TECHNICAL SUPPORT DOCUMENT FOR ENERGY CONSERVATION STANDARDS FOR ROOM AIR CONDITIONERS

(Docket Numbers EE-RM-90-201 & EE-RM-93-801-RAC)

SEPTEMBER 1997

LAWRENCE BERKELEY NATIONAL LABORATORY
Energy & Environment Division
Technology and Market Assessment Group
Berkeley, CA 94720

Prepared for

U.S. DEPARTMENT OF ENERGY
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VOLUME 2 - DETAILED ANALYSIS OF EFFICIENCY LEVELS

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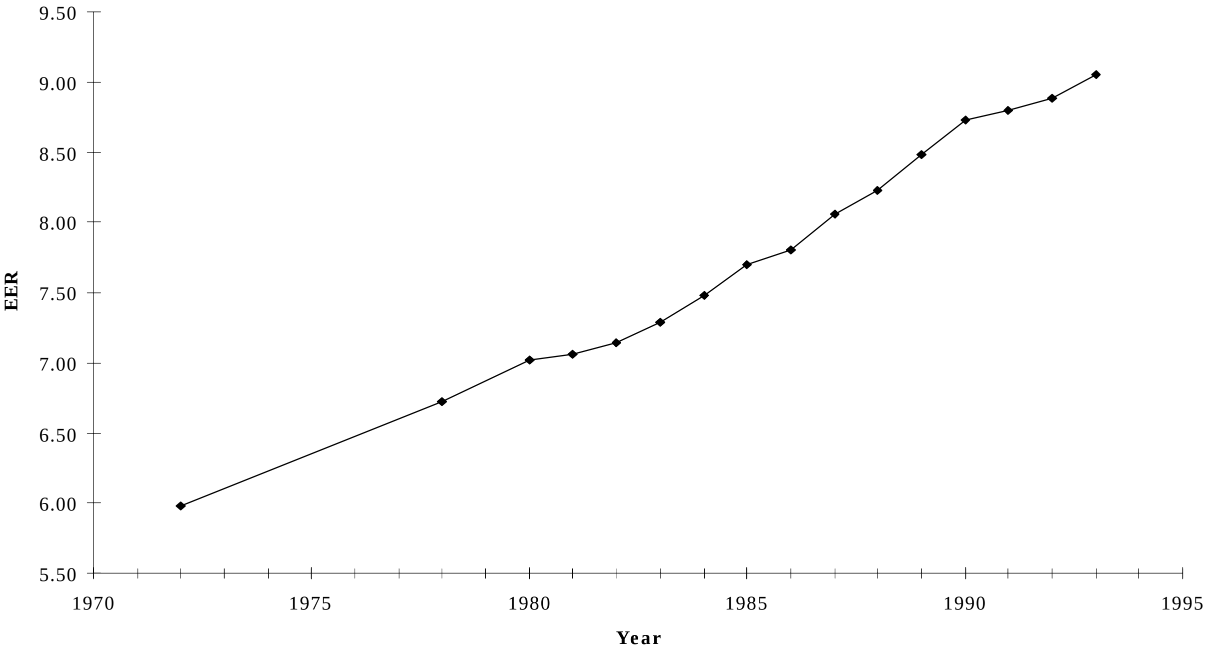
EXECUTIVE SUMMARY

A room air conditioner is an encased assembly designed as a unit to be mounted in a window or through a wall that provides cool or warm conditioned air to an enclosed room or space. In 1987, the National Appliance Energy Conservation Act (NAECA) was signed into law establishing minimum energy efficiency standards for thirteen household appliances, including room air conditioners. The energy efficiency descriptor for room air conditioners is the energy efficiency ratio (EER). The EER is the ratio of the cooling capacity (in Btu/hr) to the power input (in Watts). Minimum EER standards prescribed by NAECA went into effect for room air conditioners on January 1, 1990 and range from 8.0 to 9.0 EER depending on the product class. Figure ES.1 shows how room air conditioner shipment-weighted efficiency has increased over the past 20 years.



Source: AHAM

Figure ES.1 Shipment-Weighted Room Air Conditioner Efficiency

This report analyzes higher efficiency levels for room air conditioners. Room air conditioners are categorized by NAECA into twelve product classes. These classes depend on the cooling capacity, intended installation, and function of the room air conditioner. Two additional classes are described in this report for units specifically designed to fit into casement-only and casement-slider windows, although a lack of engineering data prevented these classes from being analyzed. In addition, three of the six classes for units designed for through-the wall installations were not analyzed because these manufacturers were not producing units in these classes at the time of the analysis. The analyses carried out for the nine remaining classes include cost-efficiency, life-cycle cost, payback period, national energy consumption and savings, net present value to the nation, manufacturer impact, electric utility impact, and environmental impact. Input data were obtained from several sources, including the Association of Home Appliance Manufacturers (AHAM) and its members. Some of the data collected from AHAM came as a result of meetings in 1990 to discuss data requirements and engineering modeling. More AHAM data was collected from their comments in response to the U.S. Department of Energy's (DOE) Notice of Proposed Rulemaking (NOPR) for room air conditioners. That NOPR for room air conditioners was issued on March 4, 1994. A Draft Report on the Potential Impact of Alternative Efficiency Levels for Room Air Conditioners was released for comment in May of 1996. The Draft Report became the basis for this Technical Support Document. A Supplemental Analysis Section has been added to provide the analysis performed subsequent to the Draft Report.

Table ES.1 summarizes the EERs corresponding to each of the five alternative energy efficiency levels analyzed in this report for the nine product classes of room air conditioners that could be assessed. As a reference point, the current NAECA minimum efficiency standard is also provided for each class. Each alternative efficiency level consists of a combination of design options that improve the overall efficiency of the product. Design options include, but are not limited to, improvements in heat exchanger design, compressor efficiency, and fan motor efficiency. It should be noted that, based on industry comments to the NOPR, rotary compressors with efficiencies ranging from 11.5 to 12.0 EER were not considered viable design options. A complete list of design options analyzed for each class and their resultant impact on system efficiency is provided in Chapter 1.

Table ES.1 Energy Efficiency Ratios for Room Air Conditioners (Btu/W-hr)

		Efficiency Level				
Product Class	NAECA	1	2	3	4	5
Without Reverse Cycle and With Side Louvers						
Less than 6000 Btu/hr	8.0	9.32	9.71	10.00	10.38	11.74
6000 to 7999 Btu/hr	8.5	9.38	9.66	9.91	10.33	11.67
8000 to 13,999 Btu/hr	9.0	9.71	9.85	10.11	10.97	12.39
14,000 to 19,999 Btu/hr	8.8	9.70	9.98	10.15	10.15	12.77
Over 20,000 Btu/hr	8.2	8.39	8.39	8.51	8.88	11.14
Without Reverse Cycle and Without Side Louvers						
6000 to 7999 Btu/hr	8.5	9.10	9.10	9.23	9.23	11.52
8000 to 13,999 Btu/hr	8.5	8.80	9.05	9.12	9.12	11.08
With Reverse Cycle and With Side Louvers	8.5	9.05	9.05	9.27	9.27	11.16
With Reverse Cycle and Without Side Louvers	8.0	8.72	8.72	8.86	8.86	10.87

In addition, a Supplemental Efficiency Level is analyzed in the Supplemental Analysis Section. This efficiency level is not based on a specific configuration of design options but rather from consideration of comments generated from the Draft Report. See Supplemental Table 1.

Please note that Annual Energy Outlook 1995 (AEO 95) energy price forecasts have been used to perform the calculations in this report. Additional Analysis, using other energy price forecasts are contained in the Supplemental Analysis Section of this report.

For each of the nine product classes analyzed in this report, Table ES.2 summarizes the life-cycle cost (LCC) results for each of the five alternative efficiency levels and the baseline. LCCs were determined for an average electricity price of $0.0735/kWh in 1995$ and an equipment lifetime of 12.5 years. Equipment prices and annual energy expenses for each class can be found in Chapter 4. It should be noted that annual energy expenses are determined from field-based energy use data rather than energy use data determined with DOE test procedure calculations. As shown in Chapter 1, field-based energy use data is 71% of that determined with DOE test procedure calculations based on 750 hours of annual operation.

Table ES.2 Life-Cycle Costs of Room Air Conditioners (@ 6% discount rate)

		Efficiency Level				
Product Class	Base	1	2	3	4	5
Without Reverse Cycle and With Side Louvers						
Less than 6000 Btu/hr	$612	$589	$586	$587	$630	$964
6000 to 7999 Btu/hr	$702	$679	$678	$679	$722	$1,047
8000 to 13,999 Btu/hr	$935	$928	$926	$924	$951	$1,260
14,000 to 19,999 Btu/hr	$1,286	$1,258	$1,247	$1,245	$1,245	$1,769
Over 20,000 Btu/hr	$1,856	$1,849	$1,849	$1,844	$1,884	$2,389
Without Reverse Cycle and Without Side Louvers						
6000 to 7999 Btu/hr	$689	$688	$688	$688	$688	$1,531
8000 to 13,999 Btu/hr	$973	$973	$965	$969	$969	$1,799
With Reverse Cycle and With Side Louvers	$1,165	$1,164	$1,164	$1,165	$1,165	$1,650
With Reverse Cycle and Without Side Louvers	$1,144	$1,144	$1,144	$1,140	$1,140	$2,088

Table ES.3 shows the payback periods for the five alternative efficiency levels. As with the LCCs, the payback periods are determined with an average electricity price of $0.0735/kWh in 1995$. Also, annual energy expenses are determined with field-based energy use data. Details of the payback calculations can be found in Chapter 4. In addition, LCC and payback calculations for the Supplemental Efficiency Level are provided in Supplemental Tables 4.1 - 4.18.

Table ES.3 Payback Periods for Room Air Conditioners (years)

	Efficiency Level				
	1	2	3	4	5
Without Reverse Cycle and With Side Louvers					
Less than 6000 Btu/hr	1.8	2.6	3.9	13.5	57.0
6000 to 7999 Btu/hr	1.9	3.5	5.0	14.9	53.1
8000 to 13,999 Btu/hr	5.3	5.4	5.9	11.6	38.2
14,000 to 19,999 Btu/hr	3.5	3.5	4.1	4.1	33.2
Over 20,000 Btu/hr	5.3	5.3	5.4	12.7	27.9
Without Reverse Cycle and Without Side Louvers					
6000 to 7999 Btu/hr	7.0	7.0	8.0	8.0	150.3
8000 to 13,999 Btu/hr	N/A	2.7	6.9	6.9	97.8
With Reverse Cycle and With Side Louvers	6.7	6.7	8.5	8.5	57.0
With Reverse Cycle and Without Side Louvers	N/A	N/A	3.4	3.4	105.8

Tables ES.4 and ES.5 show the results of a national consumer analysis that estimates cumulative national energy savings and national net present benefit to consumers. Because increased efficiency levels for room air conditioners are forecasted to impact the sales and national energy use of both central air conditioners and central heat pumps, Table ES.4 details the impact the five alternative efficiency levels on all three of these space cooling systems. With regard to the net present values presented in Table ES.5, efficiency level 3 provides the maximum value at an amount of $0.59 billion in 1995$. Additional analysis regarding cumulative national energy savings and national net present value for the Supplemental Efficiency Level using AEO 1995 and other energy price forecasts are provided in the Supplemental Analysis Section of this report.

Table ES.4 Space Cooling Energy Consumption and Savings (Quadrillion Btu, Primary)

		Efficiency Level				
	Baseline	1	2	3	4	5
Cumulative Electricity Use, 1999-2030						
Room Air Conditioners	14.63	14.23	14.04	13.84	13.29	10.53
Central Air Conditioners	40.56	40.59	40.61	40.65	40.88	43.39
Central Heat Pumps (cooling)	12.44	12.44	12.45	12.45	12.50	12.99
Total Cooling Electricity Use	67.62	67.26	67.10	66.93	66.66	66.90
Cumulative Energy Savings, 1999-2030						
Room Air Conditioners		0.39	0.59	0.79	1.34	4.10
Central Air Conditioners		-0.03	-0.05	-0.09	-0.32	-2.83
Central Heat Pumps (cooling)		-0.01	-0.01	-0.02	-0.06	-0.55
Total Energy Savings		0.36	0.52	0.69	0.96	0.72

Table ES.5 Net Present Value, Benefits, and Costs to Society of Efficiency Levels for Room Air Conditioners Purchased from 1999-2030 (Billion 1990 Dollars, Discounted at 7% Real)

	Efficiency Level				
	1	2	3	4	5
Energy Savings	0.55	0.81	1.07	1.61	2.83
Equipment Cost	0.16	0.27	0.48	1.87	13.75
Net Present Value	0.40	0.54	0.59	-0.26	-10.92

Tables ES.6, ES.7, and ES.8 provide the results from an analysis of how the five alternative efficiency levels impact manufacturers. Tables ES.6 and ES.7 provide long- and short-run manufacturer impact data by detailing how shipments, price, revenue, net income, and return on equity are affected by the increased efficiency levels. Note that in the short run, the efficiency levels have more of a negative impact on manufacturers' return on equity than in the long run. Table ES.8 provides additional manufacturer impact data for the purpose of determining the industry's net present value for each of the five alternative efficiency levels. It should be noted that base case determinations of shipments and total revenue are different for Tables ES.6 and ES.7 and for Table ES.8. This is due to the different calculation methods that were used for determining the values in Tables ES.6 and ES.7 and the values in Table ES.8. Assumptions for such items as capital maintenance expenses differed between the two methods. More details on the manufacturer impact analysis can be found in Chapter 5.

Table ES.6 Long-Run Manufacturer Impacts for Room Air Conditioners

		Efficiency Level				
	1996 Base	1	2	3	4	5
Shipments (in million)	0.61	0.61	0.61	0.61	0.59	0.48
Percent Change		0.04%	-0.05%	-0.32%	-2.71%	-21.20%
Standard Error		1.07%	1.37%	2.30%	3.63%	14.11%
Price	$304.35	$307.67	$309.86	$313.72	$338.27	$593.46
Percent Change		1.09%	1.81%	3.08%	11.15%	94.99%
Standard Error		1.29%	1.30%	1.88%	3.93%	27.19%
Revenue (in million dollars)	186.03	188.13	189.31	191.15	201.16	285.84
Percent Change		1.13%	1.76%	2.75%	8.13%	53.65%
Standard Error		1.07%	1.42%	2.06%	4.27%	30.47%
Net Income (in million dollars)	10.600	10.625	10.646	10.696	10.829	11.090
Difference		0.025	0.045	0.096	0.228	0.490
Standard Error		0.173	0.252	0.400	1.250	11.796
Return on Equity	10.88%	10.83%	10.80%	10.78%	10.28%	7.22%
Difference		-0.05%	-0.08%	-0.09%	-0.59%	-3.66%
Standard Error		0.14%	0.21%	0.29%	1.05%	7.22%

Table ES.7 Short-Run Manufacturer Impacts for Room Air Conditioners

		Efficiency Level				
	1996 Base	1	2	3	4	5
Shipments (in million)	0.611	0.612	0.611	0.610	0.596	0.488
Percent Change		0.07%	-0.01%	-0.27%	-2.53%	-20.14%
Price	$304.35	$307.40	$309.54	$313.28	$336.60	$574.22
Percent Change		1.00%	1.71%	2.93%	10.59%	88.67%
Revenue (in million dollars)	186.03	188.03	189.18	190.98	200.53	280.31
Percent Change		1.07%	1.69%	2.66%	7.79%	50.67%
Net Income (in million dollars)	10.601	10.465	10.450	10.420	9.236	0.195
Difference		-0.136	-0.151	-0.181	-1.364	-10.405
Return on Equity	10.88%	10.67%	10.60%	10.50%	8.77%	0.13%
Difference		-0.21%	-0.27%	-0.37%	-2.11%	-10.75%
Standard Error		0.34%	0.44%	0.61%	1.54%	8.99%

Table ES.8 Manufacturer Impacts for the Purpose of Determining Industry Net Present Value

		Efficiency Level				
	1996 Base	1	2	3	4	5
Shipments (in million)	3.06	3.02	3.01	3.00	2.90	2.25
Difference		-0.04	-0.04	-0.05	-0.16	-0.80
Percent Change		-1.24%	-1.38%	-1.73%	-5.25%	-26.32%
Price	$304.35	$318.85	$321.51	$326.24	$363.02	$698.99
Difference		14.50	17.16	21.89	58.67	394.64
Percent Change		4.76%	5.64%	7.19%	19.28%	129.67%
Total Revenues (in million dollars)	930.17	962.39	969.07	979.82	1051.29	1573.96
Difference		32.21	38.90	49.65	121.12	643.78
Percent Change		3.46%	4.18%	5.34%	13.02%	69.21%
Profit after Tax (in million dollars)	35.72	41.00	42.06	43.98	70.25	198.66
Difference		5.28	6.34	8.26	34.53	162.94
Percent Change		14.78%	17.75%	23.13%	96.67%	456.19%
Net Cash Flow (in million dollars)	$28.74	$28.54	$28.47	$28.56	$42.68	$82.24
Difference		-0.20	-0.27	-0.18	13.94	53.50
Percent Change		-0.69%	-0.95%	-0.63%	48.50%	186.14%
Industry Value (in million dollars)	239.52	245.37	245.97	247.44	251.97	211.23
Difference		5.85	6.45	7.92	12.45	-28.29
Percent Change		2.44%	2.69%	3.31%	5.20%	-11.81%

Table ES.9 shows the present value of net revenue losses for electric utilities at a 5% real utility discount rate for all alternative efficiency levels and for two cases regarding regulatory behavior; one case which assumes that regulators will adjust electricity rates to reflect the reduced electricity sales in five years that result from more efficient room air conditioners, and another case which assumes that they never adjust electricity rates. A negative revenue loss signifies that cost savings exceed revenue losses. The present value of net gained revenues may range from $6 to 66 million for a five-year lag, and, if regulators did not adjust rates, utilities would actually receive increased revenues of as much as $.9 billion. The present values over the period 1998 to 2030 also represent the rate decreases needed over this period to compensate for increased revenues, assuming that regulators adjust them immediately. Refer to Chapter 6 for more details regarding the utility impact analysis.

Table ES.9 Cumulative Present Value of Revenue Losses (MM $1990)

	Efficiency Level				
Regulatory Lag	1	2	3	4	5
1998 to 2002	-6	-9	-10	-21	-66
1998 to 2030	-88	-128	-176	-299	-921

Table ES.10 summarizes the results of the environmental impact analysis for one of the alternative efficiency levels; Level 3. The reduction in power plant emissions of sulfur oxides (SO_2), nitrogen oxides (NO_x), and carbon dioxide (CO_2) are shown. Chapter 7 shows similar data for all five alternative efficiency levels. Also see Supplemental Tables 7.6 and 7.7 for environmental impact analysis for the Supplemental Efficiency Level.

Table ES.10 Projected Emissions at Alternative Efficiency Level 3 for SO_2, NO_x, and CO_2

SO_2

Year	Abated from Power Plants		Abated from In-House		Total Reduction in Emissions		Reduction as a % of Total Res. Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	1.43	1.57	0.00	0.00	1.43	1.57	0.04
2005	3.65	4.02	0.00	0.00	3.65	4.02	0.12
2010	5.04	5.56	0.00	0.00	5.04	5.56	0.18
2015	4.22	4.65	0.00	0.00	4.22	4.65	0.17
2020	3.51	3.87	0.00	0.00	3.51	3.87	0.17
2025	2.91	3.20	0.00	0.00	2.91	3.20	0.17
2030	2.27	2.50	0.13	0.15	2.41	2.65	0.18
Cumulative SO_2 reduction (kt):			111		(short tons):	122 000	

NO_x

Year	Abated from Power Plants		Abated from In-House		Total Reduction in Emissions		Reduction as a % of Total Res. Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	1.06	1.17	0.05	0.05	1.11	1.22	0.04
2005	2.94	3.24	0.00	0.00	2.94	3.24	0.11
2010	4.38	4.83	0.00	0.00	4.38	4.83	0.16
2015	3.91	4.31	0.05	0.05	3.95	4.36	0.16
2020	3.51	3.87	0.00	0.00	3.51	3.87	0.16
2025	3.18	3.51	0.05	0.05	3.23	3.56	0.16
2030	2.79	3.08	0.10	0.10	2.90	3.19	0.15
Cumulative NO_x reduction (kt):			104		(short tons):	115 000	

CO_2

Year	Abated from Power Plants		Abated from In-House		Total Reduction in Emissions		Reduction as a % of Total Res. Emissions
	Mt	million short tons	Mt	million short tons	Mt	million short tons	
2000	0.40	0.44	0.05	0.05	0.44	0.49	0.04
2005	1.20	1.32	0.00	0.00	1.20	1.32	0.09
2010	1.93	2.13	0.00	0.00	1.93	2.13	0.14
2015	2.01	2.21	0.05	0.05	2.05	2.26	0.14
2020	2.08	2.29	0.00	0.00	2.08	2.29	0.14
2025	2.22	2.44	0.05	0.05	2.26	2.49	0.15
2030	2.28	2.51	0.12	0.13	2.40	2.64	0.15
Cumulative CO_2 reduction (Mt):			57		(short tons):	63 000 000	

CHAPTER 1. ENGINEERING ANALYSIS

1.1 INTRODUCTION

A room air conditioner is an encased assembly designed as a unit to be mounted in a window or through a wall. It is designed primarily to provide cool or warm conditioned air to an enclosed space, room, or zone. Heat is sometimes provided by a heat pump operation, electric resistance elements, or by a combination of both.

