEC standards use about 25% less energy than the units being replaced. If the old unit has a very low EER, say 5.0, then it could pay, on energy savings alone, to retire it prematurely.

The 1979 CEC standard for 115-volt room air conditioners is EER = 8.7 (COP = 2.55). The standard requires a slightly lower EER (8.2) for units operating above 200 volts. (It is more difficult to achieve high efficiencies in the 200+ volt models.)[3] Since the standards are mandatory, the additional investment is zero.

Measure 60: Buy Most Efficient Model Available. Air conditioners with efficiencies exceeding the CEC standards are now widely available. Manufacturers have achieved this by, for example, enlarging condenser coils and improving motor efficiencies. The best 10,000 Btu/hour air conditioner unit has an EER of about 10.6.[4] We estimate that efficiency improvements cost 25 cents per watt, or $52 to boost EER from 8.7 to 10.6.[5]

Replacing an air conditioner of EER = 6.0 with one of EER = 10.6 results in an electricity savings of roughly 40% while still providing the same amount of "coolth." Table 2-34 summarizes our assumptions and calculations for measures 94 and 60.

Measure 95: Replace Unit with Evaporative Cooler. Evaporative coolers have been used in California for over a century. They are particularly effective in hot, dry climates and, as a result, are widely used in the Central Valley region. Evaporative coolers provide slightly more

Table 2-34. Typical 10,000 Btu/hour room air conditioner energy use.

	Electrical Input	
EER	Power (kW)	Electricity[a] (kWh)
6	1.67	1,080
8.7	1.15	750
10.6	0.94	610

[a] Based on 650 cooling hours per year.

humid--some claim sticky--cool air than conventional absorption air conditioners. Because of this, the conversion may be unacceptable to some people. Nevertheless, evaporative coolers remain a viable conservation measure for many homes. Manufacturers claim that evaporative coolers save 66-85% of the electricity required by conventional air conditioners.[6] This corresponds to a savings of over 710 kWh per year (taking the lower bound of the estimate). A good 10,000 Btu/hour cooler costs about $250, that is, $100 less than an air conditioner with comparable output.

Statewide Savings

There are about 1.46 million room air conditioners in California (an equivalent saturation of 16%). Altogether, they consume about 0.7 TWh of electricity. The average EER of room air conditioners already in use is around 6.5.[7] Room air conditioners have an average lifetime of 12 years.[8]

Measure 94: Replace Unit with One Meeting CEC Standards. The weighted average EER of room air conditioners complying with 1979 CEC standards is 8.8.[9] Room air conditioners have an average cooling capacity of 12,000 Btu per hour[10] and consume 480 kWh per year.[11] This is low, probably because a large number of room air conditioners are located in the Los Angeles area, where the number of cooling hours is not very great, relative to the Central Valley. Hotter regions generally have more central units. The average energy savings from this measure will be about 125 kWh per year. Since all new units must comply with CEC standards, we have not included an additional cost to the consumer.

Measure 60: Buy Most Efficient Model Available. There are room air conditioners with efficiencies well above CEC standards. The weighted maximum EER is 9.3.[12] Assuming that improved efficiency costs 25 cents per electrical watt input, the average additional cost will be $18. Table 2-35 summarizes our calculations for measures 94 and 60.

Table 2-35. Average annual energy used by room air conditioners.

EER	Size (kW_e input)	Electricity (kWh/yr)[a]
6.5	1.85	480
8.8	1.36	355
9.3	1.29	335

[a] Assumes 12,000 Btu/hour capacity, 260 operating hours/year.

CENTRAL AIR CONDITIONERS

Conservation Measures

Air conditioning requirements, and the way in which they are provided, vary widely through the state. Likewise, appropriate conservation measures also vary. We chose an inland California climate (like Fresno) for our calculations in order to demonstrate the importance of conservation in a region with a large demand for space cooling. Obviously, the energy savings from the measures will be lower in most other regions of California.

We assume that a typical Fresno home is equipped with a 36,000 Btu per hour (3 ton) central air conditioning unit using 3,600 kWh per year. This is based on 650 hours cooling,[13] and a unit efficiency of EER = 6.5.[14] We assume the house already has R-11 insulation in the attic.

The savings of the first four measures are sequential; these measures involve both reducing the cooling load and improving the efficiency of the cooling unit. The last two measures, evaporative coolers and whole-house fans, are two alternatives that rely on increased ventilation to provide cooling.

Measure 89: Add R-11 Insulation to Walls.[15] Summer heat gains through walls can be a greater factor in energy use than winter heat losses. The sun shines directly on the the walls and heats them considerably above the air temperature ("sol-air temperature"). Thus, heat gains through walls in the summer will exceed those predicted by a simple calculation based on the indoor-outdoor temperature difference. As a result, wall insulation will lead to a significant drop in cooling losses.

Computer simulations on the DOE-2 model indicate that R-11 wall insulation in our representative Fresno house will cut cooling loads 17%, or 610 kWh per year.[16] We have apportioned the estimated $900 cost of adding R-11 between the cooling and heating savings for uninsulated houses with central air conditioners (see measures 5, 23, 49, 106 p.35).

Measure 90: Replace Unit with One Meeting CEC Standard. Central air conditioners meeting the 1979 CEC standard (EER = 8.0)[17] use substantially less electricity than the average of older units. Thus, replacement of the old central unit (when it wears out) will itself save energy, without any further measures by the homeowner. In addition, the retrofit of R-11 in the walls (measure 89) will have lowered the peak cooling load, so the new unit can be smaller. The lower cost for a smaller unit will partly offset the increase in cost for higher efficiency.

The R-11 insulation allows a downsizing from 36,000 to 30,000 Btu per hour output or, in terms of electrical input, 5.5 to 4.6 kW (at EER = 6.5) or 4.5 to 3.7 kW (at EER = 8.0). We estimate that downsizing saves 12 cents per watt (electric).[18] But since the consumer will be choosing only between units meeting the CEC standard, the appropriate power savings from downsizing is 4.50 kW - 3.75 kW = 0.75 kW, giving a cash savings of $90. However, we have not decreased the investment cost for this measure, but note that air conditioner downsizing could be a significant economic benefit of wall insulation. Table 2-36 shows the path of our (tortuous) logic. Since this measure merely reflects existing CEC regulations, it requires no additional investment.

Measure 59: Buy Most Efficient Unit Available. There are central air conditioning units with efficiencies well above the CEC standard.[19] The most efficient models have EERs around 10.3 (although we expect several models with EERs exceeding 13 to be available before the summer of 1981). We estimate that they cost $210 more than a model that simply meets the CEC standard of EER = 8.0.[20] A typical saving will be 480 kWh per year.

Measure 91: Window Shading. Solar heat gains through windows add greatly to cooling loads. There is a wide variety of options available to limit such gains. These range from simple paste-on reflective films to permanent exterior shading devices (like awnings). In addition to saving energy, shaded windows increase occupant comfort and reduce fading of materials.

Table 2-36. Conservation alternatives for typical central air-conditioning units in the Central Valley. The arrows show the sequence of application of measures 89, 90 and 59.

	Capacity (Btu/h)	Operating Time (h/y)	Power Rating (kW_e input) EER 6.5	EER 8.0	EER 10.3
Base case	36,000	650	5.54 ↓	4.50	3.50
With R-11 in walls	30,000	540	4.62 →	3.75 →	2.91

In this analysis, we chose a measure of moderate cost, namely reflective mylar film in a tight track. When not in use, the film is stored rolled up like a blind. The film can be drawn down in its track when the sun shines through the window. A track system costs about $110 for a 16 square foot window.[21] The film cuts solar transmission from 96% to 20%; that is, only 20% of the sun's heat will enter the room. We have assumed that the reflective film is installed in one 16 square foot, west-facing window. This reduces heat gain by 1.7 million Btu per cooling season.[22] This will lower cooling loads 10%. At an EER = 6.5, this would save 260 kWh per year. But with our efficient unit of EER = 10.3, the energy saving is only 160 kWh per year. (The film can also be pulled down during winter nights to reduce heat loss through windows; we did not include this saving.) The track system keeps the mylar from wrinkling, which extends the lifetime beyond most solar control films.

Measure 92: Replace Unit with Evaporative Cooler. Manufacturers claim that evaporative coolers save 66-85% of the electricity required by a central air conditioner. A good evaporative cooler, sufficient to cool a whole house in a dry climate, costs about $350-$500 less than a conventional air conditioner. Assuming a 66% savings (the lower estimate), the annual energy savings from replacement of a central air conditioner with an evaporative cooler would be about 2,370 kWh.

Measure 93: Install Whole-House Attic Fan. A whole-house fan provides more comfort by increasing ventilation. By raising the inside air speed to an equivalent of 10 air changes per hour, the occupants can tolerate slightly higher indoor temperatures. This measure can only be applied in regions where more than 90% of the summer hours have temperatures less than the high 80s. In such a climate, 400 cooling hours per cooling season is typical. A fully automatic whole-house fan retails for

$250 and draws about 400 watts.[23] (It takes about half a day for a professional to install.)

Statewide Savings

About 1.26 million homes in California have central air conditioners (a saturation of 14%). The average central air conditioner in a single-family home uses about 2,500 kWh per year; in a multifamily unit it uses 1,470 kWh per year. We estimate that, altogether, central air conditioners use 2.8 TWh per year.

<u>Measure 89: Add R-11 Insulation to Walls.</u> We estimate that 20% of gas-heated and nearly all electric-heated homes already have wall insulation.[24] The saturation of central air conditioners is probably higher in newer houses, which are also more likely to have wall insulation. We assume that 70% of the homes with central air conditioning systems lack wall insulation; that is, 70% of the houses are eligible for this measure. We estimate that a central air conditioner in an average uninsulated single-family house uses 2,320 kWh per year. Wall insulation saves an average of 400 kWh per year for air conditioning in a single-family home. But about 30% of central air conditioning systems are in multifamily units.[25] The average saving for <u>all</u> homes would be about 350 kWh per year.

It will probably be cheaper to insulate multifamily units because the wall area per unit is smaller. We estimate an average cost of $900 for retrofitting wall insulation in a single-family home, and $350 for a multifamily unit.[26] This cost is apportioned between heating and cooling savings.

<u>Measure 90: Replace Unit with One Meeting CEC Standard.</u> The average EER in the 1978 central air conditioner stock is 7.0.[27] CEC standards prohibit sale of central air conditioners with an EER less than 8.0. The energy savings is based on the difference of the electrical power input (4.29 - 3.75 = 0.54 kW), multiplied by the average 375 operating hours. The average energy savings from compliance with CEC standards is thus 200 kWh per year. There is no investment cost assigned to this measure because the consumer has no choice. Table 2-37 lists our assumptions.

<u>Measure 59: Buy Most Efficient Model Available.</u> The maximum EER of central air conditioners, weighted by sales, is 10.2.[28] The savings are (3.75 kW - 2.94 kW) x 375 hours = 300 kWh. Again, using our estimate that efficiency improvements cost 25 cents per electrical watt input, the average cost is $200. Table 2-37 lists our assumptions.

Table 2-37. Conservation alternatives for average central air conditioners. The arrows show the sequence of application of measures 89, 90 and 59.

	Cooling capacity (Btu/h)	Operating time (h/y)	Size (kW_e input)		
			EER 7.0	EER 8.0	EER 10.2
Base case	36,000	450	5.14 ↓	4.50	3.53
with R-11 in walls	30,000	375	4.29 →	3.75 →	2.94

Measure 91: Window Shading. The savings from this measure depend on the orientation of the shaded windows. (Windows facing west collect the most heat in summer.) We estimate that there will be an average saving of 150 kWh per year. This assumes (1) reflective film is placed on one 16 square foot, west-facing window, and (2) half of the centrally air conditioned homes have an eligible window (some, especially multifamily residences, have none and some already have shade trees or awnings).

REFERENCES AND NOTES

1.

$$EER = \frac{\text{cooling capacity (Btu/h)}}{\text{power rating (watts)}}$$

$$COP = \frac{\text{rate of heat removal (watts)}}{\text{power rating (watts)}}$$

$$= \frac{EER}{3.41\ \text{(Btu/Wh)}}$$

Throughout, EERs are seasonal energy efficiency ratios, which are lower than steady-state EERs. Most room air conditioners available in 1972 had EERs less than 7 (Moyers, 1973).

2. A PG&E survey in 1963-64 in the Fresno area gave an average of 700 operating hours (D.B. Goldstein and R.B. Weisenmiller in Berman et al., 1976, Appendix 4).

