Title

ECONOMICS OF EFFICIENCY IMPROVEMENTS IN RESIDENTIAL APPLIANCES AND SPACE CONDITIONING EQUIPMENT

Authors

Levine, M.D.
Koomey, J.
Ruderman, H.

Publication Date

1985-09-01

LBL-26952 c.2
UC-95d

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

APPLIED SCIENCE DIVISION

Economics of Efficiency Improvements in Residential Appliances and Space Conditioning Equipment

M.D. Levine, J. Koomey, H. Ruderman, P. Craig,
J. McMahon, and P. Chan

September 1985

APPLIED SCIENCE DIVISION

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.

DISCLAIMER

LBL-26952

ECONOMICS OF EFFICIENCY IMPROVEMENTS IN RESIDENTIAL APPLIANCES AND SPACE CONDITIONING EQUIPMENT

M.D. Levine, J. Koomey, H. Ruderman, P. Craig, J. McMahon, and P. Chan

Energy Analysis Program
Applied Science Division
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

September 1985

This work was supported by the Assistant Secretary of Conservation and Renewable Energy, Office of Building and Community Systems, Building Equipment Division of the U.S. Department of Energy under Contract DE-AC03-76SF00098.

Economics of Efficiency Improvements in Residential Appliances and Space Conditioning Equipment

M.D. Levine, J. Koomey, H. Ruderman,
P. Craig[†], J. McMahon, and P. Chan

Energy Analysis Program
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

[†]Department of Applied Science
University of California
Davis, California 95616

INTRODUCTION

The large amounts of energy consumed by residential appliances and space conditioning equipment make this sector a fruitful area for efficiency improvements. We examine eight major residential appliances that in the U.S. currently consume 9.4 exajoules/year (8.9 quads/year*) representing more than 12 percent of total 1984 U.S. energy use. Expenditures on energy for these appliances totaled over $56 billion in 1984. Our results indicate that improving the efficiency of all these appliances to economically optimal levels would reduce these annual expenditures by almost thirty percent, a savings of $17 billion per year. In steady state, the annualized additional investment cost to achieve this efficiency improvement is $7 billion, so the net savings is about $10 billion per year**.

This paper describes and analyzes energy efficiency choices for residential appliances and space conditioning equipment.*** The first section briefly

*An exajoule equals 10^{18} joules. A quad equals one quadrillion (10^{15}) Btus. In this paper, both the price and the energy value of electricity are measured as resource energy at 11,500 Btus per kWh.

**Assuming that the optimum efficiencies are calculated using a real ten percent discount rate, at current fuel prices, and in 1984 dollars. The expenditure and the energy use numbers are derived from LBL Energy Demand and Forecasting Model Runs (a new model based on the original model developed by ORNL, see reference 1). The additional investment costs are annualized by dividing by the present worth factor (PWF).

***The term appliances will henceforth include space conditioning equipment.

illustrates historical trends in the average efficiencies of new appliances sold in the United States during the last decade. The second section shows results of the life-cycle cost analysis of eight major residential appliances. Our results provide striking evidence that the market is not achieving economically optimal efficiency levels.

To a physicist, optimal efficiency is defined as the maximum second-law efficiency that is theoretically attainable. However, the physicist's optimal efficiency level often cannot be obtained at reasonable cost. The economist defines optimal efficiency as the efficiency that minimizes the total cost of purchasing, operating, and maintaining a device over its lifetime. The latter definition of optimality is helpful in assessing the cost effectiveness of efficiency improvements, because it balances the cost to improve energy efficiency against the benefits of reduced fuel use.

When homeowners buy appliances, they make implicit tradeoffs between current capital expenditures and future operating expenses. Using a concept known as life-cycle cost (LCC), we can characterize the capital vs. operating cost tradeoffs that will leave the purchaser most well-off in the long run. LCC is the sum total of capital, maintenance, and operating costs over the life of the appliance, properly discounted to account for the time value of money. Results from LCC analysis reveal that purchasers often do not choose the "optimal" efficiency (i.e., the efficiency of the appliance with the lowest LCC), because they prefer to minimize present outlays at the cost of increased future expenditures. In some cases, purchasers ignore investments with simple payback times of one to two years, equivalent to a return on investment of 50 to 100 percent. One would not expect a "rational" investor to turn down such high returns, but the majority of purchasers of residential appliances do (3,4).

The simple payback time is the time required for the operating cost savings of a more efficient appliance to repay its additional capital cost. The payback times that we derive are of two types. The first type, used in the initial LCC analysis, we designate the "payback time" for an investment in a large, discrete change in efficiency from a current efficiency level to the optimum one. The second represents the approximate "incremental payback time" for an infinitesimal or marginal increase in efficiency from current market levels. The second type approximates the rate of return for the next dollar invested in efficiency improvements. We determined both payback times and life-cycle costs from data on the efficiency and purchase cost of appliances purchased between 1978 and 1984.

A major finding of this study is that the payback times for moving from the current average efficiency sold on the market today to an optimum efficiency as determined by LCC analysis range from one to nine years, with most payback times less than five years. The rates of return implied by these payback times are attractive, and they reveal that the potential for efficiency improvements in the residential appliance sector is not yet close to being realized.

Another important result of our analysis is that the incremental payback periods for investment in increasing the energy efficiency of most household appliances are less than three years, except for air conditioners. We conclude from this result that the market for energy efficiency is not performing well. In the last section, several possible explanations of the underinvestment in efficiency are proposed: 1) lack of information about the costs and benefits of energy efficiency; 2) lack of access to capital markets; 3) expected savings are too small in absolute terms to be of interest to purchasers; 4) prevalence of third party purchasers; 5) unavailability of highly efficient equipment without other features for some products; 6) long manufacturing lead times; and 7) other marketing strategies.

CHANGES IN EFFICIENCY OVER THE PAST DECADE

We focus on the efficiency choices for eight major appliances: gas central space heaters, oil central space heaters, room air conditioners, central air conditioners, electric water heaters, gas water heaters, refrigerators, and freezers. Central space heaters include boilers and furnaces. We chose these products because they account for a major part of residential energy consumption and because data on their efficiency and costs are readily available. Electric resistance heaters are not included because no significant improvement in their efficiency is possible. Data on the incremental costs of efficiency improvements for heat pumps and gas or oil room heaters were unavailable at the time of publication (incremental costs for heat pumps are likely to be similar to those of central air conditioners).