A room air conditioner consists of refrigerant-side and air-side components all contained within one cabinet. The refrigerant-side components are the evaporator (indoor conditioning coil), the compressor, the condenser (outdoor coil), and the capillary tube. These components are all connected via refrigerant tubing. The air-side components consist of the fan motor, the evaporator fan, and condenser fan. One fan motor is used to drive both fans. The cabinet, which contains these components, is split into an indoor and outdoor side. The two sides are separated by a divider wall, which is usually insulated. The insulation serves to reduce heat transfer between the two sides. The indoor components are the evaporator and evaporator fan. The outdoor components are the compressor, condenser, capillary tube, fan motor, and condenser fan.

A room air conditioner provides conditioned air by drawing warm air from the space or room over the evaporator (indoor coil). In passing over the coil, the air gives up its latent and sensible heat. This conditioned air is then delivered back to the space or room by the evaporator fan. The compressor takes the vaporized refrigerant coming out of the evaporator and raises it to a temperature exceeding that of the outside air. The refrigerant passes on to the condenser (outside coil) where the condenser fan blows outside air over it. The refrigerant gives its heat up to the cooler outside air and condenses. The liquid refrigerant is taken by the capillary tube and its pressure and temperature are reduced. The refrigerant re-enters the evaporator where the refrigeration cycle is repeated.

The present DOE test procedure specifies a steady-state efficiency test to evaluate the efficiency of a room air conditioner. Standard test conditions are defined as 80°F and 50% relative humidity for the room air and 95°F and 40% relative humidity for the outdoor air. The DOE test procedure requires that the room air conditioner be operated and tested within a calorimeter room. Specifications for the calorimeter room are detailed in the test procedure (1).

Once test conditions are maintained for at least one hour, data, such as the room air conditioner’s cooling capacity and electrical input, are recorded. The energy efficiency ratio (EER), the energy descriptor for room air conditioners, is obtained by dividing the cooling capacity (specified in Btu/hr) by the electrical input (watts). The annual energy use is determined by multiplying the electrical input measured from the steady-state test by the annual hours of operation. As provided in the DOE test procedure, the representative average for the annual hours of operation is 750 (2). This value comes from an analysis the Association of Home Appliance Manufacturers (AHAM) performed to establish the annual hours of operation of a room air conditioner. The results of this study are contained in an appendix to the test method for room air conditioners (3). Since the DOE test procedure is a steady-state test, design options, which can improve the efficiency of the unit on a seasonal basis, cannot be evaluated by it. Other sources of information will be used to evaluate these types of design options.

A large-volume room air conditioner manufacturer typically relies on a combination of automated and manual processes in the manufacturing flow. A manufacturing flow diagram is shown in Figure 1.1. Cabinets and heat exchangers are produced in-house. Cabinets are composed out of both sheet metal and plastic components. Cabinet sheet metal is either bought pre-cut to the proper size or cut in-house from large sheet metal rolls. The sheet metal is then manually bent and stamped to form the correct cabinet shape. The plastic component, which consists of the front indoor grill, is either bought from a sub-contractor or molded in house. The heat exchanger is composed of aluminum fins and copper tubing. Aluminum sheets are cut from large rolls and then stamped with the desired fin pattern. Copper tubing is cut from large rolls to the desired tube length. Stamping of the aluminum also includes puncturing it with the desired tube row pattern. The punch press die that is used to cut and stamp the aluminum also automatically stacks the sheets (fins). This stacking process is set up so that the proper amount of fins will be contained in each stack. The copper tubing is then manually shoved through the aluminum fin stack and mechanically expanded within the stack to create a solid contact between the fins and tubes. Return bends are then brazed onto the ends of the copper tubing through either a manual or fully automated process. The completed heat exchanger is tested for leaks before being taken to the assembly line. The assembly of the room air conditioner, including purchased parts (i.e., compressor, fan motor, fans, controls), the heat exchanger, and the cabinet, is done exclusively with manual labor. After being charged with refrigerant, the entire unit is tested for leaks before being packaged, labeled, and prepared for shipment.

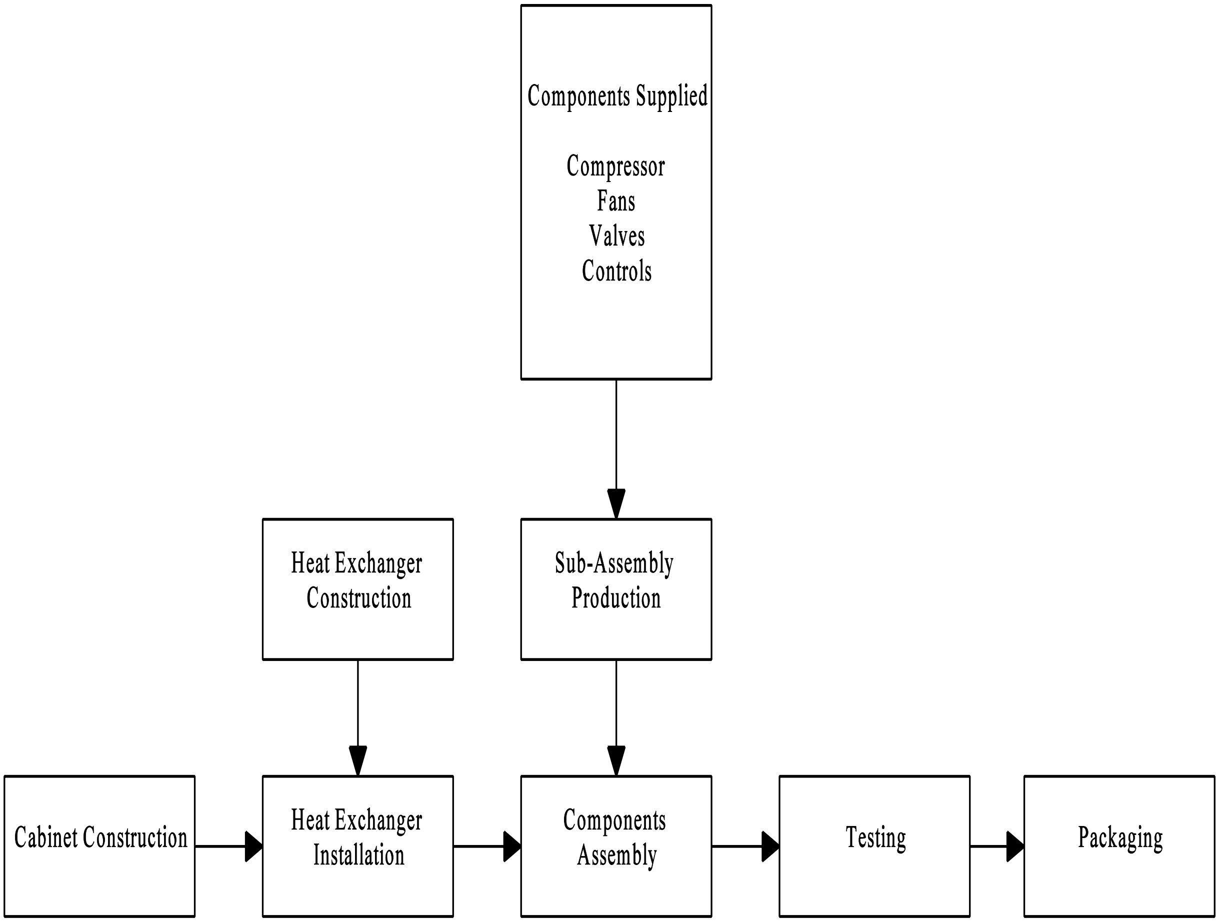


Figure 1.1 Manufacturing Flow Diagram for Room Air Conditioners

1.2 PRODUCT CLASSES

The Department of Energy (DOE) has adopted new product classes in addition to the twelve product classes specified by NAECA (listed in Table 1.1). The twelve product classes specified by NAECA apply to units that are designed to be installed in single- or double-hung windows and are defined according to the following criteria: capacity, whether the outside portion of the cabinet has louvered sides, and whether a reversing valve is present. The Department has split class 11 into units of capacity less than 20,000 Btu/h and units 20,000 Btu/h or more. Likewise, Class 12 has been split into units less than 14,000 Btu/h and units 14,000 Btu/h or more. In addition, two new classes have been established for units that are designed to be installed in casement-slider and casement-only windows. Due to the size constraints imposed by casement windows, casement units are small in size and typically deliver 5000 to 10000 Btu/hr in cooling capacity.

Table 1.1 Product Classes for Room Air Conditioners

Without Reverse Cycle and with Louvered Sides
1. Less than 6000 Btu/hr
2. 6000 to 7999 Btu/hr
3. 8000 to 13999 Btu/hr
4. 14000 to 19999 Btu/hr
5. Greater than 20000 Btu/hr
Without Reverse Cycle and without Louvered Sides
6. Less than 6000 Btu/hr
7. 6000 to 7999 Btu/hr
8. 8000 to 13999 Btu/hr
9. 14000 to 19999 Btu/hr
10. Greater than 20000 Btu/hr
11. With Reverse Cycle and with Louvered Sides
12. With Reverse Cycle and without Louvered Sides

NAECA states that additional classes are warranted for products within a particular class if the products "have a capacity or other performance-related feature that other products within such class do not have and such feature justifies a higher or lower standard from that which applies to other products within such class." When different capacity classes for room air conditioners were established in NAECA, it was assumed that it was justified due to this NAECA provision. Justification was probably based upon the manufacturers' need to standardize cabinet production. The reasons for this standardization are based on both economic and installation considerations.

Manufacturers state that every room air conditioner unit could be designed to optimize performance and efficiency as long as a specific cabinet could be built to best suit the unit's particular capacity and efficiency. A room unit's most typical installation is in a single- or double-hung window. Manufacturers cannot afford the luxury of optimizing every model they produce so they limit their production of cabinets to three or four sizes, taking into account the size of the most typical single- or double-hung windows. Each cabinet is designed to accommodate models that have roughly the same capacity. Having the same cabinet, these models will tend to have the same design constraints. Since these constraints have a direct impact on efficiency, models of the same relative capacity size will also tend to have the same efficiency. The combined effect of economic and installation constraints results in efficiency being a function of capacity. This effect warrants that the five capacity classes established by NAECA for units without reversing valves be retained.

Additional classes for casement-slider and casement-only room air conditioners are warranted because they meet the criteria established by NAECA for adopting new product classes. The performance-related feature which they offer, fitting into casement windows, justifies that a lower energy efficiency level be applied to them. Casement windows impose more severe limitations on room air conditioner size than single- or double-hung windows. Chassis sizes are smaller for casement units resulting in the use of smaller coils. This also limits the flexibility in coil, air handling system, and compressor arrangement. All these design constraints result in lower system efficiency which necessitates that additional classes be established for casement-type units. Class divisions by capacity are not necessary for casement units because of the narrow range of capacities that models are currently available in. According to the Association of Home Appliance Manufacturers' 1994 Directory of Certified Room Air Conditioners (4), casement-slider units range in capacity from 6000 to 7999 Btu/hr while casement-only units range in capacity from 5000 to 10000 Btu/hr. Because detailed engineering data were not available, an engineering analysis was not performed for casement-type units.

Side louvers have a significant effect on unit performance. Side louvers are stamped on the outdoor sides of the cabinet and enhance the movement of air over the outdoor coil. Units without side louvers operate at a lower efficiency due to the additional compressor power required for compensating for the decreased air flow over the outdoor coil. Units which are intended for installation though a wall require a non-louvered sleeve or a smooth-sided cabinet. By providing consumers with the performance-related feature of wall installation, separate classes become warranted for non-louvered room air conditioners.

Reversing valves allow a room air conditioner to operate as a heat pump and provide space heat in addition to space cooling. The reversing valve adds an additional load to the system that increases the unit's power requirement by an estimated 5% (5). Because of the additional power requirement and the unique utility of also providing space heat, separate classes are warranted for units using reversing valves.

1.3 DESIGN OPTIONS

The design options are listed in Table 1.2. They are changes that can be incorporated into the design of a room air conditioner to improve its efficiency. Some of the options are found in existing products; others are being developed.

Table 1.2 Design Options for Room Air Conditioners

Increase Heat-Transfer Surface Area
1. Increase Frontal Coil Area
2. Increase Depth of Coil (Add Tube Rows)
3. Increase Fin Density
4. Add Subcooler to Condenser Coil
Increase Heat-Transfer Coefficients
5. Improve Fin Design
6. Improve Tube Design
7. Spray Condensate onto Condenser Coil
8. Improve Fan and Fan Motor Efficiency
9. Improve Compressor Efficiency
10. Variable Speed Compressors
11. Alternative Refrigerants
12. Electronic Expansion Valves
13. Thermostatic Cyclic Controls

As evidenced by the design option table, increasing heat transfer performance can be accomplished by either increasing the heat transfer surface area or the heat transfer coefficients. Design improvements to the heat exchangers are categorized according to these two methods.

As stated in the introduction, design options that are intended to improve efficiency under cycling conditions cannot be evaluated under the steady-state conditions defined by the DOE test procedure. The three design options which improve efficiency solely on a cyclic basis (variable speed compressors, electronic expansion valves, cyclic controls) have been used, not on room units, but on central systems. It has been argued that the operating conditions central systems perform under are very different than those experienced by room units. When room units are turned on, the room temperature is likely to be high, thus reducing the amount of cycling as compared to central systems. Thus, the energy-saving benefits from design options that reduce energy consumption on a cyclic basis are less likely to affect the performance of room units. Before any attempt is made to modify the DOE test procedure to a seasonal rating procedure, thorough field testing must be performed to determine the extent of cycling in room units. Until such testing is performed, estimates of savings due to “cyclic” design options must be extrapolated from their effect on central systems resulting in a relatively large uncertainty in energy savings for such options.

Design option effects were quantified by analyzing an actual room air conditioner model for each product class where detailed engineering data were made available by manufacturers. Through their trade organization, AHAM, several manufacturers provided data on actual room air conditioner models for nine of the fourteen room air conditioner product classes. As discussed previously, engineering data were not available for the two casement-type classes. In addition, engineering data were not available for three of the five classes without reverse cycle and without louvered sides, as manufacturers currently did not produce units in these classes. (Currently, units are manufactured in only three of the five classes for units without reverse cycle and without side louvers.) For those nine classes where data were provided, a representative unit was chosen from the pool of units that were made available by manufacturers. The selection of the baseline unit was done in consultation with AHAM. Two criteria were used to choose a representative baseline unit; capacity and EER. The capacity of the unit had to be typical of a majority of the models listed in the AHAM directory of room air conditioners and the EER had to be close to the minimum allowed under NAECA effective in 1990. The analysis performed on this unit established what increase in efficiency could be expected for the entire product class. In the process of choosing a representative unit, it became apparent that each manufacturer used a different set of design considerations to develop their models. To attain a certain efficiency rating, one manufacturer might use a high-efficiency compressor with relatively small-sized heat exchangers. Another manufacturer might increase the size of the heat exchangers but retain a low- to mid-efficiency compressor. Thus, the baseline design of the representative unit dictates which design options can be applied to it.

The following discussion describes each design option. Comments of manufacturers on the feasibility of each design option are included.

Increase Frontal Coil Area

One of the most common ways of increasing heat transfer surface area is by using a coil with a larger frontal area. With a greater amount of coil face area, the heat transfer performance of the coil is increased. In the case of the condenser, more heat can be rejected from the refrigerant to the outside air stream. With regard to the evaporator, more of the room air's sensible and latent heat can be used to evaporate the refrigerant. Enhancing the heat-transfer process in either one of the coils results in an increased efficiency for the entire system.

Manufacturers assert that the frontal area of coils in existing room air conditioner chassis designs is so large that any significant increase in system performance requires an increase in the size of the cabinet. This was found to be true in almost all room air conditioner designs. Since the incremental cost of increasing the chassis is relatively significant, manufacturers usually look for other ways to improve system efficiency before attempting to increase the frontal coil area.

Manufacturers also express concern about the impact of increased heat exchanger size on a unit's ability to provide adequate dehumidification. The resultant improvement in the evaporator's performance increases the evaporating temperature. An evaporating temperature which is too high reduces the evaporator's ability to extract latent heat from the room air. In order to prevent inadequate dehumidification, manufacturers recommend a minimum latent heat ratio of 25%. (The latent heat ratio is the latent heat removal rate divided by the total cooling capacity.) Thus, to ensure that increased coil areas would not decrease latent heat ratios to unacceptable levels, the engineering analysis was conducted to prevent latent heat ratios from dropping below 25%.

Since manufacturers provided detailed engineering data for a model in each of the capacity product classes, it was possible to select an appropriate increase in frontal coil area for each representative baseline unit. For example, in the case of the representative baseline unit chosen for the less than 6000 Btu/hr product class, the face coil areas were 0.87 and 1.68 square feet for the evaporator and condenser, respectively. Since the manufacturer of this representative baseline unit also provided detailed engineering data on its next largest model, an appropriate increase in coil size could be made. The next largest model has face coil areas of 1.13 and 2.16 square feet for the evaporator and condenser, respectively. It was assumed that these face coil areas defined the limit to which coil sizes could be increased for the 6000 Btu/hr product class. This method of analysis assumes that the chassis size must be enlarged, as the coil sizes in the larger model require more space than is available in the baseline unit’s cabinet.

Increase Depth of Coil

Heat-transfer area can also be increased by adding rows of tubes to the coil. Manufacturers assert that each room air conditioner chassis is designed for a maximum depth evaporator and condenser. Vertical tube rows may be added up to that maximum depth but there is a limit to the number of tube rows that can be added before the chassis size must be increased. Increasing the chassis size is a relatively significant cost and could result in prohibiting any tube rows from being added. Besides chassis size, issues of weight, refrigerant charge, and diminishing effectiveness must also be considered.

Manufacturers state that there is a practical limit to the depth of a room air conditioner which is related to weight, appearance, and strength of the mounting. That limit is not well-defined.

With regard to the issue of refrigerant charge, manufacturers point out that the internal volume and, therefore, the amount of refrigerant required, is increased due to the addition of vertical tube rows. Because the larger coil size increases the efficiency of the room air conditioner by increasing its capacity, manufacturers state they must reduce the compressor capacity in order to maintain the capacity of the system. (This assumes the compressor capacity is reduced in a manner which does not affect the efficiency gain resulting from the increased coil size.) Since the smaller compressor has a lower refrigerant charge limitation, the reliability of the compressor could be sacrificed due to the increased possibility that excess refrigerant could be used by the system.

Manufacturers also assert that each successive row in a coil is only about 70% as effective as the preceding row. The addition of a tube row to a coil already containing three to four rows would probably have small effect on the overall efficiency of the system.

To assist in the proper evaluation of this design option, the detailed engineering data provided by manufacturers included information on how many additional tube rows could be accommodated by each coil without having to enlarge the unit's cabinet. It was assumed that the manufacturers' responses accounted for any impacts on compressor reliability.

Increase Fin Density

Increased fin density is still another method for increasing the amount of heat-transfer surface area. Although increasing the fin density improves heat transfer, manufacturers state that its effect on fan power, water drainage, and dirt build-up place a limit on how much the density can be increased.

Fin density has a direct effect on the fan power required to draw or blow air over the coil. Increasing the fin density increases the air-side pressure drop over the coil, resulting in more power being used by the fan motor. This reduction in air passage also has the effect of negating some of the improvement in heat transfer that results from increasing the fin density. Increased fin density also causes increased water retention. The condensate that forms on the evaporator and which is slung onto the condenser is not able to drain off as easily. This increases the air-side pressure drop, which results in the effects mentioned above (increased fan power and reduced heat-transfer performance). The build-up of dirt is accelerated by an increase in fin density. Smaller air passageways through the coils will be more likely to retain dirt. Over the course of a unit's life, performance could actually decrease if the amount of dirt retained is too great.

Obviously, optimizing fin density must take into account all of its resultant effects so as not to put an overall burden on the system. In order to place practical limits on fin density increases, manufacturers suggested fin density maximums for a variety of coils. These fin density maximums are a function of the type of coil (i.e., evaporator, condenser), the fin type (i.e., wavy, louvered, enhanced), the number of tube rows, and the tube diameter. It must be noted these maximums are derived from manufacturers' judgement and not from actual tests.

Add Subcooler to Condenser Coil

Typical subcoolers are added between the condenser outlet and the capillary tube inlet and are submerged near the condenser in the condensate produced by the evaporator. The effect of adding a subcooler is to increase the size of the condenser coil as it further cools the refrigerant coming out of the condenser. Because it is relatively difficult to incorporate a subcooler into a room air conditioner, most manufacturers will try to improve the effectiveness of the condenser in other ways before attempting to add one.

Consideration of a subcooler as a design option is directly related to how much space is available in the room air conditioner chassis for its incorporation. If little space is available, the chassis would have to be enlarged to create the necessary room. The cost of adding a subcooler would be significant if enlargement of the chassis were required.

