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ENERGY & ENVIRONMENT DIVISION

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July 1980

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Life-Cycle Cost Analysis of Major Appliances

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ABSTRACT

The Department of Energy has proposed energy efficiency standards for eight types of appliances. One of the criteria used to establish these standards is the economic impact of the standard on the consumers of the regulated products. A life-cycle cost analysis was performed for 32 classes of these eight appliances in order to gain a measure of the economic impact of equipment purchases on the consumer. Simple payback times were also computed to indicate how much time is required for the consumer to recapture his or her initial added investment in a more efficient product.

Using national average energy use for each appliance type, we found that the proposed 1985 standards are cost-effective with respect to the energy efficiency levels projected to occur in the absence of standards for all classes of products. Simple payback periods range from several months for refrigerators and freezers to a maximum of 5.3 years for split system central air conditioners.

A regional life-cycle cost analysis indicated that the distribution of costs and benefits from the proposed national standards varies significantly among the different regions for air conditioners and furnaces. In the region with the least cooling load hours, simple payback times are quite lengthy for air conditioners, and in some cases exceed the appliance lifetime.

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I. Introduction

The Energy Policy and Conservation Act (Public Law 94-163) as amended by the National Energy Conservation Policy Act (Public Law 95-619) established the Consumer Products Efficiency Standards Program and assigned the Department of Energy (DOE) the task of establishing mandatory minimum energy efficiency standards for 13 consumer products. In accordance with this requirement, DOE has proposed minimum energy efficiency standards for various classes of eight appliances: refrigerators and refrigerator-freezers, freezers, clothes dryers, water heaters, room air conditioners, ranges and ovens, central air conditioners, and furnaces.¹ The remaining five consumer products have been placed on a slower schedule with standards to be proposed at a later date.

DOE is required to set standards at a level that achieves the max-

imum improvement in energy efficiency that is technologically feasible and economically justified. One of the criteria on which this determination is based is the economic impact of the standards on consumers of the regulated products.

This paper provides a methodology for assessing the economic costs and benefits to the consumer who purchases appliances of varying initial costs and energy efficiency. In particular, DOE's three 1985 trial standard levels and the proposed 1985 standard are examined for each class of appliance. The basis for the method of analysis is the use of life-cycle costing.²

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 which 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. The assumption is also made that the cost of maintenance over the lifetime of the appliance is unchanged as the efficiency of a model is increased or decreased. Therefore, the maintenance cost is not included in the life-cycle cost calculation, as exclusion of maintenance costs has no effect on the differences in life-cycle costs among models of different efficiencies. In order to consider first cost and operating costs on a time equivalent basis, all future operating costs are discounted to present value.

One of DOE's objectives is to minimize total cost to the consumer while insuring that there is no significant adverse impact on appliance

manufacturers or other groups. In effect life-cycle costs are compared for classes of appliances of the same capacity but different efficiencies. A more energy efficient product is often more expensive than one of low efficiency, all other features of the product being equal. However, the more energy efficient model uses less energy than a less efficient one and thus costs less to operate. If the more efficient model has lower total costs to the consumer over the life of the appliance the consumer benefits, although a higher initial investment may cause an adverse impact over the short term.

This potential problem of higher first costs associated with lower life-cycle costs of more energy efficient products can be assessed in terms of a simple payback period. The simple payback period (see Appendix 1) is the amount of time required for the consumer to recoup his or her additional investment in a more energy efficient product. For example, if the simple payback period is 11 months, then the extra costs of the purchase of a more efficient product are fully recovered in reduced energy bills during the first 11 months of operation of the product. This is equivalent to a return on investment of greater than 100% per year to the consumer. If on the other hand, the simple payback is 20 years, then the rate of return on the initial investment is small (unless energy prices escalate rapidly).

Because energy prices and appliance utilization patterns vary regionally, the imposition of national standards may result in an inequitable distribution of costs and benefits among regions. For example, improving the efficiency of a baseline central air conditioner to that of the proposed standard will generally result in a significant

reduction in operating energy costs and, therefore, life-cycle costs, in Miami. However, the modest reductions in the operating costs of this more efficient unit expected to occur in Minneapolis would result in a relatively long payback period, and possibly an increase in life-cycle costs. Since variations in energy consumption are most significant among space heating and cooling products, regional analyses will focus on gas-fired and oil-fired furnaces, central air conditioners, and room air conditioners.

To summarize, 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 most of the energy and fuel cost savings derived from the purchase of a more energy efficient product occur in the future. The simple payback concept is an approximate way of indicating how much time is required for the consumer to recapture his or her initial added investment in a more efficient product. When the payback time is a few years or less the simple payback approach is a very good approximation to the actual payback time. A discussion of the methodology used to obtain life-cycle cost curves follows.

II. Methodology and Assumptions

The total life-cycle cost, L.C.C., of an appliance is given by equation (1):

$$LCC = I.C. + \sum_{i=1}^N (ENC)_i \times \frac{(PF)(1+f)^i}{(1+d)^i} \quad (1)$$

where

- I.C. = initial cost of appliance, in dollars
- ENC_i = energy consumption in year i, in million Btus
- PF = fuel price in year 1, in dollars per million Btus
- N = lifetime of appliance, in years
- f = annual fuel escalation rate in constant dollars
- d = discount rate in constant dollars

DOE is proposing two sets of energy performance standards for consumer products: one set applies in 1981 and a tighter set applies in 1985. The life-cycle cost analysis applies only to the 1985 standards, because the tighter 1985 standards are intended to achieve substantial life-cycle cost savings to the consumer. The 1981 standards achieve much smaller life-cycle cost savings because of the relatively small energy efficiency improvements mandated by these near term standards.

In the analysis as performed, yearly energy consumption (ENC_i) and the fuel escalation rate (f) are assumed to be constant over the appliance lifetime. Thus, equation (1) may be simplified to

$$LCC = I.C. + (ENC) \times (PF) \times PWF \quad (2)$$

where

$$PWF = \sum_{i=1}^N \left(\frac{1+f}{1+d} \right)^i \quad (3)$$

Table 1 shows the national average fuel prices and escalation rates

used in the life-cycle cost calculations. Both a high and a low fuel price escalation rate are presented to illustrate the effects of differing price scenarios on life-cycle costs.⁺ (These two price scenarios are used in the analysis to represent the U.S. Department of Energy estimates of likely upper and lower bounds of fuel prices.) Both the first cost and the fuel prices are expressed as

Table 1 - FUEL PRICES AND ESCALATION RATES

	1985 Fuel Price \$/10 ⁶ Btu (in 1978 \$)	Annual Escalation Rate (Percent)	
		High Case	Low Case
Electricity	15.70*	2.5	1.0
Gas	3.46	3.0	1.5
Oil	6.39	3.0	1.5

*Corresponds to 5.36¢/kwh at the building boundary.

1985 prices measured in 1978 dollars: as such, the LCC results are expressed in constant 1978 dollars. The fuel price escalation rates and the discount rate are expressed in real dollars, that is, a rate above that of inflation. The discount rate was chosen to be 5% real; sensitivity analyses for discount rates of 3% and 10% are discussed in Section VI. Table 2 presents the appliance lifetimes used in the LCC analysis.

⁺The relative life-cycle costs and payback periods for products of differing energy efficiencies are not greatly changed between the two price scenarios. Only the high price case results are presented in this Section. Selected results for the low price case are presented in the Sensitivity Analysis Section.

Table 2 - APPLIANCE LIFETIMES

Central heating	20
Water heating	10
Ranges & Ovens	14
Dryers (electric)	14*
Central Air Conditioners	14
Room Air Conditioners	10
Refrigerator	15
Freezer	20

* 11 for gas dryers

Source: U.S. Department of energy (DOE)

Summarizing, the major economic assumptions are that:

- (1) average national energy prices are used (Table 1);
- (2) The annual escalation rates for fuel prices in the high price case are 2.5% for electricity and 3.0% for oil and gas in real dollars; the rates in the low price case are 1.0% for electricity and 1.5% for oil and gas (Table 1);
- (3) the discount rate is taken to be 5% in real dollars (equivalent to a return on investment of the rate of inflation plus 5%);
- (4) DOE appliance lifetimes in Table 2 were used; and
- (5) the increase in purchase price of the appliance is assumed to be equal to that of inflation (equivalent to a real cost escalation rate of zero percent).