The efficiency of residential appliances has increased in the past twelve years. Figure 1 shows these improvements based on the shipment weighted energy factors (SWEFs) of products sold in the United States between 1972 and 1984. The efficiency of refrigerators and freezers increased about 60 percent from 1972 levels. The improvements for other products were less dramatic, but were significant for gas water heaters, gas furnaces, room air conditioners, and central air conditioners, ranging from 16 to 30 percent. The remaining products--oil furnaces and electric water heaters--showed less than 8 percent improvement in energy efficiency over the indicated time period. Table 1 shows the average efficiencies for selected appliances between 1972 and 1984, from which Figure 1 was derived. For an analysis of the technical changes that led to these efficiency improvements, see Howard Geller's paper in this volume.

LIFE-CYCLE COST ANALYSIS

This section provides a methodology for assessing the economic costs and benefits to the consumer who purchases appliances of varying initial costs and energy efficiency. The basis for analysis is the use of life-cycle costing.

The life-cycle cost of owning and operating an appliance is equal to the first cost or purchase price plus the operating and maintenance costs over the lifetime of the appliance. The first cost may be paid when the product is purchased or the consumer may borrow money that is paid back with interest after the purchase is made. For the purpose of this analysis it is assumed that the consumer makes a cash purchase of the appliance. We also assume that the cost of maintenance over the lifetime of the appliance is independent of efficiency; thus the maintenance cost is not included in the life-cycle cost calculation. In order to consider first cost and operating costs on a time-equivalent basis, all future operating costs are discounted to present value. Life-cycle costs are compared for classes of appliances of the

FIGURE 1:
PERCENT IMPROVEMENT IN EFFICIENCY IN MAJOR RESIDENTIAL APPLIANCES

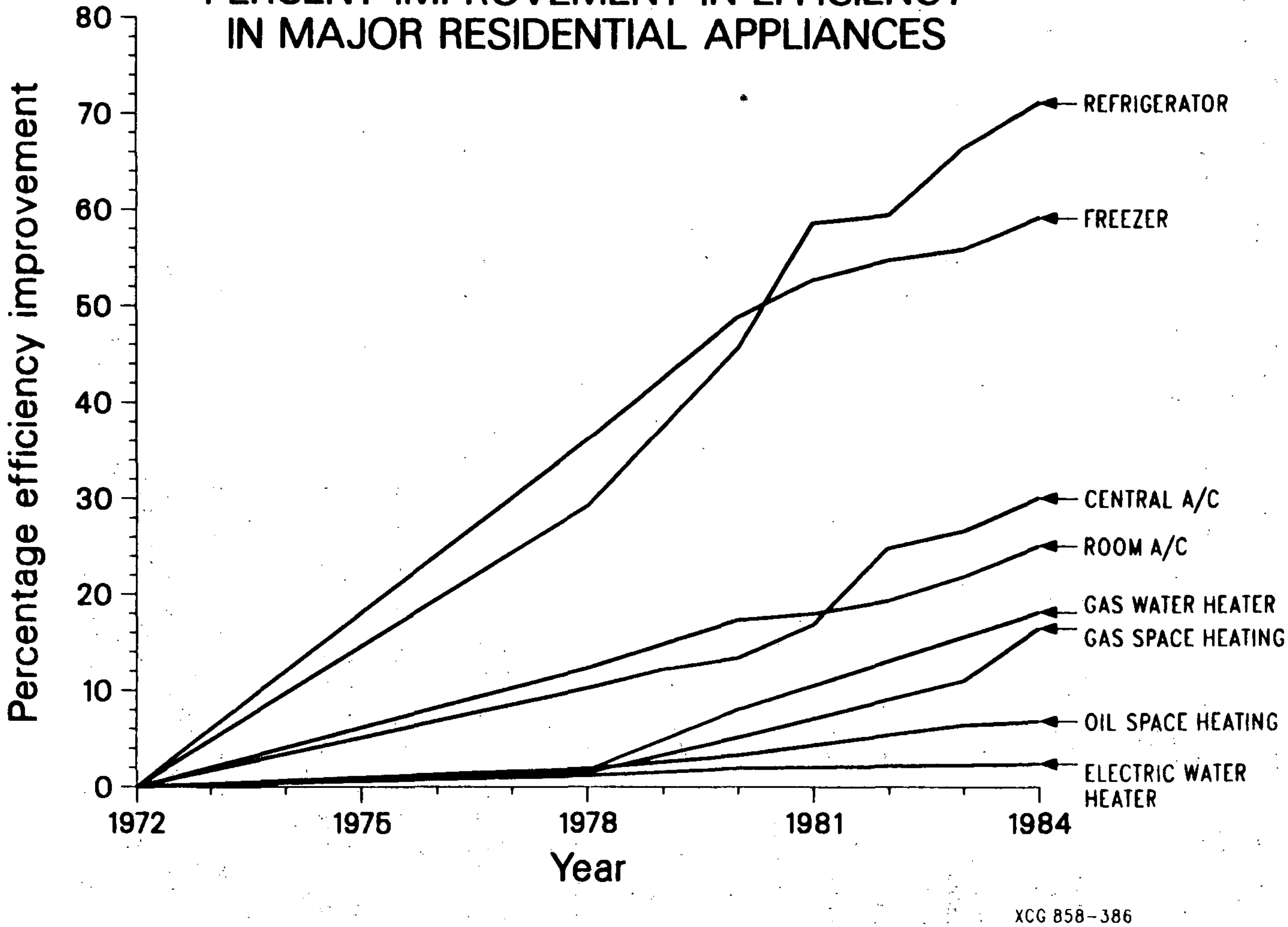


Table 1. Shipment-Weighted Energy Factors (SWEF)

Appliance	Source	1972	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
Gas Central	CS-179	--	62.7	--	--	63.6	--	65.9*	--	--	--	--
Space Heater	Lennox	--	65.0	65.0	65.1	65.5	66.3	66.6	67.0	--	--	--
(AFUE%)	Carrier	--	63.7	--	--	65.1	66.3	66.7	66.5	--	--	--
	GAMA	--	--	--	--	--	--	--	--	--	69.6	73.0
Oil Central	CS-179	--	73.6	--	--	75.0	--	76.0*	--	--	--	--
Space Heater	GAMA	--	--	--	--	--	--	--	--	--	78.3	78.6
(AFUE%)												
Room Air	CS-179	6.22	--	--	--	6.75	--	7.03*	--	--	--	--
Conditioner	AHAM	5.98	--	--	--	6.72	--	7.02	7.06	7.14	7.29	7.48
(EER)												
Central Air	CS-179	6.66	--	--	--	6.99	--	7.76*	--	--	--	--
Conditioner	Lennox	--	6.19	6.94	7.02	7.00	7.05	7.14	7.73	8.18	--	--
(SEER)	ARI	6.66	--	7.03	7.13	7.34	7.47	7.55	7.78	8.31	8.43	8.66
Electric Water Heater (Percent)	CS-179	79.8	--	--	--	80.7	--	81.3*	--	--	--	81.7**
Gas Water Heater (Percent)	CS-179	47.4	--	--	--	48.2	--	51.2*	--	--	--	56.0**
Refrigerator	CS-179	4.22	--	--	--	5.09	--	5.72*	--	--	--	--
(cu.ft./kWh/day)	AHAM	3.84	--	--	--	4.96	--	5.59	6.09	6.12	6.39	6.57
Freezer	CS-179	8.08	--	--	--	10.07	--	10.83*	--	--	--	--
(cu.ft./kWh/day)	AHAM	7.29	--	--	--	9.92	--	10.85	11.13	11.28	11.36	11.60

