Center for Advanced Computation

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APPLIANCE ENERGY USE

by

Robert A. Herendeen

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I. INTRODUCTION

Energy is required to make and maintain appliances as well as to operate them. The magnitudes of these "other" energy costs imply different strategies for energy conservation. For example, does increasing the durability by x years save as much energy as improving the operating efficiency y percent? In this report I evaluate the relative importance of operating energy for 30 household and kitchen appliances. I also look at the total energy (gross energy requirement)[†] for 3 example kitchens, from plush to rather Spartan, and discuss the economic aspects of more efficient room air conditioners.

II. TOTAL ENERGY REQUIREMENTS OF 30 APPLIANCES

I'll consider typical appliances for the year 1971, assumed to be subjected to average use (according to the appliance industry). This is an "all or nothing" approach, not an investigation of the effect of reduced use. I should note that results are indicators of implied potential for energy conservation, but actual potential depends on the actual technology of the device (or, of course, on the potential of the user to cut down). I have no expertise in the technology of appliances, and defer to others for specific studies (1,2).

The energy cost of an appliance is the sum of energies of manufacture, maintenance, operation, and disposal. For comparison, we normalize this to a single year

$$\text{Energy/year} = \frac{E_{manuf} + E_{maint} + E_{disp}}{N} + E_{op} \qquad (1)^{*}$$

E_{op} is measured per year, while the other three energies are for the total lifetime of N years. Since maintenance is often sporadic, it is

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[†]Gross energy requirement (GER) is a term suggested for adoption at the meeting on Energy Analysis held in Guldsmedhyttan, Sweden, August, 1974.

[*]A similar expression would apply to dollar cost, except for the role of interest rates. There are no interest rates for energy.

not usually perceived as an annual cost and hence I separate it from operation.

In Eq. (1) the energies could be any of several kinds (gas, electricity, coal). Here I will lump all energy types together, and talk only of primary gross energy requirement. This is the total resource energy (coal, crude oil and gas, hydro and nuclear power, with hydro and nuclear costed as if the electricity were produced in a fossil fuel burning power plant.)

This approach accounts for the energy lost in extraction, transmission, and conversion. The efficiency of production of residential gas and electricity from energy resources is only 86% and 26%, respectively (3).

I obtain the energy of manufacture and maintenance by converting the dollar costs using a technique based on Input-Output economics. The method is described elsewhere (4) but a few words are in order. It views the energy dissipated in an economic sector as being "embodied" in the output of that sector. In principle, it accounts for <u>all</u> energy required along the chain of extraction of raw materials - refining - fabrication - final manufacture and sales. Its usefulness is limited by aggregation - the economy is broken down into 368 sectors, but only 6 of these apply to appliances and only 1 applies to maintenance services.

The energy cost of disposal is relatively small and difficult to obtain, so I assume it is zero. We then rewrite Eq. 1 as

$$\text{Energy/year} = (1 + Q/N)E_{op} \tag{2}$$

where $Q = (E_{manuf} + E_{maint})/E_{op}$, that is, the energy required to make

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and maintain the device over its lifetime divided by the yearly operational energy (Q has units of years). The ratio Q/N expresses the importance of the non-operational energies. Appliances which provide heating or cooling tend to have low Q/N (e.g., a gas clothes dryer, Q/N = 0.15), while those that provide mechanical motion or communication tend to have high Q/N (e.g., a food mixer, Q/N = 0.53). Besides neglecting of disposal costs, I also had to use rough estimates on maintenance and lifetime. (In our study Sebald and I found such data very difficult to obtain, especially from appliance manufacturers). These were estimated according to the following scheme: if the appliance cost less than $20 (1971 prices), it was assumed to last 8 years and be discarded without maintenance. If it cost more than $20, it was assumed to last 14 years and receive a total lifetime maintenance expenditure equalling one half of the purchase price. (Exception: water heaters were assumed to fall in the first category).