There are two other very important inputs to the LCC computations. These are: cost versus efficiency and annual energy consumption for each class of appliance.

Cost versus efficiency data⁺ were provided by Arthur D. Little, Inc. (ADL).³ ADL began with a base case appliance which reflected 1978 sales weighted energy efficiency data taken from an industry survey (DOE Form CS 179). The baseline unit was defined as the unit with an efficiency, input, output, and size approximately equal to that of the most commonly produced unit in 1978. For the analysis of the various design

⁺Also referred to as ADL cost book.

options each baseline unit was characterized in terms of the features that most influence the energy efficiency of the unit.

Using engineering analysis and computer simulations, ADL estimated, the efficiency improvements resulting from implementation of various design options. For the analysis, the design options considered were limited to those based on available technology defined as those technologies presently implemented in units available in the marketplace at least in limited production quantities. Only those design options were considered which were represented by existing test procedures. The analysis resulted in estimates of the per unit change in materials and purchased parts required to achieve specific efficiency levels.

Added costs were estimated from an analysis of the components requiring tooling changes to achieve the design options. In addition, design options which require investments in capital equipment were identified. The final cost estimates were made using these data as described below.

Four basic cost elements (investment, materials, purchased components, and labor) were considered. These four cost elements were summed to estimate the added factory cost. Estimates of the added cost to the consumer were made by marking-up factory cost by 35% to obtain an estimate of the cost to a wholesaler-distributor. The wholesaler-distributor cost was increased by 60% for water heaters, furnaces, and central air conditioners and 70% for refrigerators and refrigerator-freezers, freezers, clothes dryers, kitchen ranges and ovens, and room air conditioners to obtain the estimated added cost to the consumer. To estimate the price of a more efficient unit to the consumer, this

estimated cost increase was added to the price of the baseline unit. The price and the efficiency of the unit were then used to generate a cost versus efficiency relationship for each product class.

Figures 1 and 2 illustrate cost versus efficiency curves for automatic defrost top mount refrigerators and split system central air conditioners, respectively. Also shown, are the design options chosen for analysis. Points on the curves are generated by implementing combinations of design options. In Figure 2, the same design options (1, 2, 3) are used for each data point. In cases of this type the design options were carried out to varying degrees. These design options are described in detail for each product type in Technical Support Document (TSD) No. 5, Engineering Analysis.⁴

Average annual energy consumption per unit is composed of two factors, an energy factor (or efficiency) and a usage factor. In general for each appliance model:

$$\text{annual energy use per unit} \propto \frac{\text{usage factor}}{\text{energy factor}}$$

In some cases the annual energy consumption in the ADL data base is significantly different from that found by Oak Ridge National Laboratory (ORNL). Table 3 compares values obtained from ORNL with data provided by ADL for the base case appliance.⁵ The ORNL values were used in the LCC analysis because the ORNL estimates were from a broader, more complete data base.

The life-cycle cost analysis was performed on a national basis for all the covered products. In addition, the analysis was performed on a regional basis for the three products whose usage is highly dependent on

Design Options:

- 1) Foam Insulation Substitution
- 2) High Efficiency Compressor Substitution
- 3) Double Door Gasket in Freezer
- 4) Place Evaporator Fan Motor Outside of Cold Space

FIGURE 1. COST VS EFFICIENCY
AUTOMATIC DEFROST-TOP MOUNT REFRIGERATOR

Design Options*:

- 1) Increased Condenser and Evaporator Heat Exchanger Surface Area
- 2) Decreased Compressor Size
- 3) Change Fan/Motor

*In cases where the same design options are used for more than one data point, these options have been carried out to varying degrees. For details see Ref. 4.

**FIGURE 2. COST VS EFFICIENCY
CENTRAL AIR CONDITIONER-SPLIT SYSTEM**

Table 3.
Annual Energy Use Per Unit⁺

Consumer Product	Fuel	ORNL*	ADL**	ORNL/ADL
Refrigerator	Electric	1740	1548.0	1.12
Freezer	Electric	1642.6	1170.5	1.40
Dryer	Electric	1114.8	1066.6	1.04
Dryer	Gas	7.0	4.2	1.67
Water Heater	Electric	4599	6620	.69
Water Heater	Gas	25.0	36.6	.68
Ranges/Ovens	Electric	1246.1	407.0	3.06
Ranges/Ovens	Gas	9.6	4.4	2.18
Air Conditioners	Room***	1708.7	1238.2	1.38
Air Conditioners	Central	3106.1	4373.7	.71
Central Space Heat	Gas	88.7	126.2	.70
Central Space Heat	Oil	141.8	118.7	1.19

+ Energy use is in kwh for electric and in 10⁶ Btu for gas and oil appliances, respectively

* 1977 Values, Weighted by Housing Units

** A.D. Little Values, Weighted by 1978 Sales

*** 1708.7 kwh is the annual energy use per household. In order to obtain annual energy use per unit for room air conditioners, divide 1708.7 kwh by 1.45, the number of room air conditioners per household (among households having room air conditioners)

weather: furnaces, central air conditioners, and room air conditioners.

The regions, shown in Figure 3, were defined by DOE as follows:

Region I	> 2,500 heating load hours ≤ 600 cooling load hours
Region II	> 1,750 < 2,500 heating load hours > 600 ≤ 1,200 cooling load hours
Region III	< 1,750 heating load hours > 1,200 cooling load hours

Heating is the major portion of the total space conditioning load in region I and cooling is the major portion of the space conditioning load in region III. Table 4 shows the fraction of total sales of room air conditioners in the three DOE regions and the average cooling load hours obtained from aggregating into the three DOE regions estimates by Science Applications, Inc.,⁶ of cooling load hours for six regions prescribed by DOE in the Federal Register of April 19, 1979. The three regional cooling load hours can be aggregated to a national average cooling load hours as follows:

$$.22(300) + .48(950) + .30(1800) = 1060$$

The fraction of total sales and cooling load hours by region in the above expression are from Table 4. Therefore, the energy use in regions I, II, and III is obtained by multiplying the national average energy use by the following fractions:

$$\frac{300}{1060} = 0.28, \frac{950}{1060} = 0.9, \text{ and } \frac{1800}{1060} = 1.7.$$

Table 5 shows the fraction of total sales of central air conditioners and the average cooling load hours in the three DOE regions. The three regional cooling load hours can be aggregated to a national

SOURCE: DOE (1980)

FIGURE 3: HEATING AND COOLING REGIONS OF THE UNITED STATES
FOR PURPOSES OF ANALYSIS OF APPLIANCE EFFICIENCY STANDARDS

average cooling load hours as shown below:

$$.10(300)+.46(950)+.44(1800)=1260$$

Therefore the relative energy use in regions I, II and III are:

$$\frac{300}{1260} = 0.24, \frac{950}{1260} = 0.75, \text{ and } \frac{1800}{1260} = 1.43.$$

respectively.

Table 4
Fraction of Sales and Regional Cooling Load Hours
Room Air Conditioners

Region	Fraction of Total Sales	CLHR
I	.22	300
II	.48	950
III	.30	1800

Sources: Science Applications, Inc. 1979;
Association of Home Appliance Manufacturers, 1978;
and American Refrigeration Institute, 1978.

Table 5
Fraction of Sales and Regional Cooling Load Hours
Central Air Conditioners

Region	Fraction of Total Sales	CLHR
I	.10	300
II	.46	950
III	.44	1800

Sources: Same as previous Table.

III. Results of Consumer Life-Cycle Costs (LCC) and Simple

Payback Period Calculations: National Average Energy Use

Equations (2) and (3) have been used to calculate consumer life-cycle costs for eight products covered by DOE's proposed regulation. The LCC curves for at least one class of each of these eight appliances are shown in Appendix 2. For cases where there is more than one class per appliance type, the class with the most sales has been illustrated. Two typical LCC curves are also reproduced in the text for purposes of discussion. Figure 4, an LCC curve for an automatic defrost top mount refrigerator/freezer is typical of most appliances studied. The LCC decreases continuously with increasing energy efficiency. In other words, the energy cost savings derived from the use of more efficient models of this class of refrigerator/freezer more than compensate for the extra initial cost of these models, when any model is compared to one of lower efficiency.