*Projection made in 1979.
**Forecast by LBL/ORNL model-no data are available

AFUE - Annual Fuel Utilization Efficiency
EER - Energy Efficiency Ratio (Btus per hour/Watts)
SEER - Seasonal Energy Efficiency Ratio

Data Sources (see reference 4)

AHAM - Association of Home Appliance Manufacturers
ARI - Air-Conditioning and Refrigeration Institute
Carrier - Carrier Corporation (estimates are for manufacturer's own products)
CS-179 - Department of Energy Survey of Manufacturers
Lennox - Lennox Corporation (estimates are for manufacturer's own products)
GAMA - Gas Manufacturers Association (Derived from reference 2).

same capacity but different efficiencies. A more energy efficient product is often more expensive than one of lower efficiency, all other features of the product being equal. However, if the more energy efficient model has lower total costs to the consumer over the life of the appliance, the consumer benefits in the long run, even though the initial investment is larger.

The trade-off between the higher first costs and lower operating costs of more energy efficient products can be assessed in terms of a simple payback time. The simple payback time is the additional cost for a more energy efficient product divided by the savings in fuel costs per unit time (expressed in months or years). For example, if the payback time is one year, then the extra first cost for a more efficient product is fully recovered in reduced energy bills during the first year of operation of the product. This rate of payback is equivalent to a return on investment of 100% per year to the consumer. If, on the other hand, the payback time is 20 years, then the rate of return on the initial investment is small.

When the payback time is a few years or less, the simple payback time closely approximates the actual payback time; for our purposes, little error will be introduced by using the simple payback time. During periods of rapidly increasing energy prices, the use of simple payback time can be misleading, but it is an understandable concept that will effectively illustrate our results. A discussion of the relationship between discount rates, life-cycle costs, and payback periods is contained in Appendix 1.

Methodology and Assumptions

The life-cycle cost analysis provides a measure of the economic impact of equipment purchases on the consumer. All other things being equal, the consumer benefits in the long run from the purchase of a product with the lowest life-cycle cost. To calculate life-cycle costs, assumptions and estimates must be made about future prices of energy and the value that a consumer places on future return on investment, because a more energy efficient appliance saves money for many years(5).

The total life-cycle cost (LCC), of an appliance is given in general by:

$$LCC = PC + \sum_{t=1}^{N} ENC_t \frac{(FP)(1+f)^t}{(1+r)^t} \quad (1)$$

where

PC = initial purchase cost of the appliance (in dollars),

ENC_t = energy consumption in year t (in million Btus),

FP = fuel price in year 1 (in dollars per million Btus),

N = lifetime of appliance (in years),

f = annual percentage change in real fuel price*

r = discount rate in constant dollars.

The fuel price in year t is given by $FP(1+f)^t$ and the total expenditure for fuel in year t is

$$FC_t = ENC_t (FP)(1+f)^t \tag{2}$$

FC_t is the fuel cost in year t as given in Appendix 1.

In the analysis as performed, yearly energy consumption (ENC_t) and the fuel prices are assumed to be constant over the appliance lifetime. While the latter assumption may not correspond to the actual price trends of recent years, it is a conservative one that makes the results more robust. Rapidly increasing fuel prices make conservation investments even more attractive. Thus, Eq. (1) may be simplified to

$$LCC = PC + (ENC)(FP)\,PWF \tag{3}$$

where

$$PWF = \sum_{t=1}^{N} \left[\frac{(1+f)^t}{(1+r)^t} \right] \tag{4}$$

Table 2 shows the national average fuel prices used in the life-cycle cost calculations. The first cost, fuel prices, and life-cycle costs are expressed in 1984 dollars. The fuel price escalation rates and the discount rate are expressed in real dollars. Electricity prices have been adjusted to account for the fact that electric space and water heating customers usually pay lower than average prices for their electricity due to promotional rate structures, and air conditioning customers typically pay an on-peak electricity price that

*A "real" rate of change is the annual percentage change after adjusting for inflation.

is higher than the national average. This adjustment also accounts for regional differences in the distribution of these appliances across the U.S. The discount rates chosen for the analysis were 3% and 10% real. Table 3 presents the appliance lifetimes used in the LCC calculations.

Table 2: 1984 National Average Fuel Prices
(1984 Dollars per Million Btu)

	Resource Energy*	Site Energy**
Electricity (Avg):	5.89	19.9
By End Use:		
Air Conditioning	6.66	22.4
Water Heat	5.12	17.3
Space Heat	4.54	15.3
Other electrical	6.48	21.8
Natural Gas	5.89	5.89
Oil	7.71	7.71

Table 3: Appliance Lifetimes (years)

Appliance	Lifetime
Central heating	23
Water heating	13
Central air conditioners	12
Room air conditioners	15
Refrigerator	19
Freezer	21

To summarize, the analysis assumes:

(1) that national average energy prices apply (electric rates are end-use specific; see Table 2);

*Price per unit of resource energy consumed; 11,500 Btu/kWh includes heat rate of electricity generation plus transmission losses.

**Price per unit of electricity consumed on-site (at 3412 Btu/kWh).

(2) no escalation of energy prices above inflation

(3) real discount rates of 3% and 10%

(4) the appliance lifetimes in Table 3; and

(5) no increase in purchase price above inflation for an appliance of given efficiency.

The other input to the LCC computations is a set of exponential curves relating the initial cost and the energy use for each class of appliance, based on an update of data developed by Arthur D. Little and reported in the Engineering Analysis Technical Support Document for DOE's Consumer Products Efficiency Standards (6).