Manufacturers provided the necessary information for evaluating a subcooler as a design option. For the representative baseline units chosen for each class, specifications were given on how large a subcooler could be to be incorporated into the existing baseline design. In addition, manufacturers provided test data detailing the effect on capacity, power consumption, and efficiency due to the addition of a subcooler (6) (7) (8) (9). Table 1.3 provides manufacturer test results on the performance improvements due to adding a subcooler. For each product class, the percent change in efficiency was used to establish the efficiency gain due to adding a subcooler. For those classes where more than one unit was tested, the average efficiency improvement was used to establish the efficiency gain. Since test data were not provided for classes with reverse cycle, subcooler efficiency improvements were based upon the results from the cooling-only class with same relative capacity size.

Table 1.3 Manufacturer Test Results: Performance Improvements due to Subcoolers

	Before subcooler added		**Percent change with subcooler added**		
Product Class	**Capacity** *(Btu/hr)*	**EER** *(Btu/W-hr)*	**Capacity**	**Power**	**EER**
Louvered side w/o reverse cycle less than 6000 Btu/hr	6338	9.19	1.0%	-2.0%	2.9%
Louvered side w/o reverse cycle 6000 to 7999 Btu/hr	7461	8.50	1.7%	-1.3%	3.0%
Louvered side w/o reverse cycle 8000 to 13999 Btu/hr	9984	9.20	-0.8%	-1.1%	1.0%
	11,668	9.00	0.8%	-0.9%	1.8%
Average Change for Product Class:			0.0%	-1.0%	1.4%
Louvered side w/o reverse cycle 14000 to 19999 Btu/hr	18,351	9.70	2.0%	0.0%	2.1%
	18,984	9.70	1.5%	-0.2%	1.6%
	17,954	9.71	1.1%	-0.3%	1.4%
Average Change for Product Class:			1.5%	-0.2%	1.7%
Louvered side w/o reverse cycle greater than 20000 Btu/hr	24,31]9	8.00	0.9%	-1.0%	1.9%
	34,947	8.00	0.3%	-0.6%	1.0%
Average Change for Product Class:			0.6%	-0.8%	1.5%
No Louvered side w/o reverse cycle 6000 to 7999 Btu/hr	6204	8.91	0.5%	-1.3%	1.8%
No Louvered side w/o reverse cycle 8000 to 13999 Btu/hr	11,300	8.51	0.2%	-2.6%	2.8%

Improve Fin Design

Enhancements to the fin design have the effect of improving the coil's air-side heat-transfer coefficient. This has the effect of improving the overall heat-transfer capability of the coil. This improvement is due in part to the increase in air turbulence over the coil caused by the enhanced fin design. Many manufacturers are using some form of fin enhancement in their coil designs. This fin improvement can be achieved by using a corrugated or wavy fin pattern or a louvered or lanced fin pattern.

Each manufacturer has developed a unique fin design to achieve the desired heat-transfer improvement. Since fin designs are unique for each manufacturer, it is difficult to quantify, in general, the absolute effects of a particular fin enhancement. Research has been performed in an attempt to develop correlations for the improvement to the air-side heat-transfer coefficient due to a few fin designs (10) (11) (12). Coils used in this research were of the type found in central air conditioners. Because of this, the limitations on the fin enhancement correlations are usually exceeded when they are applied to room air conditioners. This necessitated a reliance on manufacturer data to make estimates of what type of enhancement value or factor should be used. Instead of serving as the primary source for estimating fin enhancements, the correlations were used as a check to determine if enhancement factors derived from manufacturer data were reasonable.

The value used for the fin enhancement factor adjusts the air-side heat-transfer coefficient of the coil. A value of one represents a coil with flat fins and no adjustment is made to the heat-transfer coefficient. Any value greater than one indicates that some enhancement was made to the fins. For example, if the value of the enhancement factor was two, the air-side heat-transfer coefficient would be doubled.

Improve Tube Design

Improvement of the refrigerant-side heat-transfer coefficient is accomplished by augmenting the smooth inside surface of the refrigerant tubes with spiral grooves. This refrigerant tubing is commonly referred to as rifled or grooved tubing. Results from laboratory research indicate that the refrigerant-side heat-transfer coefficient for grooved tubing is significantly greater than that for conventional smooth tubing.

As with fin enhancements, manufacturers of refrigerant tubing have developed various types of grooved tubing to improve the heat-transfer capability of air conditioning coils. Improvement to the refrigerant-side heat-transfer coefficient is a function of the width, height, and spacing of the grooves as well as the concentration of lubricant oil being circulated within the refrigerant. Statistical equations have been developed to predict what type of enhancement can be expected for both evaporator and condenser coils (13). These equations are in terms of heat transfer and pressure drop enhancement factors and are simple functions of system average oil concentrations and the refrigerant mass flux. The following statistical equations for evaporation are for 300-SUS oil and provide for the following cases; 1) performance comparison of refrigerant-oil mixtures to pure refrigerant in smooth tubes (s'/s), 2) performance comparison of refrigerant-oil mixtures to pure refrigerant in augmented tubes (a′/a), and 3) augmented tube performance to smooth tube performance with pure refrigerant (a/s).

$$EF_{s'/s} = 1.03 \cdot e^{\omega_o \cdot (4.98 \cdot G' - 8.77)} \qquad \textbf{(1.1)}$$

$$EF_{a'/a} = 1.04 \cdot e^{\omega_o \cdot (89.2 \cdot \omega_o + 2.87 \cdot G' - 13.5)} \qquad \textbf{(1.2)}$$

$$EF_{a/s} = 1.9 \cdot \left(\frac{G}{257{,}000}\right)^{-0.32} \qquad \textbf{(1.3)}$$

$$PF_{s'/s} = 1.03 \cdot e^{5.59 \cdot \omega_o} \qquad \textbf{(1.4)}$$

$$PF_{a'/a} = 1.05 \cdot e^{4.58 \cdot \omega_o} \qquad \textbf{(1.5)}$$

$$PF_{a/s} = 1.4 \qquad \textbf{(1.6)}$$

The following statistical equations for condensation are also for 300-SUS oil and provide for the same performance comparisons as were given for evaporation.

$$EF_{s'/s} = e^{-3.2 \cdot \omega_o} \qquad \textbf{(1.7)}$$

$$EF_{a'/a} = e^{-4.0 \cdot \omega_o} \qquad \textbf{(1.8)}$$

$$EF_{a/s} = 1.9 \cdot \left(\frac{G}{147{,}000}\right)^{-0.21} \qquad \textbf{(1.9)}$$

$$PF_{s'/s} = 1.0 \qquad \textbf{(1.10)}$$

$$PF_{a'/a} = 1.02 \cdot e^{4.38 \cdot \omega_o} \qquad \textbf{(1.11)}$$

$$PF_{a/s} = 1.7 \qquad \textbf{(1.12)}$$

where EF = heat transfer enhancement factor
PF = pressure drop enhancement factor
a = augmented (rifled) tube with pure refrigerant
a' = augmented (rifled) tube with refrigerant-oil mixture
s = smooth tube with pure refrigerant
s' = smooth tube with refrigerant-oil mixture
G = mass flux (based on actual flow area)
G′ = normalized mass flux using 221000 lb/hr·ft^2
ω_o = mass fraction of oil

The above equations do not provide for the case of augmented tube performance with refrigerant-oil mixtures to smooth tube performance with similar mixtures (a′/s′). But the above equations can be combined to estimate the combined effects of oil and augmentation. The following equations for the heat transfer and pressure drop enhancement factors demonstrate how the above equations can be used to derive for the case of augmented tube performance with refrigerant-oil mixtures to smooth tube performance with similar mixtures.

$$EF_{a'/s'} = \frac{EF_{a/s} \cdot EF_{a'/a}}{EF_{s'/s}}. \qquad \textbf{(1.13)}$$

Room air conditioner manufacturers provided data estimating the heat transfer enhancement factors due to grooved tubing. But according to the values predicted by the above statistical equations, the manufacturer data significantly over-estimates the benefits of grooved tubing. In addition, the manufacturer data did not provide estimates for enhancements to the pressure drop. Because the data provided by manufacturers were both suspect and incomplete, the heat transfer and pressure drop enhancement factors were estimated with the above statistical equations. The enhancement factors combining the effects of oil and augmentation were used assuming an oil concentration of 1.5%. Typical oil concentrations are between 1.0% and 2.0% (14).

$$PF_{a'/s'} = \frac{PF_{a/s} \cdot PF_{a'/a}}{PF_{s'/s}} \qquad \textbf{(1.14)}$$

The values used for the tube enhancement factors adjust the refrigerant-side heat-transfer coefficient and pressure drop of the coil. A value of one represents a coil with smooth tubes where no adjustments are made to the refrigerant-side heat-transfer coefficient and pressure drop. Any value greater than one indicates that some enhancement was made to the tubes. For example, if the value of the enhancement factor for heat transfer was two, the refrigerant-side heat-transfer coefficient would be doubled.

Spray Condensate onto Condenser Coil

The condensate that forms on and drips off of the evaporator coil is collected in a condensate pan. The pan is located near the condenser and is placed directly underneath the condenser fan. The condenser fan is equipped with a slinger ring. The slinger ring is located at the fan blade tips and is able to collect and spray small amounts of condensate onto the condenser coil as the fan rotates. Spraying condensate onto the condenser improves the air-side heat-transfer coefficient of the coil. Spraying condensate onto the condenser coil is such common practice that most, if not all, room air conditioners already incorporate it into their designs.

For the engineering data supplied by manufacturers, all units were found to spray condensate onto their condenser coils. Therefore, condensate spray was not analyzed as a design option to improve room air conditioner efficiency. All representative baseline units included condensate spray in their design. The effect of condensate spray on room air conditioner performance was based upon research to determine the effect that water spray had on heat exchanger performance (15).

Improve Fan and Fan Motor Efficiency

The air delivery system of a room air conditioner consists of one motor driving two fans, the evaporator, and condenser fans. The evaporator fan is usually a blower wheel (centrifugal forward curved fan), the exception being units with capacity less than 6000 Btu/hr where propeller type fans are typically used. The condenser fan is a propeller type fan with a slinger ring attached to it. As mentioned earlier, the slinger ring sprays condensate onto the condenser coil. Quantifying the efficiency improvements to the room air conditioner's air delivery system was restricted to analyzing the efficiency improvements to the fan motor only.

Manufacturers state that their fans come from primarily one fan manufacturer leading to standardization of these air system components. Because of this, it is extremely difficult for room air conditioner manufacturers to implement any individual design improvements to raise the efficiency of their fans. Standardization might serve to explain why data provided by fan manufacturers does not clearly indicate if fan performance can be improved. The fan data was provided in graphical form with brake horsepower as a function of air delivered in cubic feet per minute. Upon inspection of the graphs, it was not apparent if significant reductions in brake horsepower could be accomplished by switching to different fan types. Thus, improving fan efficiency was not analyzed as a design option to improve room air conditioner efficiency.

Air system efficiency can also be improved by reducing the restrictions to air flow. Without making modifications to the heat exchangers, manufacturers state that air flow improvements can only by accomplished by creating more space within the cabinet. This necessitates enlarging the chassis size which, as stated earlier, is costly. In the analysis of increasing the frontal coil area, increases in system efficiency were assumed to be a result not only of the enlarged coil, but also the improvement in air flow due to the larger cabinet. Therefore, improvements in air flow are already inherently considered in the analysis of increased frontal coil areas.

Room air conditioner manufacturers maintain that only small improvements in current fan motor technology are possible. Most room air conditioner manufacturers have gone from low-efficiency shaded pole motors to higher efficiency permanent split capacitor (PSC) motors. Manufacturers claim that 98% of room air conditioner models already use PSC motors. PSC motors range in efficiency from 50% to 70% with larger motors being more efficient.

The next significant jump in efficiency is accomplished by using electronically commutated motors (ECM), otherwise known as brushless permanent magnet motors (BPM). Depending on motor size, ECMs range in efficiency from 70% to 80%. Because ECMs weigh approximately twice that of a standard PSC motor, structural changes to the room air conditioner chassis may be required to accommodate the increased weight. Although ECMs currently are not available with double-ended shafts as controls block one end of the motor, there is no apparent reason why the controls cannot be moved to another location on the motor. This would allow for a double-ended shaft to be incorporated into the motor allowing for their use in room air conditioner applications where one motor drives two fans.

Both shaded pole and PSC motors are produced in large quantities, making them relatively inexpensive for room air conditioner manufacturers to purchase. Although ECMs are being produced by most motor manufacturers, they are still more expensive to produce than PSC motors. In addition, their production volumes are presently very low resulting in costs to the manufacturer that are now 2.5 to 5 times more than that of standard PSC motors.

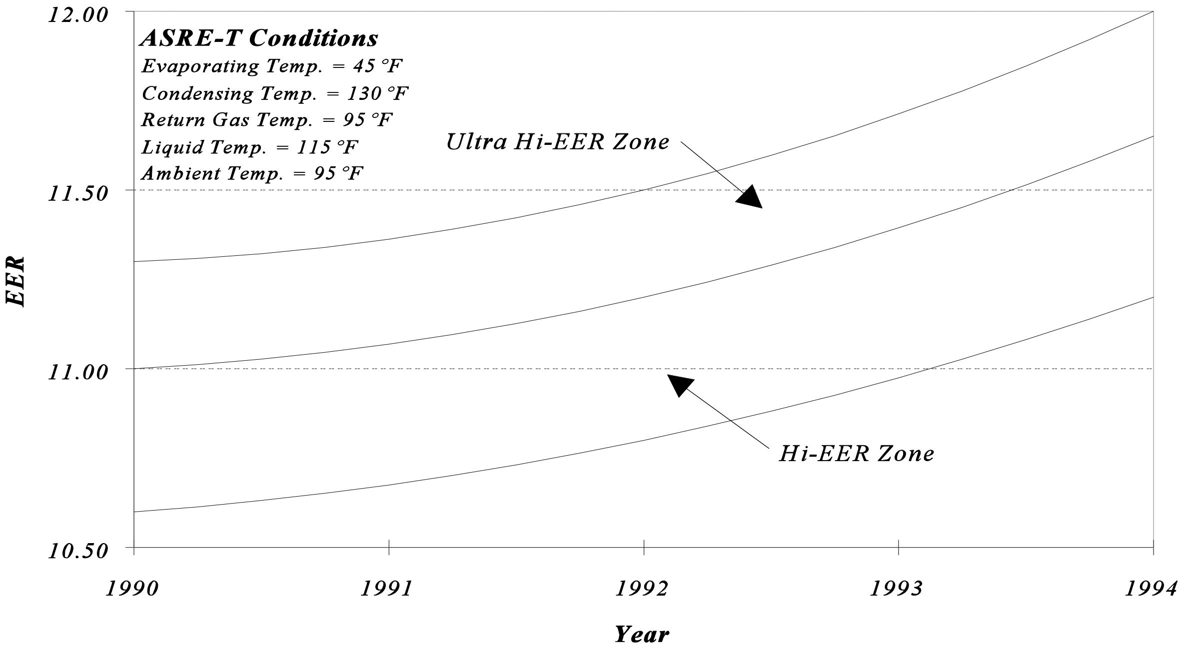


Figure 1.2 Sanyo Rotary Compressor Development Plans in 1990

Improve Compressor Efficiency

Most room air conditioner manufacturers incorporate rotary compressors into their units. Although current maximum rotary compressor efficiencies range from 10.7 to 11.1 EER, at least one compressor manufacturer planned to develop very efficient rotary compressors. Figure 1.2 is from a rotary compressor manufacturer's technical manual demonstrating its plans in 1990 to develop a 12.0 EER (ultra hi-EER) compressor by the year 1994 (16). These development plans were canceled due to the difficulty of developing materials for a more efficient compressor motor. Although most rotary compressor manufacturers anticipate developments that will be able to yield compressor efficiencies of 11.1 to 11.3 EER, they state that this will require the development of high-efficiency motors, use of higher-grade materials in the rotary compressor mechanism, and new compressor productions methods and equipment. Thus, only rotary compressors currently on the market were considered as options for improving room air conditioner efficiency.

The "inertia" compressor is a new technology that allows reciprocating compressors to approach efficiencies of 12.0 EER (17). The compressor's high efficiency is primarily due to the use of responsive light-weight valves and cooler refrigerant gas entering the cylinders because of an innovative approach to refrigerant gas management. The suction gas, which enters the compressor, is directed over the motor end turns and away from the head of the compressor. This prevents the gas from picking up an additional 20°F to 25°F superheat, reducing efficiency losses by up to 4%. Once the gas is in the cylinder, the more responsive valve action results in higher cylinder volumetric efficiencies. Current "inertia" compressors range in efficiency from 11.2 to 11.8 EER and are available for air conditioning systems with capacities exceeding 18000 Btu/hr. Thus, this new type of reciprocating compressor was analyzed for the two largest capacity classes of room air conditioners. Although "inertia" compressors are very efficient, they are significantly heavier, larger, and noisier than the rotary compressors that are currently used in room air conditioner applications. Manufacturers claim that larger chassis sizes would be required to accommodate the increased weight and size of the "inertia" compressor. As a result, in addition to the cost of the compressor and accompanying sound blanket, application costs for enlarging and bracing the chassis must also be taken into account. Thus, when "inertia" compressors were analyzed as replacements for rotary compressors, an increase in chassis size was required for those situations where they were significantly heavier and larger than the rotary compressors they were intended to replace.

Scroll compressors are being produced in large quantities, making them accessible to the air conditioning industry. Scroll compressors, which are an old technology, until relatively recently have been difficult to manufacture because of the high precision required to produce its internal components. Advances in manufacturing processes have allowed for the production of operational scroll compressors. As with "inertia" compressors, scroll compressors are currently produced in capacity sizes which make them available only to the two largest capacity classes of room air conditioners. But one scroll compressor manufacturer has been cited by room air conditioner manufacturers as having announced plans to develop a new, smaller scroll design optimized in the 14000 to 24000 Btu/hr capacity range. But because it is uncertain whether this new design would be available by the time new energy efficiency levels would be implemented for room air conditioners, this smaller capacity scroll compressor was not analyzed as an option to improve room air conditioner efficiency. Only scroll compressors currently on the market were considered in the analysis.

Variable Speed Compressors

Variable speed compressors were developed as a way to better match the load in a room or building. Rather than having only on-off control, modulating the cooling capacity can better match the required load. There are many advantages to variable speed control including quieter operation at low speeds, enhanced comfort by eliminating large fluctuations in room temperature, and improved seasonal energy efficiency.

The control of variable speed compressors is accomplished through the use of electronic adjustable speed drives (ASD) at the motor. Because electronic ASDs are compact and do not have to be mechanically coupled to the motor, they can be easily retrofitted to fractional size horsepower motors that are typical of many home appliances, including room air conditioners. Inverter-based ASDs are the most common systems for induction motors while converter-based ASDs are used for brushless permanent magnet brushless motors. There are two inverter types that are applicable to room air conditioner compressor (induction) motors: voltage source (VSI) and pulse width modulated voltage source (PWM) inverters. In either inverter case, the input ac power supply is first converted to dc by using a solid-state rectifier. The dc signal is than taken by the inverter to supply a variable-frequency, variable-voltage ac waveform to the motor. The waveform is released in short steps or pulses of power. The speed of the motor will then change in proportion to the frequency.

ASDs have been demonstrated to perform well with both rotary and scroll compressors. The heat pump market in Japan is now dominated by split systems equipped with variable speed rotary compressors. The most common motor used in this application is an induction motor. But the HVAC industry is now showing a strong interest in brushless permanent magnet motors due to their high efficiency. Though variable speed technology has yet to be employed by room air conditioners, there seem to be no technological barriers to their implementation.

As discussed earlier, design options that primarily improve efficiency on a seasonal basis will not demonstrate any efficiency improvement according to the steady-state conditions of the DOE test procedure. The greatest benefit of variable speed systems is to save energy on a seasonal basis. Because tests have not been performed to determine the amount of cycling in room air conditioners, it is not clear if seasonal energy savings are available in room air units. Research has demonstrated that energy savings from 15% to 40% are attainable in central systems using variable speed compressors (18) (19) (20). Because room air units do demonstrate some cycling effects, a conservative energy savings estimate of 10% will be applied to room air conditioners that incorporate variable speed compressors.

Alternative Refrigerants

The refrigerant that is used in all room air conditioners is HCFC-22. But because HCFC-22 is a hydrochlorofluorocarbon (HCFC) and demonstrates ozone depletion potential (ODP) the Environmental Protection Agency (EPA) has banned its production and use by January 1, 2020 (21). In addition, HCFC-22 exhibits global warming potential (GWP). As a result, a great deal of research is being performed to find a replacement for it. Both ozone depletion and global warming are world-wide concerns and any serious discussion of alternative refrigerants must take these issues into consideration.

In considering energy-efficient replacement refrigerants, the research has concerned itself with both the direct and indirect effects on global warming due to replacement refrigerants. The direct contribution of HCFCs to the GWP could be reduced by simply replacing it with a refrigerant with a lower GWP. However, if the replacement refrigerant is less energy-efficient, the indirect contribution to global warming will be increased due to the end-use efficiency change and the associated increased CO_2 emissions. Thus, a lower efficiency replacement refrigerant could actually increase the contributions to global warming even though its direct GWP is lower than that of the refrigerant it is replacing (22).