Figure 5, for a split system central air conditioner, is illustrative of classes of appliances where the minimum life-cycle cost does not occur for the highest efficiency model. There are four other cases (all room air conditioners (RAC) except those of capacity greater than 20,000 Btu/h, and gas clothes dryers) where the minimum in LCC occurs before the highest efficiency model. For appliances of this type, consumers do not benefit most by purchasing the highest efficiency model available.

Table 6 illustrates the three 1985 trial standard levels for each appliance class. Table 7 compares the proposed 1985 standards, the sales weighted energy factor (SWEF) in 1978, and the projected 1985 SWEF (in the absence of standards). The projected 1985 SWEF (baseline

*Evaluated at a 5%
real discount rate
and DOE's high energy
price case (2.5% per
year real electricity
price escalation rate).

FIGURE 4. LIFE-CYCLE COSTS OF REFRIGERATORS*
(AUTOMATIC DEFROST-TOP MOUNT)

*Evaluated at a 5%
real discount rate
and DOE's high energy
price case (2.5% per
year real electricity
price escalation
rate).

FIGURE 5. LIFE-CYCLE COSTS OF CENTRAL AIR CONDITIONERS*
(SPLIT SYSTEM 30,000 BTU/HR)

efficiency) was obtained by multiplying the 1978 SWEF by a factor equal to the improvement in energy efficiency predicted to occur between 1978 and 1985 (obtained from the ORNL residential energy use model). The LCC for the projected base case efficiency and the three 1985 trial standard levels have been calculated for each product class. These results are presented in Appendix 3 Tables 1-8. Tables 1-8 in Appendix 4 contain the simple payback periods for the investment in greater efficiency required by the 1985 trial standard levels compared with the projected 1985 sales weighted energy factors.

For most of the regulated product classes the level 3 trial standard is the same as the proposed standard. Exceptions are 2 room air conditioners, the two central air conditioners and the manual upright freezer. For these five classes trial level 3 is higher than the 1985 proposed standard. The LCC changes and simple payback periods for the proposed Standards compared to the projected 1985 SWEF are not found in the appendices but have been calculated for each of these cases and are discussed in the text.

Table 6.
1985 Trial Standard Levels

	Level 1	Level 2	Level 3
<u>CAC</u>			
Split	9.2	10.1	11.1
Single	8.5	9.6	10.7
<u>RAC</u>			
< 6,000 Btu	7.5	8.4	9.1
6,000 Btu to 20,000 Btu	8.6	9.1	9.5
>20000 Btu	7.5	8.0	8.4
Through wall & Reverse Cycle	8.6	9.0	9.5
<u>FURNACES</u>			
Gas Indoor Forced Air	67	73	81
Gas Boiler	67	73	79
Gas, Outdoor Horizontal non-weatherized	65	70	74
Gas Outdoor Weatherized	70	72	76
Oil, Forced Indoor	--	75	80
Oil, Boiler	78	80	82
Oil, Outdoor, Forced Air	--	--	78
<u>WATER HEATERS</u>			
Gas	61	62	63
Electric	82	92	93
<u>CLOTHES DRYERS</u>			
Electric, Standard	2.7	2.9	3.0
Electric, Compact, 120V	--	--	2.85
Electric, Compact, 240V	--	--	2.54
Gas	--	--	2.60
<u>RANGES AND OVENS</u>			
Gas Cook Top	--	42	45
Gas Oven	3.8	4.0	6.4
Gas Oven Self Clean	3.7	5.5	6.0
Electric Cook Top	--	--	79
Electric Oven	--	--	14.1
Electric Oven Self Clean	--	--	13.6
<u>REFRIGERATORS/FREEZERS</u>			
Refrigerator Manual	8.6	10.0	17.2
Part. Auto	6.0	8.2	11.6
Auto-Top Mount	5.3	7.0	8.2
Auto-Bottom Mount	6.4	6.9	7.4
Auto Side by Side	6.0	6.5	7.0
Auto; TM w/TTD	4.8	6.5	7.7
Auto; Side by Side TTD	5.5	6.0	6.3
<u>FREEZERS</u>			
Manual Chest	12.2	16.1	18.7
Manual Upright	11.5	13.8	16.5
Auto, Upright	5.5	8.4	9.6

Table 7.
Compilation of Proposed 1985 Standards and Base Case Energy Efficiencies

Product	DOE'S Proposed 1985 Standard	SWEF (1978)	SWEF* (1985)
<u>CAC</u>			
Split	11.0	7.02	7.63
Single	10.5	6.90	7.50
<u>RAC</u>			
< 6,000 Btu	8.4	6.17	6.65
6,000 Btu to 20,000 Btu	9.5	7.25	7.80
>20,000 Btu	8.4	6.74	7.25
Through Wall & Reverse Cycle	9.0	6.55	7.05
<u>FURNACES</u>			
Gas Indoor Forced Air	81	64.6	69.8
Gas Boiler	79	65.1	70.4
Gas, Outdoor Horizontal, Non-weatherized	74	56.0	60.6
Gas, Outdoor Weatherized	76	68.0	73.4
Oil, Forced Indoor	80	75.25	79.6
Oil, Boiler	82	75.8	80.2
Oil, Outdoor Forced Air	78		
<u>WATER HEATERS</u>			
Gas	63	48.2	51.3
Electric	93	80.67	84.3
<u>CLOTHES DRYERS</u>			
Electric Standard	3.0	2.6	2.70
Electric Compact, 120V	2.85	2.63	2.73
Electric Compact, 240V	2.54	2.35	2.44
Gas	2.60	2.38	2.44
<u>RANGES AND OVENS</u>			
Gas Cook Top	45.0	30.8	36.2
Gas Oven	6.4	4.6	5.4
Gas Oven, Self Clean	6.0	4.8	5.6
Electric Cook Top	79	75.0	77.2
Electric Oven	14.1	13.0	13.4
Electric Oven, Self Clean	13.6	12.6	13.0
<u>REFRIGERATORS</u>			
Refrigerator, Manual	17.2	7.11	8.3
Part. Auto	11.6	5.35	6.24
Auto-Top Mount	8.2	4.73	5.52
Auto Side by Side	7.0	5.01	5.85
Auto Side by Side TTD	6.3	5.03	5.87
<u>FREEZERS</u>			
Manual Chest	18.7	11.29	12.92
Manual Upright	16.3	9.21	10.54
Auto, Upright	9.6	6.36	7.28

* The projected 1985 SWEF is obtained by multiplying the 1978 SWEF by the improvement in efficiency predicted by the ORNL residential energy use model.

LCC Results for Refrigerators/Freezers

The costs and benefits of improvements in the energy efficiency of refrigerator/freezers have been evaluated for five of the seven classes, accounting for 95 percent of current sales. In all cases, the most efficient model evaluated for each class (corresponding to the proposed 1985 standards) has the lowest life-cycle cost.

The longest time period for a simple payback on investment in energy conservation is less than 10 months, using estimates of 1985 energy prices stated earlier. For all of these calculations, the proposed 1985 standards are compared with a model meeting the projected class average energy factor in 1985. The average consumer achieves a return on investment of greater than 100 percent per year in choosing to purchase a refrigerator/freezer meeting the proposed standard in 1985 rather than a product with the projected average energy efficiency of 1985 purchases.

Life-cycle cost reductions in absolute terms range from 91 dollars for the side by side automatic defrost model with through the door (TTD) access to 324 dollars for the automatic defrost top mount model. The simple payback times range from 6 months for the manual defrost model to 9.6 months for the partial automatic defrost models. Purchase of the most energy efficient models of refrigerator/freezer available is highly beneficial to the consumer.