Table 4: Parameters of Purchase Cost/Unit Energy Consumption Curves

Appliance	A	$E\infty/E_o$	PC_o	E_o	Baseline Efficiency
Gas furnaces	5.76	0.65	2480	81.7	63
Oil furnaces	8.47	0.79	3750	125	76
Room air conditioners	3.77	0.51	593	12.3	6.7
Central air conditioners	2.00	0.44	1640	33.8	7.1
Electric water heaters	9.22	0.82	207	52.1	78
Gas water heaters	5.67	0.56	256	21.6	48
Refrigerator-freezers	21.6	0.39	674	14.0	4.9
Freezers	10.6	0.38	444	13.3	9.7

These exponential curves are of the form

$$E = E_\infty + (E_0 - E_\infty)\exp[-A(C-1)] \quad (5)$$

where

E = unit energy consumption (UEC) million Btu/yr of resource energy

E_0 = base year UEC

E_∞ = minimum UEC attainable at infinite purchase cost

C = PC/PC_o

PC = purchase cost corresponding to E, 1984 dollars/unit

PC_o = purchase cost corresponding to E_o, 1984 dollars/unit and A is a parameter.

Table 4 shows the values for the parameters in the equation for the eight appliances. The engineering data relating cost and energy use were fitted to the above equations using standard regression techniques. Energy use is inversely proportional to efficiency, so the cost/efficiency relationship can be obtained by inserting the value of E for a given purchase cost from equation (5) into equation (6).

$$Efficiency = (E_o / E)\ (Baseline\ Efficiency) \tag{6}$$

We first look at two appliances to illustrate the return from an investment in efficiency improvements. Because these are various classes (defining different capacities and combinations of features) within an appliance type, we then use the aggregated parameters in Table 4 to describe the life-cycle costs of eight major appliances.

Results

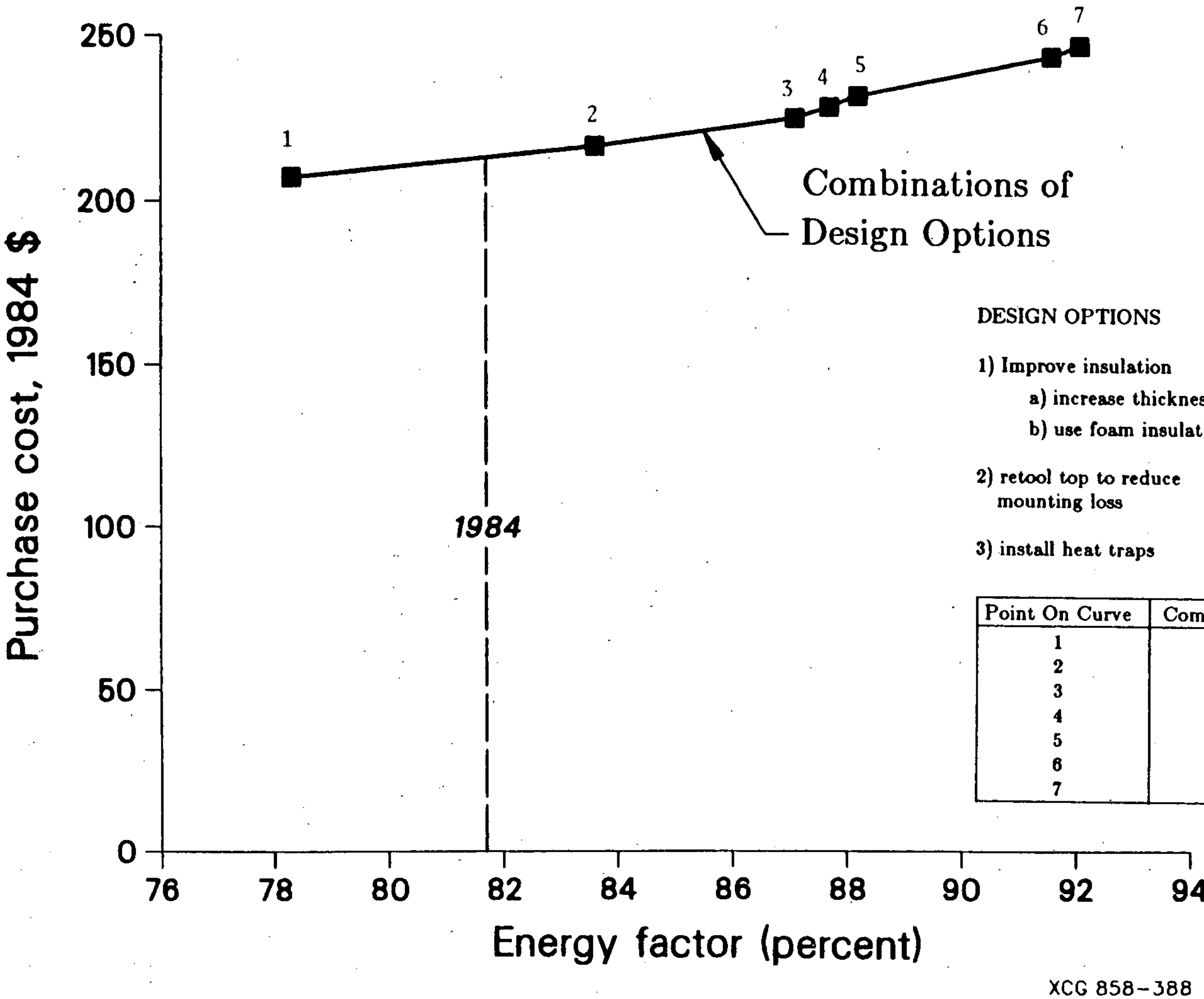
Figures 2 and 3 illustrate cost/efficiency curves for electric water heaters and room air conditioners with less than 8000 Btu/hr capacity, respectively. Also shown are the design options chosen for analysis. Points on the curves are generated by implementing combinations of design options to varying degrees.*

Figure 2 shows that improving the insulation and installing heat traps on electric water heaters can yield an increase in efficiency of eight percentage points (from 84 to 92 percent) at a cost of about $30. Considering that an average electric water heater sold in 1984 consumes about 4300 kWh per year and costs $256 to operate annually, the $30 investment yields an *annual* return of $22.

Figure 3 shows similarly large returns on an investment in the energy efficiency of room air conditioners up to an energy efficiency ratio (EER) of 8.8. This efficiency level is achieved by a combination of measures, as described in the figure. Using current technology and manufacturing

*These design options are described in detail for each product type in Reference 6.