Table 1 lists various energy use data on 30 appliances.[5] We can see that the energy impact can be as much as 2.3 times as much as that from operation. However, we also note that those with a high Q/N value tend to be small energy users. For example, the clothes washer uses the most energy of any appliance with Q/N > 0.5, but it still uses only about one-tenth as much as a kitchen range (this does not include hot water for the washer). When the longer energy users are considered (range, refrigerator, freezer, air conditioner, dryer, water heater), the average Q/N is less than 0.1. For these, non operational energy is over 90% of the total; this also implies relatively low payoff from increased durability.* For example, doubting the lifetime of a gas range from 14 to 28 years with no increase in maintenance costs reduces the yearly energy use by no more than 4%.

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*Note that use of the Q/N factor implies a steady state assumption on appliance population. If appliance numbers are growing, the energy to make them is required right now. To assess this we need a "birth-death" model for that appliance.

For these appliances, therefore, the conservation potential appears to lie in operation, i.e., in "efficiency".

Two other observations should be made. First, electric appliances require more primary energy than gas, due mainly to the low thermal efficiency of electricity production. Second, frost free devices are more energy intensive than conventional.

III. THE ENERGY COST OF THREE KITCHENS

An arbitrary kitchen may be constructed from Table 1. I have chosen three, from fully appointed to rather Spartan. Results are in Table 2.

We see that the full set (which includes frost-free options where available) has a yearly energy impact of about 120 million Btu (gas) and 150 million Btu (electric). This is the equivalent of 5 or 6 tons of coal, or 20 or 25 barrels of oil.

The "moderate" kitchen differs from the full in its substitution of conventional freezer and refrigerator for frostless models where possible, its absence of a dishwasher and many smaller appliances (blender, can opener, disposal, exhaust fan, electric frying pan, hot plate, electric knife, and waffle iron). Its energy impact is about 4/5 of that of the full kitchen. Many of the rejected appliances are small energy users.

The Spartan kitchen retains only four basic appliances: range, clothes washer, water heater*, and refrigerator (not frostless). Here, the energy cost is about 55 percent of the full kitchen. Thus, these four appliances are responsible for over half the energy required by the full kitchen set of 20.

IV. ECONOMICS OF ENERGY CONSERVATION

There are appliances of differing energy efficiency on the market, and in many cases there is an economic incentive to adopt the more efficient ones (1). A similar case holds for home insulation, which effectively increases the efficiency of the heating plant (6). Here I

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*We have not computed the reduced use of the water heater due to a lack of a dishwasher. Roughly speaking, hand and machine dishwashing require the same amount of hot water (5).

present some results for energy and dollar costs for room air conditioners. My only claim to originality is that the approach explicitly takes account of rising electricity prices, and to the energy of manufacture. The latter is a small effect, but the former can be significant given today's price trends.

For this particular calculation (7), I conformed to conventions of the U. S. General Services Administration (GSA) and ignored the energy and dollar costs of maintenance and disposal and used N = 7 years. Then the yearly costs are:

Dollars: Operational Cost + Amortized Initial Cost

Energy: $E_{op} + E_{manuf} / N$

Details are in Appendix A and in reference 7. In Table 3 I list dollar and energy cost calculations for 5 different models of each of 6 sizes of room air conditioners, assumed to have average office use in Springfield, Illinois. (An explanation of terminology is in Table 4.) The basic data source was Moyers (1); it is now 3 years old and prices have changed considerably. Therefore, the results are only indicative. The question is how the dollar cost (which is cheapest to own and operate?) compares with the energy cost. As discussed in Appendix A, the dollar cost depends on the bank interest rate on loans (r) and the rate of increase of energy price (s).

I illustrate for a 14000 Btu air conditioner. From Table 3 we see that the air conditioner with highest initial cost (Option 4, cost = $370) also has the highest efficiency (EER = 9.9), although this is not always true. As a result it has the lowest energy cost, 35.6% <u>below</u> that of the air conditioner with lowest initial cost (Option 2, cost = $290).

For the unrealistic case of r = 0.00 and s = 0.00, i.e., free bank loans and no increase in energy price, Option 4 also has the lowest annual dollar cost, 9.8% below that of Option 2, which had the lowest initial cost In this case the cheapest option saves the most energy.