In addition to ODP, GWP, and energy efficiency, replacement refrigerants must contend with an array of criteria including non-toxicity, non-flammability, and chemical stability and inertness. Research has yet to identify any pure fluid that can be considered a suitable substitute for HCFC-22. Thus, a great deal of attention is being focused on finding binary or ternary replacement mixtures. Because of the concern expressed by the central air conditioner and heat pump industry over the phase-out of HCFC-22, the Air Conditioning and Refrigeration Institute initiated the Alternative Refrigerant Evaluation Program (AREP). AREP has identified several HCFC-22 alternatives. Two of the more promising replacements include a low-glide ternary blend consisting of HFC-32, HFC-125, and HFC-134a refrigerants and an azeotrope consisting of HFC-32 and HFC-125 refrigerants. A summary of what is presently known about these two potential substitutes follows.

The ternary blend of HFC-32/HFC-125/HFC-134a that has been formulated for use in air conditioning equipment has a composition of 23/25/52% by weight. It is currently being produced by DuPont Fluorochemicals, Allied-Signal, and ICI under the trade names of Suva 9000, Genetron 407C, and KLEA-407C, respectively. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has given a numerical assignment of R-407C to this ternary blend. This blend has a moderate temperature glide (8-10°F) and can be used as a near drop-in replacement for HCFC-22. Drop-in tests have been conducted at DuPont where the only alteration made from the original equipment was that the mineral oil lubricant in the compressor was changed to a polyol ester to ensure refrigerant/lubricant miscibility with the HFC mixture. Equipment testing of two central heat pump systems have demonstrated cooling efficiency decreases ranging from 3 to 6% as compared with HCFC-22. In the heating mode, efficiency decreases range from 5 to 6%. Testing of one window-type room air conditioner demonstrated a 3% decrease in efficiency as compared with HCFC-22. With the use of computer simulation modeling, DuPont has demonstrated that "soft-optimization" of the equipment can yield performance improvements. Through the use of liquid line/suction line heat exchange (LSHX) and counterflow air-to-refrigerant heat exchangers, efficiency increases of 1.6 to 7.5% have been shown over systems charged with HCFC-22 (23). Compressor calorimeter and system drop-in tests conducted under AREP indicate similar results (24). Allied-Signal has also conducted drop-in tests with the ternary blend demonstrating similar results to those demonstrated by DuPont. In addition, Allied-Signal also performed equipment tests on a "soft-optimized" 2.5-ton split system air conditioner. Counter to DuPont's computer simulation results, equipment testing indicates that "soft-optimized" systems do not yield efficiencies matching that of HCFC-22-charged systems. Although liquid line/suction line heat exchange was demonstrated to provide an efficiency improvement of 4% over a non-optimized system, the system efficiency was still 3 to 5% less than that of HCFC-22. With regard to counterflow heat exchangers, a near-counterflow evaporator was demonstrated to be ineffective at improving system efficiency (25).

The R-32/R-125 azeotrope (in a 50/50 wt% composition) is being provided by Allied-Signal and DuPont under the trade names of AZ-20 and Suva 9100, respectively. ASHRAE has given a numerical assignment of R-410A to this azeotrope. Until recently, DuPont had produced an R-32/R-125 azeotrope (R-410B) in a different composition (45/55 wt%) than R-410A. But partially due to laboratory tests indicating that residential air conditioning and heat pump equipment perform better when charged with R-410A than with R-410B, DuPont purchased licensing rights from Allied Signal to manufacture AZ-20 and halted production of R-410B. Although R-410A has been demonstrated to yield higher efficiencies and capacities in near drop-in tests, they significantly increase system refrigerant pressures affecting the stress level of the various components within the unit. Depending on the acceptability of the increased stress of a particular component, designs may have to be altered. In near drop-in tests conducted at Allied-Signal with R-410A, where a smaller capacity compressor and a modified expansion valve were used to match HCFC-22 capacity, cooling efficiencies in a 2.5-ton split system air conditioner were approximately 2% lower than with HCFC-22. The decrease in efficiency was attributable to the lower capacity compressor that was used in the tests. This compressor was 3 to 4% less efficient than the larger compressor it was replacing. In "soft-optimized" equipment, where both the evaporator and condenser were re-circuited, efficiency gains of 5% were demonstrated as compared to HCFC-22 (26). "Soft-optimized" testing conducted under AREP also demonstrated higher cooling efficiencies as efficiencies exceeded those in HCFC-22-charged equipment by 1 to 6% (27).

Although two of the more promising alternatives demonstrate some disadvantages as compared to R-22, the Department expects that the performance characteristics of these refrigerant blends will improve as more experience is gained with their use in different formulations.

Electronic Expansion Valves

The capillary tube is the flow control device that is currently used by all room air conditioners. The capillary tube is a pressure-reducing device that consists of a small diameter line that connects the outlet of the condenser to the inlet of the evaporator. It is designed to provide optimum energy characteristics at one design point. If sized properly, the capillary tube compensates automatically for load and system variations and gives acceptable performance over a wide range of operating conditions. The thermostatic expansion valve (TXV) is another type of flow control device and is commonly used in central air-conditioning systems. It regulates the flow of liquid refrigerant entering the evaporator in response to the superheat of the refrigerant leaving it. TXVs can adapt better to changes in operating conditions such as those due to the variation in ambient temperatures, which effect the condensing temperature. As a result, TXVs can improve the seasonal energy efficiency of air-conditioning equipment.

Electronic expansion valves are similar to TXVs but, since they can be controlled by either digital or electronic circuits, they give the additional flexibility to consider control schemes that are impossible for conventional TXVs. As with TXVs, electronic valves can use the superheat control method to regulate refrigerant flow. Other methods, such as controlling compressor discharge temperature, can also be used. Research has demonstrated that when incorporated into air-conditioning systems using inverter-driven variable speed compressors, electronic expansion valves improve seasonal energy efficiency beyond that of systems using conventional TXVs.

As with variable speed compressors, the main benefit of electronic expansion valves is to improve efficiency on a seasonal basis. In addition, no room air conditioner prototypes have been developed using either conventional TXVs or electronic expansion valves. Due to these reasons, expansion valves were not analyzed as design options for room air conditioners.

Thermostatic Cyclic Controls

Remote thermostatic cyclic controls more accurately monitor room temperature than the current built-in thermostats. Research work has been investigating the use of a fuzzy logic controllers for HVAC applications. These controller types have been shown to improve the performance of HVAC systems over that of conventional controllers. Though a remote thermostat, whether it be a conventional or fuzzy type, may offer comfort improvements, efficiency gains would most likely require that it be coupled with an improved air flow discharge and distribution system so as to better mix the room air. Whether or not an improved air-distribution system were required, thermostatic controls would only yield efficiency gains on a seasonal basis.

As with variable speed compressors and expansion valves, the DOE test procedure can only measure energy efficiency improvements based on steady-state conditions. In addition, no data were found or presented that indicated how the performance of room air conditioners could be enhanced with thermostatic cyclic controls. Due to these reasons, thermostatic cyclic controls were not analyzed as a design option for room air conditioners.

1.4 ENERGY USE DATA

Data from room air conditioner manufacturers and AHAM were used to determine representative baseline models for nine of the fourteen room air conditioner product classes. According to 1993 room air conditioner domestic shipments data provided by AHAM, over 95% of the units shipped were from the five classes with louvered sides and without reverse cycle (Table 1.4). As stated in the previous section regarding design options, manufacturers and AHAM provided detailed engineering data on actual room air conditioner models for nine of the fourteen product classes. Data were not provided for casement-type units. In addition, data were not available for three of the five classes without louvered sides and without reverse cycle. For the nine classes where data were available, a representative baseline unit was chosen from the pool of units that were provided. Two criteria were used to choose a representative baseline unit; capacity and EER. The capacity of the unit had to be typical of a majority of the models listed in the AHAM directory of room air conditioners and the EER had to be close to the minimum allowed under NAECA effective in 1990. Figures 1.3 through 1.11 show the distribution of models by efficiency for the nine classes where baseline units were selected (28). As evidenced by the figures, most models are manufactured with EERs either at or close to the NAECA minimum. The NAECA minimum EER is provided with each figure.

Table 1.4 1993 Room Air Conditioner Domestic Shipments

Product Class	Percent of Total Shipments
Without Reverse Cycle and with Louvers	
Less than 6000 Btu/hr	28.0%
6000 to 7999 Btu/hr	15.1%
8000 to 13999 Btu/hr	34.4%
14000 to 19999 Btu/hr	13.7%
Over 20000 Btu/hr	6.6%
Without Reverse Cycle and without Louvers	NA
With Reverse Cycle and with Louvers	2.2%
With Reverse Cycle and without Louvers	NA

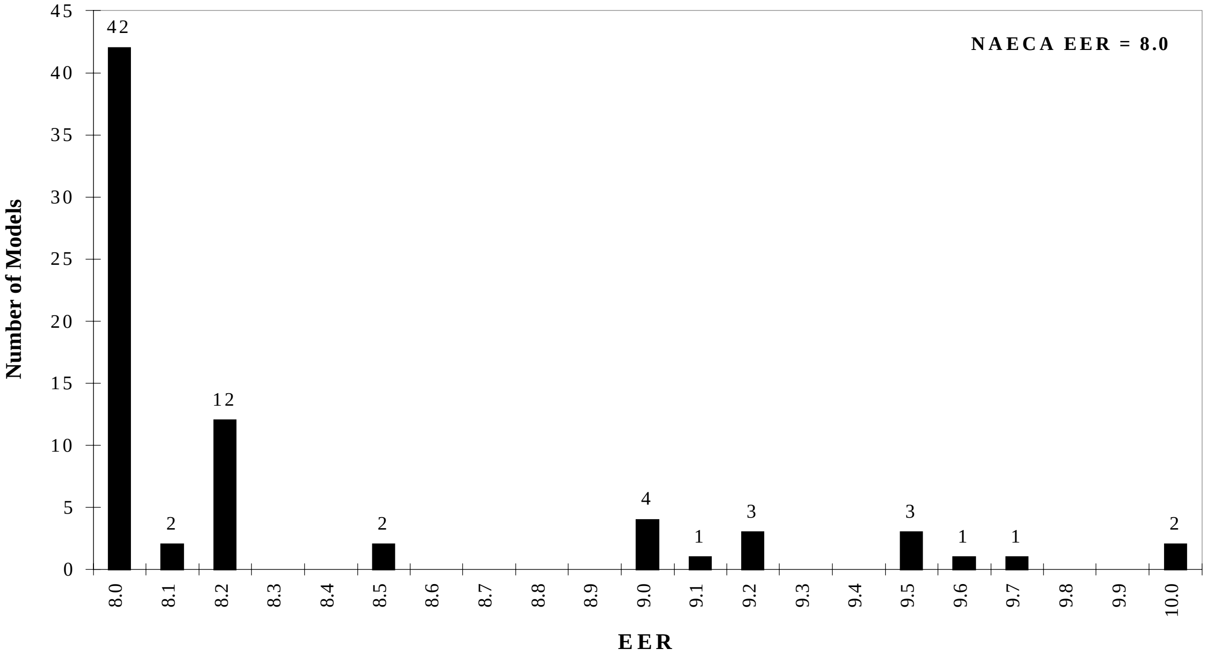


Figure 1.3 Distribution of Models by EER: Without Reverse Cycle and With Louv. Sides, Less than 6000 Btu/hr

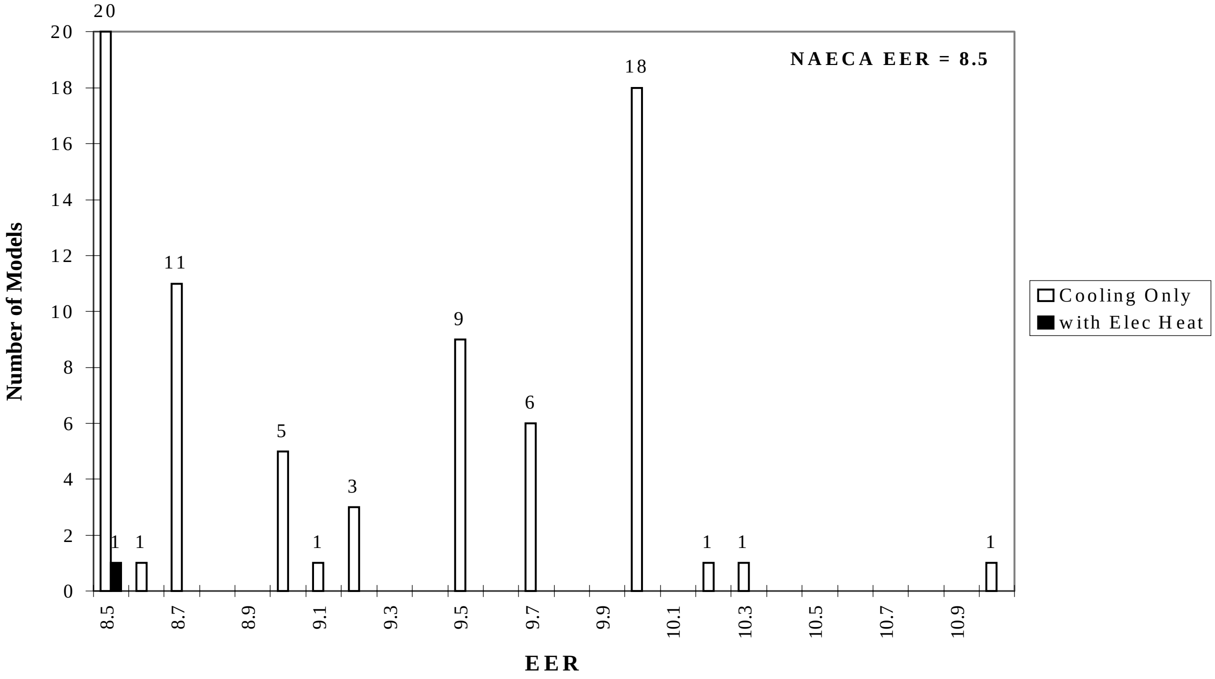


Figure 1.4 Distribution of Models by EER: Without Reverse Cycle and With Louv. Sides, 6000 to 7999 Btu/hr

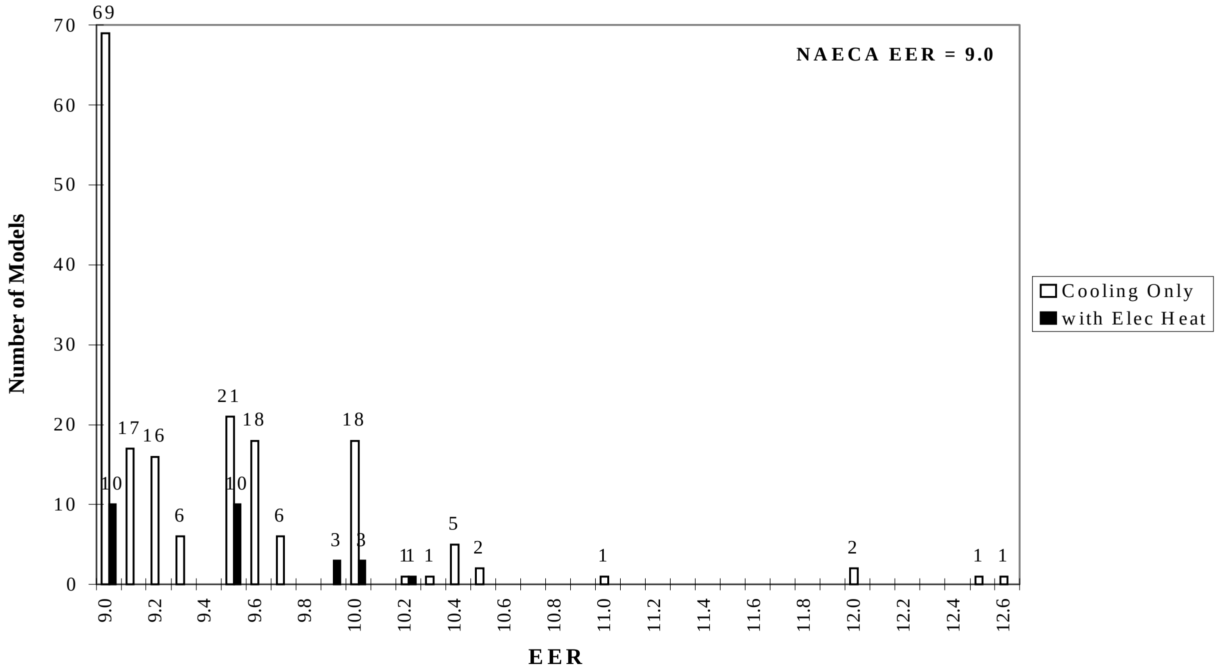


Figure 1.5 Distribution of Models by EER: Without Reverse Cycle and With Louv. Sides, 8000 to 13999 Btu/hr

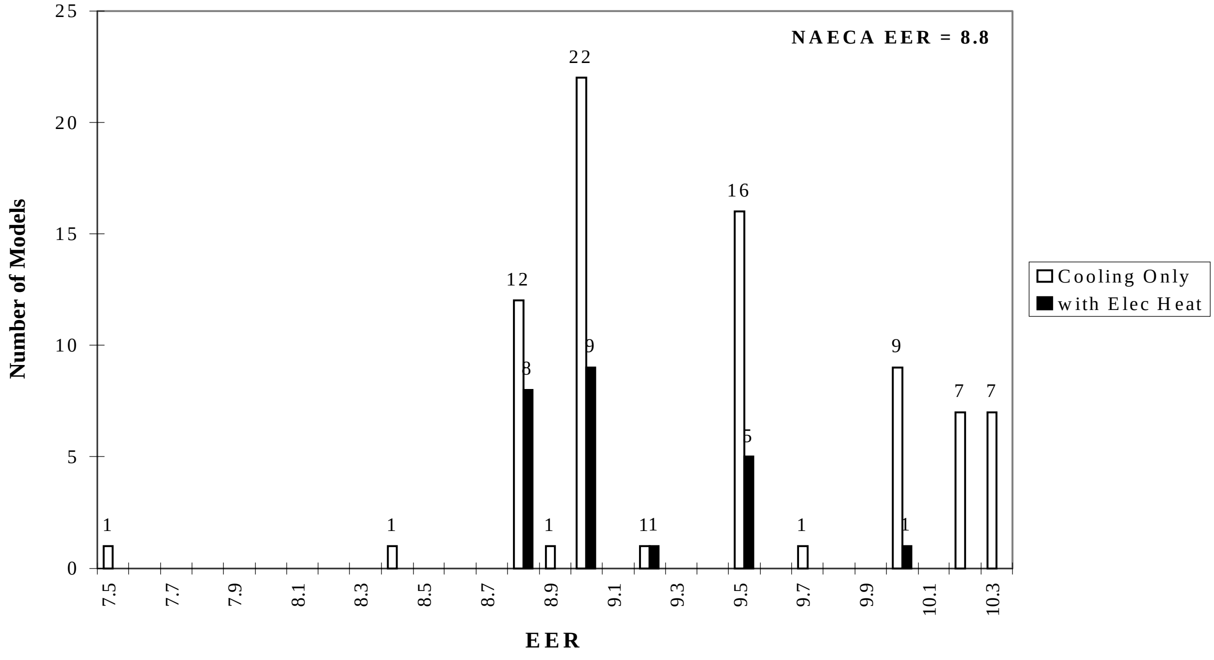


Figure 1.6 Distribution of Models by EER: Without Reverse Cycle and With Louv. Sides, 14000 to 19999 Btu/hr

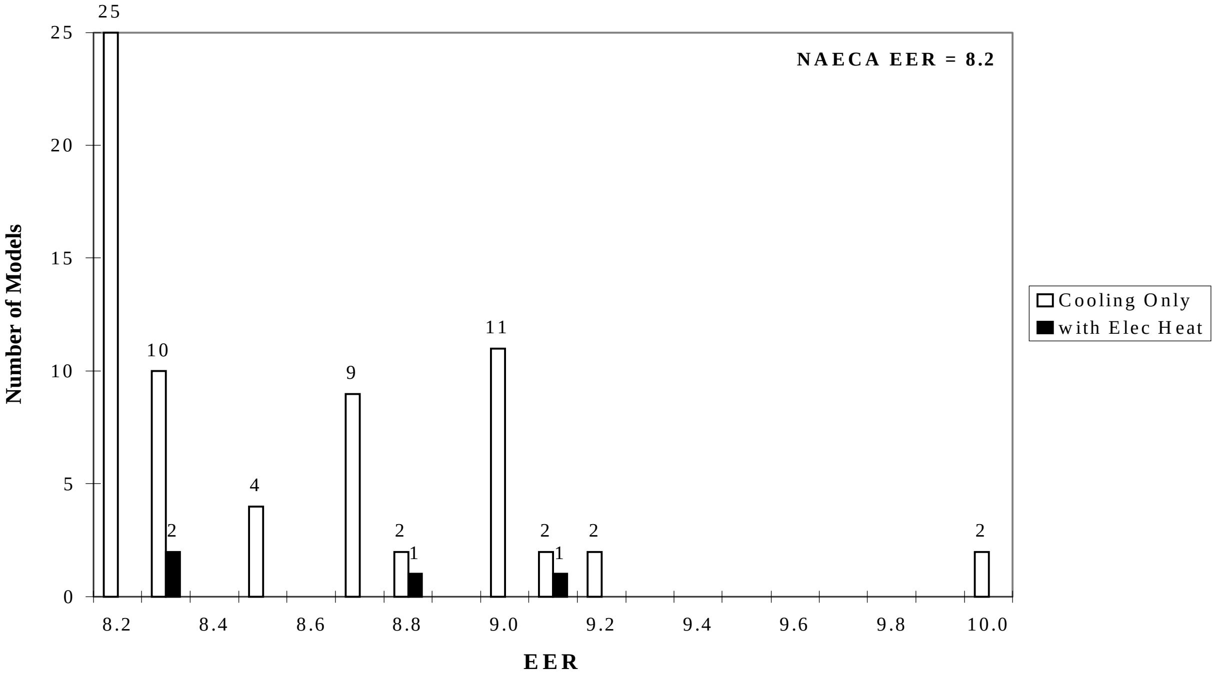


Figure 1.7 Distribution of Models by EER: Without Reverse Cycle and With Louv. Sides, 20000 Btu/hr and over