FIGURE 2: COST vs. EFFICIENCY FOR
STANDARD ELECTRIC WATER HEATERS



DESIGN OPTIONS

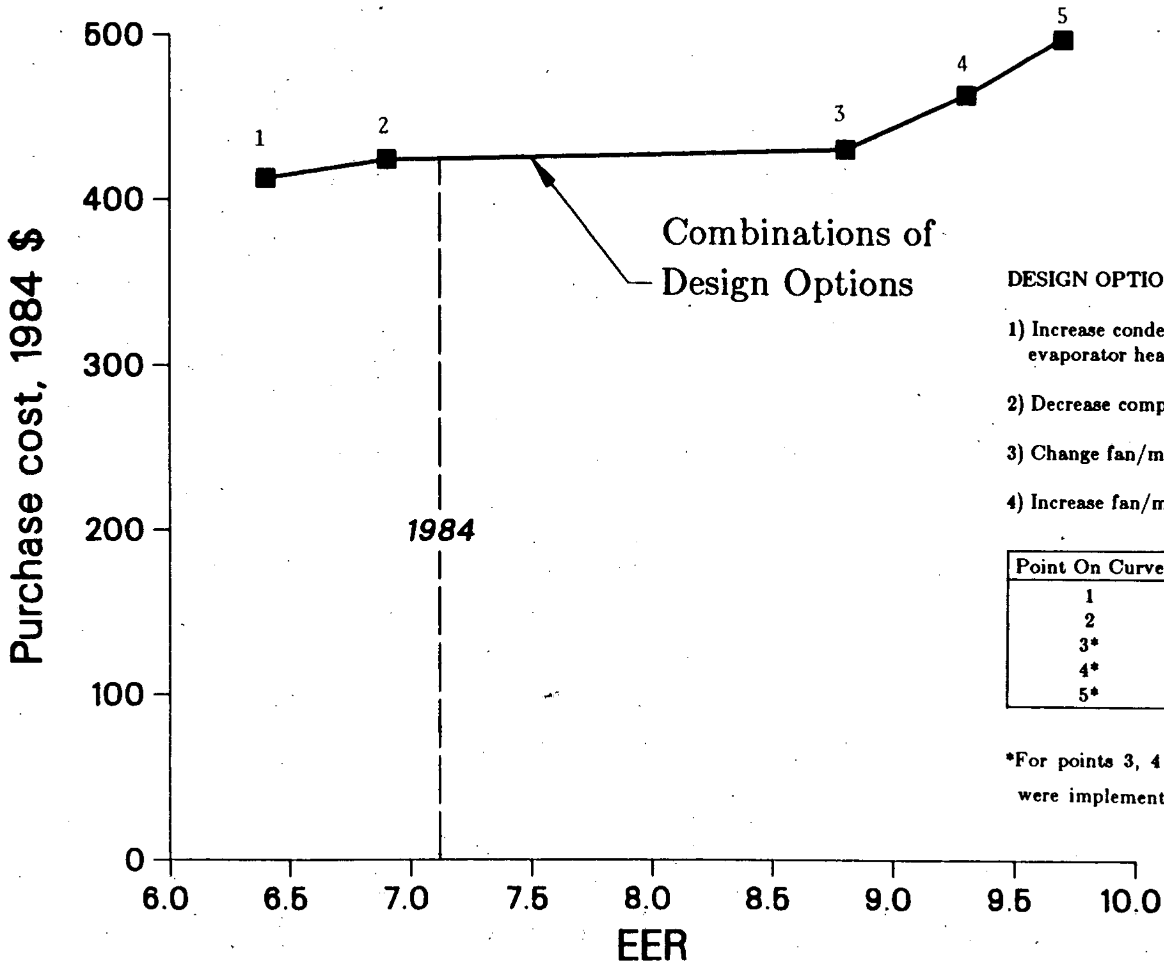
1) Improve insulation
   a) increase thickness
   b) use foam insulation

2) retool top to reduce mounting loss

3) install heat traps

Point On Curve	Combinations of Options
1	baseline
2	1, 2
3	1
4	1
5	1
6	1, 3
7	1, 3

FIGURE 3: COST vs. EFFICIENCY FOR ROOM AIR CONDITIONERS, 8000 Btu/hr



DESIGN OPTIONS

1) Increase condensor and evaporator heat exchanger area

2) Decrease compressor size

3) Change fan/motor

4) Increase fan/motor efficiency

Point On Curve	Combinations of Options
1	baseline
2	1, 2, 3
3*	1, 2, 3, 4
4*	1, 2, 3, 4
5*	1, 2, 3, 4

*For points 3, 4 and 5, the four design options were implemented to varying degrees

XCG 858-387

processes in the United States, the cost to increase the EER of room air conditioners in this class beyond 9 is relatively high. However, the EER of the typical new unit can be raised from 7.2 to 8.8 (an efficiency gain of 22%) at low cost.

These curves represent the cost/energy use relationships for subgroups of room air conditioners and electric water heaters. The analysis aggregates the cost/energy use data points for all subgroups within each product type (i.e., all room air conditioners), to get the aggregate cost/energy use curves represented by the parameters in Table 4.

Tables 5 through 7 illustrate the results of LCC analysis for the eight appliances. Table 5 shows the efficiency levels for each appliance corresponding to the 1984 stock efficiency, the 1984 SWEF, and the minimum LCC appliance. Table 6 compares the LCCs at the 1984 SWEF efficiency with those for the LCC minimum efficiency, using two different discount rates (3 and 10 percent). Table 7 shows the simple payback times for investing in efficiency improvements from the 1984 national average efficiency to the minimum LCC and from the 1984 SWEF to the minimum LCC, at the two discount rates. Note that these payback periods are the paybacks for an investment that improves the efficiency a discrete amount. Later we will calculate the payback for the next dollar spent on infinitesimal efficiency improvements. Because of diminishing returns, we expect the incremental payback times to be shorter than the discrete payback times, and we find this to be the case.

Table 6 reveals that all appliances examined except for central A/Cs are currently operating at life-cycle costs that are substantially higher than economically optimal levels. Freezers show the most impressive potential decrease in costs, with LCC reduced between 23% and 32% by adopting optimal efficiency levels from the 1984 national average efficiency. Freezers also show the largest potential efficiency improvement, offering a factor of 2.5 improvement in efficiency from 1984 national average levels to the LCC minimum efficiency. Note, however, that these efficiency improvements for freezers are based on prototype designs. The details of the manufacturing process are not worked out; unanticipated difficulties and costs could lower

Table 5: Efficiencies of Selected Appliances

Appliance	1984 Stock	1984 SWEF (new units)	Efficiency* of LCC min at 10%	3%
Gas Furnaces (percent)	64	73	85	90
Oil Furnaces (percent)	74	79	90	93
Room A/C (EER)	6.6	7.5	9.3	10
Central A/C (SEER)	6.9	8.7	8.0	9.5
Electric Water Heater (percent)	81	82	94	94
Gas Water Heater (percent)	50	56	80	82
Refrigerator-Freezer (ft^3/kWh/day)	4.7	6.6	11	12
Freezer(ft^3/kWh/day)	8.9	12	23	24