GSA assumed a bank interest rate of 10% per year (r = 0.10), but no increase in energy price (s = 0.00). From Table 3 for this case, we

see that all options cost more per year, and Option 4 is no longer cheapest, though it is nearly so. The effect of the bank interest rate has been to push dollar and energy conservation in opposite directions.

More realistically, energy prices are increasing too. If we allow the electricity price to increase at 10% per year i.e., a doubling in 7 years (so that now $r = 0.10$, $s = 0.10$), Option 4 is once again lowest in dollar cost. Rising energy prices push dollar and energy conservation in the same direction.

In practice, detailed calculations of this sort should be performed and made available to consumers. We might ask if there is not some simple maxim that comes from all of this. It is not necessarily true that the cheapest option is the most energy efficient, but suppose we adopted that viewpoint: "Suppose we pick the air conditioner with the lowest annual dollar cost in each of the 6 sizes - how much energy would be saved over the device with lowest initial cost?" In Table 5 I make the comparison. In all 6 cases energy is saved. For the larger sizes, energy savings are around 30%. In most, but not all, cases, this simple strategy also yields the <u>maximum</u> energy savings.

Table 1. Energy Use by 30 Appliances[a)]

Appliance	(kwh/yr.)	E_{op} (10^5 Btu/yr.)[b)]	Q (years)	N (years)	Q/N	Operational Energy (%)	Total energy[b)] (10^5 Btu/yr.)
Air conditioner (room)	860	114	1.3	14	0.09	92	124
Electric blanket	147	19.4	0.55	8	0.07	93	20.8
Blender	15	2.0	7.2	14	0.51	66	3.0
Can opener	5	0.66	10.5	8	1.32	43	1.5
Clothes washer	103	13.6	13.6	14	0.97	51	26.9
Clothes dryer, gas	--	70.2	2.2	14	0.15	87	81.0
Clothes dryer, electric	993	131	0.97	14	0.07	93	140
Coffeemaker	106	14	0.61	8	0.08	93	15.1
Dishwasher	363	48	3.7	14	0.26	79	60.6
Disposer	30	4.0	12	14	0.87	53	7.4
Exhaust fan	43	5.7	2.5	14	0.18	85	6.7
Freezer, conv., 15 cu. ft.	1195	158	1.1	14	0.08	93	170
Freezer, frost-less, 15 cu.ft.	1761	233	0.73	14	0.05	95	245
Frying pan	186	24.6	0.82	14	0.06	94	26.0

a) Source: Ref. 5, and unpublished calculations.

b) Primary gross energy requirement.

TABLE 1 (continued)

Appliance	(kwh/yr.)	E_{op} (10^5 Btu/yr.)[b]	Q (years)	N (years)	Q/N	Operational Energy (%)	Total energy (10^5 Btu/yr.)
Hot plate	90	11.9	0.54	8	0.07	93	12.7
Iron	144	19.0	0.48	8	0.06	94	20.2
Electric knife	8	1.06	13	14	0.96	51	2.07
Mixer	13	1.72	7.5	14	0.53	65	2.6
Radio (table)	86	11.4	1.17	14	0.08	93	12.3
Range, gas	--	123	1.3	14	0.09	92	134
Range, electric	1175	155	1.2	14	0.08	93	168
Refrigerator, conv., 12 cu. ft.	728	96.3	2.2	14	0.16	86	111
Refrigerator, frost-less, 12 cu. ft.	1217	161	1.3	14	0.09	92	176
Toaster	39	5.2	1.9	8	0.23	81	6.4
TV, B&W	362	47.9	1.70	14	0.12	89	53.7
TV, Color	502	66.4	4.99	14	0.36	74	90.1
Vacuum cleaner	46	6.1	6.4	14	0.45	69	8.8
Water heater, gas	--	370	0.15	8	0.02	98	377
Water heater, electric	4219	558	0.11	8	0.01	99	565
Waffle iron	22	2.91	3.1	8	0.39	72	4.1

a) Source: Ref. 5, and unpublished calculations.

b) Primary gross energy requirement.