The short payback period is readily apparent from a consideration of the following figures: an average (without standards) automatic defrost top mount refrigerator purchased in 1985 would consume 1564 kwh

per year, at an estimated cost of 84 dollars per year in 1985 (in 1978 dollars). A refrigerator/freezer of this class at the proposed standard would consume about 1055 kwh per year, at an estimated cost of 57 dollars per year in 1985. Thus, the reduction in fuel costs in 1985 is estimated to be 27 dollars. Since the additional cost to the consumer is 16 dollars for the more efficient model the simple payback time is (16 dollars/27 dollars) times 12 months; slightly more than 7 months.

LCC Results for Freezers

The changes in life-cycle costs for freezers are highly beneficial to the consumer. The reduction in life-cycle costs (relative to an average freezer purchased in 1985) ranges from about 295 dollars for a manual defrost chest model to 546 dollars for a manual defrost upright model, for the proposed 1985 standards. These reductions are about 20 % and 30 % respectively of base case life-cycle costs. The payback period is 2.4 months for automatic defrost models, 2.4 months for manual defrost uprights, and 4.8 months for manual defrost chest freezers. For manual defrost upright freezers, level 3 (16.5) is higher than the proposed standard (16.3). When level 3 is compared to the projected 1985 SWEF the corresponding LCC reduction is 532 dollars (32%) and the simple payback period is 2.4 months.

LCC Results for Clothes Dryers

Minimum efficiency standards have been proposed for 3 classes of electric clothes dryers and one class of gas dryer. The reductions in life-cycle cost for units meeting the proposed 1985 standards relative to an average dryer purchased in 1985 are 46 dollars for the 240V stan-

dard electric, 7 dollars for the 120V compact electric, and 5 dollars for gas dryers. These reductions are quite small, ranging from about 2% to 5% of the base case LCC. The simple payback times (for the proposed standards) are 2.4 years for the 240V standard electric dryer, 2.3 years for the 120V electric compact and 4.2 years for the gas dryer. Although these payback times are not as short as for refrigerator/freezers or freezers, the small increase in initial cost (13 dollars) for the three classes of dryers makes the purchase of the most energy efficient model available a desirable consumer decision.

LCC Results for Water Heaters

The life cycle costs of standard gas and electric water heaters have been evaluated. In both cases, the most efficient model evaluated (corresponding to that of the proposed standard) has the lowest life-cycle cost.

The life-cycle cost to the consumer for an electric water heater with an energy efficiency at the proposed 1985 standard is approximately 170 dollars lower than the life-cycle cost of the projected average electric water heater that would be purchased in 1985 without standards. This is a reduction of about 8 percent in the life-cycle cost of a projected average 1985 electric water heater. The additional investment to achieve the proposed standard is approximately 15 dollars. The annual reduction in fuel bill for electric water heaters meeting the proposed standard in 1985 would be 21 dollars. This corresponds to a simple payback of less than 9 months.

The LCC to the consumer for a gas water heater for the proposed

1985 standard is 130 dollars (15%) lower than the LCC of the projected average gas water heater that would be purchased in 1985 without standards. The additional investment to achieve the proposed standard is approximately 15 dollars and the annual reduction in the fuel bill in 1985 is also about 15 dollars. Thus the simple payback time is approximately 1 year. The purchase of both gas and electric water heaters with efficiencies at the proposed 1985 standards is a highly beneficial choice for the consumer.

LCC Results for Room Air Conditioners

The life-cycle costs of four classes of room air conditioners (RAC's) have been evaluated. For one of the four classes (>20,000 Btu/h), the most efficient model evaluated (EER=8.4) has the lowest life-cycle cost. The other three classes of RAC's have a minimum in life-cycle cost at an EER of 9.1. The most efficient model evaluated for these three classes of RAC's has an EER of 9.5. The proposed 1985 standard is within 3% of the LCC minimum (or at the end of the LCC curve because of lack of information about the costs of additional energy efficiency improvements) for three of the four classes of room air conditioners. The proposed 1985 standard is about 8 percent below the LCC minimum for models of capacity less than 6,000 Btu/h. For two classes of RAC's (<6,000 Btu/h and those without side louvers) the proposed standard is below level 3. In these cases we have calculated LCC reductions and simple payback periods for both level 3 and the proposed standards compared to the projected 1985 SWEF. When the proposed standard is compared to the 1985 SWEF, LCC reductions range from 33 dollars (4.9%) for units with capacity between 6,000 and 20,000 Btu/h to 112

dollars (6.5%) for units with capacity greater than 20,000 Btu/h. The simple payback times range from 1.5 years for RAC's with capacity less than 6,000 Btu/h to 4.6 years for RAC's with capacity between 6,000 and 20,000 Btu/h. When level 3 is compared to the 1985 SWEF, LCC reductions have the same range and the simple payback times change to a range of 1.3 years for RAC's with capacity less than 6,000 Btu/h to 4.5 years for RAC's with capacity between 6,000 and 20,000 Btu/h.

LCC Results for Ranges and Ovens

The life-cycle costs of three classes of gas ranges and ovens and three classes of electric ranges and ovens have been evaluated. For all six classes the most efficient model evaluated has the lowest life-cycle cost. For the two gas ovens, the reductions in the life-cycle cost are 51 dollars (9%) for the standard model and 15 dollars (2%) for the self cleaning oven when the proposed standards are compared to the projected 1985 SWEF. For the gas cooktop model, the LCC reduction is 90 dollars (17%). These LCC reductions are achievable with initial cost increases of 29 dollars (13.5%), 27 dollars (6%) and 26 dollars (17%) for standard gas ovens, self cleaning gas ovens, and gas cooktops respectively. The simple payback times are 1.2 years for the gas cooktop, 2.3 years for the standard gas oven and 3.1 years for the self cleaning gas oven when proposed 1985 standards are compared to the projected 1985 SWEF.

For electric cooktops and self cleaning electric ovens the efficiency of the proposed 1985 standards is greater than the maximum efficiency given in the cost book. However, energy consumption options up to the highest energy factor in the cost book (75.0 and 13.0 respectively) are cost effective. For the standard electric oven the reduction in

life-cycle cost is 30 dollars when the proposed 1985 standard is compared to the projected 1985 SWEF. The simple payback time is 1.6 years for the standard electric oven.

LCC Results for Central Air Conditioners

The life-cycle costs of two classes of central air conditioners (CAC) have been evaluated. For the split system CAC, the next to highest efficiency models with a SEER of 10.4 have the lowest life-cycle cost, and for the single package unit the highest efficiency models (SEER=10.7) have the lowest life-cycle cost. When proposed 1985 standards are compared to the projected 1985 SWEF, the reductions in life-cycle cost are 311 dollars (11%) and 430 dollars (15%) respectively for split systems and single package CAC's. The increased initial cost necessary to achieve these reductions in LCC are 250 dollars and 107 dollars for split system and single package systems respectively. The simple payback times are 5.3 and 2.3 years respectively for split system and single package CAC's for an investment to meet the proposed 1985 standards compared to the projected 1985 SWEF. The split system has a longer payback time than the packaged unit because the proposed standard for the split system is beyond the minimum life-cycle cost.

When level 3 is compared to the projected 1985 SWEF, the reductions in LCC are only slightly changed from the case above and the simple payback times are 5.5 and 2.5 years respectively for split system and single package CAC's.

LCC Results for Furnaces

The life-cycle costs of six classes of furnaces have been

evaluated. Four are gas fired and two are oil fired furnaces. For all six classes, the most efficient model evaluated for each class has the lowest life-cycle cost. When models meeting the proposed 1985 standards are compared to the projected 1985 SWEF, the reductions in life-cycle cost range from 62 dollars (.5%) for warm air oil furnaces to 624 dollars (9%) for indoor gas boilers. The simple payback times range from a minimum of 3 months for warm air oil furnaces to 2.6 years for forced air gas furnaces. Forced air gas furnaces account for almost 60% of sales. The increased initial cost for the most energy-efficient model (81%) of forced air gas furnaces is approximately \$102 and the yearly energy savings is about 38 dollars.

Simple payback times have not been calculated for gas fired outdoor horizontal furnaces since the maximum efficiency furnace of this class is below the 1985 sales weighted energy factor as projected by the ORNL residential energy use model.