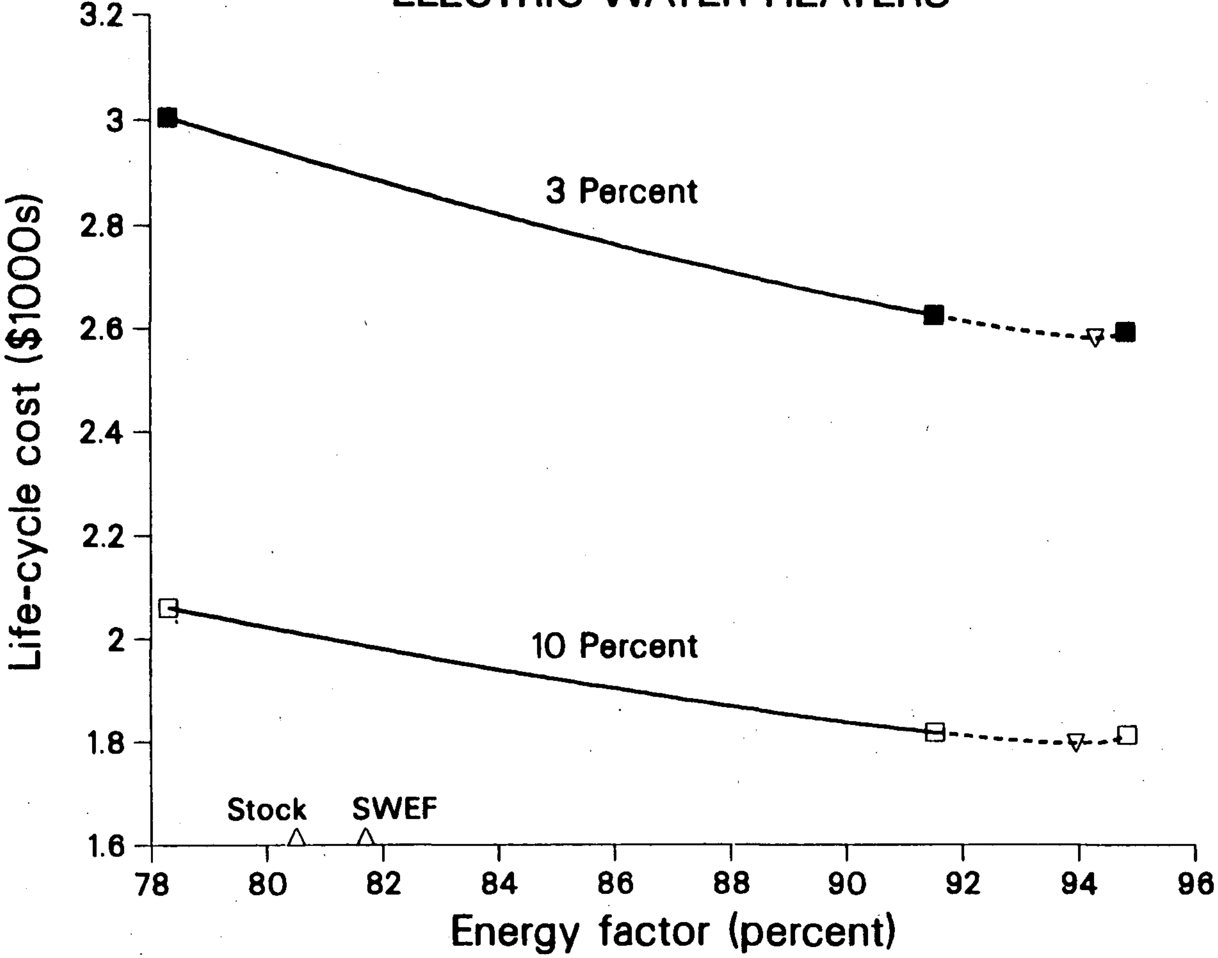
*For all products except gas furnaces, central air conditioners, and refrigerator-freezers, the efficiency at the LCC minimum is based on prototype designs that do not presently exist in the market.

the efficiency at the LCC minimum. The payback periods are all under nine years, and most of them are less than five. Refrigerator-freezers, freezers, and water heaters offer 1.3 to 2.6 year paybacks, excellent rates of return by any measure.

Figures 4 and 5 show the LCC curves for two representative appliances at three and ten percent discount rates: electric water heaters and room air conditioners. The solid portion of the curves corresponds to commercially available design options, while the dashed portion is an extrapolation to an estimated maximum technologically feasible efficiency point. As previously noted, for oil space heaters, gas and electric water heaters, and freezers, the appliances with LCC minimum efficiency are not commercially available. The LCC increases at low efficiencies, because of greater expenditures for fuel. It also increases at high efficiencies because of the higher cost of efficiency improvements.

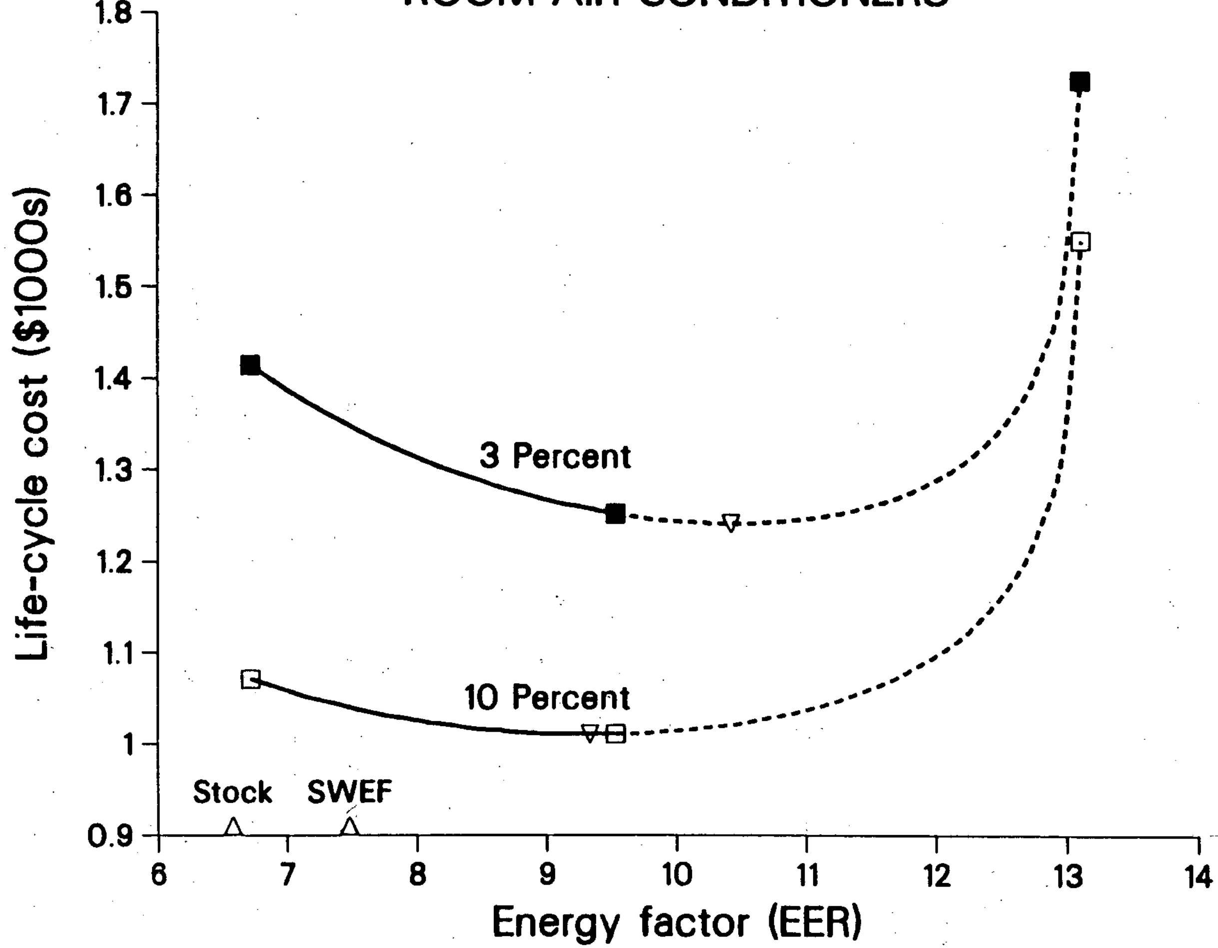
FIGURE 4:

LIFE-CYCLE COST OF APPLIANCES, 1984
ELECTRIC WATER HEATERS



XCG 858-390

FIGURE 5:
LIFE-CYCLE COST OF APPLIANCES, 1984
ROOM AIR CONDITIONERS



XCG 858-389

Table 6: Comparison of the LCC of Appliances with 1984 SWEF Efficiency to Those with LCC Minimum Efficiency				
	3%		10%	
	$LCC\ 1984SWEF - LCC_{min}$ (1984 dollars)	$\frac{LCC_{min}}{LCC\ SWEF}$	LCC 1984 SWEF - LCC_{min} (1984 dollars)	$\frac{LCC_{min}}{LCC\ SWEF}$
Gas Furnace	$614	0.92	158	0.97
Oil Furnace	1,240	0.92	424	0.96
Room A/C	106	0.92	30	0.97
Central A/C	16	0.99	8	1.00
Elect. Water Heater	309	0.89	190	0.90
Gas Water Heater	281	0.80	161	0.84
Refrigerator	353	0.77	179	0.84
Freezer	475	0.68	228	0.77

The location of the LCC minimum is marked on the curves. Life-cycle costs and consequently efficiency choice depend on the consumer's perception of the time value of money. Consumers with low discount rates who minimize their life-cycle costs would choose more efficient appliances than those with high discount rates. The difference is small for electric water heaters, as shown in Figure 4. For room air conditioners, on the other hand, the use of a 3 percent rather than a 10 percent discount rate will increases the efficiency of the LCC minimum appliance by almost 10 percent, as shown in Figure 5.

The economically optimum choice of electric water heater efficiency is close to the practical limit, because efficiency improvements are relatively inexpensive for this appliance. Room air conditioners show a broad minimum in their LCC curve. Consumers pay about the same LCCs when choosing air conditioners with SEERs in the range 9 to 11.5. Society as a whole, however, would benefit from the choice of higher efficiency air conditioners, because these devices reduce the need for additional peak electric generating capacity

Table 7: Payback Times for Investments in Energy Efficiency That Increase Efficiency From Existing Levels to Optimum Levels				
	Payback to Increase 1984 Existing Stock Eff. to LCCmin (in years)		Payback to Increase 1984 SWEF (new sales) to LCCmin (in years)	
Discount Rate	3%	10%	3%	10%
Gas Furnace	5.4	4.3	7.3	5.7
Oil Furnace	4.9	4.0	5.7	4.5
Room A/C	5.8	4.9	6.7	5.5
Central A/C	7.1	6.0	8.9	7.4
Electric Water Heater	1.5	1.3	1.6	1.4
Gas Water Heater	2.0	1.8	2.5	2.2
Refrigerator-Freezer	1.8	1.6	2.4	2.1
Freezer	2.3	2.0	2.6	2.2

and for the oil and gas needed to supply the peak power. Air conditioners are one example of an efficiency investment for which the economic costs and benefits to the purchaser differ markedly from the costs and benefits to society.

The numbers in Table 8 illustrate the approximate "marginal" efficiency investments for the dominant subgroups of each appliance. This table shows the simple payback times for investments that increase efficiency from the efficiency point nearest the 1984 SWEF to the next point on the cost/efficiency curve. For both electric water heaters and air conditioners, the payback times calculated are for an efficiency improvement from point 2 to point 3 on the curves in Figures 2 and 3 respectively. These payback times

Table 8: Approximate Incremental Payback Times (years)	
Appliance (Dominant Class)	Incremental Payback Time
Gas Forced-Air Furnace	2.8
Oil Forced-Air Furnace	0.85
Room A/C (cap.<8000Btuh)	0.38
Split System Central A/C (cap.<39000 Btuh)	4.5
Electric Water Heaters	0.58
Gas Water Heaters	1.9
Refrigerator-Freezer (auto. def., top mount)	1.5
Chest Freezer, Manual defrost	1.1

indicate that purchasers are rejecting excellent returns on the next dollar invested in efficiency improvements.

The average appliance purchased does not include some energy efficiency measures that yield very high returns on investment. For example, an investment of $26 to include increased door insulation, a higher compressor efficiency, a double door gasket, and an anti-sweat heater switch in a refrigerator would save $28/year at 1984 fuel prices, and yield an annualized rate of return of 107 percent on the investment. Yet the average refrigerator purchased in 1984 did not have these features. Previous analysis confirms that the payback times calculated here for the dominant subgroups of each appliance type are representative of the entire market for these residential appliances* (3,4).