TABLE 2. Energy Requirements for 3 Kitchens

APPLIANCE	SPARTAN G	SPARTAN E	MODERATE G	MODERATE E	FULL G	FULL E
Blender						x
Can opener						x
Clothes washer		x		x		x
Clothes dryer, gas			x		x	
Clothes dryer, electric				x		x
Coffee maker				x		x
Dishwasher						x
Disposer						x
Exhaust fan						x
Freezer, conv., 15 cu. ft.				x		
Freezer, frostless, 15 cu. ft.						x
Frying pan						x
Hot plate						x
Iron				x		x
Electric knife						x
Mixer				x		x
Range, gas	x		x		x	
Range, electric		x		x		x
Refrigerator, conv., 12 cu ft.		x		x		
Refrigerator, frostless, 12 cu.ft.						x
Toaster				x		x
Vacuum cleaner				x		x
Water heater, gas	x		x		x	
Water heater, electric		x		x		x
Waffle iron						x

Option	Energy (10^5 Btu/yr.) SPARTAN	MODERATE	FULL
Gas	649 (54%)	953 (80%)	1170 (100%)
Electric	871 (59%)	1234 (84%)	1478 (100%)

G = Gas, E = Electric.

COST ANALYSIS FOR APPLIANCE: AIR-CONDITIONER, 6000 BTUS/HR

WITH APPLIANCE LIFE OF 7 YEARS
ASSUMING INTEREST RATE OF 0.0 AND ENERGY INFLATION RATE OF 0.0
WHERE PRICE OF ENERGY = 0.02950 $/KWH AND CONVERSION COEFF. = 68000.00 BTUS/$
THE PRIMARY ELECTRICITY CONVERSION FACTOR IS 13276. BTUS / KWH.

OPTION	MANUFACT.	EER	CAPITAL COST $'S	OPERATING COST KWH / YEAR	ANNUAL COST $'S	PERCENT	ANNUAL ENERGY COST IN BTUS	PERCENT
1	A	4.90	200.00	730.	50.11	124.8	11634337.	124.6
2	A	6.10	160.00	586.	40.14	100.0	9334021.	100.0
3	B	7.00	170.00	511.	39.36	98.0	8435464.	90.4
4	C	6.00	180.00	596.	43.30	107.9	9661067.	103.5
5	C	6.90	190.00	518.	42.42	105.7	8722682.	93.5

COST ANALYSIS FOR APPLIANCE: AIR-CONDITIONER, 6000 BTUS/HR

WITH APPLIANCE LIFE OF 7 YEARS
ASSUMING INTEREST RATE OF 0.100 AND ENERGY INFLATION RATE OF 0.0
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1	A	4.90	200.00	730.	64.77	124.8	11634337.	124.6
2	A	6.10	160.00	586.	51.88	100.0	9334021.	100.0
3	B	7.00	170.00	511.	51.50	99.3	8435464.	90.4
4	C	6.00	180.00	596.	56.31	108.5	9661067.	103.5
5	C	6.90	190.00	518.	55.84	107.6	8722682.	93.5

COST ANALYSIS FOR APPLIANCE: AIR-CONDITIONER, 6000 BTUS/HR

WITH APPLIANCE LIFE OF 7 YEARS
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1	A	4.90	200.00	730.	72.05	124.8	11634337.	124.6
2	A	6.10	160.00	586.	57.72	100.0	9334021.	100.0
3	B	7.00	170.00	511.	56.59	98.0	8435464.	90.4
4	C	6.00	180.00	596.	62.25	107.9	9661067.	103.5
5	C	6.90	190.00	518.	61.00	105.7	8722682.	93.5

Table 3. Comparison of Dollar and Energy Costs of Various Air-conditioners for Different Values of Interest Rate and of Rate of Increase of Energy Price.

See Table 4 for Explanation of Terms.