IV. Results of Consumer Life-Cycle Costs (LCC) and Simple

Payback Calculations: Regional Energy Use

Equations (2) and (3) have also been used to calculate life-cycle costs on a regional basis for three products whose usage is weather dependent: room air conditioners, central air conditioners and furnaces. The LCC curves for at least one class of each of these three appliances are shown for the three DOE regions in Appendix 5. Projected 1985 fuel prices are assumed to be the same in each region as in the national analysis.

Room Air Conditioners

The life-cycle costs of four classes of room air conditioners (RAC) have been evaluated for the three DOE regions (see Appendix 6 Table 1). The life-cycle costs for the class of RAC's with capacities under 6,000 Btu/h are lowest in each region for the unit with EER=9.1 (the highest efficiency evaluated). Life-cycle cost savings and associated simple payback periods when level 3 is compared to the projected 1985 SWEF are, respectively, 10 dollars (4%) and 4.5 years in region I, 55 dollars (13%) and 1.4 years in region II, and 113 dollars (18%) and .8 years in region III. (See Appendix 7, Table 1). Level 3 (EER=9.1) is higher than the proposed standard (EER=8.4) for this class of RAC. Life-cycle costs associated with improving the efficiency of these models from their projected 1985 SWEF to the proposed standard are reduced by 6 dollars (2%) in region I, 42 dollars (10%) in region II, and 86 dollars (13%) in region III. Simple payback periods are 5.0 years in region I, 1.6 years in region II, and .8 years in region III.

One model of RAC with capacity between 6,000 and 20,000 Btu/h was analyzed. For the 8,500 Btu/h capacity RAC, life-cycle costs are lowest for the unit with EER=7.3 in region I, EER=9.1 in region II, and EER=9.5 in region III. The life-cycle costs associated with improving the efficiency of this model from its projected 1985 SWEF to the proposed standard (same as level 3) are increased by 15 dollars (3%) in region I with a payback of 15.2 years. In regions II and III, however, life-cycle costs are reduced 28 dollars (4%) and 85 dollars (9%), respectively. Paybacks are 4.8 years in region II and 2.5 years in region III.

For RAC's with capacities greater than 20,000 Btu/h, life-cycle

costs are lowest to consumers in each region for the highest efficiency unit evaluated. Life-cycle cost savings associated with improving the efficiency of this model from the projected 1985 SWEF to the proposed standard (same as level 3) range from 7 dollars (1%) in region I to 229 dollars (9%) in region III. Payback periods are 7.4 years in region I, 2.3 years in region II, and 1.3 years in region III.

The life-cycle costs for RAC's without side louvers (through the wall) are lowest in region I for the unit with EER=8.7, in region II for the unit with EER=9.1, and in region III for the unit with EER=9.5. When the level 3 standard is compared to the projected 1985 SWEF, life-cycle costs are increased by 16 dollars (4%) in region I with a payback of 13.2 years. Life-cycle cost is reduced by 53 dollars (8%) in region II and 145 dollars (14%) in region III, with simple paybacks of 4.2 years and 2.2 years, respectively. Level 3 is higher than the proposed standard for this class of RAC's. Life-cycle cost savings and associated simple paybacks when the proposed standard is compared to the projected 1985 SWEF are, respectively, 5 dollars (1%) and 7.3 years in region I, 63 dollars (9%) and 2.3 years in region II, and 139 dollars (13%) and 1.2 years in region III.

Central Air Conditioners

The life-cycle costs of two classes of central air conditioners have been evaluated for each of the three DOE regions (see Appendix 6, Table 2). The lowest life-cycle costs to consumers in regions II and III for the split-system are realized for the unit with SEER = 10.4. Life-cycle costs to consumers in region I are lowest for the unit with SEER = 8.5.

Improving the efficiency of this model from its projected 1985 SWEF to the proposed 1985 standard results in an increase in LCC of 119 dollars (8%) in region I and reductions of 172 dollars (7%) and 552 dollars (15%) in regions II and III, respectively. The simple payback periods are 22.1 years in region I, 7 years in region II and 3.7 years in region III (see Appendix 7, Table 2).

If the efficiency of a split system CAC is improved from its projected SWEF to the level 3 trial standard, the LCC is increased by \$134 (9%) in region I, decreased by \$163 (7%) in region II and decreased by \$550 (15%) in region III. The simple payback periods are 23.2, 7.3 and 3.9 years in regions I, II, and III, respectively.

For the single package CAC the life-cycle cost is lowest in region I for the next to most efficient unit analyzed (SEER = 9.7), and in regions II and III for the most efficient unit analyzed (SEER = 10.7). Life-cycle cost savings derived from improving the efficiency of this model from the projected 1985 SWEF to the proposed 1985 standard are 20 dollars in region I, 297 dollars in region II, and 659 dollars in region III. Simple payback times are 9.8 years in region I, 3.1 years in region II and 1.6 years in region III. Life-cycle cost reductions derived from improving the efficiency of single package systems from the projected 1985 SWEF to the level 3 standard are \$14 (1%) in region I, \$304 (12%) in region II and 684 dollars (19%) in region III. Simple payback times are 10.5, 3.3, and 1.7 years in regions I, II, and III, respectively.

Furnaces

The life-cycle costs of six classes of furnaces have been evaluated for each of the three DOE heating regions (see Appendix 6, Table 3). Four are gas fired and two are oil fired furnaces. For each class it is the most efficient unit studied which minimizes life-cycle costs to consumers in all three regions.

Improving the efficiency of a gas indoor forced air furnace from its projected 1985 SWEF (70%) to the proposed 1985 standard (81%) reduces life-cycle costs to consumers by 778 dollars (12%) in region I, 570 dollars (11%) in region II, and 298 dollars (9%) in region III. The associated payback periods in these three regions are 1.9 years, 2.5 years, and 4.2 years, respectively (see Appendix 7, Table 3).

For the remaining gas fired furnace classes life-cycle cost savings range from a high of 877 dollars (payback 0.9 years) for gas boilers in region I to a low of 70 dollars (payback 1.9 years) for gas outdoor furnaces in region III.

Life-cycle cost savings for oil fired furnaces range from 85 dollars in region I to 38 dollars in region III for a forced air oil furnace, and from 226 dollars in region I to 98 dollars in region III for oil boilers.* The relatively small LCC savings for oil fired furnaces (less than 1 percent in all cases) occurs because the proposed 1985 standards are less than 1 percent more stringent than the projected 1985 SWEF. Simple paybacks are 0.2 years, 0.2 years, and 0.3 years for forced air oil furnaces in regions I, II, and III, respectively, and .6

* The highest efficiency (81%) in the ADL Cost Book was used in this analysis rather than the proposed standard (82%).

years, .8 years, and 1.5 years for an oil boiler in regions I, II, and III, respectively.

V. Sensitivity Analyses of LCC Results

LCC's at the National Level

The results of the economic analysis described above are dependent on estimates for several factors. These include: discount rate, fuel price escalation rate and initial fuel price. There is almost always some uncertainty in projecting values for these parameters. Thus, a sensitivity analysis was performed for each product class.

One important result of the analysis is that: the position of the minimum on the LCC curve for each product class is insensitive to changes in discount rates between 3 and 10%, fuel price escalation rates between zero and 2.5%, and initial fuel price variations of + 30%. Figures 6 and 7 illustrate this conclusion for automatic defrost-top mount refrigerators and split system central air conditioners, respectively.

Another method of assessing the sensitivity of the LCC results to changes in key variables (beyond noting the changes in the position of the LCC minimum) is to calculate the changes in LCC cost reductions and simple payback times resulting from changes in the variables. To illustrate this approach, we have compared LCC reductions and simple payback times obtained for four appliance types under the high and low fuel price escalation cases discussed earlier. (The high price case has a 2.5 percent real annual price increase for electricity and a 3.0 percent real annual price increase for oil and gas; the low price case has a 1.0 percent real annual price increase for electricity and a 1.5 percent

Base Case
 Discount rate = 5%
 Fuel Escalation = 2.5%
 Fuel Price = \$.0536/Kwh

FIGURE 6. LIFE-CYCLE COST SENSITIVITY
 AUTOMATIC DEFROST-TOP MOUNT REFRIGERATOR

Base Case
 Discount rate = 5%
 Fuel Escalation = 2.5%
 Fuel Price = \$.0536/Kwh

FIGURE 7. LIFE-CYCLE COST SENSITIVITY
 CENTRAL AIR CONDITIONER-SPLIT SYSTEM

real annual price increase for oil and gas.)