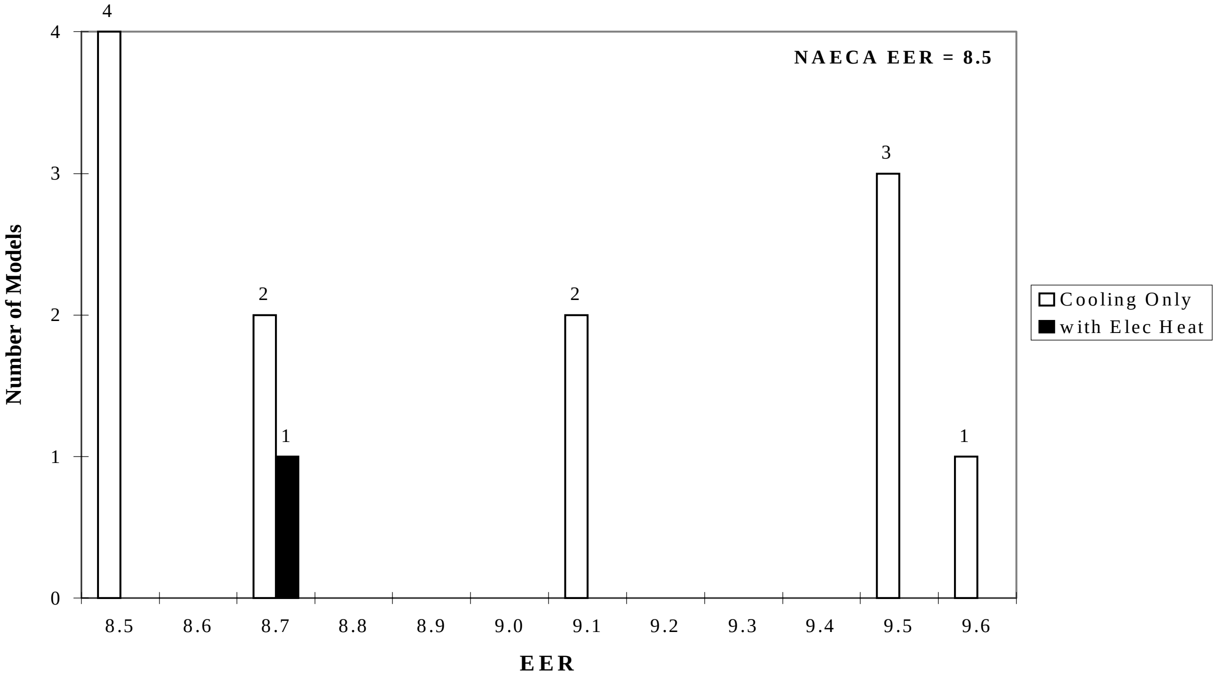


Figure 1.8 Distribution of Models by EER: Without Reverse Cyc. and Without Louv. Sides, 6000 to 7999 Btu/hr

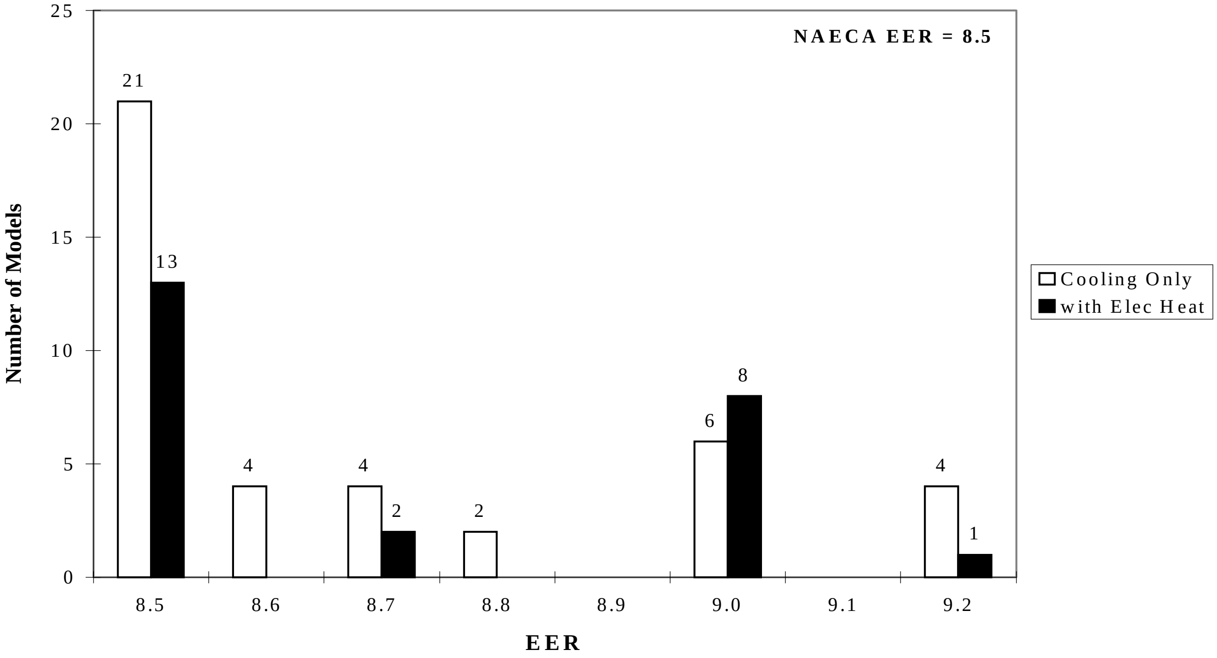


Figure 1.9 Distribution of Models by EER: Without Rev. Cyc. and Without Louv. Sides, 8000 to 13999 Btu/hr

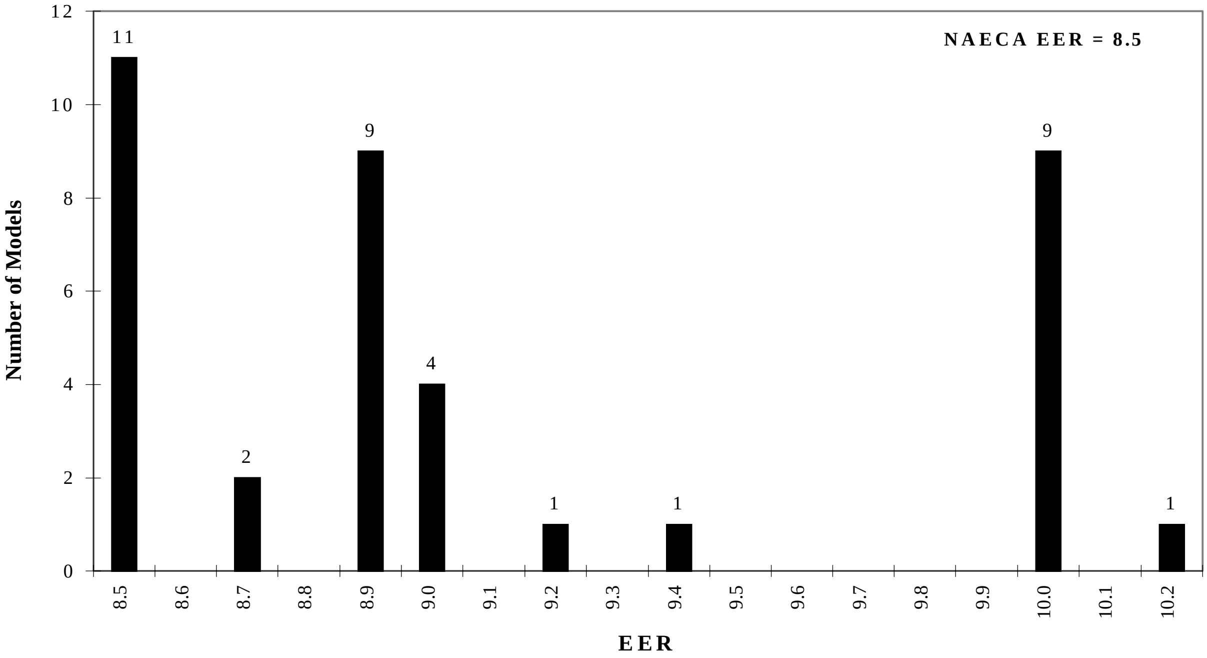


Figure 1.10 Distribution of Models by EER: With Reverse Cycle and With Louvered Sides

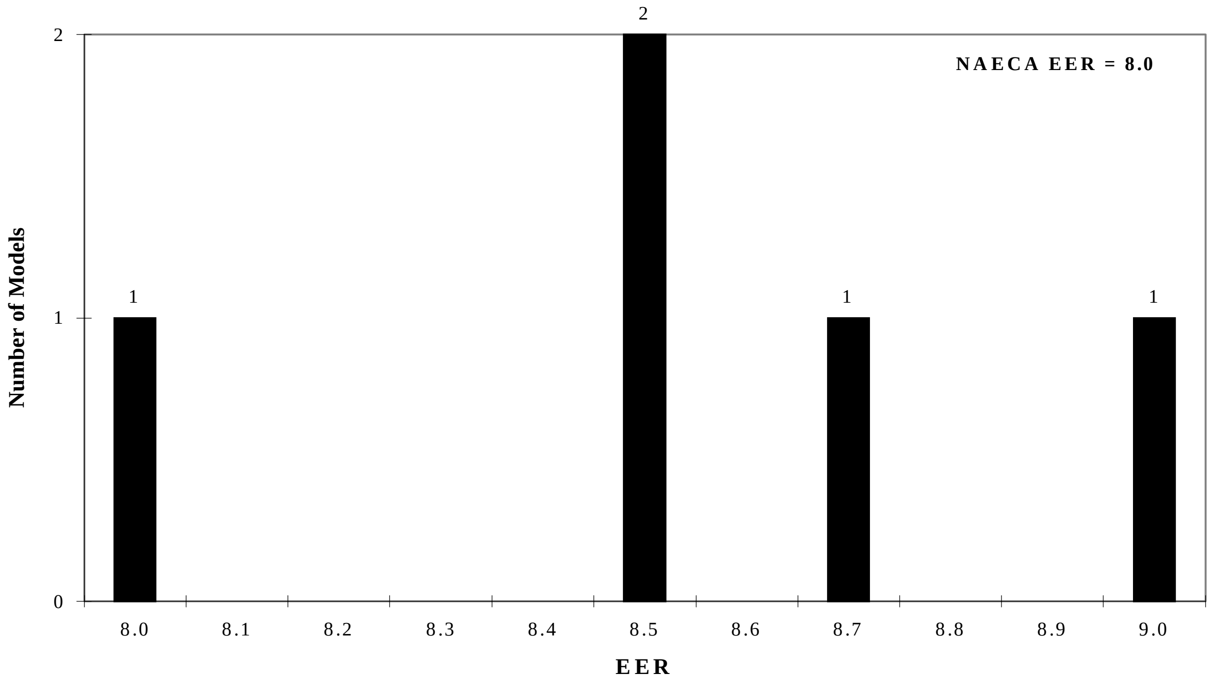


Figure 1.11 Distribution of Models by EER: With Reverse Cycle and Without Louvered Sides

Figure 1.12 shows the distribution of models by efficiency for the two casement-type product classes. As discussed previously, because detailed engineering data were not available, an engineering analysis was not performed for casement-type units.

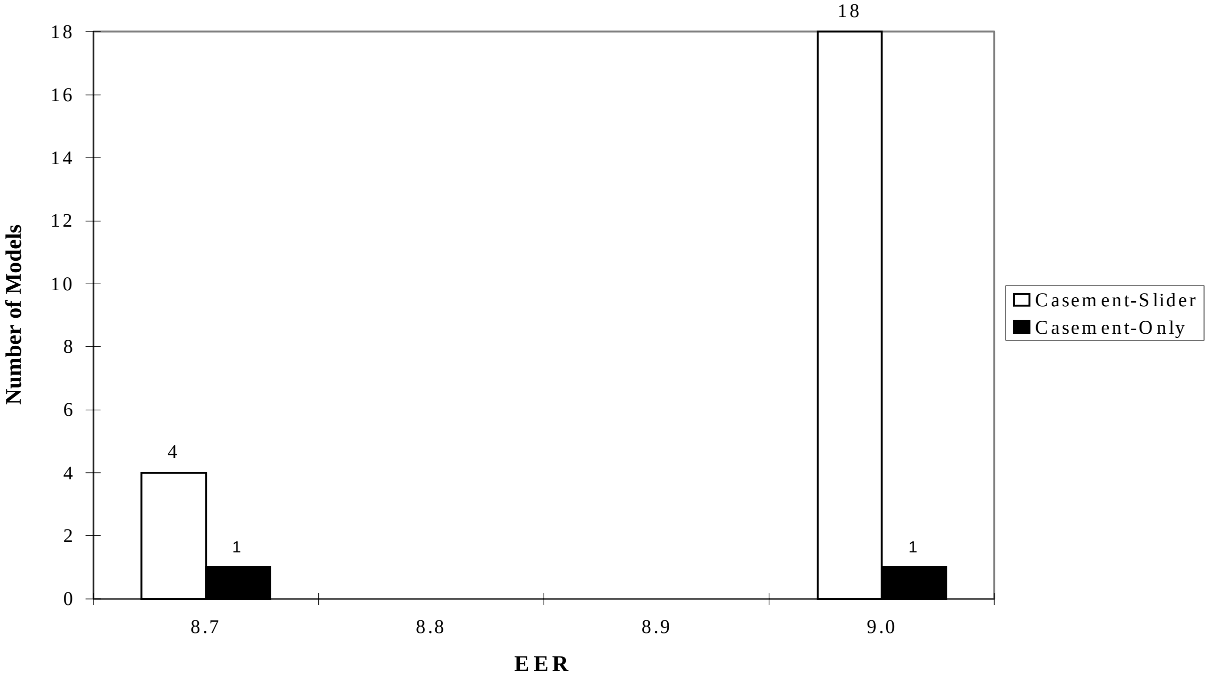


Figure 1.12 Distribution of Models by EER: Casement-Slider and Casement-Only Units

Table 1.5 summarizes some of the important data for the representative baseline units chosen for the nine room air conditioner product classes where engineering data were made available. In addition to the data shown in Table 1.5, detailed geometric and refrigeration system information is needed to perform energy-use simulations. These detailed data were provided by room air conditioner manufacturers and AHAM and were used to carry out simulations for each of the nine product classes. Both rated and measured EERs and capacities are provided in Table 1.5. The rated quantities are those that would be listed in "official" directories and are typical of most models that are produced. The measured quantities represent the EER and capacity of a specific model that has been tested under DOE test conditions. Calibration of the simulation model was based on the measured, rather than the rated quantities. The first section of Appendix A (herein) provides a detailed description of the input data for each of the baseline units that were modeled.

It should be noted that for classes without louvered sides and/or with reverse cycle, the representative baseline units selected have efficiencies which significantly exceed the NAECA minimums. This was due to the limited selection of baseline units provided by manufacturers for these classes. Of the pool of units made available which also had sufficient test data to perform calibrations, all had efficiencies exceeding the NAECA minimums.

Table 1.5 Baseline Room Air Conditioner Characteristics

	EER		Capacity		Evaporator Coil			Condenser Coil			Compressor			Capillary Tube		
Product Class	Rated[1]	Measured[2]	Rated[1] *Btu/hr*	Measured[2] *Btu/hr*	Area *sq.ft.*	Fin Design	Tube Design	Area *sq.ft.*	Fin Design	Tube Design	Displc. *cu.in*	EER	Capacity *Btu/hr*	No.	I.D. *in.*	Length *in.*
With Louvered Sides and Without Reverse Cycle																
Less than 6000	8.2	8.2	5950	5850	0.87	Corr[3]	Smooth	1.68	Corr[3]	Smooth	0.579	10.8	6670	1	0.049	41.5
6000 to 7999	8.5	8.45	7550	7480	0.87	Corr[3]	Smooth	1.68	Corr[3]	Smooth	0.697	10.9	8100	1	0.054	45
8000 to 13999	9.0	9.3	12000	12155	1.06	Enhanc	Smooth	1.81	Enhanc	Smooth	1.12	10.3	12780	2	0.049	33
14000 to 19999	9.0	9.0	17900	17965	1.56	Louver	Grooved	2.54	Louver	Smooth	1.54	10.0	17540	1	0.075	38
Over 20000	8.2	8.22	24200	24283	2.04	Louver	Grooved	2.86	Louver	Grooved	2.18	10.61	29400	1	0.09	40
Without Louvered Sides and Without Reverse Cycle																
6000 to 7999	8.8	8.85	6300	6353	1.03	Louver	Grooved	1.35	Louver	Grooved	0.579	10.45	6670	1	0.054	45
8000 to 13999	8.7	8.80	10700	10812	1.03	Louver	Grooved	1.35	Louver	Grooved	1.00	10.9	11350	1	0.064	40
With Reverse Cycle																
Louvers	8.9	8.92	12400	12565	1.38	Louver	Grooved	2.08	Louver	Groove	1.12	10.39	12780	1	0.064	40
No Louver	8.7	8.72	11300	11360	1.26	Louver	Grooved	1.77	Wavy	Grooved	0.99	11.09	11700	1	0.059	30

[1] Rated: “official” values as reported in AHAM directory

[2] Measured: actual values for unit as tested according to DOE test procedure

[3] Corr: corrugated fin pattern

Simulation Model

Simulations were carried out using a modified version of the Oak Ridge Heat Pump Design Model, Mark III version (29) (30). The Oak Ridge Model is a comprehensive program for the simulation of an electrically driven, air-source heat pump. It is a steady-state model that is able to calculate the EER of the equipment being modeled at specified ambient conditions. In the performance evaluation of room air conditioners, the conditions were specified according to those listed in the DOE test procedure. The Mark III version of the Oak Ridge Model is divided into two main parts; the high side and the low side. The high side includes models for the compressor, the condenser, and the expansion device, while the low side contains the evaporator. The model first performs a high-side balance based on calculating a mass flow rate through the flow control device that matches the one determined for the compressor. Once a high-side balance is achieved, a low-side balance is performed in which the evaporator model seeks an air inlet temperature that ensures the previous balance at the high side. This model is insensitive to the amount of refrigerant in the system. Modifications were made to the simulation model in order to simulate the performance of room air conditioners (31). These modifications included the following: addition of routines to model subcoolers and condensate spray, elimination of the reversing valve model, modification of the capillary tube model, and addition of adjustment factors to model grooved tubing.

AHAM reviewed the modified Oak Ridge Model and asserted that additional changes were necessary (32). AHAM requested the following changes: 1) modification of the compressor subroutine to model rotary compressors and better simulate reciprocating compressors, 2) correction of the condensate spray subroutine to better predict its effect on system performance, 3) addition of correction factors to account for indoor/outdoor air leakage, short-circuiting of indoor air, and heat leakage through the divider wall, 4) addition of multiplication factors to modify coil heat-transfer coefficients as a result of using enhanced fin surfaces, 5) addition of correction factors to modify such values as the compressor power and refrigerant mass flow rate in order to assist in calibrating the model to test data, and 6) addition of a psychometric heat-balance routine to check that the results from the simulation model are thermodynamically consistent. All of these changes, with the exception of adding a psychometric heat-balance routine, were made to the simulation model. A psychometric routine was found to be unnecessary as the simulation model was determined to be thermodynamically consistent. Modifications were made to the simulation model to ensure that the condensate spray's effect on exiting condenser air temperature was accounted for. The condensate spray routine itself remained unchanged from the original version. Instead, a condensate spray correction factor was added to the simulation model giving the user the option of adjusting the spray's effect on the condenser's air-side heat-transfer coefficient. Although efforts were made to develop an accurate routine to quantify the effects due to condensate spray, having an accurate method was not crucial since all baseline models already incorporated condensate spray in their designs.