COST ANALYSIS FOR APPLIANCE: AIR-CONDITIONER, 8000 BTUS/HR

WITH APPLIANCE LIFE OF 7 YEARS
ASSUMING INTEREST RATE OF 0.0 AND ENERGY INFLATION RATE OF 0.0
WHERE PRICE OF ENERGY = 0.02950 $/KWH AND CONVERSION COEFF. = 68000.00 BTUS/$
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OPTION	MANUFACT.	EER	CAPITAL COST $'S	OPERATING COST KWH / YEAR	ANNUAL COST $'S	PERCENT	ANNUAL ENERGY COST IN BTUS	PERCENT
1	A	5.90	190.00	808.	50.98	100.0	12572722.	100.0
2	A	8.40	260.00	568.	53.90	105.7	10066482.	80.1
3	B	6.20	190.00	769.	49.83	97.7	12054958.	95.9
4	C	5.90	220.00	808.	55.26	108.4	12864150.	102.3
5	C	9.20	260.00	518.	52.42	102.8	9402682.	74.8

COST ANALYSIS FOR APPLIANCE: AIR-CONDITIONER, 8000 BTUS/HR

WITH APPLIANCE LIFE OF 7 YEARS
ASSUMING INTEREST RATE OF 0.100 AND ENERGY INFLATION RATE OF 0.0
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1	A	5.90	190.00	808.	65.25	100.0	12572722.	100.0
2	A	8.40	260.00	568.	71.84	110.1	10066482.	80.1
3	B	6.20	190.00	769.	63.98	98.1	12054958.	95.9
4	C	5.90	220.00	808.	71.41	109.4	12864150.	102.3
5	C	9.20	260.00	518.	70.21	107.6	9402682.	74.8

COST ANALYSIS FOR APPLIANCE: AIR-CONDITIONER, 8000 BTUS/HR

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1	A	5.90	190.00	808.	73.30	100.0	12572722.	100.0
2	A	8.40	260.00	568.	77.50	105.7	10066482.	80.1
3	B	6.20	190.00	769.	71.65	97.7	12054958.	95.9
4	C	5.90	220.00	808.	79.46	108.4	12864150.	102.3
5	C	9.20	260.00	518.	75.38	102.8	9402682.	74.8

COST ANALYSIS FOR APPLIANCE: AIR-CONDITIONER, 10000 BTUS/HR

WITH APPLIANCE LIFE OF 7 YEARS
ASSUMING INTEPEST RATE OF 0.0 AND ENERGY INFLATION RATE OF 0.0
WHERE PRICE OF ENERGY = 0.02950 $/KWH AND CONVERSION COEFF. = 68000.00 BTUS/$
THE PRIMARY ELECTRICITY CONVERSION FACTOR IS 13276. BTUS / KWH.

OPTION	MANUFACT.	EER	CAPITAL COST $'S	OPERATING COST KWH / YEAR	ANNUAL COST $'S	PERCENT	ANNUAL ENERGY COST IN BTUS	PERCENT
1	A	5.40	250.00	1104.	68.28	100.0	17085264.	100.0
2	A	6.70	280.00	890.	66.25	97.0	14535640.	85.1
3	A	7.20	280.00	828.	64.43	94.4	13712528.	80.3
4	A	7.40	260.00	805.	60.89	89.2	13212894.	77.3
5	A	11.00	350.00	542.	65.99	96.6	10595592.	62.0

COST ANALYSIS FOR APPLIANCE: AIR-CONDITIONEF, 10000 BTUS/HR

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1	A	5.40	250.00	1104.	87.18	100.0	17085264.	100.0
2	A	6.70	280.00	890.	86.39	99.1	14535640.	85.1
3	A	7.20	280.00	828.	84.38	96.8	13712528.	80.3
4	A	7.40	260.00	805.	79.53	91.2	13212894.	77.3
5	A	11.00	350.00	542.	89.48	102.6	10595592.	62.0

COST ANALYSIS FOR APPLIANCE: AIR-CONDITIONER, 10000 BTUS/HR

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1	A	5.40	250.00	1104.	98.18	100.0	17085264.	100.0
2	A	6.70	280.00	890.	95.26	97.0	14535640.	85.1
3	A	7.20	280.00	828.	92.63	94.4	13712528.	80.3
4	A	7.40	260.00	805.	87.55	89.2	13212894.	77.3
5	A	11.00	350.00	542.	94.88	96.6	10595592.	62.0

COST ANALYSIS FOR APPLIANCE: AIR-CONDITIONER, 12000 BTUS/HR

WITH APPLIANCE LIFE OF 7 YEARS
ASSUMING INTEREST RATE OF 0.0 AND ENERGY INFLATION RATE OF 0.0
WHERE PRICE OF ENERGY = 0.02950 $/KWH AND CONVERSION COEFF. = 68000.00 BTUS/$
THE PRIMARY ELECTRICITY CONVERSION FACTOR IS 13276. BTUS / KWH.