Table 8 presents the results of the sensitivity analysis of LCC reductions and simple payback periods for the four appliances. The reduction in life-cycle costs is 5-30 percent greater for the low price case than the high price case for standard gas and electric ovens and automatic top mount refrigerators; for gas furnaces and central air conditioners, the reduction in LCC's is between 4 and 16 percent less for the low price case than the high price case. Simple payback periods change only slightly (generally less than a few months or 10 percent) between the low and high price cases.

LCC's at a Regional Level

Sensitivity analyses were also performed for all classes of central air conditioners, room air conditioners and furnaces in each of the three DOE regions. As in the national analysis the parameters of interest are the discount rate, fuel price escalation rate and initial fuel price.

For central air conditioners and room air conditioners, the analysis focused primarily on region I, where cooling represents the smaller portion of the space conditioning load. The greatest sensitivity to input assumptions and parameters can be expected to occur in this region. Over a range of discount rates from 3% to 10%, fuel price escalation rates from 0% to 2.5%, and initial fuel price variations of $\pm$ 30%, the position of the minimum on the LCC curves for all classes of central air conditioners and room air conditioners does not change. Figure 8 illustrates this result for split system central air conditioners.

TABLE 8 Sensitivity of LCC Reductions and Simple Payback Periods to Fuel Escalation

Appliance	High Price Case*			Low Price Case**			Difference in LCC Reduction & Simple Payback between High & Low Price Cases	
	1985 SWEF	Δ LCC	Simple Pay- Back Time (in years)	1985 SWEF	Δ LCC	Simple Pay- Back Time (in years)	Δ LCC	Simple Pay- Back Time (in years)
Auto Defrost Top Mount Refrigerators	5.50	324	.6	5.04	342	.7	+ 5.6%	+16.7%
CAC Split System	7.63	311	5.3	7.36	263	5.3	-15.4%	No Change
Furnace - Gas	69.9	538	2.6	67.6	516	2.5	- 4.1%	- 3.8%
Forced Air Range/Oven-								
Gas Standard Model	5.44	50	2.3	5.01	66	2.3	+29.4%	No Change
Electric Standard Model	13.35	30	1.6	13.2	32	1.6	+ 6.7%	No Change

* The 1985 electricity and gas fuel prices are \$.0536/kwh and \$3.46/10⁶ Btu respectively.

**The 1985 electricity and gas fuel prices are \$.0498/kwh and \$3.22/10⁶ Btu respectively.

Base Case
 Discount rate = 5%
 Fuel Escalation = 2.5%
 Fuel Price = \$.0536/Kwh

FIGURE 8. REGION 1 LIFE-CYCLE COST SENSITIVITY
 CENTRAL AIR CONDITIONER-SPLIT SYSTEM

For furnaces, the life-cycle cost curves are truncated before a true minimum is reached in each of the three regions. This occurs because the LCC curve is decreasing in cost up to the highest efficiency unit. This decrease in cost at the most efficient unit occurs for all discount rates ranging from 3 to 10 percent real, annual fuel price escalation rates ranging from 0 to 2.5 percent real, and initial fuel prices within a range of $\pm$ 30 percent of nominal values.

VI. Summary and Conclusions

The life-cycle cost of eight consumer product types (32 classes in all) has been calculated as a function of energy efficiency. Three of these product types; central space heating, room air conditioners, and central air conditioners, have been evaluated with both national average annual energy use and a regional annual energy use per unit. Life-cycle costs and simple payback periods have been calculated for the three trial levels as compared to the projected 1985 SWEF. Sensitivity of life-cycle cost minima, life-cycle cost reductions and payback periods to changes in initial fuel price and fuel price escalation factors were investigated. Life-cycle cost minima were also examined for sensitivity to changes in the discount rate.

On a national basis, the proposed 1985 standards are cost-effective with respect to the energy efficiency levels projected to occur in the absence of standards for all classes of products. The proposed 1985 standards are above the energy efficiencies corresponding to the LCC minimum* for five of the 32 classes of consumer products analyzed. For

*In three cases (electric oven self clean, electric cooktop ranges, and gas outdoor horizontal non-weatherized furnaces) the LCC curve does not reach a true minimum. A true minimum is reached for split system central air conditioners and for room air conditioners between 6,000 and 20,000 Btu/h.

four of those classes the proposed 1985 standard is less than 6 percent above the LCC minimum level. The exception is for gas outdoor horizontal non-weatherized furnaces where the standard is set at an AFUE of 79% and the highest efficiency unit in the ADL cost book has an AFUE of 59%.

The proposed 1985 standard produces higher life-cycle cost savings than a standard at a lower energy efficiency except for two cases, split system central air conditioners and room air conditioners of 6,000 to 20,000 Btu/h capacity. However, in both cases, the life-cycle cost reduction achieved by the proposed standard is only slightly less ($< 1\%$) than that achieved at any lower trial level. In our view, this small increase in life-cycle cost for these two cases, is justified by the resulting greater energy savings to the nation.

In two cases the proposed efficiency standard is below the trial level where the life-cycle cost minimum occurs. These are room air conditioners of capacity less than 6,000 Btu/h, where the proposed standard is at an EER of 8.4 and the LCC minimum is at 9.1 and single package central air conditioners, where the proposed standard is set at an SEER of 10.5 and the LCC minimum is at 10.7.

Data were not available to analyze the life-cycle costs of many advanced-technology options (including product redesigns) required to achieve higher levels of energy efficiency for most of the consumer products. As a result, no conclusions can be reached about the potential of many advanced-technology options for reducing life-cycle cost to the consumer. Advanced technologies that should be analyzed in the future include heat pump water heaters, integrated space and water heating appliances and condensing furnaces.⁷

Simple payback periods are considerably less than the equipment service lifetime for all products evaluated. For the proposed standards, they range from several months for refrigerators and freezers to a maximum of 5.3 years for split-system central air conditioners. For most products, the payback period is less than 2 years.

The regional life-cycle cost analysis indicates that the distribution of costs and benefits from the proposed national standards varies significantly among the different regions for room and central air conditioners and for furnaces. For the product class with greatest variation, the split-system central air conditioner, the change in consumer life-cycle cost at the proposed standard ranges from an increase of \$119 (8% of total LCC) in region I to a decrease of \$552 (15% of total LCC) in region III. For room air conditioners of capacity 6,000 to 20,000 Btu/h the change in consumer life-cycle cost at the proposed standard ranges from an increase of 15 dollars (4%) in region I to a decrease of 85 dollars (9%) in region III.

Simple payback periods are longer in region I than those obtained in the national analysis for all classes of air conditioners. For two cases, the simple payback periods are greater than the average appliance lifetime.* These are: split system central air conditioners (22.1 years) and room air conditioners of capacity 6,000 to 20,000 Btu/h (15.2 years).

One potential method of redressing the inequity in costs and benefits among the regions for air conditioners is to promulgate regional

*Simple payback period is greater than the appliance lifetime whenever there is an increase in life-cycle cost.

efficiency standards. This is a subject of continuing research and no firm conclusions have been reached as yet.

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APPENDIX 1.

Simple Payback Period

A purchaser of a new appliance will often wish to know how long it will take for the more energy efficient (and more costly) model to pay for itself in reduced fuel bills. This time period is known as the payback time for a particular conservation investment. It is defined as the time required for the future fuel cost savings produced by an energy conservation investment to equal the initial additional investment. In the case of appliance purchases, we have assumed that the initial purchase is paid for with cash.

There are several variables which influence the result obtained in this calculation of payback time. One can ignore the price escalation for energy and the time value of money and simply divide the dollar value of the energy conservation investment by the dollar value of the yearly energy savings. This is the simple payback approach.

The discounted payback corrects the above approach which is an approximate method of computing payback time. In this case, the time value of money is accounted for by using the appropriate discount rate. In addition, fuel price escalation rates can be incorporated into this approach. There is little difference between the simple and the discounted payback periods for investments having short payback times (less than two years simple payback). The rate of escalation in energy prices also has little impact in the short run. Both factors, however, become significant in determining the payback time for longer periods.