Upon review of input data files and simulation results produced in support of DOE's proposed rulemaking for room air conditioners, AHAM stated that the following modeling errors were made (33): 1) combined fan/fan motor efficiencies were incorrectly used as input to the simulation model to describe the air delivery system, 2) simulated efficiency increases resulting from the addition of subcoolers were over-estimated, and 3) the amount of superheat was incorrectly specified. With regard to the air delivery system, AHAM recommended that the fan motor power be used directly as an input to the simulation model. It claims that the use of a combined fan/fan motor efficiency yields over-estimated values for the overall room air conditioner efficiency. Since the two methods of describing the air delivery system do yield different overall efficiency results, it was determined that the scheme used to model the fan motor did not fully account for the motor's heat loss. Corrections were made to account for the full motor heat loss. This yielded simulation results similar to those estimated by AHAM. With regard to the modeling of subcoolers, as mentioned previously, test data provided by manufacturers were used to calibrate the simulated efficiency improvements. This was accomplished by adjusting the temperature of the condensate pool, which the subcooler is immersed in, until the simulated efficiency increase matched that specified by the test data. With regard to superheat, AHAM claims that it was incorrectly specified from manufacturer test data as being the difference between the accumulator inlet and the mid-evaporator temperatures. But this method for specifiying the superheat was done in accordance with recommendations previously made by AHAM. These recommendations included making modifications to the simulation model in order to account for the presence of an accumulator. The modifications were based on treating the inlet to the accumulator as the inlet to the compressor shell (for rotary compressors). In order to account for superheating occuring within the accumulator, the simulation model was modified to include provisions to account for the temperature and pressure increases that occur within the accumulator. The location on the suction line where the temperature was measured was at the accumulator inlet (i.e., the suction line outlet). In the simulation model, superheat is defined as the difference between the compressor shell inlet's refrigerant and saturation temperatures; therefore, knowing that the suction line temperature was measured at the accumulator inlet provided confidence in using it to specify the superheat. Because the test data did not provide the accumulator inlet's saturation temperature, the mid-evaporator temperature was used as a close approximation of the evaporator saturation temperature, which is also a close approximation for the compressor shell inlet saturation temperature. Therefore, the Department believes it appropriate to use the difference between the mid-evaporator and accumulator inlet temperatures to specify the superheat. Since in the simulation model the superheat is defined as the difference between the compressor shell inlet's refrigerant and saturation temepratures, knowing that the suction line temperature was actually measured at the accumulator inlet, and not just somewhere on the suction line, provided confidence in using it to specify the superheat. Because the test data did not provide the accumulator inlet's saturation temperature, the mid-evaporator temperature was used as a close approximation. Therefore, using the difference between the mid-evaporator and accumulator inlet temperatures was retained as the method for specifying the superheat.

Appendix A contains a more detailed description of the modified Oak Ridge Heat Pump simulation model. Included is a description of all the changes made to the simulation model and its accompanying input data requirements.

Calibration of Simulation Model

Room air conditioner performance data taken at DOE test conditions were included with the engineering data that were provided by manufacturers and AHAM. These performance data allowed for the calibration of the simulation model to actual test data. As stated earlier in the discussion of product classes (Section 1.2), non-louvered sides and reversing valves negatively impact room air conditioner performance. Therefore, calibrations were conducted by applying power consumption penalties to the compressor for those units either without louvered sides or with a reversing valve. In performing calibrations for units without louvered sides, the simulation model applied a 4% power consumption penalty to the compressor (34). For those calibrations performed for units with a reversing valve, the simulation model applied a 5% power penalty (35). For units without louvered sides and with a reversing valve, a 9% power penalty (the sum of the individual power penalties) was used.

For each representative baseline unit chosen for each class, correction factors to adjust the calculated compressor power and refrigerant mass flow rate were used to match the predicted performance of the room air conditioner to that indicated by the test data. In addition to the above correction factors, the length and/or the diameter of the capillary tube and the compressor shell heat loss were also adjusted to calibrate the model. Although changes to any single input to the model can have repercussions throughout the refrigerant system, adjustments made to the capillary tube and shell heat loss rate were done primarily to alter specific system quantities. Capillary tube adjustments were made to change the amount of subcooling. Adjustments to the compressor shell heat loss rate were made to affect high-side refrigerant temperatures. Values for the percentage of condensate spray that actually reaches the condenser coil before evaporation (PERC) were assumed to be 95% for all representative baseline units. Correction factors for condensate spray effects were not used as simulated condenser air-side heat transfer coefficients were determined to be reasonable.

Calibrations were conducted on the basis of matching the following “primary” quantities: EER, capacity, and compressor power. Other quantities were also considered in the calibrations. These “secondary” quantities included the following: condensate spray rate, amount of subcooling, evaporator and condenser inlet, outlet, and mid-point (saturation) refrigerant temperatures, compressor inlet and outlet refrigerant temperatures, and capillary tube inlet refrigerant temperature. Although both “primary” and “secondary” quantities were considered, the main objective of the calibration was to achieve small differences between the measured and simulated results for only the “primary” quantities. Small differences for the “primary” quantities were considered to be less than 1% since correction factors to adjust the compressor power and refrigerant mass flow rate could be utilized to achieve accurate simulation results for the EER, capacity, and compressor power. Differences between measured and simulated results for the “secondary” quantities were allowed to be significantly larger than for the “primary” quantities. As a measure for what may be an acceptable difference for the “secondary” quantities, manufacturers’ compressor map data are usually stated to be accurate to ±5%. Thus, a 5% error should be the expected best agreement between measured and simulated results. Since 5% errors are the best one could expect, differences of up to 10% were still considered reasonable for the “secondary” quantities.

Table 1.6 presents a comparison between the manufacturers’ test data and the data predicted from the simulation model for the nine product classes where baseline models were selected. Included in the comparison is the percentage difference between the two sets of values.

Discussion of Calibration Results

With regard to all the refrigerant temperatures being analyzed in Table 1.6 (72 total temperatures at an average of 8 temperatures per unit), 14 of the simulated values (or 19%) have differences with the measured values that exceed ±10%. Of these 14 simulated values, four are high-side temperatures, which illustrates the point that high simulation errors are more likely to occur for low-side refrigerant temperatures than high-side temperatures. For example, a simulation error of 5°F for a 120°F condensing temperature yields a difference of 4.2% while the same simulation error for a 45°F evaporating temperature yields a difference of 11.1%. Thus, although simulation errors do occur when modeling refrigerant temperatures, large errors (those exceeding 10%) are more due to the absolute value of the temperatures to which the simulations are being compared. Although the model's capability to predict refrigerant temperatures might give some indication of how "good" it is at simulating room air conditioner performance, a better measure would be the model's capability to predict the temperature's effect on the entire system. To do this, test data would also need to provide refrigerant pressures as well as temperatures. With both refrigerant properties, the system's heat removal and heat rejection could be calculated. Comparison of the measured and predicted heat removal and heat rejection would obviously provide a better indication of the model's simulation capabilities. Since test data did not provide refrigerant pressures, the effect of any one single temperature point change on system performance could not be evaluated.

Another item to consider in comparing measured and predicted refrigerant temperatures is the issue of measurement errors in acquiring test data. The most accurate method of taking refrigerant temperatures would be to immerse sensors directly in the refrigerant flow. With this method, errors would be expected to be small. But if the sensor is attached to the copper tubing, then depending on how well the sensor is secured and insulated, measurement errors could be large. It is believed that the latter method of test measurement was used by manufacturers. In measuring temperatures in this manner, one would expect that measured high-side temperatures would be lower than those predicted by the model and that measured low-side temperatures would be higher. The ambient temperatures have the effect of lowering measured high-side temperatures and raising low-side temperatures. Of the temperature data being analyzed, 87% exhibit this behavior.

The bottom line in evaluating model performance is how accurately it predicts EER and capacity. The calculation of refrigerant temperatures is an intermediary step in determining the efficiency and capacity of the system. The model's capability to predict temperatures should not be viewed as its primary objective. After making all the necessary corrections and adjustments to the input files, both EER and capacity for all capacity classes were predicted to within 0.5% of values determined from test measurements.

As evidenced by the data presented in Table 1.6, for the representative baseline models selected for the nine product classes for which an engineering analysis was performed, compressor energy use ranged from a minimum of 82.4% to a maximum of 87.3% of the total room air conditioner energy consumption. The rest of the energy use went to drive the fans. These results indicate that the greatest energy conservation opportunity lies in reductions in compressor energy use. Compressor energy use can be reduced by using more efficient compressors or improving the heat-transfer performance of the evaporator and condenser coils. Of course, since fan motor energy use accounts for at least 12% of the total energy consumption, opportunities for conserving energy are also available by improving the efficiency of the air delivery system and the fan motor. In addition, improving the fan motor efficiency results in additional compressor energy savings as less heat needs to be removed by the system because less heat is being rejected by the fan motor.

Table 1.6 Room Air Conditioner Test Data vs. Simulation Model Data

		"Primary" and "Secondary" Quantities													
		EER	Capacity *Btu/hr*	Compressor Power *watts*	Spray Rate *lb_m/hr*	Subcooling *°F*	Suction Line Inlet *°F*	Compressor Shell Outlet *°F*	Condenser Inlet *°F*	Condenser Outlet *°F*	Capillary Tube *°F*	Evaporator Inlet *°F*	Evaporator Outlet *°F*	Evaporating *°F*	Condensing *°F*
Louvered Sides	Test	8.20	5850	585	2.00	27.0	57.0	172.0	NA	95.0	95.0	NA	40.3	41.0	122.0
Less than 6000 Btu/hr	Model	8.23	5852	586	2.06	27.4	54.7	180.7	175.6	104.3	100.8	40.5	54.7	38.8	132.1
	% Diff	0.4%	0.0%	0.2%	3.0%	1.5%	-4.0%	5.1%	NA	9.8%	6.1%	NA	35.7%	-5.4%	8.3%
Louvered Sides	Test	8.45	7480	753	2.30	25.0	48.0	175.0	NA	103.0	102.0	NA	43.5	44.6	127.0
6000 to 7999 Btu/hr	Model	8.46	7481	753	2.49	26.0	45.1	181.8	178.0	103.4	100.7	45.7	45.1	41.9	130.5
	% Diff	0.1%	0.0%	0.0%	8.3%	4.0%	-6.0%	3.9%	NA	0.4%	-1.3%	NA	3.7%	-6.1%	2.8%
Louvered Sides	Test	9.30	12155	1128	3.90	24.0	54.0	168.0	168.0	96.0	NA	47.0	48.0	45.0	120.0
8000 to 13999 Btu/hr	Model	9.32	12153	1128	4.04	22.3	44.5	180.1	177.8	105.5	103.9	41.2	44.5	35.5	127.8
	% Diff	0.2%	0.0%	0.0%	3.6%	-7.1%	-17.6%	7.2%	5.8%	9.9%	NA	-12.3%	-7.3%	-21.1%	6.5%
Louvered Sides	Test	9.00	17965	1698	5.50	21.4	58.4	182.5	181.2	102.0	102.0	49.3	48.4	48.8	123.4
14000 to 20000 Btu/hr	Model	9.00	17966	1699	5.25	22.8	55.9	184.2	182.4	106.8	105.7	47.8	55.9	46.5	130.2
	% Diff	0.0%	0.0%	0.1%	-4.5%	6.5%	-4.3%	0.9%	0.7%	4.7%	3.6%	-3.0%	15.5%	-4.7%	5.5%
Louvered Sides	Test	8.22	24283	2579	8.45	18.0	61.9	185.7	182.0	106.5	106.5	44.7	47.9	43.6	124.5
Over 20000 Btu/hr	Model	8.22	24290	2579	8.25	18.5	58.4	192.3	190.8	108.0	107.2	44.0	58.4	40.7	129.0
	% Diff	0.0%	0.0%	0.0%	-2.4%	2.8%	-5.7%	3.6%	4.8%	1.4%	0.7%	-1.6%	21.9%	-6.7%	3.6%
Non-Louvered Sides	Test	8.85	6353	615	1.47	15.7	57.9	171.9	NA	109.3	NA	50.1	49.0	48.6	125.0
6000 to 7999 Btu/hr	Model	8.86	6353	615	1.79	15.5	56.5	173.0	168.4	110.7	107.6	49.9	56.5	47.4	127.4
	% Diff	0.1%	0.0%	0.0%	21.8%	-1.3%	-2.4%	0.6%	NA	1.3%	NA	-0.4%	15.3%	-2.5%	1.9%
Non-Louvered Sides	Test	8.80	10812	1089	3.20	18.8	54.2	181.5	NA	112.0	NA	48.4	48.3	48.3	130.8
8000 to 13999 Btu/hr	Model	8.80	10811	1089	3.12	18.9	52.7	186.5	183.8	123.7	122.1	48.7	52.7	47.0	146.5
	% Diff	0.0%	0.0%	0.0%	-2.5%	0.5%	-2.8%	2.8%	NA	10.4%	NA	0.6%	9.1%	-2.7%	12.0%
Reverse Cycle with	Test	8.92	12565	1214	3.78	27.3	66.6	187.4	176.3	97.7	97.7	49.3	47.8	48.2	125.0
Louvered Sides	Model	8.92	12566	1214	3.65	27.7	62.8	192.2	189.7	103.4	101.7	46.0	62.8	44.6	131.2
	% Diff	0.0%	0.0%	0.0%	-3.4%	1.5%	-5.7%	2.6%	7.6%	5.8%	4.1%	-6.7%	31.4%	-7.5%	5.0%
Reverse Cycle without	Test	8.72	11360	1072	3.02	23.9	52.3	171.4	171.4	102.6	102.6	49.7	49.8	49.8	126.5
Louvered Sides	Model	8.72	11360	1073	3.63	23.3	46.8	176.5	174.1	115.2	113.6	47.9	46.8	44.3	138.7
	% Diff	0.0%	0.0%	0.1%	20.2%	-2.5%	-10.5%	3.0%	1.6%	12.3%	10.7%	-3.6%	-6.0%	-11.0%	9.6%

1.5 COST-EFFICIENCY DATA

In this section, manufacturer cost and energy efficiency data are presented for the nine product classes which were analyzed. The manufacturer cost is the cost to the manufacturer of producing products with the design options shown and does not include markups to wholesalers or retailers. The energy efficiency is expressed in EER, except for design options which incorporate variable speed compressors. Design options incorporating variable speed compressors are rated with SEER (seasonal EER) because they improve efficiency on a seasonal rather than a steady-state basis.

The results of the simulation analyses for the nine room air conditioner product classes are shown in Tables 1.10 to 1.18. For each design level, unit capacity, EER, annual hours of operation, and annual energy use are shown. Two values are presented for the annual energy use; one based on calculations found in the DOE test procedure and the other based on field data. Also included in the tables are total manufacturing costs.

In order to determine the annual energy use according to DOE test procedure calculations, the heat-removal capability of the unit is assumed to remain constant regardless of how a particular design option might effect its capacity. Thus, the unit will run a shorter number of hours if a particular design option increases its capacity. For each of the representative baseline units, the annual hours of operation is set to 750 hours. As stated previously, 750 hours is the accepted national average for the annual hours of operation of a room air conditioner. It comes from an analysis AHAM performed to establish its value (36). The annual heat removal of each representative unit is determined by multiplying the baseline capacity by 750 hours. For every design option that is analyzed, the annual hours of operation is determined by taking the calculated heat removal capability and dividing it by its new capacity. Since most design options increase the capacity of the unit, the annual hours of operation continuously decreases as each new design option is applied. The annual energy use is simply determined by multiplying the total power by the hours of operation.

Recent field data indicate that the annual energy use of room air conditioners is significantly lower than that determined with DOE test procedure calculations based on an annual hours of operation of 750. The field data are presented in Table 1.7 as the 1990 stock average annual energy use. These annual energy use data are presented by house type and are constructed from a variety of sources that include utility conditional demand estimates, national conditional demand estimates, survey results, and engineering estimates (37). Also included in Table 1.7 is the breakdown of the 1990 housing stock by house type (38) as well as the percentage of homes (by house type) that use room air conditioners (39). Weighting the 1990 stock average annual energy use in Table 1.7 by both the house type and the percentage of each house type using room air conditioners results in a 1990 stock-weighted average annual energy use of 762 kWh/year. This value of 762 kWh/yr corresponds to a 1990 stock average room air conditioner efficiency of 7.48 EER (40). For each vintage block range listed in Table 1.8, both the shipment-weighted EER (41) and the percentage share of the 1990 stock (42) are known. Weighting the shipment-weighted EERs by the percentage share of the 1990 housing stock results in the 1990 stock average efficiency of 7.48 EER.

Table 1.7 1990 Room Air Conditioner Stock Average Energy Use by House Type

Housing Type	**1990 Energy Use** *kWh/yr*	**1990 Housing Stock Breakdown**	**Housing Stock with Room A/C**
Single-Family	870	63.8%	27.1%
Multifamily	530	24.5%	30.6%
Mobile Homes	680	5.1%	30.6%
Stock-Weighted Average	762		

Table 1.8 1990 Room Air Conditioner Stock Average Efficiency

Vintage Block Range	**Shipment-Weighted EER** *Btu/Watt-hr*	**Share of 1990 Housing Stock**
pre 1971	5.82	6.9%
1971 to 1980	6.51	26.8%
1981 to 1985	7.43	30.5%
1986 to 1988	8.52	23.7%
1989 to 1990	8.64	12.7%
Stock Average	7.48	

The stock-weighted average annual energy use in Table 1.7 is now compared to the annual energy use as determined by DOE test procedure calculations based on 750 annual hours of operation. Table 1.9 presents for each of the nine product classes being analyzed the baseline efficiency and the corresponding “DOE test procedure” annual energy use. (The baseline efficiency and annual energy use data are taken from Tables 1.10 through 1.18.) For each class, the baseline efficiency and annual energy use are assumed to be representative of all units shipped in 1990. Also presented in Table 1.9 are 1990 room air conditioner shipment data provided by AHAM. The shipment-weighted efficiency and the corresponding “DOE test procedure” annual energy use are 8.74 EER and 930 kWh/year, respectively.

Table 1.9 Efficiency and "DOE Test Procedure" Energy Use of Room A/Cs Shipped in 1990

Product Class	1990 Baseline EER *Btu/Watt-hr*	"DOE test procedure" Energy Use *kWh/yr*	1990 Percent of Shipments
Without Reverse Cycle and With Louvers			
Less than 6,000 Btu/hr	8.23	533	27.1%
6,000 to 7,999 Btu/hr	8.46	664	17.1%
8000 to 13,999 Btu/hr	9.32	978	31.7%
14,000 to 19,999 Btu/hr	9.00	1497	12.0%
Over 20,000 Btu/hr	8.22	2215	5.8%
Without Rev. Cycle and Without Louvers			
6,000 to 7,999 Btu/hr	8.88	538	1.7%
8,000 to 13,999 Btu/hr	8.80	922	1.7%
With Reverse Cycle and With Louvers	8.92	1057	2.3%
With Reverse Cycle and Without Louvers	8.72	977	0.5%[1]
Shipment-Weighted Average	8.74	930	

[1] Shipment data not provided. Assumed to comprise 0.5% of shipments.

In order to make a direct comparison between the field-based stock-weighted annual energy use (762 kWh/yr) in Table 1.7 and the test procedure-based shipment-weighted annual energy use (930 kWh/yr) in Table 1.9 , the stock-weighted value is converted or "normalized" to a shipment-weighted value. Equation 1.15 presents the calculation for "normalizing" the field-based stock-weighted value.

$$EU_{field,ship} = EU_{field,stock} \cdot \left(\frac{EER_{stock}}{EER_{ship}}\right) = 762\ kWh/yr \cdot \left(\frac{7.48}{8.74}\right) = 652\ kWh/yr \tag{1.15}$$

where $EU_{field,ship}$ = field-based shipment-weighted annual energy use
$EU_{filed,stock}$ = field-based stock-weighted annual energy use
EER_{stock} = 1990 stock average efficiency
EER_{ship} = 1990 shipment-weighted efficiency

The field-based shipment-weighted annual energy use of 652 kWh/yr is approximately 71% of the test procedure-based value of 930 kWh/yr. This comparison implies that the annual hours of operation of room air conditioners have decreased by 71% from 750 hours to 533 hours. In order to derive the field-based annual energy use values in Tables 1.10 to 1.18, the "DOE test procedure" annual energy use values are multiplied by 71%.

Table 1.10 Cost-Efficiency Table for Room Air Conditioners Without Reverse Cycle and With Louvered Sides, less than 6000 Btu/hour

							DOE test procedure		Field
Level	Design	Design Options		Mfg Cost *1990$*	Capacity *Btu/hr*	EER *Btu/W-hr*	Energy Use *kWh/yr*	Hours	Energy Use *kWh/yr*
	0	Baseline	(1)	179.39	5852.1	8.23	533.1	750.0	378.5
	1	0 + Evap/Cond Enhanced Fins	(2)	180.17	6061.6	8.70	504.7	724.1	358.3
1	2	1 + PSC Fan Motor	(3)	183.17	6076.0	9.32	471.0	722.4	334.4
2	3	2 + Evap/Cond Grooved Tubes	(4)	186.01	6509.3	9.71	452.0	674.3	320.9
3	4	3 + Add Subcooler	(5)	189.76	6567.9	10.00	439.0	668.3	311.7
4	5	4 + Increase Evap/Cond Coil Area	(6)	216.90	6729.8	10.38	422.8	652.2	300.2
	6	5 + BPM Fan Motor	(7)	276.90	6731.3	10.57	415.3	652.0	294.9
5	7	6 + **Variable Speed Compressor	(8)	400.74	6731.3	11.74	373.8	652.0	265.4

** - Design options incorporating Variable Speed Compressors are rated with SEER

NOTES

Efficiency:

1 Baseline: Compressor is Matsushita 2R10S3R126A, 6.67 kBtu/hr, 10.76 EER; Smooth Refrigerant Tubes; Wavy Fins; Shaded Pole Fan Motor

2 Evaporator/Condenser Enhanced Fins: Replace wavy fins with enhanced fins; Evap air-side enhancement=2.18, Cond air-side enhancement=2.14

3 Permanent Split Capacitor Fan Motor: Replace 30% efficiency shaded pole motor with 50% efficiency PSC motor

4 Evaporator/Condenser Grooved Tubes: Replace smooth tubes with grooved tubes; Evaporator: refrg-side enhancement=2.27,pressure-drop multiplier=1.41; Condenser: refrg-side enhancement=1.95, pressure-drop multiplier=1.85

5 Subcooler: Add a subcooler; Length=65", DIA=3/8", Condensate temperature=90.80°F

6 Increased Evaporator/Condenser Coil Area: Evap Face Area increased from 0.87 to 1.13 sq.ft., Cond Face Area increased from 1.68 to 2.06 sq.ft.