3. CEC, 1978e, and 1979b.

4. Ibid.

5. Although the price of air conditioners usually increases with efficiency, the size of the price increase is difficult to estimate. One attempt at a correlation, for 1973 room air conditioners, is

$$\text{cost} = 0.375\ S^{0.583}\ E^{0.549},$$

where S = capacity in Btu per hour and E = EER (Dole, 1975, p.101). For our typical case, this gives a cost of 15 cents for each watt of conserved power.

Moyers also looked at the efficiencies and retail prices of the room air conditioners produced in 1973 by three manufacturers. Among the 10,000 Btu per hour models, one with an EER of 7.4 was only $10 more expensive than one with an EER of 5.4 (equivalent to 2 cents per watt) and $20 cheaper than another with an EER of 6.7 (all three were made by the same manufacturer). Going to a much higher EER (11.0) cost about 15 cents per watt. Moyers concluded that "improving the efficiency from 6 to 10 Btu per Wh increases the price from 13 to 29%, depending on the manufacturer" (Moyers, 1973, p.25 and p.26).

For a survey of more recent prices and efficiencies of room air conditioners, see Consumers' Research magazine, June 1979. The high-efficiency room air conditioners sold by Sears cost $40 more than the standard units, regardless of cooling capacity or size of the improvement in efficiency (Sears, 1979). It seems virtually impossible to generalize, but 25 cents per watt seems adequate to cover price increases due to efficiency improvements.

6. Sears, 1979.

7. CEC, 1979c, p.5-73 and p.E-24.

8. Estimate by David Goldstein, Energy Efficient Buildings Program, Lawrence Berkeley Laboratory, August, 1979.

9. See note 7.

10. CEC, 1979c, pp.E-25, 29.

11. Based on statistically estimated energy consumptions and saturations for CEC forecast zones (CEC, 1979c, p.4-90 to 4-107, and p.5-73).

12. See note 10.

13. See note 2.

14. On the average, central air conditioners are slightly more efficient than room air conditioners (Dole, 1975, p.100).

15. Insulating the attic will also reduce cooling loads, but we suspect most centrally air conditioned homes already have some ceiling insulation.

16. DOE-2 is a computer model of building energy loads developed at Lawrence Berkeley Laboratory.

17. CEC, 1978e.

18. This was estimated by comparing the prices of central air conditioners with the same efficiency but different cooling capacity.

19. CEC, 1978a.

20. Using an increase in price of 25 cents per watt (see note 5).

21. A series of these blinds with different reflectivities are marketed by Shadeco. The least reflective film track cassette systems retail for around $4 per square foot.

22. Calculation based on amount of sunlight falling on one square foot of west-facing vertical surface in Fresno during the cooling season, as given by Kusuda and Ishii, 1977.

23. Sears, 1979.

24. This is discussed fully in the section "Space Heating" (see pp.48,52). The wall insulation in most electrically heated houses is only R-7.

25. Saturations of central air conditioning systems by housing type are given for 15 forecast zones in CEC, 1979c, pp.4-90 to 4-107.

26. See note 24.

27. The CEC assumes an average EER of 6.5 for central air conditioning systems (CEC, 1979c, p.5-68) but this is based on estimates in 1975 and 1976. Also, central air conditioners are typically more efficient than room air conditioners (Dole, 1975, p.100).

28. CEC, 1979c, p.E-29.

Electric Appliances

THE SUPPLY CURVE

In the supply curve for electric appliances (Figure 2-15) the cost of conserved energy climbs sharply after two no-cost measures and one low-cost measure. The cumulative savings after the final measure is about 17% of the 13,700 GWh per year used by electric appliances.

Simple turnover of the television stock will result in about a 28% drop in electrical consumption by televisions. This amount of conserved electricity is nearly one fifth of a typical power plant's output.

The electricity saved from the switch-to-gas measures (the fourth and sixth on the curve) is actually somewhat higher than indicated. We subtracted the energy needed by the new gas appliance from the electricity savings (at 10,300 Btu per kWh), so part of the electricity savings is cancelled out by the increase in gas consumption. These measures are expensive because of the high costs of conversion from electric to gas.

One gas conservation measure, pool covers, also saves electricity by shortening filter pump operating time. The reduced demand coincides with the summer peak, so the savings are particularly important (because peak power as well as electricity is saved).*

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* PG&E has at least one program to switch pool pumps to off-peak hours. This will not save any electricity, but it will save peaking facilities. One scheme, reported in <u>PG&E Progress</u> (January 1980), involved resetting clocks on swimming pool filter pumps to operate during off-peak hours. This shaved 15 megawatts off the utility's peak and cost only $64,000. The cost of conserved <u>power</u> in this project was only $4 per kW, a fraction of the cost of supplying peak power (somewhere around $300-$800 per kW).

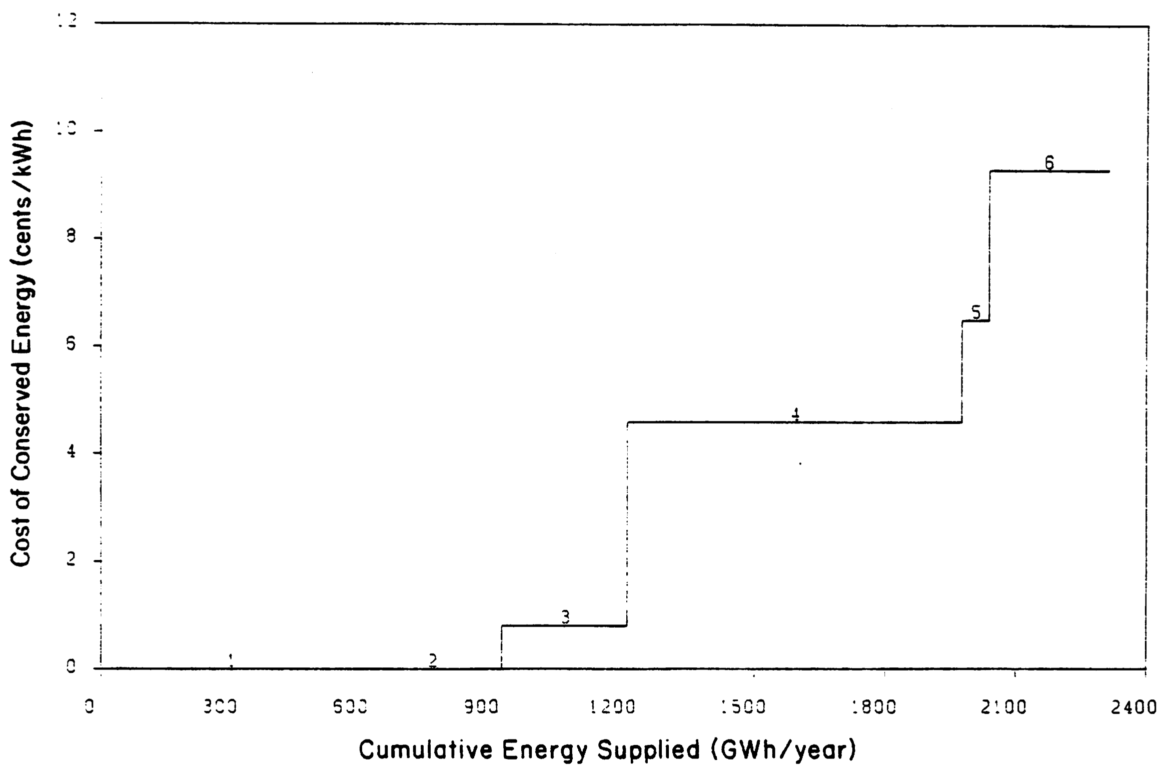

Figure 2-15. Supply curve of conserved electricity: electric appliances. Total electricity used by residential miscellaneous electric appliances in California in 1978 was 13,700 GWh.

Table 2-38. Table of data for the supply curve in Figure 2-15. The time horizon is 10 years; the discount rate is five percent. Costs of conserved energy are in 1979 dollars.

	Measure*	Cost of Conserved Energy (cents/kWh)		Energy Supplied (GWh/y)		Total Dollars Invested (millions)	Meas. No.
		Marginal	Average	Per Meas.	Total		
1	Solid-state color TV	0	0	599.1	599	0	68
2	Solid-state black-and-white TV	0	0	322.3	921	0	67
3	Pool filter savings from cover	.8	.2	287.0	1,208	4	70
4	Switch to gas clothes dryer	4.6	1.9	766.7	1,975	279	45
5	Buy most efficient elec. dryer	6.5	2.1	62.0	2,037	310	57
6	Switch to gas range	9.3	2.9	274.2	2,311	506	43

*The conservation measures are listed in the order they appear in the supply curve, i.e., according to cost of conserved energy. The measure number (last column) is the number used throughout the report to identify the measure.

ELECTRIC CLOTHES DRYERS

Conservation Measures

Electric clothes dryers use about 1,180 kWh per year in a single-family house and 790 kWh per year in a multifamily residence.[1]

Measure 45: Switch to Gas Dryer. As the existing stock of electric dryers wears out, some consumers have the opportunity to replace them with gas dryers. Although this measure saves electricity, it increases gas use by about 50 therms per year in a single-family home and 35 therms per year in a multifamily residence.[2] To trade off the electricity savings with the increased gas usage, we converted the gas to electricity at PG&E's fossil fuel heat rate of 10,300 Btu/kWh. Table 2-39 summarizes our calculations. A gas clothes dryer costs about $40 more than a comparable electric model.[3] We allowed an additional $150 to cover the cost of extending gas lines to the laundry.

Table 2-39. Savings from replacing electric clothes dryers with gas clothes dryers.

	Electric Dryer Use (kWh/y)	Gas Dryer Use (therms/y)	Gas Dryer Elec. Equiv.[a] (kWh/y)	Electricity Savings (kWh/y)
Single-family	1,200	50	490	710
Multifamily	790	35	340	450

[a] Assumes a heat rate of 10,300 Btu/kWh.

Measure 57: Buy Efficient Electric Clothes Dryer. Low-cost clothes dryers have manual timers, which allow overdrying. Two types of automatic sensors now exist to switch off the dryer when the clothes are dry. The cheaper type has a thermostat that senses the exhaust temperature. The expensive type has a solid-state sensor that "feels" moisture in the clothes. The machines with sensors cost roughly $50 more than ones with manual timers,[4] but they also have other features covered by the added cost. We assume the sensor will save 10% of the dryer's electricity use.

Statewide Savings

In 1978 about 35% of all California households had electric clothes dryers.[5] Most of them are in single-family homes; we estimate the average electric clothes dryer uses 1,000 kWh per year. Thus, the 3.1 million electric dryers in California use roughly 3.1 TWh, about 6% of the total residential electricity. The average lifetime of an electric dryer is 15 years.[6]

<u>Measure 45: Switch to Gas Dryer.</u> About 70% of electric clothes dryers are in homes that already use gas for heating.[7] Based on our estimates of energy use of gas dryers, we estimate that the average pilotless gas dryer that replaces the electric model will use 48 therms per year. At a conversion rate of 10,300 Btu per kWh, the energy saved is 530 kWh per year (1,000 kWh - 48 therms).

<u>Measure 57: Buy Efficient Electric Clothes Dryer.</u> We estimate that the 30% of current electric dryers that cannot be converted to gas will all be replaced with efficient electric dryers.

ELECTRIC RANGES

Conservation Measures

Once an electric range is installed it is difficult to conserve energy through specific measures. However, changes in lifestyle are reducing the amount of cooking done on the range. There has been a trend toward purchase of prepared foods ("fast foods") that require no cooking at home. (Consumer spending on food has been partly diverted from the supermarkets to eating out.) In addition, several new appliances have taken over traditional uses of the range. These include toaster-ovens, microwave ovens, convection ovens, crock-pots, and electric skillets. Happily, these appliances, while purchased for convenience, are also more efficient than electric ranges. Thus, barring any momentous change in behavior, consumers with electric ranges will gradually use the range less.

We estimate typical electricity use of ranges in single-family homes to be 750 kWh per yr, and 550 kWh per yr in multifamily residences.[8] Ranges in multifamily residences tend to use less energy because they are smaller and cooking is done for fewer persons.

<u>Measure 43: Switch to Gas Range.</u> Many homes with gas heating have electric ranges and thus could convert to pilot-free gas ranges when the electric ranges are retired. A gas range costs about $50 more than a comparable electric model.[9] In addition, some homes will need an extension of gas lines to the kitchen, which could be very expensive-- we estimate $150. However, many older homes with gas heating will already

have gas lines to the kitchen. Even with the trend over the last two decades of converting from gas to electric ranges, we believe most homes have not removed kitchen gas connections. We assume our typical house is one of these, and allow an additional $50 to cover connecting the new gas range.