An example illustrates the comparison between simple and discounted

payback periods. Assume that the simple payback time for an energy conservation investment were found to be equal to 5 years. If the fuel price escalation rate is 2.5% and the discount rate were 5%, the discounted payback period for this same investment would be approximately 5.6 years.⁸

APPENDIX 2

Life-Cycle Cost Curves

Appliances

1. Refrigerators
2. Freezers
3. Clothes Dryers
4. Water Heaters
5. Room Air Conditioners
6. Ranges/Ovens
7. Central Air Conditioners
8. Furnaces

Economic Assumptions

1. Discount rate equals 5%
2. Fuel escalation rate 2.5% electricity, 3% gas and oil
3. Initial fuel price (1985) \$.0536/kwh, \$3.46/10⁶ Btu, \$6.39/10⁶ Btu for electricity, gas and oil, respectively.

REFRIGERATOR AUTOMATIC DEFROST-TOP MOUNT

Design Options:

- 1) Foam Insulation Substitution
- 2) High Efficiency Compressor Substitution
- 3) Double Door Gasket in Freezer
- 4) Place Evaporator Fan Motor Outside of Cold Space

FREEZER CHEST-MANUAL DEFROST

Design Options:

- 1) Foam Insulation Substitution
- 2) High Efficiency Compressor Substitution
- 3) Replace existing Condenser with Static Back Mounted Condenser

CLOTHES DRYER 240 VOLT ELECTRIC-STANDARD

Design Options:

- 1) Moisture Sensor
- 2) Insulation
- 3) Reduced Temperature
- 4) Temperature Sensor

CLOTHES DRYERS GAS

Design Options:

- 1) Moisture Sensor
- 2) Temperature Sensor

WATER HEATER ELECTRIC STANDARD

Design Options*:

- 1) Improved Insulation
 - a) Increase Thickness
 - b) Foam Insulation
- 2) Heat Traps

*In cases where the same design options are used for more than one data point, these options have been carried out to varying degrees. For details see Ref. 4.

WATER HEATER GAS STANDARD

Design Options*:

- 1) Improved Insulation
 - a) Increase Thickness
 - b) Foam Insulation
- 2) Increase Flue Heat Transfer
- 3) Heat Traps

*In cases where the same design options are used for more than one data point, these options have been carried out to varying degrees. For details see Ref. 4.

energy factor

ROOM AIR CONDITIONER 5000 BTU PER HOUR

Design Options*:

- 1) Increased Condenser and Evaporator Heat Exchanger Surface Area
- 2) Increased Fan/Motor Efficiency

*In cases where the same design options are used for more than one data point, these options have been carried out to varying degrees. For details see Ref. 4.

ROOM AIR CONDITIONER 8500 BTU PER HOUR

Design Options*:

- 1) Increased Condenser and Evaporator Heat Exchanger Surface Area
- 2) Increased Fan/Motor Efficiency

*In cases where the same design options are used for more than one data point, these options have been carried out to varying degrees. For details see Ref. 4.

ELECTRIC COOKTOP

Design Options:

- 1) Reduced Contact Resistance
- 2) Reflective Pans Under Burners

energy factor

GAS OVEN STANDARD

Design Options:

- 1) Increased Insulation
- 2) Improved Gasket or Reduced Excess Air
- 3) IID-Intermittent Ignition Device

CENTRAL AIR COND SPLIT SYSTEM

Design Options*:

- 1) Increased Condenser and Evaporator Heat Exchanger Surface Area
- 2) Decreased Compressor Size
- 3) Change Fan/Motor

*In cases where the same design options are used for more than one data point, these options have been carried out to varying degrees. For details see Ref. 4.

GAS FURNACE (WARM AIR)

Design Options:

- 1) Increased Heat Exchanger Surface Area
 - a) Gas Furnace Indoor
 - b) Gas Boiler Indoor (Cast Iron)
 - c) Oil Furnace Indoor
 - d) Oil Boiler Indoor
 - e) Gas Furnace Horizontal
 - f) Gas Furnace Outdoor
- 2) IID-Intermittent Ignition Device
- 3) Flue Damper
- 4) Power Burner or Power Vent

APPENDIX 3.

Consumer Life Cycle Costs for Base Case and
Three Trial Standard Levels

Footnotes:

- a 1985 SWEF greater than trial level
- b No trial level established
- c Maximum efficiencies in A.D. Little Cost Book less than 1985 trial level.

TABLE 1

CONSUMER LIFE-CYCLE COSTS (1978 \$)

Product Type	Standard Level			
	Base Case LCC	1	2	3
REFRIGERATORS				
Manual Defrost	782	763	718	539
Partial Auto	981	1003	828	681
Auto Top Mount	1520	1562	1315	1196
Auto Side by Side	2007	1981	1896	1811
Auto-SS-TTD	2172	2250	2144	2081

TABLE 2
CONSUMER LIFE-CYCLE COSTS (1978 \$)

Product Type	Standard Level			
	Base Case LCC	1	2	3
FREEZERS				
Manual Chest	1267	1317	1076	972
Manual Upright	1685	1581	1332	1139
Auto Upright	2479	3091	2170	1953

TABLE 3

CONSUMER LIFE-CYCLE COSTS (1978 \$)

Product	Standard Level			
Type	Base Case LCC	1	2	3
CLOTHES DRYERS				
Electric Standard	837	837	805	791
Electric Compact (120V)	433	b	b	426
Electric Compact (240V)*	--	--	--	--
Gas	341	b	b	336

*No data in cost book.

TABLE 4

CONSUMER LIFE-CYCLE COSTS (1978 \$)

Product		Standard Level			
Type	Base Case LCC	1	2	3	
WATER HEATERS					
Gas	890	772	766	760	
Electric	2093	2151	1940	1923	

TABLE 5

CONSUMER LIFE-CYCLE COSTS (1978 \$)

Product Type	Standard Level			
	Base Case LCC	1	2	3
ROOM AIR				
CONDITIONERS				
<6,000 Btu/h	440	414	395	381
6,000-20,000 Btu/h*	678	660	642	645
>20,000 Btu/h	1654	1629	1580	1542
Through the Wall				
Reverse Cycle	715	656	647	655

*8,500 Btu/h capacity unit evaluated.

TABLE 6
CONSUMER LIFE-CYCLE COSTS (1978 \$)

Product Type	Standard Level			
	Base Case LCC	1	2	3
<hr/> RANGES/OVENS <hr/>				
Gas Cook Top	524	b	458	434
Gas Oven Standard	589	726	700	538
Gas Oven Self Clean	769	939	773	754
Electric Cook Top	c	b	b	c
Electric Oven Standard	860	b	b	830
Electric Oven Self Clean	960	b	b	c

TABLE 7

CONSUMER LIFE-CYCLE COSTS (1978 \$)

Product Type	Standard Level			
	Base Case LCC	1	2	3
CENTRAL AIR				
CONDITIONERS				
Split System	2827	2581	2503	2523
Single Package	2907	2714	2548	2463

TABLE 8
CONSUMER LIFE-CYCLE COSTS (1978 \$)

Product Type	Standard Level			
	Base Case LCC	1	2	3
FURNACES				
Gas Indoor Forced Air	4897	5064	4721	4359
Gas Boiler	6767	7053	6562	6143
Gas Outdoor Horizontal	c	c	c	c
Gas Outdoor Weatherized	4589	4769	4659	4471
Oil Forced Air	12198	b	12904	12136
Oil Boiler	17520	17963	17560	c

APPENDIX 4.

Simple Payback Period for
Three Trial Standard Levels
Relative to Base Case

Footnotes:

- a 1985 SWEF greater than trial level
- b No trial level established
- c Maximum efficiencies in A.D. Little Cost Book less than 1985 trial level

TABLE 1
CALCULATED PAYBACK PERIOD (years)

Product Type	Standard Level		
	1	2	3
REFRIGERATORS			
Manual Defrost	.5	.6	.5
Partial Auto	a	.6	.8
Auto Top Mount	a	.6	.6
Auto Side by Side	.7	.7	.7
Auto SS-TTD	a	.7	.7

TABLE 2

CALCULATED PAYBACK PERIOD (years)

Product Type	Standard Level		
	1	2	3
FREEZERS			
Manual Chest	a	.3	.4
Manual Upright	0	0	.2
Auto Upright	a	0*	.2

*Level 2 energy factor greater than 1985 SWEF, however
Level 2 purchase price is less than 1985 SWEF purchase price.