7 Brushless Permanent Magnet Fan Motor: Replace 50% efficiency PSC motor with 70% efficiency BPM motor

8 Variable Speed Compressor: Replace single-speed compressor with variable-speed compressor

Table 1.11 Cost-Efficiency Table for Room Air Conditioners Without Reverse Cycle and With Louvered Sides, 6000 to 7999 Btu/hour

Level	Design	Design Options		Mfg Cost *1990$*	Capacity *Btu/hr*	EER *Btu/W-hr*	DOE test procedure		Field
							Energy Use *kWh/yr*	Hours	Energy Use *kWh/yr*
	0	Baseline	(1)	199.33	7481.2	8.46	663.5	750.0	471.1
	1	0 + Evap/Cond Enhanced Fins	(2)	200.41	7706.6	8.80	637.7	728.1	452.8
1	2	1 + PSC Fan Motor	(3)	203.41	7722.4	9.38	598.4	726.6	424.9
2	3	2 + Add Subcooler	(4)	207.16	7803.8	9.66	580.7	719.0	412.3
3	4	3 + Evap/Cond Grooved Tubes	(5)	211.42	8059.1	9.91	566.2	696.2	402.0
4	5	4 + Increase Evap/Cond Coil Area	(6)	240.50	8216.0	10.33	543.2	682.9	385.7
	6	5 + BPM Fan Motor	(7)	302.33	8218.5	10.50	534.2	682.7	379.3
5	7	6 + **Variable Speed Compressor	(8)	426.90	8218.5	11.67	480.8	682.7	341.4

** - Design options incorporating Variable Speed Compressors are rated with SEER

NOTES

Efficiency:

1 Baseline: Compressor is Tecumseh RK5480E (RK114AT), 8.10 kBtu/hr, 10.95 EER; Smooth Refrigerant Tubes; Wavy Fins; Shaded Pole Fan Motor

2 Evaporator/Condenser Enhanced Fins: Replace wavy fins with enhanced fins; Evap air-side enhancement=1.84, Cond air-side enhancement=1.86

3 Permanent Split Capacitor Fan Motor: Replace 30% efficiency shaded pole motor with 50% efficiency PSC motor

4 Subcooler: Add a subcooler to condenser; Length=65", DIA=3/8", Condensate temperature=86.30°F

5 Evaporator/Condenser Grooved Tubes: Replace smooth tubes with grooved tubes; Evaporator: refrg-side enhancement=2.08,pressure-drop multiplier=1.41; Condenser: refrg-side enhancement=1.85, pressure-drop multiplier=1.85

6 Increased Evaporator/Condenser Coil Area: Evap Face Area increased from 0.87 to 1.13 sq.ft., Cond Face Area increased from 1.68 to 2.16 sq.ft.

7 Brushless Permanent Magnet Fan Motor: Replace 50% efficiency PSC motor with 70% efficiency BPM motor

8 Variable Speed Compressor: Replace single-speed compressor with variable-speed compressor

Table 1.12 Cost-Efficiency Table for Room Air Conditioners Without Reverse Cycle and With Louvered Sides, 8000 to 13999 Btu/hour

							DOE test procedure		Field
Level	Design	Design Options		Mfg Cost *1990$*	Capacity *Btu/hr*	EER *Btu/W-hr*	Energy Use *kWh/yr*	Hours	Energy Use *kWh/yr*
	0	Baseline	(1)	256.51	12152.7	9.32	977.6	750.0	694.1
1	1	0 +Incr Compressor EER to 10.8	(2)	262.62	12439.5	9.71	938.7	732.7	666.4
2	2	1 + Add Subcooler	(3)	264.88	12512.4	9.85	925.6	728.4	657.2
3	3	2 + Evap/Cond Grooved Tubes	(4)	269.68	13049.1	10.11	901.4	698.5	640.0
4	4	3 + Increase Evap/Cond Coil Area	(5)	303.60	13477.4	10.97	831.0	676.3	590.0
	5	4 + BPM Fan Motor	(6)	368.18	13482.0	11.15	817.3	676.1	580.3
5	6	5 + **Variable Speed Compressor	(7)	499.03	13482.0	12.39	735.6	676.1	522.3

** - Design options incorporating Variable Speed Compressors are rated with SEER

NOTES

Efficiency:

1 Baseline: Compressor is Matsushita 2P19C3R126A, 12.78 kBtu/hr, 10.3 EER; Smooth Refrigerant Tubes; Enhanced Fins; PSC Fan Motor

2 Increased Compressor Efficiency: Replace Matsushita 2P19C3R126A, 12.78 kBtu/hr, 10.3 EER with Tecumseh RK5513E (RK157AT), 13.2 kBtu/hr, 10.82 EER

3 Subcooler: Add a subcooler to condenser; Length=34", DIA=5/16", Condensate temperature=91.30°F

4 Evaporator/Condenser Grooved Tubes: Replace smooth tubes with grooved tubes; Evaporator: refrg-side enhancement=2.16,pressure-drop multiplier=1.41; Condenser: refrg-side enhancement=1.67, pressure-drop multiplier=1.85

5 Increased Evaporator/Condenser Coil Area: Evap Face Area increased from 1.06 to 1.50 sq.ft., Cond Face Area increased from 1.72 to 2.38 sq.ft.

6 Brushless Permanent Magnet Fan Motor: Replace 67% efficiency PSC motor with 80% efficiency BPM motor

7 Variable Speed Compressor: Replace single-speed compressor with variable-speed compressor

Table 1.13 Cost-Efficiency Table for Room Air Conditioners Without Reverse Cycle and With Louvered Sides, 14000 to 19999 Btu/hour

						DOE test procedure		Field
Level	Design	Design Options	Mfg Cost *1990$*	Capacity *Btu/hr*	EER *Btu/W-hr*	Energy Use *kWh/yr*	Hours	Energy Use *kWh/yr*
	0	Baseline (1)	327.67	17966.2	9.00	1496.9	750.0	1062.8
1	1	0 + Incr Compressor EER to 10.8 (2)	339.18	18447.8	9.70	1389.9	730.4	986.8
2	2	1 + Condenser Grooved Tubes (3)	343.44	18688.7	9.98	1350.6	721.0	958.9
3,4	3	2 + Add Subcooler (4)	348.02	18759.1	10.15	1328.1	718.3	943.0
	4	3 + Increase Evap/Cond Coil Area (5)	444.94	19299.6	10.74	1254.4	698.2	890.6
	5	4 + Incr Compressor EER to 11.3 (6)	477.45	19523.2	11.09	1215.6	690.2	863.1
	6	5 + Incr Compressor EER to 11.4 (7)	492.44	19527.5	11.18	1205.8	690.0	856.1
	7	6 + BPM Fan Motor (8)	570.77	19548.5	11.50	1172.2	689.3	832.3
5	8	7 +**Variable Speed Compressor (9)	718.48	19548.5	12.77	1055.0	689.3	749.1

** - Design options incorporating Variable Speed Compressors are rated with SEER

NOTES

Efficiency:

1 Baseline: Compressor is Matsushita 2K25C3R236A, 17.54 kBtu/hr,10.0 EER; Grooved Evaporator Refrigerant Tubes, Enhanced Fins, PSC Fan Motor

2 Increased Compressor Efficiency: Replace Matsushita 2K25C3R236A, 17.54 kBtu/hr, 10.0 EER with Matsushita 2K25S3R236A, 18.05 kBtu/hr, 10.78 EER

3 Condenser Grooved Tubes: Replace smooth tubes with grooved tubes; Condenser: refrg-side enhancement=1.70, pressure-drop multiplier=1.85

4 Subcooler: Add a subcooler to condenser; Length=85", DIA=3/8", Condensate temperature=92.70°F

5 Increased Evaporator/Condenser Coil Area: Evap Face Area increased from 1.56 to 2.04 sq.ft., Cond Face Area increased from 2.54 to 2.86 sq.ft

6 Increased Compressor Efficiency: Replace Matsushita 2K25S3R236A, 18.05 kBtu/hr, 10.78 EER with Bristol H26B18, 18.30 kBtu/hr, 11.3 EER

7 Increased Compressor Efficiency: Replace Bristol H26B18, 18.30 kBtu/hr, 11.3 EER with Bristol H27B18, 18.00 kBtu/hr, 11.4 EER

8 Brushless Permanent Magnet Fan Motor: Replace 59% efficiency PSC motor with 79% efficiency BPM motor

9 Variable Speed Compressor: Replace single-speed compressor with variable-speed compressor

Table 1.14 Cost-Efficiency Table for Room Air Conditioners Without Reverse Cycle and With Louvered Sides, greater than 20000 Btu/hour

Level	Design	Design Options		Mfg Cost *1990$*	Capacity *Btu/hr*	EER *Btu/W-hr*	DOE test procedure Energy Use *kWh/yr*	DOE test procedure Hours	Field Energy Use *kWh/yr*
	0	Baseline	(1)	405.07	24289.7	8.22	2215.1	750.0	1572.7
1,2	1	0 + Incr Compressor EER to 10.9	(2)	411.00	24192.2	8.39	2172.6	753.0	1542.5
3	2	1 + Add Subcooler	(3)	415.58	24269.4	8.51	2141.4	750.6	1520.4
4	3	2 + Incr Compressor EER to 11.5	(4)	454.73	23752.3	8.88	2052.7	767.0	1457.4
	4	3 + Increase Evap/Cond Coil Area	(5)	512.88	24484.8	9.42	1933.3	744.0	1372.6
	5	4 + Incr Compressor EER to 11.7	(6)	532.86	24209.7	9.84	1851.7	752.5	1314.7
	6	5 + BPM Fan Motor	(7)	620.36	24226.5	10.03	1816.3	752.0	1289.6
5	7	6 +**Variable Speed Compressor	(8)	802.97	24226.5	11.14	1634.7	752.0	1160.6

** - Design options incorporating Variable Speed Compressors are rated with SEER

NOTES

Efficiency:

1 Baseline: Compressor is Matsushita 2J39C3R236B (1991 Model), 29.4 kBtu/hr,10.61 EER; Grooved Refrigerant Tubes; Enhanced Fins; PSC Fan Motor

2 Increased Compressor Efficiency: Replace Matsushita 2J39C3R236B (1991 Model), 29.4 kBtu/hr, 10.61 EER with Matsushita 2J39C3R236B (1994 Model), 29.4 kBtu/hr, 10.89 EER

3 Subcooler: Add a subcooler to condenser; Length=85", DIA=3/8", Condensate temperature=96.10°F

4 Increased Compressor Efficiency: Replace Matsushita 2J39C3R236B (1994 Model), 29.4 kBtu/hr, 10.89 EER with Bristol H26B28, 28.7 kBtu/hr, 11.5 EER

5 Increased Evaporator/Condenser Coil Area: Evap Face Area increased from 2.04 to 2.67 sq.ft., Cond Face Area increased from 2.86 to 3.22 sq.ft.

6 Increased Compressor Efficiency: Replace Bristol H26B28, 28.7 kBtu/hr, 11.5 EER with Bristol H27A28, 28.2 kBtu/hr, 11.7 EER

7 Brushless Permanent Magnet Fan Motor: Replace 66.8% efficiency PSC motor with 80% efficiency BPM motor

8 Variable Speed Compressor: Replace single-speed compressor with variable-speed compressor

Table 1.15 Cost-Efficiency Table for Room Air Conditioners Without Reverse Cycle and Without Louvered Sides, 6000 to 7999 Btu/hour

						DOE test procedure		Field
Level	Design	Design Options	Mfg Cost *1990$*	Capacity *Btu/hr*	EER *Btu/W-hr*	Energy Use *kWh/yr*	Hours	Energy Use *kWh/yr*
	0	Baseline (1)	185.52	6352.6	8.86	538.1	750.0	382.1
1,2	1	0 + Incr Compressor EER to 10.8 (2)	187.98	6366.8	9.10	523.9	748.3	372.0
3,4	2	1 + Add Subcooler (3)	189.74	6405.9	9.23	516.4	743.8	366.6
	3	2 + BPM Fan Motor (4)	251.57	6417.1	9.65	493.9	742.5	350.7
	4	3 +**Variable Speed Compressor (5)	375.41	6417.1	10.72	444.5	742.5	315.6
5	5	4 + **Incr Evap/Cond Coil Area (6)	404.49	6608.5	11.52	413.7	721.0	293.7

** - Design options incorporating Variable Speed Compressors are rated with SEER

NOTES

Efficiency:

1 Baseline: Compressor is Matsushita 2R10B3R126C, 6.67 kBtu/hr,10.45 EER; Grooved Refrigerant Tubes; Enhanced Fins; PSC Fan Motor

2 Increased Compressor Efficiency: Replace Matsushita 2R10B3R126C, 6.67 kBtu/hr, 10.45 EER with Matsushita 2R10S3R126A, 6.67 kBtu/hr, 10.76 EER

3 Subcooler: Add a subcooler to condenser; Length=20", DIA=5/16", Condensate temperature=99.00°F

4 Brushless Permanent Magnet Fan Motor: Replace 53.3% efficiency PSC motor with 73.3% efficiency BPM motor.

5 Variable Speed Compressor: Replace single-speed compressor with variable-speed compressor

6 Increased Evaporator/Condenser Coil Area: Evap Face Area increased from 1.03 to 1.34 sq.ft., Cond Face Area increased from 1.35 to 1.74 sq.ft.

Table 1.16 Cost-Efficiency Table for Room Air Conditioners Without Reverse Cycle and Without Louvered Sides, 8000 to 13999 Btu/hour

Level	Design	Design Options		Mfg Cost *1990$*	Capacity *Btu/hr*	EER *Btu/W-hr*	DOE test procedure		Field
							Energy Use *kWh/yr*	Hours	Energy Use *kWh/yr*
1	0	Baseline	(1)	240.09	10811.2	8.80	921.7	750.0	654.4
2	1	0 + Add Subcooler	(2)	241.93	10982.4	9.05	896.5	738.3	636.5
3,4	2	1 + Incr Compressor EER to 11.09	(3)	245.20	11412.1	9.12	889.6	710.5	631.6
	3	2 + BPM Fan Motor	(4)	309.78	11435.2	9.44	859.2	709.1	610.0
	4	3 + **Variable Speed Compressor	(5)	439.97	11435.2	10.49	773.3	709.1	549.0
5	5	4 + **Incr Evap/Cond Coil Area	(6)	473.89	11780.0	11.08	731.5	688.3	519.4

** - Design options incorporating Variable Speed Compressors are rated with SEER

NOTES

Efficiency:

1	Baseline: Compressor is Matsushita 2P17S3R236A, 11.35 kBtu/hr, 10.9 EER; Grooved Refrigerant Tubes; Enhanced Fins; PSC Fan Motor
2	Subcooler: Add a subcooler to condenser; Length=22.5", DIA=5/16", Condensate temperature=98.40°F
3	Increased Compressor Efficiency: Replace Matsushita 2P17S3R236A, 11.35 kBtu/hr, 10.9 EER with Tecumseh RK5512E (RK147ET), 11.70 kBtu/hr, 11.09 EER
4	Brushless Permanent Magnet Fan Motor: Replace 55.0% efficiency PSC motor with 75.0% efficiency BPM motor.
5	Variable Speed Compressor: Replace single-speed compressor with variable-speed compressor
6	Increased Evaporator/Condenser Coil Area: Evap Face Area increased from 1.03 to 1.34 sq.ft., Cond Face Area increased from 1.35 to 1.74 sq.ft.

Table 1.17 Cost-Efficiency Table for Room Air Conditioners With Reverse Cycle and With Louvered Sides

Level	Design	Design Options		Mfg Cost *1990$*	Capacity *Btu/hr*	EER *Btu/W-hr*	DOE test procedure Energy Use *kWh/yr*	DOE test procedure Hours	Field Energy Use *kWh/yr*
	0	Baseline	(1)	261.57	12566.1	8.92	1056.6	750.0	750.2
1,2	1	0 + Add Subcooler	(2)	263.83	12609.5	9.05	1041.3	747.4	739.3
3,4	2	1 + Incr Compressor EER to 10.8	(3)	268.88	12906.8	9.27	1016.3	730.2	721.6
	3	2 + Increase Evap/Cond Coil Area	(4)	302.80	13358.9	9.83	958.7	705.5	680.7
	4	3 + BPM Fan Motor	(5)	367.38	13366.2	10.05	938.2	705.1	666.1
5	5	4 + **Variable Speed Compressor	(6)	498.23	13366.2	11.16	844.4	705.1	599.5

** - Design options incorporating Variable Speed Compressors are rated with SEER

NOTES

Efficiency:

1 Baseline: Compressor is Matsushita 2P19C3R236A, 12.78 kBtu/hr,10.39 EER; Grooved Refrigerant Tubes, Enhanced Fins, PSC Fan Motor

2 Subcooler: Add a subcooler to condenser; Length=34", DIA=5/16", Condensate temperature=91.80°F

3 Increased Compressor Efficiency: Replace Matsushita 2P19C3R236A, 12.78 kBtu/hr, 10.39 EER with Tecumseh RK5513E (RK157ET), 13.20 kBtu/hr, 10.82 EER

4 Increased Evaporator/Condenser Coil Area: Evap Face Area increased from 1.38 to 1.80 sq.ft., Cond Face Area increased from 2.08 to 2.34 sq.ft.

5 Brushless Permanent Magnet Fan Motor: Replace 64.6% efficiency PSC motor with 80.0% efficiency BPM motor.

6 Variable Speed Compressor: Replace single-speed compressor with variable-speed compressor

Table 1.18 Cost-Efficiency Table for Room Air Conditioners With Reverse Cycle and Without Louvered Sides

Level	Design	Design Options		Mfg Cost *1990$*	Capacity *Btu/hr*	EER *Btu/W-hr*	DOE test procedure Energy Use *kWh/yr*	DOE test procedure Hours	Field Energy Use *kWh/yr*
1,2	0	Baseline	(1)	246.80	11359.5	8.72	977.4	750.0	694.0
3,4	1	0 + Condenser Enahanced Fins	(2)	247.66	11422.8	8.86	961.6	745.8	682.7
	2	1 + BPM Fan Motor	(3)	312.24	11453.9	9.20	926.5	743.8	657.8
	3	2 + **Variable Speed Compressor	(4)	442.44	11453.9	10.22	833.9	743.8	592.1
5	4	3 + **Incr Evap/Cond Coil Area	(5)	476.36	11711.9	10.87	783.9	727.4	556.6

** - Design options incorporating Variable Speed Compressors are rated with SEER

NOTES

Efficiency:

1 Baseline: Compressor is Tecumseh RK5512E (RK147ET), 11.70 kBtu/hr, 11.09 EER; Grooved Refrigerant Tubes; Evap Enhanced Fins; PSC Fan Motor; Subcooler

2 Condenser Enhanced Fins: Replace wavy fins with enhanced fins; Cond air-side enhancement=1.89

3 Brushless Permanent Magnet Fan Motor: Replace 64.6% efficiency PSC motor with 80.0% efficiency BPM motor.

4 Variable Speed Compressor: Replace single-speed compressor with variable-speed compressor

5 Increased Evaporator/Condenser Coil Area: Evap Face Area increased from 1.26 to 1.64 sq.ft., Cond Face Area increased from 1.77 to 1.99 sq.ft.

In order not to restrict the number of design options that could be considered for a particular class, capacity limits were not considered in the analysis of design options. In the case of the two smallest product classes, the capacity was even allowed to exceed the defined capacity limit. Without capacity limits, design options can be applied one after the other without consideration given to how capacity will be effected. In this way the analysis is not burdened with having to downsize components just for the purpose of keeping the capacity within an artificially defined limit. It was assumed that if room air conditioner manufacturers viewed capacity as a concern, they would be able to design their units to incorporate any design option so that the particular capacity of interest was not exceeded.