The measure itself saves electricity but increases gas use by about 50 therms for a single-family home and 45 therms for a multifamily residence.[10] We converted the natural gas energy to electricity at a rate of 10,300 Btu per kWh (this is close to PG&E's fossil fuel heat rate). We then subtracted that electricity from the range's original electricity use. Table 2-40 summarizes our calculations.

Table 2-40. Savings from replacing electric ranges with gas ranges.

	Electric Range Use (kWh/yr)	Gas Range Use (therms/yr)	Gas Range Elec. Equiv.[a] (kWh/yr)	Elec. Savings (kWh/yr)
Single family	750	50	485	265
Multifamily	550	45	437	113

[a] Assumes a heat rate of 10,300 Btu/kWh.

Statewide Savings

In 1978 about 41% of all California households had electric ranges.[11] We estimate the average electric range uses 680 kWh per year. Thus, in 1978 the 3.7 million electric ranges used about 2.5 TWh, or 5% of total residential electricity. Other specialized electric cooking appliances may use an additional 0.8 TWh.

Measure 43: Switch to Gas Range. Despite the trend toward all-electric kitchens, many homes with electric ranges still have gas connections for either water or space heating. Rough estimates of saturations indicate that at least 85% of all homes have some gas appliance, but 41% have electric ranges.[12] Therefore, about 60% of all homes with electric ranges have gas connections. Of this 60%, we assume that half have gas lines to the kitchen. Hence, the average installation cost is $100. The total cost is the difference between the prices of comparable gas and electric ranges ($50) plus the installation cost, or $150.

Saturations for gas space heating are 90% in single-family homes and 74% in multifamily residences.[13] Electricity savings will consequently be weighted somewhat toward the larger savings in single-family homes.

TELEVISIONS

Conservation Measures

Two countervailing trends have affected the energy use of televisions. First, many people are switching from black-and-white to color sets (about half of the color sets now in California were bought in the last few years).[14] These color sets use more electricity than comparably sized black-and-white models. At the same time, however, older tube-type TV's are being replaced with more efficient solid-state models. Television energy use directly depends on viewing time; external events, such as gas rationing, could easily affect the number of viewing hours.

Measure 67: Replace Black-and-White Televisions with Solid-State Models. An old black-and-white tube-type television uses about 170 kWh per year, although this obviously depends on size and hours watched.[15] New, solid-state sets consume much less electricity, around 40 kWh per year under comparable conditions. These models cost no more; indeed, the tube-models have virtually disappeared from the market. We have assumed a 14-year lifetime.[16] Many people replace televisions long before they actually break down. Since current models use significantly less electricity, consumers gain some energy savings through early retirement of a set.

Measure 68: Replace Color Televisions with Solid-State Models. Color televisions have also undergone a dramatic improvement in efficiency. Thus, the greatest savings will result when the older units are replaced. The earliest models typically used 530 kWh per year.[17] Comparable current models use about 220 kWh per year. Thus, replacing an old color televisions may save about 300 kWh per year. Replacing newer models will save much less. No investment cost has been assigned to this measure since only solid-state models having low electricity consumption are sold. Color televisions last 15 years but are often replaced prematurely because of the attractiveness of the improved quality of newer models.[18]

Measure 96: Eliminate Instant-On Switch. Some consumers might choose to by-pass the instant-on switch on their televisions. This involves either simply pulling the plug out when the television is not in use or installing a switch on the cord. The instant-on feature on older color televisions often uses as much as 100 kWh per year, all of which can be saved.

Statewide Savings

The 13 million television sets in California homes in 1978 consumed about 3.3 TWh, or roughly 6% of total residential electricity. Table 2-41 gives the average electricity consumption of televisions in 1975, the average consumption of new sets bought in 1975, and an estimate for 1980. Based on this table and the way in which the saturations of the two types of sets have changed recently, we estimate that in 1978 a black-and-white set used 130 kWh per year and a color set 330 kWh per year. Table 2-42 summarizes the characteristics of California's (1978) stock of televisions. Despite the extraordinary number of hours people watch televisions, they use a relatively small amount of the total residential electricity.

Table 2-41. Annual electricity use (kWh/year) of televisions in California. (Source: Berman et al., 1976.)

	Black/ white	Color
Average of stock in 1975	140	420
Average of sets bought in 1975	60	255
Projection of sets bought in 1980	35	220

Table 2-42. Characteristics of television stock (1978) in California.

	Black/ white	Color
Saturation[a]	54%	92%
Number (millions)	4.75	8.17
Total electricity use (TWh/yr)	0.6	2.7
Average electricity use (kWh/yr)	130	330

[a]CEC, 1979c, p.4-48.

Measure 67: Replace Black-and-White Televisions with Solid-State Models. The average electricity savings per unit will be 95 kWh per year.

Measure 68: Replace Color Televisions with Solid-State Models. The average energy savings per unit will be 110 kWh per year.

MISCELLANEOUS ELECTRIC APPLIANCES

Conservation Measures

There are dozens of electric appliances that, even when combined, use only a few percent of a home's electricity. Most of them draw little power or are used for short periods. Still, these appliances deserve note even if no specific measures are presented.

Dishwashers use nearly 270 kWh per year. They use much less if the drying cycle is skipped (many people already do this at least part of the time).[19]. Clotheswashers use about 70 kWh per year (excluding water heating requirements).

Waterbeds may be the largest single end use of electricity in smaller homes. Experiments done by Chemelex show that a typical king-size waterbed (the most popular size) needs 115 kWh per month to maintain an 87°F water temperature. Waterbed salespersons commonly estimate 100-200 kWh per month.[20] Conceivably, the addition of insulation around the sides and bottom could lower the energy use, although to our knowledge no experiments have been done. There are new, hybrid waterbeds that contain much less water and have a mattress bonded to the top. These need no heating, yet provide much of the same sensations of a regular waterbed.

Measure 70: Add Pool Cover to Save Electricity. A pool cover saves electricity by reducing the amount of dirt, leaves, and litter that must be removed by the filter and sweep.[21] A typical filter pump uses 3,440 kWh per year, and we estimate that a pool cover could save 40% of this. The assumptions are the same as those discussed in the section "Swimming Pools" (pp.127-8). We apportioned the pool cover cost over two measures; this measure's share was $20 (see measures 38 and 40, p.128).

Statewide Savings

We estimate there are 300,000 waterbeds in California.[22] Assuming 75% of them are heated and use an average of 110 kWh per month, altogether they use 0.3 TWh per year (this comprises about one-half of one percent of California's residential electricity). The 4.5 million dishwashers in California in 1978 used around 1.2 TWh per year. The 6 million clotheswashers used about 0.4 TWh per year. The 410,000 pools used 0.9 TWh for filtering and cleaning (we assume that only heated pools are filtered).

REFERENCES AND NOTES

1. Derived from consumptions estimated by the CEC (1979c, p.5-97).

2. See "Gas Clothes Dryers" (p.120).

3. Consumer Reports, January 1979.

4. Sears, 1979.

5. Estimated by weighting the saturations of appliances as reported by the major Californian utilities (CEC, 1978c, Appendix A, p.III-43).

6. C.J. Blumstein et al., in Berman et al., 1976, Appendix 13.

7. See note 5.

8. CEC, 1979c, p.5-111. In 1976 R.D. Clear and D.B. Goldstein estimated the average electric range use as 1,200 kWh per year but thought this probably included other small electric cooking appliances.

9. See note 4.

10. See "Gas Ranges" (p.121).

11. See note 5.

12. Ibid.

13. See "Space Heating" (p.41).

14. The following table shows saturations of televisions as estimated in 1975 by Berman et al., and in 1978 by the CEC Forecasting Group:

	1975	1978
Black/white	80%	54%
Color	75	92

This seems to suggest that (1) a quarter of the color televisions in 1978 were purchased in the preceding three years and (2) a large number of black-and-white televisions have been prematurely junked.

15. R.D. Clear and D.B. Goldstein (in Berman et al., 1976, Appendix 9) estimate that the average viewing time is 1,700 hours per year for color televisions and 850 hours per year for black-and-white televisions (more families have a color set as their only television). Old color TV's draw about 310 watts and old black-and-white TV's draw about 200 watts. New solid-state units average 131 and 42 watts, respectively.

16. See note 6.

17. See note 15.

18. See note 6.

19. CEC, 1979c, p.5-91 and p.5-119.

20. Tests done by the Iowa Electric Light and Power Company indicate that the lower end of the range is more likely.

21. According to the National Swimming Institute, most private pools require 6-8 hours of filtration a day. Use of a pool cover should cut this by about 40%.

22. In the July/August 1977 issue of the Journal of Property Management, William C. Moore states that "over two million Americans have purchased waterbeds." Given the rapid growth in sales and California's fraction of the national population, a reasonable estimate for California is 300,000.

Gas Appliances

We have not presented a supply curve for gas appliances because we include only three measures. Two of these measures, buying new gas stoves and clothes dryers with spark ignition devices, are already incorporated in the CEC standards. The elimination of pilot lights as the stock of gas ranges and clothes dryers turns over should see a 20% reduction in the gas consumed by these appliances. The third measure, buying an efficient gas clothes dryer, is very expensive.

GAS CLOTHES DRYERS

Conservation Measures

With the exception of a change in the amount of drying done, no conservation measures are practical for an existing dryer. Some savings can be gained through natural turnover as pilot lights are phased out. There is some variation in dryer energy use among single- and multifamily homes (Table 2-43).

Measure 44: Replace Dryer with Spark Ignition Model. The CEC now requires all new gas clothes dryers to be equipped with spark ignition. Thus, the consumer need not invest extra money for this measure. A pilot light in a dryer uses roughly 30 therms per year; a spark ignition system will save all of this.

Measure 56: Buy Efficient Gas Clothes Dryer. As with electric dryers, a gas dryer with a sensor costs $50 more than one with a manual timer. We estimate that the sensor saves 10% of the gas.

Table 2-43. Annual energy use (therms/year) of the typical gas clothes dryer.[a]

	Single family	Multi-family
With pilot	80	65
With spark ignition	50	35

[a]Derived from estimates by the CEC (1979c, p.5-97). for electric clothes dryers. Gas clothes dryers have an efficiency of 80%; the pilot lights burn 350 Btu per hour (Rosenfeld, 1977, p.20).

Statewide Savings

In 1978 roughly 27% of all homes, or 2.4 million, had gas clothes dryers.[1] The average lifetime is 15 years.[2] Average use is about 57 therms per year,[3] hence statewide consumption is about 14 TBtu, or 2% of total residential gas use.

Measure 44: Replace Dryer with Spark Ignition Model. About 30% of all gas dryers still have pilot lights.[4] These units are probably older than average; hence, normal turnover will realize the potential savings in less than 10 years.

Measure 56: Buy Efficient Gas Clothes Dryer. All existing gas clothes dryers, plus those that could conceivably replace 70% of the electric dryers (measure 45, p.112), are eligible for this measure.

GAS RANGES

Conservation Measures

It is hard to lower the energy use of gas ranges without changing cooking habits. Nevertheless, natural gas used for cooking has probably declined owing to the increasing use of more specialized electrical cooking appliances. (It is not clear whether this shift results in a net energy saving. It is generally wasteful to use electricity as a source of heat but these small appliances use the heat more efficiently.)

Measure 42: Replace Stove with Spark Ignition Model. Spark ignition systems eliminate the need for pilot lights. The CEC now requires all new gas stoves sold to be equipped with spark ignition. The energy savings resulting from this measure will depend on the number of pilot lights replaced. Ranges in single-family homes are generally larger and have more pilots than those in multifamily units. Therefore we estimate that a typical single-family range will save 40 therms per year and a typical multifamily range 30 therms per year (Table 2-44). Consumers will not need to invest extra money to get this option since it is required by law. If the resident has already turned off the top burner pilots on the old range, then the savings with a new range will be somewhat smaller.

Pilot lights also contribute to winter "free heat" and summer cooling loads. In hot regions, spark ignition could save 50 kWh of air conditioning load; we did not include these savings. Likewise, we did not consider internal gains from pilot lights during winter; since the kitchen has excessive internal gains, much of this free heat is vented to maintain a comfortable temperature. In most cases, removal of range pilots will not require compensating furnace output.