OPTION	MANUFACT.	EER	CAPITAL COST $'S	OPERATING COST KWH / YEAR	ANNUAL COST $'S	PERCENT	ANNUAL ENERGY COST IN BTUS	PERCENT
1	A	5.80	250.00	1233.	72.09	100.0	18797872.	100.0
2	A	6.00	270.00	1192.	73.74	102.3	18447840.	98.1
3	B	8.70	310.00	822.	68.53	95.1	13924300.	74.1
4	C	5.60	260.00	1277.	74.81	103.8	19479152.	103.6
5	C	6.00	290.00	1192.	76.59	106.2	18642128.	99.2

COST ANALYSIS FOR APPLIANCE: AIR-CONDITIONER, 12000 BTUS/HR

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1	A	5.80	250.00	1233.	91.36	100.0	18797872.	100.0
2	A	6.00	270.00	1192.	94.14	103.0	18447840.	98.1
3	B	8.70	310.00	822.	90.35	98.9	13924300.	74.1
4	C	5.60	260.00	1277.	94.84	103.8	19479152.	103.6
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1	A	5.80	250.00	1233.	103.65	100.0	18797872.	100.0
2	A	6.00	270.00	1192.	106.02	102.3	18447840.	98.1
3	B	8.70	310.00	822.	98.54	95.1	13924300.	74.1
4	C	5.60	260.00	1277.	107.57	103.8	19479152.	103.6
5	C	6.00	290.00	1192.	110.13	106.2	18642128.	99.2

COST ANALYSIS FOR APPLIANCE: AIR-CONDITIONER, 14000 BTUS/HR

WITH APPLIANCE LIFE OF 7 YEARS
ASSUMING INTEREST RATE OF 0.0 AND ENERGY INFLATION RATE OF 0.0
WHERE PRICE OF ENERGY = 0.02950 $/KWH AND CONVERSION COEFF. = 68000.00 BTUS/$
THE PRIMARY ELECTRICITY CONVERSION FACTOR IS 13276. BTUS / KWH.

OPTION	MANUFACT.	EER	CAPITAL COST $'S	OPERATING COST KWH / YEAR	ANNUAL COST $'S	PERCENT	ANNUAL ENERGY COST IN BTUS	PERCENT
1	A	5.10	310.00	1636.	92.55	107.4	24730960.	107.7
2	A	5.50	290.00	1517.	86.18	100.0	22956816.	100.0
3	A	8.80	350.00	948.	77.97	90.5	15985643.	69.6
4	A	9.90	370.00	843.	77.73	90.2	14785953.	64.4
5	C	6.00	300.00	1391.	83.89	97.3	21381184.	93.1

COST ANALYSIS FOR APPLIANCE: AIR-CONDITIONER, 14000 BTUS/HR

WITH APPLIANCE LIFE OF 7 YEARS
ASSUMING INTEREST RATE OF 0.100 AND ENERGY INFLATION RATE OF 0.0
WHERE PRICE OF ENERGY = 0.02950 $/KWH AND CONVERSION COEFF. = 68000.00 BTUS/$
THE PRIMARY ELECTRICITY CONVERSION FACTOR IS 13276. BTUS / KWH.

OPTION	MANUFACT.	EER	CAPITAL COST $'S	OPERATING COST KWH / YEAR	ANNUAL COST $'S	PERCENT	ANNUAL ENERGY COST IN BTUS	PERCENT
1	A	5.10	310.00	1636.	116.76	107.3	24730960.	107.7
2	A	5.50	290.00	1517.	108.79	100.0	22956816.	100.0
3	A	8.80	350.00	948.	102.65	94.4	15985648.	69.6
4	A	9.90	370.00	843.	103.36	95.0	14785953.	64.4
5	C	6.00	300.00	1391.	106.76	98.1	21351184.	93.1

COST ANALYSIS FOR APPLIANCE: AIR-CONDITIONER, 14000 BTUS/HR

WITH APPLIANCE LIFE OF 7 YEARS
ASSUMING INTEREST RATE OF 0.100 AND ENERGY INFLATION RATE OF 0.100
WHERE PRICE OF ENERGY = 0.02950 $/KWH AND CONVERSION COEFF. = 68000.00 BTUS/$
THE PRIMARY ELECTRICITY CONVERSION FACTOR IS 13276. BTUS / KWH.