INTERPRETATION OF PAYBACK TIMES

The short payback times observed in this analysis suggests that the market for energy efficiency is far from rational. If a consumer demands a rate of return higher than the current loan interest rate, he or she would borrow money to purchase a more efficient appliance. The return on his/her

*The extremely short payback time calculated for room air conditioners with less than 8000 Btu/hour capacity is caused by a peculiarity in the cost/energy use curve for this subgroup. It is not representative of all room air conditioners, for which the marginal payback is closer to that of central air conditioners.

investment, namely lower fuel bills, would more than pay for the interest due on the borrowed amount. The data and previous analysis (3,4), however, indicate that this does not occur. Except for air conditioners, higher efficiency in appliances is purchased only if it pays for itself in less than three years (and much shorter time periods for several products). These results suggest that imperfections in the market inhibit economically optimal decisions. The payback times calculated in this paper for "marginal" efficiency improvements correspond to a rate of return on the investment from twenty to several hundred percent per year, far greater than real interest rates or the discount rates commonly used in LCC analysis (3,4).

Several explanations of underinvestment in energy efficiency in the residential sector can be found in the literature. (For a full discussion of this subject, see Reference 7.) These explanations include:

(1) Purchasers lack information about costs and benefits of energy efficiency improvements or may not understand how to use this information if it is available;

(2) Purchasers may not have sufficient capital to acquire funds to purchase more energy-efficient products;

(3) Purchasers may have a threshold below which savings may not be significant or worth the additional effort to obtain.

(4) The prevalence of indirect or forced purchase decisions (e.g., builder and landlord purchase of equipment for rental property; need for immediate replacement of malfunctioning equipment);

(5) The most efficient appliances may not be available in retail stores or may be available only with other features that may not be desired by most purchasers;

(6) Manufacturer's decisions to improve product efficiency are often secondary to other design changes and take several years to implement;

(7) Marketing strategies by manufacturer or retailer may intentionally lead to sales of less efficient equipment.

CONCLUSIONS

This paper demonstrates that consumers significantly underinvest in the efficiency of major household appliances. For many products, efficiency options are available that pay back in months or one to two years. These options are typically not included in new appliances.

The problem is a significant one for the nation. The appliances treated in this paper constitute more than 12 percent of U.S. energy demand, at a cost of more than $50 billion per year. Currently available, cost-effective efficiency improvements could reduce these fuel costs by $5 to $8 billion per year. Over the longer term, the national fuel bill could be reduced by $17 billion per year (net savings of $10 billion per year) through the purchase of efficiency measures at the life-cycle cost minimum. Because the market lags behind the economic "optimum," these savings are not likely to be achieved quickly without significant improvements in consumer awareness, leadership by manufacturers to produce and market cost-effective, efficient appliances, and public and private programs to strongly promote increased investment in efficient household products.

Appendix 1: Discount Rates and Life-Cycle Costs

A discount rate is a measure of the present value of money received or spent in the future. For example, if someone values an income of $110 received a year from today the same as an income of $100 received today, that person has a discount rate of 10 percent per year. Given the discount rate r, one can calculate the present value of a stream of income (or expenditures) using the formula

$$PV = \sum_{t=1}^{N} \frac{X_t}{(1+r)^t}, \tag{1}$$

where

X_t = Income in time period t

and

N = Duration of income stream.

For a constant stream of income, this formula becomes

$$PV = PWF \cdot X_t,$$

where we have defined the present worth factor PWF by

$$PWF = \sum_{t=1}^{N} \frac{1}{(1+r)^t} = \frac{1}{r}\left(1 - \frac{1}{(1+r)^N}\right). \tag{2}$$

The life-cycle cost for owning and operating an appliance is the sum of the purchase cost and the discounted operating cost. Assuming that the only operating cost is for energy, the life-cycle cost is given by

$$LCC = PC + \sum_{t=1}^{N} \frac{FC_t}{(1+r)^t}. \tag{3}$$

In this equation, PC is the purchase cost, FC_t is the fuel cost in period t, and N is the lifetime of the appliance. Maintenance costs are assumed to be independent of efficiency choice, hence they can be ignored in calculating market discount rates. For constant fuel costs, Equation 3 becomes

$$LCC = PC + PWF \cdot FP \cdot E, \tag{4}$$

where PWF is the present worth factor defined above, FP is the average fuel price, and E is the average energy consumption by the appliance. Under conditions of perfect competition, the market selects an energy use (or efficiency) that minimizes the average life-cycle cost of the appliance. Mathematically, this is equivalent to finding the energy use E_s such that

$$\left.\frac{dLCC}{dE}\right|_{E_s} = \left.\frac{dPC}{dE}\right|_{E_s} + PWF \cdot FP = 0. \tag{5}$$

Solving this for the present worth factor gives

$$PWF = \frac{-1}{FP} \left. \frac{dPC}{dE} \right|_{E_s} . \qquad (6)$$

Hence, given the analytic form of the cost-efficiency curve, we can evaluate the derivative $\frac{dPC}{dE}$ at the average efficiency purchased and, using Equations 6 and 2, calculate the discount rate.

The simple payback period is defined as the time needed to recoup an initial investment in energy efficiency. Numerically, the payback period is equal to the increase in purchase cost divided by the decrease in annual operating cost. Assuming the operating costs change only because fuel use decreases, we have

$$Payback = \frac{\Delta PC}{FP \cdot \Delta E} = \frac{-1}{FP} \frac{dPC}{dE} = PWF. \qquad (7)$$

Thus for a continuous cost-efficiency curve the payback period is just the present worth factor. From Equation 2, we can see that for large discount rates and long lifetimes, the payback period and discount rate are approximately reciprocal to each other.

REFERENCES

(1) J.E. McMahon, "The LBL Residential Energy Model: An Improved Policy Analysis Tool," September 1985, Unpublished Lawrence Berkeley Lab (LBL) Report: LBL-18622.

(2) "Consumer Interest in High Efficiency Appliances Grows," *Appliance Manufacturer*, May 1985, p. 10.

(3) H. Ruderman, M.D. Levine, and J.E. McMahon, "Energy Efficiency Choice in the Purchase of Residential Appliances," LBL Report LBL-17889, July 1984.

(4) H. Ruderman, M.D. Levine, and J.E. McMahon, "The Behavior of the Market for Energy Efficiency in Residential Appliances Including Heating and Cooling Equipment," LBL Report LBL-15304, Sept. 1984.

(5) I. Turiel, H. Estrada, and M.D. Levine, "Life-cycle Cost Analysis of Major Appliances," *Energy*, v. 6, no. 9, pp. 945-970, 1981.

(6) U.S. Department of Energy, Consumer Products Efficiency Standards Engineering Analysis Document, March 1982, DOE/CE-00030.

(7) M. Levine and P. Craig, "Energy Conservation and Energy Decentralization: Issues and Prospects," in *Decentralized Energy*, ed. by P. Craig and M. Levine, AAAS Selected Symposium 72, Westview Press, Inc. (1982).

LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
1 CYCLOTRON ROAD
BERKELEY, CALIFORNIA 94720