Table 2-44. Typical gas consumption (therms/year) in ranges with and without spark ignition.

	Single Family	Multi-family
With pilot lights[a]	90[b]	75[b]
With spark ignition	50	45

[a]Pilot lights on stove tops burn 300 Btu per hour, and in the oven 175 Btu per hour (CEC, 1979c, p.5-110).

[b]In 1975 the PG&E Marketing Research and Services Department estimated an annual use of 108 therms per year for a gas range in a single-family home and 90 therms per year for a one in a multifamily home. Presumably, these values have fallen in the past five years because of increasing use of specialized cooking appliances and "fast food."

Measure 88: Use Electric Hand-Starter for Top Burners. Small, hand-held piezo-electric sparkers can replace pilot lights on stove-top burners. These devices provide a reliable spark, while leaving the hands and fingers a safe distance from the flame. These sparkers cost about $8. We assume they will replace two pilot lights, each using 13 therms per year, and will last five years.[5]

Statewide Savings

In 1978 roughly 57% of all California homes, or 5 million, had gas ranges.[6] There was a trend toward electric stoves in the 1960s, encouraged both by the utilities and the lower prices for electric ranges. We estimate 40 TBtu of gas is used each year in California for cooking. This is about 7% of total residential gas use. The average lifetime of a gas range is 17 years.[7]

Measure 42: Replace Stoves with Spark Ignition Model. Probably 10% of the gas ranges in California already have spark ignition.[8] We estimated the average savings to be 37 therms per year. Our assumptions are shown in Table 2-45. All retired ranges will be replaced with spark ignition models as required by CEC standards.

Table 2-45. Average annual gas use (therms per year) by ranges with and without spark ignition.

	Single Family	Multi-family	Weighted Average
With pilots	90	75	85
With spark ignition	50	45	48
Energy savings	40	30	37

MISCELLANEOUS GAS APPLIANCES

A small amount of gas is used to heat hot tubs and spas, operate decorative fires and lighting (the latter is now illegal, however), and start fires. It is impossible to generalize about the energy used in any of these activities because they depend so much on the individual. We discuss these appliances because, while they may not be significant end uses of energy throughout the state, they may be in a single home.

Heated spas are made of fiberglass and are sometimes not insulated. As a result, after use, the temperature may fall as much as 25°F a day. Redwood tubs ("hot tubs") have better natural insulation. With a good cover (costing $200), the temperature will fall less than 5°F per day after use. A six-foot-diameter tub, the most popular size, typically uses 0.85 therms per day if maintained at the normal use temperature of about 105°F (about 1 therm per day if the pilot light consumption is included).[9] This is about the same amount used by a domestic water heater. We estimate that in 1978 there were about 150,000 hot tubs and spas in California.[10] Assuming that 30% are used regularly, we suspect that altogether they consume 2 TBtu. Since hot tubs and spas have become very popular, this figure has undoubtedly risen since 1978.

Solar heating of spas and hot tubs is relatively cheap, owing to the low temperature of hot water desired. An 80-square-foot collector will provide 70-80% of the hot tub's hot water needs and cost $2000-2500. The cost of conserved energy for such a measure would be around $4 per MBtu (including the tax credit).

REFERENCES AND NOTES

1. Estimated by weighting the saturations of appliances as reported by the major Californian utilities (CEC, 1978c, Appendix A, p.III-43).

2. Table III-3 in CEC, 1978c, gives three different estimates of the lifetime of gas clothes dryers: 11 years (CEC), 10 years (American Gas Assoc.), and 15.3 years (Lawrence Berkeley Lab.). We selected the LBL estimate since the other studies measured the time dryers were retained by the first owner.

3. This is a weighted average of the typical uses given in Table 2-43.

4. Private communication from David Goldstein, Lawrence Berkeley Laboratory, 1979.

5. CEC, 1979c, p.5-110.

6. See Note 1.

7. CEC, 1978c, Appendix A, Table III-3.

8. Estimation by David Goldstein, Lawrence Berkeley Laboratory, 1979.

9. Information about hot tubs and solar installations from Norman Potter, The Tubmakers, Berkeley, CA, June 1980.

10. In 1978, 36% of national sales (by revenue) were to Californians (Spa and Sauna, July 1979). National estimates of units appear in Spa and Sauna, August 1979.

Swimming Pools

THE SUPPLY CURVE

The supply curve for swimming pools (Figure 2-16) begins with two cheap measures conserving most of the gas used to heat pools. The cumulative savings after the final measure amounts to 86% of the estimated 22 TBtu used to heat pools. (Conservation measures for the pool filter pump system, which uses considerable electricity, are discussed in the section "Electric Appliances," p.116.)

Conscientious use of pool covers can save more than three-fourths of all the natural gas used for heating pools at very low costs of conserved energy. The cost of conserved energy for the same measure in the north and south differs because each measure saves more energy in the north. The last two measures, pool heater tune-ups, have a high cost of conserved energy only because there remains so little gas to save after a pool cover is installed. The energy saved would be higher, and the cost of conserved energy would be lower, if the tune-up were done first. The cost of conserved energy would be much lower, and

Solar heating is especially effective for swimming pools because there is a good coincidence of demand for heated water and sunny days. No thermal storage is needed because the pool acts as the reservoir. Finally, since the acceptable water temperature is low, simple collection and plumbing systems can be used.

We have made rough estimates of the cost of solar energy in order to compare it to the cost of conservation.[1] Solar energy ranges from $3 to $9 per MBtu (or about half that if one includes the 55% tax credit). The cost depends upon the amount of conservation done; the less heating required, the more expensive solar energy becomes. Moreover, once a solar collector is installed, many pool owners will probably substitute solar energy for conserved energy by, for example, leaving the pool cover off for longer periods. These factors suggest that a cost range

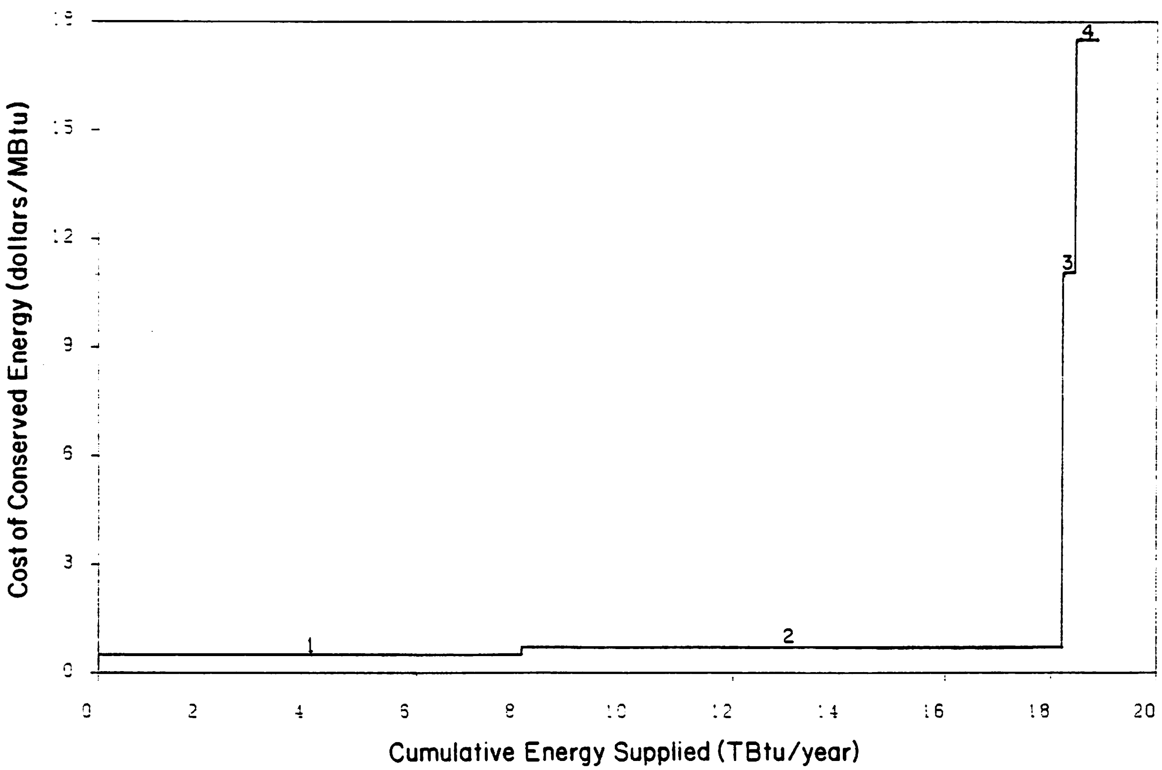

Figure 2-16. Supply curve of conserved gas: swimming pools. Total gas used to heat residential swimming pools in California in 1978 was 22 TBtu.

Table 2-46. Table of data for the supply curve in Figure 2-16. The time horizon is 10 years; the discount rate is five percent. Costs of conserved energy are in 1979 dollars.

	Measure*	Cost of Conserved Energy ($/MBtu)		Energy Supplied (TBtu/y)		Total Dollars Invested	Meas.
		Marginal	Average	Per Meas.	Total	(millions)	No.
1	Pool cover North CA	.5	.5	7.7	8	7	38
2	Pool cover South CA	.7	.6	10.5	18	21	40
3	Tune up pool heater North CA	11.1	.7	.2	18	28	86
4	Tune up pool heater South CA	17.5	1.0	.3	19	41	87

*The conservation measures are listed in the order they appear in the supply curve, i.e., according to cost of conserved energy. The measure number (last column) is the number used throughout the report to identify the measure.

for solar energy is more appropriate than a single figure.

The chief conclusion here is that virtually all of the natural gas used to heat pools can be saved with pool covers, or pool covers in conjunction with solar heating systems.

CONSERVATION MEASURES

Among homes with swimming pools, the gas used to heat the pool constitutes the largest single end-use of energy in the home. Virtually all pools are heated with natural gas. Since pools are typically heated to around 80°F, relatively low-quality heat is needed. Thus, solar heating has enormous potential, especially because maximum insolation levels coincide with the swimming season. In addition, a 55% California solar tax credit, along with a steeply inverted summer gas rate structure, make solar pool heating economically attractive.

We have divided the stock of pools into those in Northern and those in Southern California because a pool's energy use depends significantly on climate. Table 2-47 lists the assumptions for the base case. Given

Table 2-47. Characteristics of a typical residential swimming pool in California.

Size[a]	470 sq. ft.
Temperature[b]	80°F
Heater capacity	130,000 Btu/h
Heater efficiency	65%
Heating season	May-Sept.

[a]Sigworth et al. (1979) give an average pool size of 600 sq. ft. (attributed to a manufacturer of pool solar heaters). An SRI study (1976) gives 550 to 600 sq. ft. as an average size, but this estimate includes pools in the commercial sector. In a private communication, Merle Dowd, energy consultant for the National Swimming Pool Institute, estimated the average area of a residential California pool to be between 450 and 500 sq. ft., 450 sq. ft. being a common size in the Los Angeles area.

[b]SRI, 1976, p.24

Table 2-48. Annual heating needs (therms per year) of a typical pool.

	Year-round Heating	May-Sept. Heating
Northern Calif	5,900	1,350
Southern Calif.	4,590	935

these assumptions, a computer model developed by Wei and his colleagues calculates heating needs.[2] The results are shown in Table 2-48. We used a climate tape for Davis as representative of Northern California and a climate tape for Los Angeles as representative of Southern California. Of course, few residential pools are heated year round. The gas required to heat a swimming pool throughout the year in a climate similar to Davis would heat as many as eight homes.

Measures 38 and 40: Add Pool Cover. Swimming pools lose heat in four ways: evaporation, radiation, convection, and conduction. Once the pool is built, it is difficult to reduce conduction losses through the walls. Fortunately, this route is relatively unimportant. The other losses, evaporation, radiation, and convection, are much greater. Evaporation alone accounts for more than half of all heat loss.

Several types of pool covers are now available. These include plastic "bubble-pack," opaque foam, and plastic sheeting (both clear and black). All types will cut heat loss substantially by reducing evaporative, convective, and radiative losses (when the covers are on).[3] Pool covers are now mandatory in California for outdoor pools equipped with a fossil fuel heater.

A foam pool cover large enough for the average pool costs $250 installed. However, this cost must be apportioned over both the gas savings from the heater and the electricity savings from the filter pump (see the section "Electric Appliances," p.116). To qualify for the state tax credit, pool covers must be guaranteed three years; we have amortized this cost over two years, since there appears to be a range in true lifetimes and performance. We assume the pool cover is the opaque foam type, 0.08" thick, and is removed daily from 10:00 A.M. to 6:00 P.M. Our model predicts that typical savings will be 1,100 therms in Northern California and 780 therms in Southern California. Obviously, savings will be much greater for a pool heated throughout the year.