TABLE 3

CALCULATED PAYBACK PERIOD (years)

Product Type	Standard Level		
	1	2	3
CLOTHES DRYERS			
Electric Standard	a	1.1	2.4
Electric Compact 120V	b	b	2.3
Electric Compact 240V*	--	--	--
Gas	b	b	4.2

*No data in cost book

TABLE 4

CALCULATED PAYBACK PERIOD (years)

Product Type	Standard Level		
	1	2	3
WATER HEATERS			
Gas	.5	.7	.9
Electric	a	.7	.7

TABLE 5
CALCULATED PAYBACK PERIOD (years)

Product Type	Standard Level		
	1	2	3
ROOM AIR CONDITIONERS			
<6000 Btu/h	1.3	1.5	1.3
6000-20000 Btu/h*	4.5	2.9	4.5
>20000 Btu/h	2.2	2.2	2.2
Through the Wall			
Reverse Cycle	1.7	2.2	3.9

*8,500 Btu/h capacity unit evaluated.

TABLE 6

CALCULATED PAYBACK PERIOD (years)

Product Type	Standard Level		
	1	2	3
RANGES/OVENS			
Gas Cook Top	b	1.5	1.2
Gas Standard	a	a	2.3
Gas Self Clean	a	a	3.1
Electric Cook Top	b	b	c
Electric Standard	b	b	1.6
Electric Self Clean	b	b	c

TABLE 7

CALCULATED PAYBACK PERIOD (years)

Product Type	Standard Level		
	1	2	3
CENTRAL AIR			
CONDITIONERS			
Split System	2.8	3.3	5.5
Single Package	1.8	1.6	2.5

TABLE 8

CALCULATED PAYBACK PERIOD (years)

Product Type	Standard Level		
	1	2	3
FURNACES			
Gas Indoor Forced Air	a	1.1	2.6
Gas Boiler	a	.6	1.2
Gas Outdoor Horizontal	c	c	c
Gas Outdoor Weatherized	a	a	1.3
Oil Forced Air	b	a	.2
Oil Boiler	a	a	c

APPENDIX 5

Life-Cycle Cost Curves

Regional Analysis

Appliances

1. Room Air Conditioners
2. Central Air Conditioners
3. Furnaces

Economic Assumptions

1. Discount rate equals 5%
2. Fuel escalation rate 2.5% electricity, 3% gas and oil
3. Initial Fuel price (1985) \$.0536/Kwh, \$3.46/10⁶ Btu, \$6.39/10⁶ Btu
for electricity, gas and oil, respectively

ROOM AIR CONDITIONER 5000 BTU PER HOUR

REGION 1

.....

REGION 2

-.-.-.-

REGION 3

ROOM AIR CONDITIONER 8500 BTU PER HOUR

REGION 1

.....

REGION 2

-.-.-.-

REGION 3

CENTRAL AIR COND SPLIT SYSTEM

REGION 1

.....

REGION 2

-. - . - . -

REGION 3

seasonal energy efficiency ratio

GAS FURNACE (WARM AIR)

REGION 1

.....

REGION 2

-.-.-.-

REGION 3

APPENDIX 6.

Consumer Life-Cycle Costs for Base Case and

Three Trial Standard Levels -

Regional Analysis

Footnotes:

- a 1985 SWEF greater than trial level
- b No trial level established
- c Maximum efficiencies in A.D. Little Cost Book less than 1985 trial level

TABLE 1
CONSUMER LIFE-CYCLE COSTS (1978 \$)

Product Type	Standard Level			
	Base Case LCC	1	2	3
<hr/> RAC <hr/>				
<6000 Btu				
Region I	260	256	254	250
Region II	425	400	383	370
Region III	639	589	553	526
6000 to 20000 Btu/h (8500 Btu/h)				
Region I	419	428	421	434
Region II	656	640	623	628
Region III	966	919	888	881
>20,000 Btu				
Region I	870	869	866	863
Region II	1588	1565	1520	1484
Region III	2526	2474	2376	2297
Through the wall				
Reverse Cycle				
Region I	428	421	423	444
Region II	691	636	628	638
Region III	1035	918	896	890

TABLE 2
CONSUMER LIFE-CYCLE COSTS (1978 \$)

Product Type	Standard Level				
	Base Case	LCC	1	2	3
CAC					
Split System					
Region I		1447	1448	1468	1581
Region II		2381	2215	2169	2218
Region III		3603	3219	3085	3053
Single Package					
Region I		1503	1484	1460	1489
Region II		2453	2317	2197	2149
Region III		3696	3406	3160	3012

TABLE 3
CONSUMER LIFE-CYCLE COSTS (1978 \$)

Product Type	Standard Level			
	Base Case LCC	1.	2	3
FURNACES				
Gas Indoor, Forced Air				
Region I	6598	6834	6352	5820
Region II	5123	5300	4939	4554
Region III	3195	3294	3090	2897
Gas Boiler				
Region I	9061	9464	8777	8184
Region II	7073	7375	6858	6415
Region III	4473	4643	4348	4101
Gas Outdoor Horizontal	c	c	c	c
Gas Outdoor Weatherized				
Region I	6054	6318	6159	5887
Region II	4784	4975	4859	4659
Region III	3124	3219	3159	3054
Oil Forced Air				
Region I	16618	b	17593	16534
Region II	12787	b	13529	12723
Region III	7777	b	8215	7739
Oil Boiler				
Region I	23785	24405	23842	c
Region II	18355	18822	18397	c
Region III	11254	11522	11278	c

APPENDIX 7.

Simple Payback Period for
Three Trial Standard Levels

Relative to Base Case:

Regional Analysis

Footnotes:

- a 1985 SWEF greater than trial level
- b No trial level established
- c Maximum efficiencies in A.D. Little Cost Book less than 1985 trial level

TABLE 1

CALCULATED PAYBACK PERIOD (years)

Product Type	Standard Level		
	1	2	3
<hr/> RAC			
<6000 Btu			
Region I	4.3	5.0	4.5
Region II	1.4	1.6	1.4
Region III	.7	.8	.8
6000 to 20000 Btu			
(8500 Btu)			
Region I	15.2	9.6	15.2
Region II	4.8	3.0	4.8
Region III	2.5	1.6	2.5
>20,000 Btu			
Region I	7.5	7.4	7.4
Region II	2.4	2.3	2.3
Region III	1.2	1.2	1.3
Through the Wall			
Reverse Cycle			
Region I	5.9	7.3	13.2
Region II	1.9	2.3	4.2
Region III	1.0	1.2	2.2

TABLE 2

CALCULATED PAYBACK PERIOD (years)

Product Type	Standard Level		
	1	2	3
<hr/> CAC			
Split System			
Region I	11.8	14.0	23.2
Region II	3.7	4.4	7.3
Region III	2.0	2.3	3.9
Single Package			
Region I	7.6	6.6	10.5
Region II	2.4	2.1	3.3
Region III	1.3	1.1	1.7

TABLE 3
CALCULATED PAYBACK PERIOD (years)

Product Type	Standard Level		
	1	2	3
FURNACES			
Gas Indoor Forced Air			
Region I	a	.8	1.9
Region II	a	1.0	2.5
Region III	a	1.7	4.2
Gas Boiler			
Region I	a	.5	.9
Region II	a	.6	1.1
Region III	a	1.0	1.9
Gas Outdoor Horizontal	c	c	c
Gas Outdoor Weatherized			
Region I	a	a	.9
Region II	a	a	1.2
Region III	a	a	2.0
Oil, Forced Air			
Region I	b	a	.2
Region II	b	a	.2
Region III	b	a	.3
Oil Boiler			
Region I	a	a	c
Region II	a	a	c
Region III	a	a	c

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