OPTION	MANUFACT.	EER	CAPITAL COST $'S	OPERATING COST KWH / YEAR	ANNUAL COST $'S	PERCENT	ANNUAL ENERGY COST IN BTUS	PERCENT
1	A	5.10	310.00	1636.	133.07	107.4	24730960.	107.7
2	A	5.50	290.00	1517.	123.91	100.0	22956816.	100.0
3	A	8.80	350.00	948.	112.10	90.5	15985648.	69.6
4	A	9.90	370.00	843.	111.76	90.2	14785953.	64.4
5	C	6.00	300.00	1391.	120.62	97.3	21381184.	93.1

COST ANALYSIS FOR APPLIANCE: AIR-CONDITIONER, 18000 BTUS/HR

WITH APPLIANCE LIFE OF 7 YEARS
ASSUMING INTEREST RATE OF 0.0 AND ENERGY INFLATION RATE OF 0.0
WHERE PRICE OF ENERGY = 0.02950 $/KWH AND CONVERSION COEFF. = 68000.00 BTUS/$
THE PRIMARY ELECTRICITY CONVERSION FACTOR IS 13276. BTUS / KWH.

OPTION	MANUFACT.	EER	CAPITAL COST $'S	OPERATING COST KWH / YEAR	ANNUAL COST $'S	PERCENT	ANNUAL ENERGY COST IN BTUS	PERCENT
1	A	6.40	360.00	1676.	100.87	102.4	25747712.	95.9
2	A	6.40	390.00	1676.	105.16	106.8	26039136.	97.0
3	A	8.80	400.00	1219.	93.10	94.6	20069152.	74.8
4	C	6.00	350.00	1788.	102.75	104.4	27137488.	101.1
5	C	6.00	320.00	1788.	98.46	100.0	26846048.	100.0

COST ANALYSIS FOR APPLIANCE: AIR-CONDITIONER, 18000 BTUS/HR

WITH APPLIANCE LIFE OF 7 YEARS
ASSUMING INTEREST RATE OF 0.100 AND ENERGY INFLATION RATE OF 0.0
WHERE PRICE OF ENERGY = 0.02950 $/KWH AND CONVERSION COEFF. = 68000.00 BTUS/$
THE PRIMARY ELECTRICITY CONVERSION FACTOR IS 13276. BTUS / KWH.

OPTION	MANUFACT.	EER	CAPITAL COST $'S	OPERATING COST KWH / YEAR	ANNUAL COST $'S	PERCENT	ANNUAL ENERGY COST IN BTUS	PERCENT
1	A	6.40	360.00	1676.	128.33	103.7	25747712.	95.9
2	A	6.40	390.00	1676.	134.49	108.7	26039136.	97.0
3	A	8.80	400.00	1219.	121.72	98.4	20069152.	74.8
4	C	6.00	350.00	1788.	129.91	105.0	27137488.	101.1
5	C	6.00	320.00	1788.	123.75	100.0	26846048.	100.0

COST ANALYSIS FOR APPLIANCE: AIR-CONDITIONER, 18000 BTUS/HR

WITH APPLIANCE LIFE OF 7 YEARS
ASSUMING INTEREST RATE OF 0.100 AND ENERGY INFLATION RATE OF 0.100
WHERE PRICE OF ENERGY = 0.02950 $/KWH AND CONVERSION COEFF. = 68000.00 BTUS/$
THE PRIMARY ELECTRICITY CONVERSION FACTOR IS 13276. BTUS / KWH.