Measures 86 and 87: Tune Up Pool Heater. In some cases pool heaters can be tuned up to their nameplate efficiency, usually 75%. This measure costs about $100 and must be repeated every two or three years. Table 2-49 shows the savings resulting from a tune-up, with and without a pool cover. New or replacement gas pool heaters installed after January 1982 in California must have efficiencies of at least 75%.

Table 2-49. Annual energy savings (therms/year) from tune-up of pool heater.

	Without cover	With cover
Northern Calif.	180	33
Southern Calif.	125	21

STATEWIDE SAVINGS

There were about 410,000 residential swimming pools in California in 1978.[4] We assume that Southern California has about twice as many as Northern California. At least 60% of the pools are heated, virtually all of them by gas.[5] About 95% of all new pools in 1979 had gas or solar heaters installed.[6]

We assume that 10% of all pools are heated and already have covers, and a further 4% have solar heaters.[7] We assume that pools without covers or collectors are heated only in the summer and use 1,300 therms per year in Northern California and 930 therms per year in Southern California.[8] This gives a total consumption of 22 TBtu per year, or about 4% of the total residential use of gas.

Measures 38 and 40: Add Pool Cover. We estimate that 50% of all swimming pools could be retrofitted with pool covers.

Measures 86 and 87: Tune Up Pool Heater. Some heaters may already be near their nameplate efficiency. We estimate that a tune-up will increase the heater efficiency of pools by an average of 10%.

REFERENCES AND NOTES

1. Our analysis is based on the computer program POOLS developed by Wei and his colleagues. We considered four combinations of solar collectors, pool covers and locations. We assumed that a 360 square foot panel system could heat our typical pool that had no cover. A pool cover cuts demand and permits a smaller collector; a 200 square foot panel system was assumed sufficient for a pool with a cover. We made separate runs for Davis and Los Angeles to represent Northern and Southern California climates. The following table lists our assumptions.

	Large System (no cover)		Small System (with cover)	
	North	South	North	South
Contractor Cost[a]	$2300	$2300	$1300	$1300
Cost with tax credit	$1030	$1030	$590	$590
Delivered energy (MBtu/yr)[b]	51	40	12	9
Gas replaced (MBtu/yr)[c]	79	61	19	14
Value of solar energy ($/MBtu)[d]	2.80	3.60	6.60	8.90
Value with tax credit ($/MBtu)	1.30	1.60	3.00	4.10

[a] Based on $5 per square foot for equipment and $1.50 per square foot for installation (Sigworth et al, 1979).

[b] Results from computer model, POOLS (Wei et al. 1978).

[c] Assumed efficiency of gas heater is 65%.

[d] Based on a real discount rate of 5% and a 15 year amortization period.

2. Wei et al., 1978. This model is called POOLS.

3. Foam and bubble-pack covers give about the same savings; uninsulated plastic sheet covers are cheaper but not so effective. Translucent covers should be left on if the sun is shining and the pool is not in use (Sigworth et al., 1979).

4. According to an SRI study (1976), there were 382,000 swimming pools in California in 1975; about 93% were in the residential sector. The study concluded that an average of 19,000 new pools per year would be built in the following few years. This gives about 408,000 residential pools in 1978.

5. Sigworth et al., 1979. Merle Dowd, energy consultant for the National Swimming Pool Institute, concurs with this estimate.

6. This estimate comes from a representative of the gas pool heater industry.

7. 15,000 pools in California in 1978 had solar heaters according to an estimate by Jerry Yudelson, director, SolarCal Office, State of California, January, 1979.

8. The SRI study (1976) estimated representative consumption to be 1,000 therms per year, but added that this figure was "likely to be conservative."

Part 3
Grand Supply Curves of Natural Gas and Electricity

Grand Supply Curves of Natural Gas and Electricity

In this part, we present supply curves of conserved gas and electricity for the entire residential sector of California. Since these curves summarize our research to some extent, it is worthwhile to review some of our critical assumptions. (Details can, of course, be found in Part 1.) Our critical assumptions are:

Cost of conserved energy is independent of energy prices

A real discount rate of five percent

Amortization times are usually 10 years or less*

Costs reflect contractor installation (not do-it-yourself)

Linear appliance turnover model (at historic rates)

No consumer cost for meeting CEC standards

Potential savings is from 1978 stock only, i.e., no growth is assumed

A ten-year time horizon for implementation of conservation measures

100% implementation of conservation measures

The supply curve of conserved gas (Figure 3-1) begins with several no-cost measures, rises slightly, continues almost flat until 211 teraBtu, climbs gradually to 288 TBtu, and then rises sharply.[†] The cumulative savings after the final measure is 313 TBtu, or about 50% of the total natural gas use in the residential sector in 1978.

The supply curve of conserved electricity (Figure 3-2) begins with several no-cost and low-cost measures, climbs steadily to 12 TWh,[**] and then climbs steeply to 12.5 TWh. The cumulative savings after the final measure amount to about 25% of all the electricity used by the residential sector in 1978.

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* The exceptions are those where the investment, e.g., for insulation, would be partly recovered on resale.

† One teraBtu (TBtu) equals 10^{12} Btu (a milliquad, if you will).

** A terawatt-hour (TWh) equals 10^9 kilowatt-hours. A typical 1000 MW power plant generates 5.7 TWh per year of useful electricity, assuming a 65% capacity factor. (Transmission and distribution losses reduce this to 5.1 delivered TWh per year.)

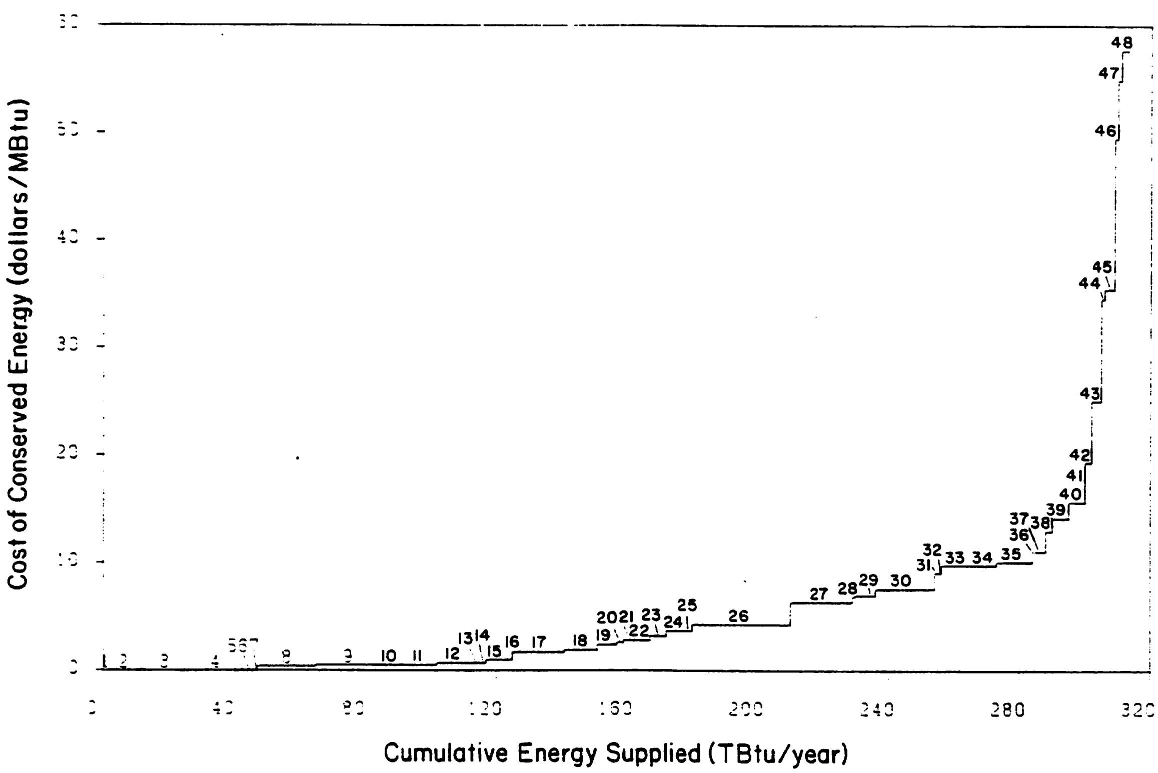

Figure 3-1. The grand conservation supply curve for natural gas. (see Table 3-1). The total residential use of gas in California in 1978 was 612 TBtu.

To estimate the reserves of conserved energy, one must choose a suitable cost of conventionally supplied energy for comparison. Those measures for which the cost of conserved energy is less than the cost of conventional fuels are economic. The energy price chosen must reflect prices over the 10-year time horizon and must be expressed in real terms (since a real discount rate is used). Using today's price for comparison implies that energy prices will rise at the same rate as inflation over the next 10 years (this is probably a conservative assumption). The tailblock rate for natural gas is now over $6 per MBtu.

About 34% of the gas used in the residential sector can be saved at costs of conserved energy below $6 per MBtu. (Thus, conservation in this sector alone could reduce total gas use in California by 12%.) This reduction corresponds to 60% of the projected flow through the Point Conception liquefied natural gas facility; gas from this facility is expected to cost residential consumers slightly less than $7 per MBtu.

Table 3-1. Table for the natural gas supply curve (Figure 3-1). The time horizon is 10 years; the discount rate is five percent. Costs of conserved energy are in 1979 dollars. In the description of the measures (first column), N = Northern California, single family; S = Southern California, single family; MF = multifamily. Total residential use of gas in California in 1978 was 612 TBtu.

	Measure*	Cost of Conserved Energy ($/MBtu)		Energy Supplied (TBtu/y)		Total Dollars Invested (millions)	Meas. No.
		Marginal	Average	Per Meas.	Total		
1	Spark ignition for dryer	0	0	1.4	1	0	44
2	Spark ignition for range	0	0	9.8	11	0	42
3	Water heater temp. setback	0	0	14.7	26	0	35
4	Cold-water laundry	0	0	15.6	42	0	34
5	Pilot off in summer (MF)	0	0	1.3	43	0	28
6	Pilot off in summer (S)	0	0	3.0	46	0	19
7	Pilot off in summer (N)	0	0	1.0	47	0	1
8	Low-flow showerhead	.4	.1	18.5	65	60	36
9	Night setback of 10°F (S)	.5	.2	18.5	84	171	20
10	Pool cover North CA	.5	.2	7.7	91	178	38
11	Night setback of 10°F (N)	.5	.3	10.7	102	243	2
12	Pool cover South CA	.7	.3	10.5	113	257	40
13	New furnace w/spark ignit. (S)	.7	.3	2.0	115	274	102
14	New furnace w/spark ignit. (N)	.7	.3	2.0	117	292	100
15	Night setback of 10°F (MF)	1.0	.3	6.8	124	374	29
16	New furnace w/spark ignit. (MF)	1.0	.4	1.5	125	391	104
17	Water heater insul. blanket	1.7	.5	16.1	141	510	37
18	Install R-19 in ceiling (N)	1.9	.6	10.0	151	744	4
19	Seal attic bypasses (N)	2.4	.7	6.2	157	931	3
20	Install R-19 in ceiling (MF)	2.6	.7	2.1	159	999	30
21	Retrofit spark ignit. (S)	2.8	.7	4.0	163	1,084	101
22	Retrofit spark ignit. (N)	2.8	.8	4.0	167	1,168	99
23	Seal attic bypasses (S)	3.2	.9	4.7	172	1,354	21
24	Install R-19 in ceiling (S)	3.7	.9	5.1	177	1,588	22

Table continued

Table 3-1 continued

	Measure*	Cost of Conserved Energy ($/MBtu)		Energy Supplied (TBtu/y)		Total Dollars Invested (millions)	Meas. No.
		Marginal	Average	Per Meas.	Total		
25	Retrofit spark ignit. (MF)	3.7	1.0	2.6	180	1,662	103
26	Install R-11 in walls (N)	4.3	1.5	31.3	211	3,356	5
27	Storm windows (N)	6.4	1.9	18.2	229	4,800	7
28	Seal attic bypasses (MF)	6.9	1.9	.5	230	4,839	105
29	Install R-11 in walls (MF)	7.0	2.0	6.7	236	5,420	106
30	Install R-11 in walls (S)	7.6	2.4	17.9	254	7,107	23
31	Fireplace damper (S)	9.1	2.4	.7	255	7,159	13
32	Fireplace damper (N)	9.1	2.4	.7	256	7,211	11
33	Water heater flue damper	9.8	2.7	9.7	265	7,620	75
34	Caulking (N)	9.8	2.9	7.2	273	8,168	6
35	Storm windows (S)	10.1	3.2	11.4	284	9,606	25
36	Tune up pool heater North CA	11.1	3.2	.2	284	9,613	86
37	Storm windows (MF)	11.1	3.3	4.0	288	10,163	32
38	Buy most efficient gas dryer	13.0	3.4	1.5	290	10,316	56
39	Caulking (S)	14.2	3.5	5.0	295	10,861	24
40	Additional R-19 in ceiling (N)	15.7	3.7	4.8	300	11,797	8
41	Tune up pool heater South CA	17.5	3.7	.3	300	11,811	87
42	Caulking (MF)	19.4	3.8	1.8	302	12,075	31
43	Additional R-19 in ceiling (S)	25.1	4.0	3.0	305	13,007	26
44	Seal ducts (N)	34.6	4.2	1.5	306	13,232	15
45	Weatherstrip (N)	35.5	4.5	3.2	309	13,730	9
46	Seal ducts (S)	49.5	4.7	1.0	310	13,953	17
47	Weatherstrip (MF)	54.9	4.8	.9	311	14,162	33
48	Weatherstrip (S)	57.7	5.2	2.0	313	14,658	27

*The conservation measures are listed in the order they appear in the supply curve, i.e., according to cost of conserved energy. The measure number (last column) is the number used throughout the report to identify the measure.

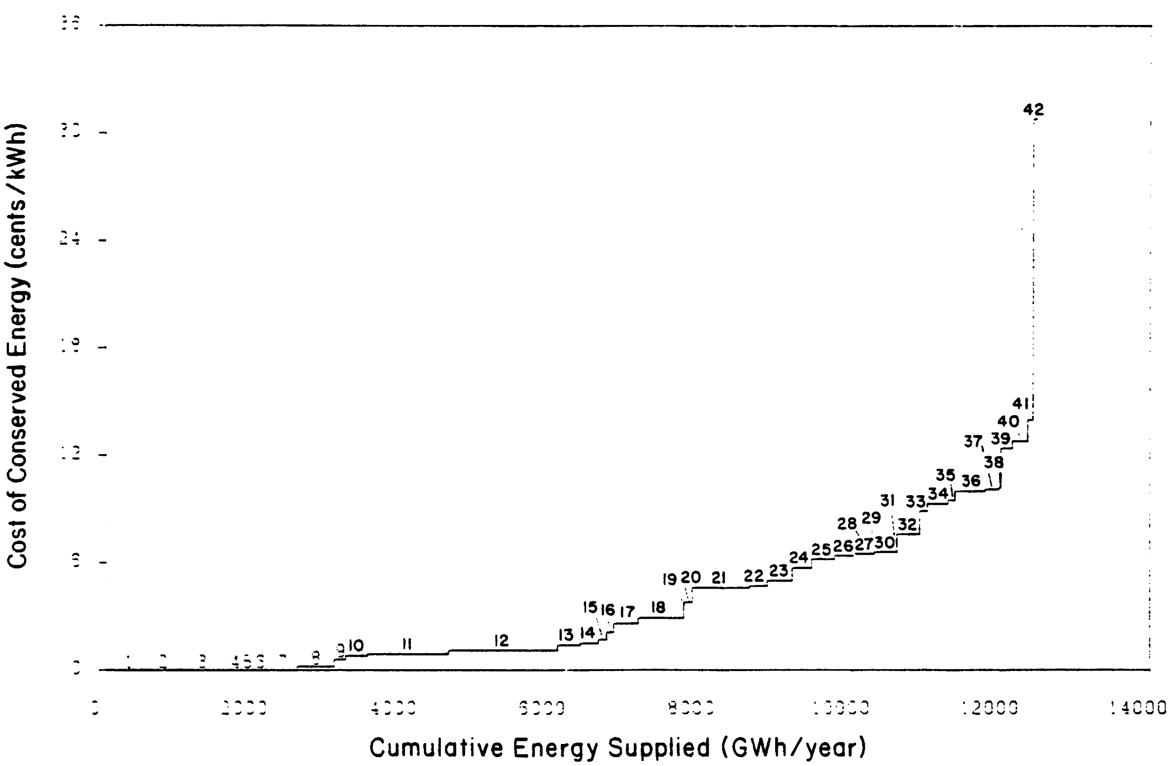

Figure 3-2. The grand conservation supply curve for electricity. (see Table 3-2). The total residential electricity use in California in 1978 was 49.6 TWh.

The tailblock rate for electricity is over 8 cents per kWh. About 22% of the current residential consumption could be saved at costs of conserved electricity below 8 cents per kWh. (Thus, conservation in the residential sector alone could reduce total electricity use in California by 7%.) This reduction corresponds to the output of two standard 1,000 MW power plants.*

In the gas supply curve most of the saved gas (about 86%) comes from water- and space-heating conservation measures. Since these measures are retrofits, the savings can be nearly all realized in the 10-year time horizon; the savings increase only slightly with a 20-year time horizon. A significant amount of water heating energy can be saved cheaply. Many

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* Here one must carefully distinguish between energy and power. Although these measures may preclude the need for the electrical output (GWh) of two power plants, they may not necessarily save the capacity (GW) of two power plants. We present the savings in equivalent output to give the reader a sense of the magnitude; we do not mean that these measures could save building two new power plants.

Table 3-2. Supply table for the electricity supply curve (Figure 3-2). The time horizon is 10 years; the discount rate is five percent. Costs of conserved energy are in 1979 dollars. Total residential use of electricity in California in 1978 was 49.6 TWh.

	Measure*	Cost of Conserved Energy (cents/kWh)		Energy Supplied (GWh/y)		Total Dollars Invested (millions)	Meas. No.
		Marginal	Average	Per Meas.	Total		
1	Solid-state color TV	0	0	599.1	599	0	68
2	Solid-state black-and-white TV	0	0	322.3	921	0	67
3	CEC standard refrigerator	0	0	728.0	1,649	0	78
4	CEC standard room A/C	0	0	152.1	1,802	0	94
5	CEC standard central A/C	0	0	168.0	1,970	0	90
6	Water heater temp. setback	0	0	186.2	2,156	0	62
7	Cold-water laundry	0	0	407.4	2,563	0	61
8	Low-flow showerhead	.2	0	496.6	3,060	8	63
9	Night setback of 10°F	.6	.1	153.1	3,213	20	46
10	Pool filter savings from cover	.8	.1	287.0	3,500	24	70
11	Buy most eff. refrigerator	.9	.3	1,092.0	4,592	102	65
12	Refrigerator package "A"	1.1	.5	1,466.4	6,058	227	79
13	Buy most eff. freezer	1.4	.5	305.8	6,364	259	66
14	Water heater insul. blanket	1.5	.6	240.6	6,605	275	64
15	3-Way bulb to high efficiency	1.7	.6	110.6	6,715	283	83
16	Seal attic bypasses	2.1	.6	92.5	6,808	307	47
17	Freezer package	2.6	.7	327.6	7,135	373	85
18	Kitchen fluorescent	2.9	.9	608.9	7,744	511	69
19	Install R-19 in ceiling	3.7	.9	9.9	7,754	515	48
20	Divert elec. clothes dryer vent	3.8	.9	105.4	7,860	546	18
21	Switch to gas clothes dryer	4.6	1.3	766.7	8,626	821	45
22	Exterior fluorescent	4.7	1.4	239.0	8,865	909	71
23	100 W bulb to fluorescent (1)	5.0	1.5	334.5	9,200	1,039	73
24	Storm windows	5.7	1.6	258.4	9,458	1,224	51
25	Central A/C wall insulation	6.2	1.7	308.7	9,767	1,462	89

Table continued

Table 3-2 continued

Measure*	Cost of Conserved Energy (cents/kWh)		Energy Supplied (GWh/y)		Total Dollars Invested (millions)	Meas. No.
	Marginal	Average	Per Meas.	Total		
26 Buy most efficient central A/C	6.4	1.9	252.0	10,019	1,630	59
27 Manual refrig. improvement	6.5	2.0	208.0	10,227	1,734	81
28 Buy most efficient elec. dryer	6.5	2.0	62.0	10,289	1,765	57
29 Fireplace damper	6.5	2.0	13.4	10,302	1,772	14
30 100 W bulb to fluorescent (2)	6.6	2.1	290.3	10,593	1,920	97
31 Install R-11 in walls	7.4	2.1	8.8	10,601	1,928	49
32 3-way bulb to fluorescent	7.6	2.3	305.3	10,907	2,108	72
33 Caulking	8.9	2.3	102.1	11,009	2,178	50
34 Switch to gas range	9.3	2.5	274.2	11,283	2,374	43
35 Window shading for central A/C	9.5	2.6	94.5	11,377	2,443	91
36 Refrigerator package "B"	10.0	2.8	405.6	11,783	2,755	80
37 100 W bulb to fluorescent (3)	10.1	2.9	191.2	11,974	2,904	98
38 Buy most efficient room A/C	10.2	2.9	24.3	11,999	2,926	60
39 75 W bulb to fluorescent	12.4	3.1	155.8	12,154	3,074	74
40 Weatherize apartments	12.8	3.2	204.0	12,358	3,346	10
41 Additional R-19 in ceiling	14.0	3.3	68.9	12,427	3,466	52
42 Weatherstrip	30.8	3.4	47.9	12,475	3,530	53

*The conservation measures are listed in the order they appear in the supply curve, i.e., according to cost of conserved energy. The measure number (last column) is the number used throughout the report to identify the measure.

of the space-heating measures are expensive because in our analysis they are done to every home rather than just to those of the high users. We do not recommend applying these measures to every home, but we lack the data to estimate costs and energy savings for a more focused program.

In the electricity supply curve the main sources of the saved energy are more diverse: refrigerators, lighting, and water heating (about 38%, 17%, and 12%, respectively). Moreover, with a 20-year time horizon, electricity savings are about 50% greater than with the 10-year time horizon we used. In particular, absolute energy savings from refrigerators and freezers double. Thus, it is crucial to introduce more efficient refrigerators and freezers as soon as possible (an inefficient refrigerator bought today will still be in operation in the year 2000). Had our model included growth, refrigerator energy use would have been even more important. Air conditioners will undergo major improvements because of new CEC standards, but the conserved power is far more valuable than the conserved electricity. Even stricter standards based on peak power needs might defer huge capital outlays for new power plants.

Beyond a certain point the supply curves rise sharply, which is misleading since this suggests that the reserves of cheap conserved energy are limited. First, in the case of the electric supply curve, we underestimated the number of potentially economic measures. Conserving electricity proved cheaper than we anticipated; we could have considered additional measures. Second, the curves reflect the fact that Californians have never confronted the high energy prices we now face and therefore have not developed suitable conservation techniques. In this study we have applied commonly available conservation measures and avoided speculating on new solutions (even though the efficiencies of our appliances and homes are far from the maxima set by the second law of thermodynamics). (See Appendix A.) Although the cost of conserved energy based on current technologies rises sharply beyond a certain point, new technologies, ingenuity, and changes in patterns of energy use will probably temper the curves' steep rise.

Supply curves of conserved energy need careful analysis of current energy demand by end use. Such a breakdown is shown as pie charts in Figure 3-3. (See also Tables B-1 and B-2.) The charts also depict the sources of the conserved energy available at costs below $6 per MBtu and 8 cents per kWh.

Why do such large cheap reserves of conserved energy exist at all? Much of it is a consequence of market failures. Poor (or worse, contradictory) consumer information, rapidly rising energy prices, and landlord-tenant impasses are just a few market failures that have created the greatest part of the cheap reserves. Also, new technologies, such as solid-state controls, flue dampers, and electronic ignition devices, will obviously take time to penetrate the market. To exploit these reserves will require diverse policies. Energy performance standards, utility rate structures, and utility financing schemes are just a few of the ways the state might tap these enormous reserves of conserved energy.

In this report we have described the technical potentials for energy conservation. There remains one final step: to transform these potentials into realistic goals. For this one must examine the feasibility of each measure. This requires another set of assumptions concerning penetration rates, effectiveness of information campaigns, and utility participation, etc. The reader may have his or her own thoughts on these matters; however, we leave that discussion to a companion paper.