OPTION	MANUFACT.	EER	CAPITAL COST $'S	OPERATING COST KWH / YEAR	ANNUAL COST $'S	PERCENT	ANNUAL ENERGY COST IN BTUS	PERCENT
1	A	6.40	360.00	1676.	145.04	102.4	25747712.	95.9
2	A	6.40	390.00	1676.	151.20	106.8	26039136.	97.0
3	A	8.80	400.00	1219.	133.87	94.6	20069152.	74.8
4	C	6.00	350.00	1788.	147.73	104.4	27137488.	101.1
5	C	6.00	320.00	1788.	141.57	100.0	26846048.	100.0

Table 4 -- Explanation of Table 3

COST ANALYSIS FOR APPLIANCE: AIR-CONDITIONER, 14000 BTUS/HR

WITH APPLIANCE LIFE OF 7 YEARS
ASSUMING INTEREST RATE OF 0.100 AND ENERGY INFLATION RATE OF 0.0
WHERE PRICE OF ENERGY = 0.02950 $/KWH AND CONVERSION COEFF. = 68000.00 BTUS/$
THE PRIMARY ELECTRICITY CONVERSION FACTOR IS 13276. BTUS / KWH.

OPTION	MANUFACT.	EER	CAPITAL COST $'S	OPERATING COST KWH / YEAR	ANNUAL COST $'S	PERCENT	ANNUAL ENERGY COST IN BTUS	PERCENT
1	A	5.10	310.00	1636.	116.76	107.3	24730960.	107.7
2	A	5.50	290.00	1517.	108.79	100.0	22956816.	100.0
3	A	8.80	350.00	948.	102.65	94.4	15985648.	69.6
4	A	9.90	370.00	843.	103.36	95.0	14785953.	64.4
5	C	6.00	300.00	1391.	106.76	98.1	21381184.	93.1

From Ref. 3

EER = Energy efficiency ratio
= Btu/hr/watts

Percents expressed in terms of option with lowest first (capital) cost.

Includes losses in power plants, etc.

Average commercial price.

Table 5. Energy Saved by Using Lowest Annual Dollar Cost as Criterion

Size (Btu/hr.)	Energy rank[b]	Energy savings[c] (%)	Dollar savings[d] (%)
	r = 0.10, s = 0.00[a]		
6000	1	10	1
8000	3	4	2
10000	2	23	9
12000	1	26	1
14000	2	30	6
18000	1	25	2
	r = 0.10, s = 0.10[a]		
6000	1	10	2
8000	3	4	2
10000	2	23	11
12000	1	26	5
14000	1	36	10
18000	1	25	5

a) r = interest rate on loan, s = rate of increase of energy cost.

b) Ranked in order of increasing energy cost: 1 = lowest.

c) Energy savings as % of device with lowest initial dollar cost.

d) Dollar savings as % of device with lowest initial dollar cost.

APPENDIX A. AMORTIZED DOLLAR COSTS

We include effects of bank interest rate and increasing energy price. Let

C_1 = initial (capital) cost of device (dollars).

C_2 = operational cost per year (dollars).

r = bank interest rate (per year).

s = inflation rate on energy price (per year).

N = lifetime of device (years).

p = levelized annual cost (dollars).

The object is to find the annual payment assuming the cost per year is constant. One way to state this is "the constant yearly payment over the lifetime you must make to a credit bank which covers all the expenses."

Thus

$$C_1 (1 + r)^N + C_2 (1 + r)^N + C_2 (1 + s) (1 + r)^{N-1}$$

$$+ C_2 (1 + s)^2 (1 + r)^{N-2} + \ldots\ldots C_2 (1 + s)^{N-1} (1 + r)$$

$$= p + p (1 + r) + \ldots\ldots p (1 + r)^{N-1}$$

Apply the geometric series formula:

$$a + an + am^2 + \ldots an^{-1} = \frac{a - am^n}{1 - m}$$

to obtain

$$p = \left\{ C_1 (1 + r)^N + C_2 (1 + r) \frac{[(1 + r)^N - (1 + s)^N]}{r - s} \right\} \frac{r}{(1 + r)^N - 1}$$

If $r = s = 0$

$$p = \frac{C_1}{N} + C_2, \text{ as expected.}$$

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