We have constructed supply curves only for California's residential sector, which uses a third of the natural gas and electricity consumed in the state. Obviously all sectors should be studied in order to ascertain the overall potential for conservation. However, for policy purposes, a sectoral approach with each end use considered separately is most useful.

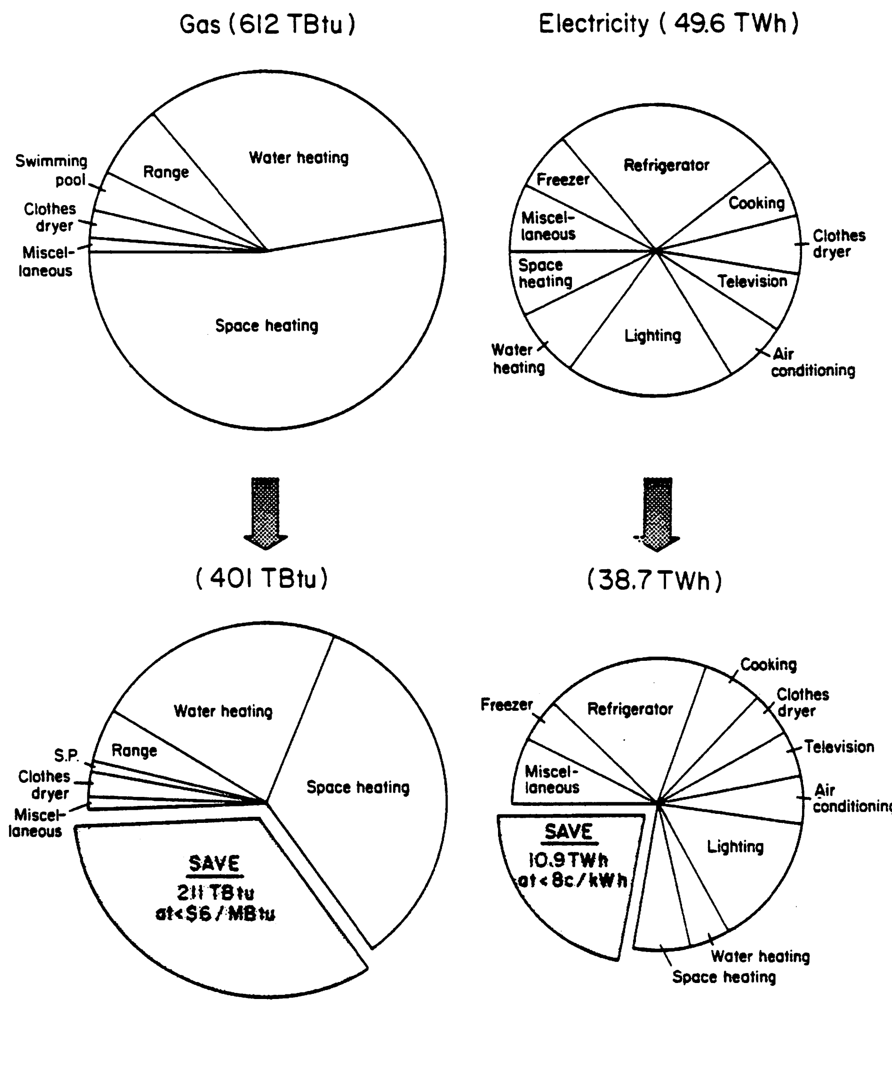

Figure 3-3. Residential energy by end use in California in 1978 (above), and the potential energy savings for a ten-year time horizon. The "saved" gas and electricity is based on a 5% real discount rate. (The areas of the pies are proportional to the energy in resource units.)

Appendix A

Energy Conservation Will Always Be With Us

Alan Meier

Statements such as, "We've conserved just about all the energy we can" or "The full potential of energy conservation has virtually been realized" are frequently heard, even from people who should know better. Is energy conservation a dead-end field because it has a finite potential? The answer is emphatically no. Energy conservation will always be with us.

Why did the discipline of energy conservation develop? Its origins can be traced to the late 1960s and early 1970s when the marginal cost of new energy supplies began to increase. But during this time the long-term, fixed-price energy supply contracts that had been written years earlier kept the average prices down. Still, a few far-sighted people recognized that, as energy prices climbed, investment in energy conservation would become increasingly attractive and possibly critical.

The 1973 oil embargo and subsequent price increases led to the renegotiation of many long-term contracts of all fuels, leading to a sharp increase in energy prices. Nationwide conservation policies were suddenly no longer a theoretical possibility but a real economic alternative.

These were the golden years for energy conservation. With greatly increased energy prices, there was "energy fat" to trim anyplace one looked. Trivial investments led to tremendous savings. Sometimes conservation measures were attractive even at pre-embargo prices, although nobody had bothered to look for them until the crisis. A good portion of energy conservation consisted of rediscovering old tricks, like building efficient motors, shading windows, and weather-stripping. It was embarrassing to find that "modern technology" often meant inefficient technology.

Accurate estimates of the potential for energy conservation required completely new types of information. While we knew very precisely where our energy came <u>from</u>, we had only the crudest idea of where it <u>went</u>. How much of the nation's energy went to heating water? to operating refrigerators? to lighting? How many refrigerators were there in America and what was their average energy consumption? In a remarkably short time estimates of energy consumption by "end use" were developed. Admittedly, they were crude estimates, but they were sufficiently accurate to indicate where significant energy savings on a national scale could be achieved.

Two other concepts also emerged: energy process analysis and embodied energy. Using energy process analysis, one could examine each stage in an industrial process to understand how energy was used. The process could then be compared in different factories. One puzzling discovery was that many European factories used 10-50% less energy to produce identical output (like a ton of steel).

The concept of embodied energy was developed to estimate the energy intensity of activities or complex products, such as autos. This type of analysis, based on macroeconomic input-output analysis, is full of assumptions and simplifications. Still, it shows how energy policies could backfire. For example, if consumers spend the money they save by insulating their houses on midwinter jet trips to Florida, the net result could be a much smaller decrease in energy consumption than expected. In other words, we cannot be certain energy is really being saved until we know the fate of the dollars saved. Macroeconomic input-output analysis also shows how shifts in consumer spending can effect energy savings. For example, the boom in personal electronic gadgetry, with little embodied energy and low energy use, has diverted some consumer spending from energy-intensive leisure activities.

In 1974, a group of physicists gathered at Princeton University to discuss energy conservation. The topic seemed to attract physicists because it was a new and undefined area. Until that time the identification of conservation measures was haphazard. Nobody knew what the ultimate conservation potential was. There was also constant confusion in the comparison of electrical and fossil fuel energy. According to conventional wisdom, a heat pump could supply two units of heat for each unit of electrical energy, while an oil furnace provided two units of heat for every three units of energy (that is, 66% efficient). Surely, heat pumps were better conservers than oil furnaces. Or were they? Heat pumps use electricity generated in a power plant that converts three units of heat to one unit of electricity; the <u>net</u> efficiency of the heat pump, including the power plant, is therefore 66%. On very cold days this efficiency may fall to a pitiful 33%, while furnaces continue at 66%. Which system is better?

Out of the Princeton conference there emerged a theoretical framework for the study of energy conservation founded on the second law of thermodynamics. The efficiency of a device is measured with respect to the minimum energy needed to do that task as determined by the second law. This is called the "second law efficiency." In this way, a typical furnace has a second law efficiency of 6%, a car 10%, and a water heater 3%. Curiously, a steam generated electrical power plant has a second law efficiency of 80%, showing that engineers have obtained very nearly the maximum electricity from this process.

The concept of "energy quality" was also developed. Electricity is high-quality energy because it can be easily converted to useful work or very high temperatures. The task of heating a home requires energy delivered no warmer than 150°F, i.e., low-quality energy. To use high-quality electrical energy to heat a home is therefore wasteful--a mismatch of energy quality--because the task of heating can be done just as well with lower-quality energy (such as that provided by the sun).

Around 1976, the environmental benefits of energy conservation became clear: less pollution, less mining, less nuclear waste, etc. All this at lower costs than new energy supplies! Careful estimates of conservation potentials became powerful arguments against the construction of new energy facilities. In California it was shown that merely requiring consumers to purchase the most efficient refrigerators available (as their old ones wore out), would create sufficient energy savings to negate the need for a proposed nuclear power plant. The total cost to consumers would be lower since the additional cost of the new refrigerator would be offset by lower electricity rates and less electricity needed.

Early on, conservation experts recognized that there exist two types of energy conservation. The simplest kind occurs when the consumer invests to reduce energy use, and the savings pays back the investment in a reasonable time. Insulating a house and buying an efficient refrigerator are examples. A second kind occurs when the benefits of investments in conservation do not accrue so much to individual consumers as much as to the supplier or society as a whole. Air conditioning is the classic example.

Air conditioning places uneconomic demands on utilities. The utilities must construct sufficient generating capacity to meet the demands of every operating air conditioner, even though they may operate only a few hours each year. After the summer peak, these expensive generating facilities lie idle until the next year. In the Southwest as much as 50% of the generating capacity of some utilities is unused for nine months of the year. Thus, although the individual consumer saves in energy bills by buying an efficient air conditioner (a unit that supplies the same amount of "coolth" with less electricity) the utility saves even more because it need not build as much capacity. That savings is eventually (and hopefully!) passed on to consumers in the form of lower electricity rates. Simply put, it is currently cheaper to conserve a kilowatt than to install a kilowatt of capacity. The utilities are only now beginning to realize this.

Recognition of the interdependency of supply and demand is forcing experts to analyze the benefits of conservation in terms of the consumer, the supplier, and the nation. Ordinarily, consumers pay an average price of energy which is now far below the marginal cost a utility must pay to provide it. (The average price is kept low in part by the long-term supply contracts that were written in an era of lower energy prices.) If the consumer paid the marginal price, much more conservation would occur, thereby reducing the need for new supplies.

Recognition of the national (or at least regional) benefits of energy conservation has forced researchers to develop new ways to express economics of new energy supplies and conservation on a similar scale. Only large-scale aggregation of energy savings can rebut the arguments that conservation is a small effect, a stopgap measure, and often expensive. One technique is to express conservation potentials in terms of the cost of conserved energy. Once the cost of conserved energy is calculated for several conservation measures, one can compare them to the cost of energy from new sources. By estimating the cost of conserved energy and the aggregate savings for many measures, one can establish an economic sequence of implementation for the measures, starting with those with the lowest cost of conserved energy. This becomes a "supply curve of conserved energy," that is, a schedule showing the energy available through conservation measures, expressed in cost per unit of energy.

Conserved energy is not perfectly analogous to conventional supplies. It can be exploited in two ways. First, conserved energy can eliminate increased demand due to growth. For example, by improving the efficiency of the nation's 90 million refrigerators, we need not build any additional power plants for the additional 26 million refrigerators expected by the year 2000. Second, supplies of conserved energy can substitute for a depleted resource, instead of replacing it with a much higher cost energy source. One current solution to the dilemma of our dwindling natural gas supplies is to import liquified natural gas. The conservation alternative, however, is to invest in measures cheaper than the LNG, thereby obviating the need for all or part of the LNG.

Only now are we able to integrate conventional energy supplies and conservation. By combining both conventional supplies and conservation, one obtains an "energy alternatives supply curve." As energy prices rise, a mix of conventional supply and conservation will become economic. Developing such "energy alternatives supply curves" would require enormous effort--Exxon has difficulty creating its own oil supply curve! Nevertheless, even recognizing that such a curve is possible would have a tremendous impact on energy policy. For the first time, conventional energy supplies and conservation would be treated as equals. "Energy alternatives supply curves" also show that conservation is not something we need be concerned with for a limited time; rather, as energy prices rise, new measures will become economic.

Will we eventually exhaust our large reserves of conserved energy? Probably not. The second law of thermodynamics dictates the minimum energy needed to perform a process; but even this can change if we redefine the task. In baking, for example, the goal is to heat the food. However, we usually accomplish this by heating the air inside an oven, which through conduction heats the food. In terms of delivering its energy to the air (the process), an electric oven is nearly 100% efficient. A microwave oven also heats the food, but with much less electricity, by heating the food directly. In a similar manner, electric power generation (the goal) may be accomplished through processes not requiring steam. One such technique uses fuel cells, which by avoiding high temperatures, produces electricity more efficiently. Examples like the microwave oven and fuel cells force us to redefine efficiency in terms of goals rather than processes.

Task redefinition resulting from new technologies, like in the two examples above, will undoubtedly serve as an important means of increasing conservation reserves. It elegantly avoids the increasingly sophisticated engineering needed to improve thermodynamic efficiency for a given process.

So what is the status of conservation and the future of research in conservation? It is very slowly gaining recognition as a legitimate alternative to the continued search for new conventional energy supplies. Problems remain, of course, particularly in the area of achieving the known technological conservation potentials. These may require the development of new institutions (whose cost should also be included in the cost of conserved energy). The crucial step is the realization that energy conservation is not a stopgap measure, but rather a necessary part of the solution to energy shortages and increasing prices.

Appendix B

Data Tables

This appendix includes four tables. Tables B-1 and B-2 give our estimates of how natural gas and electricity were used in the residential sector in 1978. Table B-3 is a sectoral breakdown of California's energy use in 1978. Finally, Table B-4 is the data base, that is, the primary inputs to the computer program, CPS 1.0, which was used to generate the supply curves.

Table B-1. Natural gas used by the residential sector in California in 1978.

End Use	Natural Gas (TBtu)[a]	Percent
Space heating	325[b]	53%
Water heating	205	33
Ranges	40	7
Swimming pools	22	4
Clothes dryers	14	2
Hot tubs and spas	2	0
Miscellaneous	4	1
Total:	612[b]	100

[a] A TBtu (teraBtu) equals 10^{12} Btu.

[b] 1978 was warmer than usual, so the actual 1978 use for space heating, 283 TBtu, was scaled to an average heating season. The total 1978 use was actually 570 TBtu. (Source: CEC, 1978d.)

Table B-2. Electricity used by the residential sector in California in 1978.

End Use	Electricity (TWh)[a]	Percent
Refrigerators	12.6	25%
Lighting	9.4	19
Water heating	3.7	7
Space heating	3.6[b]	7
Air conditioning	3.5	7
Cooking	3.3	7
Televisions	3.3	7
Clothes dryers	3.1	6
Freezers	3.1	6
Dishwashers	1.2	2
Swimming pool filters	0.9	2
Clotheswashers	0.4	1
Waterbeds	0.3	1
Miscellaneous	1.2	2
Total:	49.6[b]	100[c]

[a] A TWh (terawatt-hour) equals a billion kilowatt-hours (or 10^{12} Wh).

[b] 1978 was warmer than usual, so the actual 1978 use for space heating, 3.1 TWh, was scaled to an average heating season. The total 1978 use was actually 49.1 TWh. (Source: CEC, 1978d.)

[c] Displayed percentages do not add to 100% due to rounding.

Table B-3. California energy use in 1978 by sector. (Source: CEC, 1978d.)

	Natural Gas		Electricity	
	TBtu/yr	%	TWh/yr	%
Residential	570	33	49	31
Commercial	170	10	45	28
Industrial	373	22	44	28
Electric generation	289	17	--	--
Other	299	18	21	13
Total:	1,701	100	159	100

Table B-4. Data base for all conservation measures discussed in the text. The measures are listed by code number. Those measures having zero eligible stock do not appear on the supply curves.

	Measure	Energy Type (gas or elect.)	Average Annual Energy Saved (MBtu or kWh)	Average Cost (1979 dollars)	Total Stock	Eligible Fraction	Roll-in Time (years)	Amortization Period (years)	Lifetime (years)
1	Pilot off in summer (N)	G	4.0	0	2,490,000	.10	2	10	1
2	Night setback of 10°F (N)	G	12.3	75	2,490,000	.35	5	20	30
3	Seal attic bypasses (N)	G	2.5	75	2,490,000	1.0	10	20	30
4	Install R-19 in ceiling (N)	G	20.1	470	2,490,000	.20	5	20	30
5	Install R-11 in walls (N)	G	15.7	850	2,490,000	.80	10	20	30
6	Caulking (N)	G	2.9	220	2,490,000	1.0	10	10	10
7	Storm windows (N)	G	7.3	580	2,490,000	1.0	15	20	30
8	Additional R-19 in ceiling (N)	G	2.4	470	2,490,000	.80	10	20	30
9	Weatherstrip (N)	G	1.3	200	2,490,000	1.0	10	5	5
10	Weatherize apartments	E	300	400	680,000	1.0	15	15	15
11	Fireplace damper (N)	G	1.0	70	2,490,000	.30	10	10	20
13	Fireplace damper (S)	G	1.0	70	2,480,000	.30	10	10	20
14	Fireplace damper	E	140	70	319,000	.30	10	10	20
15	Seal ducts (N)	G	2.0	300	2,490,000	.30	10	5	10
17	Seal ducts (S)	G	1.4	300	2,480,000	.30	10	5	10

18	Divert elec. clothes dryer vent	E	170	50	3,100,000	.20	5	10	15
19	Pilot off in summer (S)	G	4.0	0	2,480,000	.30	2	10	1
20	Night setback of 10^oF (S)	G	12.4	75	2,480,000	.60	5	20	30
21	Seal attic bypasses (S)	G	1.9	75	2,480,000	1.0	10	20	30
22	Install R-19 in ceilings (S)	G	10.3	470	2,480,000	.20	5	20	30
23	Install R-11 in walls (S)	G	9.0	850	2,480,000	.80	10	20	30
24	Caulking (S)	G	2.0	220	2,480,000	1.0	10	10	10
25	Storm windows (S)	G	4.6	580	2,480,000	1.0	15	20	30
26	Additional R-19 in ceilings (S)	G	1.5	470	2,480,000	.80	10	20	30
27	Weatherstrip (S)	G	.8	200	2,480,000	1.0	10	5	5
28	Pilot off in summer (MF)	G	3.0	0	2,200,000	.20	2	10	1
29	Night setback of 10^oF (MF)	G	6.2	75	2,200,000	.50	5	20	30
30	Install R-19 in ceiling (MF)	G	9.5	310	2,200,000	.10	5	20	30
31	Caulking (MF)	G	.8	120	2,200,000	1.0	10	10	10
32	Storm windows (MF)	G	1.8	250	2,200,000	1.0	15	20	30
33	Weatherstrip (MF)	G	.4	95	2,200,000	1.0	10	5	5
34	Cold-water laundry	G	3.0	0	7,440,000	.70	5	10	1
35	Water heater temp. setback	G	3.3	0	7,440,000	.60	5	10	10
36	Low-flow showerhead	G	3.1	10	7,440,000	.80	5	10	10
37	Water heater insul. blanket	G	2.7	20	7,440,000	.80	5	5	5

Table continued

Table B-4 continued

	Measure	Energy Type (gas or elect.)	Average Annual Energy Saved (MBtu or kWh)	Average Cost (1979 dollars)	Total Stock	Eligible Fraction	Roll-in Time (years)	Amortization Period (years)	Lifetime (years)
38	Pool cover North CA	G	110.0	100	140,000	.50	2	2	3
40	Pool cover South CA	G	78.0	100	270,000	.50	2	2	3
42	Spark ignition for range	G	3.7	0	5,000,000	.90	17	10	17
43	Switch to gas range	E	210	150	3,700,000	.60	17	10	17
44	Spark ignition for dryer	G	3.0	0	2,400,000	.30	15	10	15
45	Switch to gas clothes dryer	E	530	190	3,100,000	.70	15	10	15
46	Night setback of 10°F	E	960	75	319,000	.50	5	20	30
47	Seal attic bypasses	E	290	75	319,000	1.0	10	20	30
48	Install R-19 in ceiling	E	1030	470	319,000	.03	5	20	30
49	Install R-11 in walls	E	920	850	319,000	.03	10	20	30
50	Caulking	E	320	220	319,000	1.0	10	10	10
51	Storm windows	E	810	580	319,000	1.0	15	20	30
52	Additional R-19 in ceiling	E	270	470	319,000	.80	10	20	30
53	Weatherstrip	E	150	200	319,000	1.0	10	5	5
56	Buy most efficient gas dryer	G	.5	50	4,570,000	1.0	15	10	15

57	Buy most efficient elec. dryer	E	100	50	3,100,000	.30	15	10	15
59	Buy most efficient central A/C	E	300	200	1,260,000	1.0	15	15	15
60	Buy most efficient room A/C	E	20	18	1,460,000	1.0	12	12	12
61	Cold-water laundry	E	600	0	970,000	.70	5	10	1
62	Water heater temp. setback	E	320	0	970,000	.60	5	10	10
63	Low-flow showerhead	E	640	10	970,000	.80	5	10	10
64	Water heater insul. blanket	E	310	20	970,000	.80	5	5	5
65	Buy most efficient refrig.	E	210	15	10,400,000	1.0	20	10	20
66	Buy most efficient freezer	E	280	30	2,730,000	1.0	25	10	25
67	Solid-state black-and-white TV	E	95	0	4,750,000	1.0	14	10	14
68	Solid-state color TV	E	110	0	8,170,000	1.0	15	10	15
69	Kitchen fluorescent	E	172	39	8,850,000	.40	5	10	20
70	Pool filter savings from cover	E	1400	20	410,000	.50	2	2	3
71	Exterior fluorescent	E	90	33	8,850,000	.30	5	10	20
72	3-way bulb to fluorescent	E	46	27	8,850,000	.75	5	10	10
73	100 W bulb to fluorescent (1)	E	54	21	8,850,000	.70	5	10	10
74	75 W bulb to fluorescent	E	22	21	8,850,000	.80	5	10	10
75	Water heater flue damper	G	1.3	55	7,440,000	1.0	15	5	5
76	Switch to gas water heater	E	1130	110	0	0	10	10	10
77	Refrig. anti-sweat switch off	E	200	0	0	0	2	10	10

Table continued

Table B-4 continued

	Measure	Energy Type elect.)	Average Annual Energy Saved kWh)	Average (1979 dollars)	Stock	Eligible Fraction	Roll-in Time (years)	Amortization Period (years)	Lifetime (years)
78	CEC standard refrigerator	E	140	0	10,400,000	1.0	20	10	20
79	Refrigerator package "A"	E	470	40	10,400,000	.60	20	10	20
80	Refrigerator package "B"	E	130	100	10,400,000	.60	20	10	20
81	Manual refrig. improvement	E	100	50	10,400,000	.40	20	10	20
82	Junk second refrigerator	E	650	0	0	0	5	10	1
83	3-way bulb to GE Halarc	E	50	4	8,850,000	.25	5	5	5
84	Freezer anti-sweat switch off	E	180	0	0	0	2	10	10
85	Freezer package	E	300	60	2,730,000	1.0	25	10	25
86	Tune up pool heater North CA	G	3.3	100	140,000	.50	1	3	3
87	Tune up pool heater South CA	G	2.1	100	270,000	.50	1	3	3
88	Hand starter for gas range	G	2.6	8.	0	0	5	5	5
89	Central A/C wall insulation	E	350	270	1,260,000	.70	10	20	30
90	CEC standard central A/C	E	200	0	1,260,000	1.0	15	15	15
91	Window shading for central A/C	E	150	110	1,260,000	.50	5	10	10
92	Central evaporative cooler	E	2370	-350	0	0	15	10	10

93	Whole-house fan-central A/C	E	500	330	0	0	5	10	10
94	CEC standard room A/C	E	125	0	1,460,000	1.0	12	12	12
95	Room evaporative cooler	E	710	-100	0	0	12	10	10
96	Bypass inst-on color TV switch	E	100	0	0	0	5	10	15
97	100 W bulb to fluorescent (2)	E	41	21	8,850,000	.80	5	10	10
98	100 W bulb to fluorescent (3)	E	27	21	8,850,000	.80	5	10	10
99	Retrofit spark ignition (N)	G	8.0	170	2,490,000	.20	5	10	10
100	New furnace w/spark ignit. (N)	G	8.0	70	2,490,000	.20	20	20	20
101	Retrofit spark ignition (S)	G	8.0	170	2,480,000	.20	5	10	10
102	New furnace w/spark ignit. (S)	G	8.0	70	2,480,000	.20	20	20	20
103	Retrofit spark ignition (MF)	G	6.0	170	2,200,000	.20	5	10	10
104	New furnace w/spark ignit. (MF)	G	6.0	70	2,200,000	.20	18	18	18
105	Seal attic bypasses (MF)	G	.7	60	2,200,000	.30	10	20	30
106	Install R-11 in walls (MF)	G	3.8	330	2,200,000	.80	10	20	30
118	Buy most effic. manual refrig.	E	240	15	0	0	20	10	20
119	CEC standard water heater	G	4.4	0	0	.90	10	10	10
120	CEC standard water heater	E	440	0	0	.90	10	10	10

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