Most of the design options in Tables 1.10 to 1.18 are self-explanatory. Notes accompany each design option to explain how it was analyzed. With regard to design options that increase compressor efficiency, the data for all compressors are from actual compressor performance data. Compressor performance data provide values of motor input power and refrigerant mass flow rate as a function of evaporating and condensing temperatures. For simulation modeling purposes, bi-quadratic functions for the input power and mass flow rate are used to describe the compressor. The form of the bi-quadratic function is provided below.

$$f(T_{outlet},T_{inlet}) = C_1 T_{outlet}^2 + C_2 T_{outlet} + C_3 T_{inlet}^2 + C_4 T_{inlet} + C_5 T_{outlet} T_{inlet} + C_6 \qquad \textbf{(1.16)}$$

where T_{outlet} = condenser saturation temperature
T_{inlet} = evaporator saturation temperature

The constants (C_1 through C_6) are derived through the use of a map-based compressor model and are used as inputs to the simulation model to describe the compressor. Detailed descriptions of the map-based compressor model and the input data files for the simulation model are provided in Appendix A. Using actual compressor performance data to model compressor operation captures the effect that different operating conditions have on room air conditioner performance. AHAM also advocates using actual compressor performance data for the analysis of more efficient compressors. But AHAM also suggests placing a ceiling on the overall room air conditioner efficiency increase (that can result from using more efficient compressors) at 75% of the nominal compressor EER increase. Limited test data provided by AHAM indicates that overall system efficiency improvements do not go beyond this level. This analysis was conducted without using AHAM's suggested 75% ceiling. Placing a ceiling on the efficiency improvement eliminates the possibility of gaining system EER increases due to more favorable compressor operating conditions. As it turns out, most of the compressors modeled as design options in the analysis yielded system efficiency increases that were equal to or less than 75% of the nominal compressor EER increase. Only one of the compressors analyzed yielded a system efficiency increase far above AHAM's suggested 75% ceiling.

With the exception of the variable speed compressor design option, energy use for all design option levels was solely determined with the simulation model. Although calibration of the model to actual test data would have been preferred, such data were not available for efficiencies above the baseline. In response to DOE's proposed rulemaking for room air conditioners, AHAM provided alternative simulation results for the five product classes without reverse cycle and with louvered sides (43). Attainable efficiency increases were demonstrated to be lower than those estimated by DOE. Discrepancies between AHAM's and DOE's simulation results were due to differences in how subcoolers, fan motors, and compressors were modeled. As discussed previously, AHAM noted errors in how DOE conducted its analysis of subcoolers and fan motors. Upon correcting these errors with the modeling analysis, simulation results ended up being much closer to those predicted by AHAM. Table 1.19 provides a comparison between the current simulation results and those generated by AHAM for the five product classes without reverse cycle and with louvered sides. For each class, results are compared for the set of design options which DOE based its selection of minimum efficiency standards for its Notice of Proposed Rulemaking (with the exception that compressors with efficiencies greater than 11.0 EER were not included). Any differences between the AHAM and DOE design option sets are noted. In the design option sets, those design options which were considered only by DOE are labeled as "DOE only". Those options considered only by AHAM are labeled as "AHAM only".

Table 1.19 Comparison of DOE and AHAM Simulation Results for Classes without Reverse Cycle and Without Louvered Sides

Product Class	Design Options		Capacity	EER
	Enhanced Fins + PSC Fan Motor +	DOE	6567.9	10.00
Less than 6000 Btu/hr	Grooved Tubes + Subcooler	AHAM	6669.6	10.00
		% Diff	1.6%	0.0%
	Enhanced Fins + PSC Fan Motor +	DOE	8059.1	9.91
6000 to 7999 Btu/hr	Grooved Tubes + Subcooler	AHAM	8171.4	9.59
		% Diff	1.4%	-3.2%
	Grooved Tubes + Subcooler +	DOE	13049.1	10.11
8000 to 13999 Btu/hr	10.8 EER Compressor (DOE only)	AHAM	12652.6	10.05
	10.7 EER Compressor (AHAM only)	% Diff	-3.0%	-0.6%
	Subcooler + 10.8 EER Compressor +	DOE	18759.1	10.15
14000 to 19999 Btu/hr	Condenser Grooved Tubes (DOE only)	AHAM	18367.6	9.81
		% Diff	-2.1%	-3.4%
	Subcooler +	DOE	24269.4	8.51
Greater than 20000 Btu/hr	10.9 EER Compressor	AHAM	24687.7	8.57
		% Diff	1.7%	0.7%

As evidenced by the above comparisons, only two classes show EER differences of greater than 1%: the 6000 to 7999 Btu/hr and 14000 to 19999 Btu/hr product classes.

With regard to the 6000 to 7999 Btu/hr class, the 3.2% EER difference is attributable to an error with the simulation model that has since been corrected. Since AHAM's results were determined with a version of the simulation model that contained this error, correcting for this error would yield a predicted EER that is much closer to that estimated by DOE. The error arose from modifications to the simulation model to account for performance improvements due to condensate spray. As discussed previously, one of the modifications made to the Oak Ridge Heat Pump model in order that it better simulate the performance of room air conditioners was to add a routine to model condensate spray. Further modifications were made to the simulation model to ensure that its condensate spray and condenser sub-models used the same condenser exiting air temperature. The acceptable difference between the exiting air temperatures calculated by each sub-model was initially set too low. For the case of the baseline unit being modeled for the 6000 to 7999 Btu/hr class, this resulted in the simulation model converging to solutions that yielded condenser heat transfer coefficients which were too small. By increasing the allowable temperature difference between the two sub-models, the simulation model yielded higher and more reasonable simulated condenser heat transfer coefficients. As a result of simulating higher heat transfer coefficients, predicted EER increases were higher than those estimated for DOE's proposed rulemaking. Appendix A provides a detailed description of the changes that were made to the simulation model to assess the benefits of condensate spray.

The EER difference between DOE and AHAM simulation results for the 14000 to 19999 Btu/hr class is due to the additional design option analyzed by DOE (condenser grooved tubes). If this design option were removed, DOE's simulated efficiency would be approximately 9.87 EER. This results in a difference of only 0.6% with AHAM's estimate.

With regard to the variable speed design option, energy use was determined by applying a 10% reduction to the previous design option's energy use. For classes without louvered sides, the "increased coil area" design option follows variable speed compressors. Although variable speed compressors cannot be simulated by the model, energy use estimates for the "increased coil area" design option were still based on results from the simulation model. The "increased coil area" design option was applied to the design option immediately preceding the variable speed compressor. In this way, the simulation model could calculate how much energy was saved by the "increased coil area" design option. The energy use reduction that was calculated was then applied to the variable speed compressor's energy use.

The design options are ordered so that those that are easiest to carry out and that are relatively more cost-effective are listed first. It is important to note that the efficiency rating for designs incorporating variable speed compressors is a seasonal rating (SEER) rather than a steady-state rating (EER). As stated previously, variable speed designs primarily improve efficiency on a seasonal rather than a steady-state basis.

For the nine product classes analyzed, the energy consumption at the maximum technologically feasible efficiency level can be obtained by the use of variable speed compressors for classes with louvered sides or by the use of increased coil areas for classes without louvered sides. For example, for the less than 6000 Btu/hr product class with side louvers and without a reversing valve, the minimum technologically feasible energy use is 374 kWh/yr. This unit employs enhanced fins and grooved tubing in both the evaporator and condenser coils, a subcooler, enlarged evaporator and condenser coils, a 10.76 EER variable speed compressor, and a brushless permanent magnet fan motor.

1.5.1 Cost Data

Most of the cost data were provided by AHAM. AHAM data were collected from several room air conditioner manufacturers and averaged in order to protect the confidentiality of data received from individual manufacturers. This data was provided by AHAM in their comments to DOE's proposed rulemaking for room air conditioners (44). Cost data were provided by AHAM for the following design options: increased rotary compressor efficiency, scroll compressors, reciprocating "inertia" compressors, increased fin density, increased tube density, grooved tubes, enhanced fins, subcoolers, increased chassis size (increased coil area), brushless permanent magnet motors, and variable speed compressors. Cost data were not provided for permanent split capacitor fan motors. Cost data supplied by component suppliers was also used to either substantiate the AHAM data or to base the cost of a design option for which AHAM did not provide information.

For design option improvements to the heat exchanger coils, costs were based solely on data provided by AHAM. Most of this cost data were expressed as a function of additional material required to incorporate the desired design change. For the increased fin density, increased tube density, and enhanced fin design options, cost was given in terms of dollars per added material volume. For the grooved tube design option, cost was given in terms of dollars per lineal foot of tubing used. For adding a subcooler, cost was a function of subcooler length. Three different "subcooler" functions were provided, each for a different diameter of tubing. Cost data for increasing the chassis size (increasing the coil area) were given as cost premiums based on product class capacity. Table 1.20 summarizes the AHAM cost data for the above heat exchanger improvements.

For units without louvered sides, otherwise known as "through-the-wall" units, increases in chassis size as a result of enlarging the heat exchanger coils were assumed to increase installation costs. Because of the overall size restrictions due to "through-the-wall" sleeves already in service, chassis sizes cannot be increased without obsoleting the existing sleeves. Higher installation costs would result as existing wall openings would need to be expanded to accommodate the larger units. Since the percentage of "through-the-wall" units used in new construction is believed to be small, all units without louvered sides were assumed to incur the added retrofit cost, regardless of its intended installation. As provided by real estate companies, manufacturers, and AHAM, the increased installation cost is estimated to be between $250 and $500 (45). The average value, $375 (in 1994$), was used as the representative value.

Table 1.20 AHAM Manufacturing Cost Data for Heat Exchanger Improvements

Item	Manufacturing Cost (1994$)
Increased Fin Density	$0.20 per cubic inch of added fin material
Increased Tube Density	$1.45 per cubic inch of added tube material; $0.20 per cubic inch of added fin material
Grooved Tubes	$0.48 premium per lineal foot
Enhanced Fins	$0.20 premium per cubic inch of fin material
Subcoolers	3/8" DIA tube = $1.07 + $0.043 • Length (inches) 5/16" DIA tube = $1.07 + $0.037 • Length (inches) 1/4" DIA tube = $1.07 + $0.027 • Length (inches)
Increased Chassis Size	Cost premiums are based on product class capacity: Less than 6000 Btu/hr = $28; 6000 to 7999 Btu/hr = $30; 8000 to 13999 Btu/hr = $35; 14000 to 19999 Btu/hr = $100; Greater than 20000 Btu/hr = $60

For improvements in compressor efficiency, data from AHAM and compressor manufacturers were used to establish the manufacturing cost. Cost data from AHAM were used for establishing the cost of making improvements in rotary compressor efficiency. These costs were given as a function of the rated capacity of the room air conditioner. Although the cost function was specified as being valid only for the nominal compressor EER range of 10.3 to 10.9, it was used to derive the costs of rotary compressors that currently exist on the market which extend beyond this range. Since the most efficient rotary compressor currently on the market has a nominal EER of 11.1, it was felt that it was reasonable to use the cost function to define the cost for this compressor. Although only data from AHAM were used to establish the costs for rotary compressors, cost data from rotary compressor manufacturers were used to confirm the reasonableness of the AHAM cost function.

For reciprocating "inertia" compressors, specific cost premiums were provided and established with data provided by the compressor manufacturer that produces "inertia" compressors (46). These cost premiums account for start assist devices. Because sound levels of "inertia" compressors are approximately double that of rotary compressors, sound blankets are required and are added to the cost of the compressor. With regard to scroll compressors, cost premiums were provided solely by AHAM.

Variable-speed compressor costs were based on data supplied by AHAM. Variable-speed compressors were stated to be 30% to 50% more expensive than single-speed compressors. A 40% increase was assumed for the analysis. In addition, an inverter control is required at a cost of approximately $100. Table 1.21 summarizes the data that were used to establish the manufacturer costs of compressors.

Table 1.21 Manufacturing Cost Data for Compressors

Compressor Type	Source	Manufacturing Cost (1994$)
Rotary	AHAM	$ per 0.1 EER increase = $0.42 + $0.060 • (unit capacity in kBtu/hr)
Inertia Reciprocating	Bristol	Compressor cost premiums are relative to most efficient rotary compressor and are based on the model line (efficiency). H26B model line (11.2 to 11.3 EER) = $20 to $30 H27B model line (11.4 to 11.6 EER) = $30 to $40 H27A model line (11.7 to 12.0 EER) = $40 to $50 Sound Blanket = $13
Scroll	AHAM	Cost premium = $36 to $41 greater than most efficient rotary compressor
Variable-Speed	AHAM	Compressor cost = 40% greater than single-speed compressor Inverter control = $100

Because both "inertia" and scroll compressors are significantly larger and heavier than rotary compressors, room air conditioner and compressor manufacturers state that additional application costs are required to both enlarge and add structural support to the chassis. Table 1.22 provides height and weights for rotary, scroll and "inertia" compressors that are suitable for room air conditioner applications.

Table 1.22 Compressor Height and Weight Comparisons

Applicable Product Class	**Compressor Type**	**Compressor** *Mfg / Mod #*	**Capacity** *Btu/hr*	**EER** *Btu/W-hr*	**Height** *inches*	**Weight** *lbs*
14000 to 19999 Btu/hr	Rotary	Matsushita 2K25C3R	17450	9.97	12.92	37.00
	Rotary	Matsushita 2K24S3R	17420	10.79	12.92	35.30
	Rotary	Matsushita 2K25S3R	18050	10.78	12.84	35.30
	Rotary	Tecumseh RK5518E	17700	10.79	12.15	30.70
	Scroll	Copeland ZR18K3	18000	10.9	~14.57	~55.00
	Inertia	Bristol H26B18	18300	11.2	14.75	68.00
	Inertia	Bristol H27B18	18000	11.4	15.00	70.00
Greater than 20000 Btu/hr	Rotary	Matsushita 2J39C3R	29400	10.89	14.33	53.80
	Scroll	Copeland ZR28K3	28500	11.1	15.07	59.00
	Scroll	Copeland ZR30K3	30500	11.1	15.97	60.00
	Inertia	Bristol H26B28	28700	11.3	15.00	69.50
	Inertia	Bristol H27A28	28200	11.7	15.63	92.50

As evidenced by the data presented in Table 1.22, both scroll and “inertia” compressors are significantly taller and heavier than rotary compressors. Although there seems to be justification in stating that chassis modifications are required, manufacturers have not provided data indicating what the application costs for making these modifications would be. Thus, for purposes of this analysis, application costs for chassis enlargements and structural upgrades were not explicitly accounted for. For those cases where the weight of the scroll or "inertia" compressor exceeded the weight of the rotary compressor by at least 30%, an increase in chassis size was assumed to be necessary for incorporating the taller and heavier compressor. Thus, design options requiring a larger chassis size (i.e., larger frontal coil areas) always precede "30% heavier" scroll or "inertia" compressors.

Cost data from fan motor manufacturers were used to establish the manufacturer cost of incorporating more efficient fan motors (i.e., permanent split capacitor and brushless permanent magnet types). As with scroll and "inertia" compressors, room air conditioner manufacturers claim that structural changes to the chassis would be needed to accommodate larger and heavier brushless permanent magnet motors. However, data were not provided by them to establish what the application costs for upgrading the chassis would be. Thus, the analysis did not account for possible application costs when evaluating brushless permanent magnet fan motors.

The cost and efficiency data were combined and are presented in Tables 1.10 through 1.18. The second section of Appendix A contains disaggregated costs for the five primary product classes. Total costs are divided into variable and capital costs. Variable costs consist of material costs, purchased parts, labor costs, shipping costs, and a portion of indirect costs. Capital costs consist of tooling and equipment costs and a portion of indirect costs. Indirect costs include expenses such a general and administrative costs, research and development, rent, utility costs, and certification tests and fees. Since cost data were provided in total cost only, assumptions were made regarding the total cost in order to determine what percentages were variable and what were capital costs. For improved designs requiring the addition of an improved purchased part (i.e., increased compressor or fan motor efficiency), the total cost was assumed to be all variable. For design options requiring changes to components manufactured in-house (i.e., heat exchanger improvements), 85% of the total cost was assumed to be variable and 15% capital. For designs requiring substantial tooling changes (i.e., variable speed compressors and increased coil areas), a split of 60% variable cost and 40% capital cost was assumed.

1.6 MAXIMUM TECHNOLOGICALLY FEASIBLE DESIGN

As mentioned earlier, the maximum technologically feasible design for the nine product classes analyzed is obtained either by the use of variable speed compressors (for units employing louvered sides) or increased coil areas (for units without louvered sides). The maximum technologically feasible design for all nine product classes includes enhanced fins and grooved tubing in both the evaporator and condenser coils, a subcooler, enlarged evaporator and condenser coils, a brushless permanent magnet fan motor, and a high-efficiency variable speed compressor. The efficiency of the "max tech" design was derived from data given by manufacturers and predicted through the use of the simulation model. All of the efficiency values (and manufacturing costs as well) in Tables 1.10 through 1.18 have some uncertainty associated with them.

For all nine room air conditioner product classes, the range of the 95% confidence interval for each of the maximum technologically feasible designs is approximately the same. The low end of the interval is, on average, 5.6% lower than the "max tech" design's SEER rating. (The "max tech" design is rated with an SEER because it incorporates a variable speed compressor.) The high end of the interval is, on average, 20.5% higher than the "max tech" design's SEER rating. Volume 1, Appendix A, of this report provides a general discussion of how the 95% confidence interval is established for "max tech" designs.

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CHAPTER 2. BASE CASE PROJECTIONS: ROOM AIR CONDITIONERS

The impacts of federal alternative energy efficiency levels are calculated by comparing projected U.S. residential energy consumption with and without the efficiency levels. The cases without imposing energy efficiency levels are referred to as *base case projections*. The base case is intended to provide a reasonable projection of future unit energy consumption, equipment price, and installations for room air conditioners, accounting for changes in the housing stock and energy prices. These base case projections are compared to projections of conditions that would be likely to prevail if efficiency levels were imposed (see Chapter 3). The difference between the two projections is defined as the incremental impact of alternative energy efficiency levels.

Projections are based upon a number of demographic, economic, and energy variables, which hold true for all end-uses, including energy prices, household income, housing stock, housing starts, mix of house types (single-family, multi-family, mobile homes), and building shell thermal characteristics. Additional (product-specific) variables include: appliance lifetimes (Section 2.2), distribution of efficiencies (Section 2.3.1), unit energy consumption (Section 2.3.1), and equipment prices (Section 2.3.4). Results include new unit EERs, unit energy consumption, number of units installed, national energy consumption, and equipment prices.

2.1 DEMOGRAPHIC AND ECONOMIC ASSUMPTIONS

The general demographic and economic assumptions are described in Volume 1: General Methodology, Chapter 5.

2.2 AVERAGE EQUIPMENT LIFETIME ASSUMPTIONS

The rates at which appliances retire as a function of years since purchase are determined by analyzing historical shipments reported by the industry trade association. Based on data assembled by the United Power Association (1), the average room air conditioner lifetime is 12.7 years (Table 2.1). For purposes of this analysis, this value was rounded down to 12.5 years and used as the representative average lifetime.

Table 2.1 Average Equipment Lifetime of Room Air Conditioners

Source	Average Lifetime *years*
DOE, 1980	10
1981 Northern States Power	14
Appliance Trade Publication, 1984	11
1985 Northern States Power	15
Wisconsin Public Service Commission, 1986	15
The Saturation Picture, *Appliance*, September, 1989	11
EPRI, 1990 (Reports: EPRI CU-6746, EPRI CU-6925)	15
Average of Above Sources	12.7

2.3 BASE CASE PROJECTION RESULTS

This section contains projections of unit energy consumption of new appliances, annual appliance installations, annual residential energy consumption, and price of purchased appliances.

2.3.1 New Appliance Unit Energy Consumptions

Annual unit energy consumption (UEC) of new appliances is projected based upon a set of designs available (each design characterized by a purchase price and the energy-efficiency ratio (EER)) and a market discount rate (derived from implicit decision-making in recent purchase decisions for the product). Average efficiency factors for new room air conditioners sold in past years are obtained from the trade association, Association of Home Appliance Manufacturers (AHAM). The LBL-REM produces projections of annual energy consumption of new appliances after 1993. As evidenced from Table 2.2, efficiency and annual UEC are projected to remain relatively constant between the years 1993 and 2030. LBL-REM assumes consumer choice is primarily a function of operating cost and equipment price. Since electricity rates are forecasted by the 1995 Annual Energy Outlook (2) to increase only slightly, operating cost savings of more efficient room air conditioners are out weighed by their increased retail cost. Thus, there is little or no incentive for consumers to select more efficient units and the increases in average efficiency and UEC for the base case are forecasted to be extremely low.

The UEC of new units decreased 21% from 1981 to 1993. The average UEC is projected to decrease by 2% from 1993 to 2030.

Table 2.2 Base Case Projection of Unit Energy Consumption for New Room Air Conditioners

Year	Average EER	UEC (*kWh/year*)
1981	7.06	920
1993	9.05	686
1996	9.11	672
1999	9.11	666
2030	9.30	652

Source: AHAM (1980-1993); LBL-REM (1994-2030).

2.3.1.1 Efficiency Distributions

For each class of appliances the range of efficiencies currently available is determined from the AHAM directory (3). The distribution is presented in Appendix B (herein). In future years in the base case projection, the relative distribution of efficiencies around the projected average is assumed to be similar to the current distribution. Imposing new efficiency levels diminishes the range of efficiencies of available models by moving models below the new efficiency to the new efficiency level and altering the shape of the distribution. For example, if a minimum efficiency level of 9.5 EER is imposed on a distribution of efficiencies with an existing minimum of 9.0 EER, all models with efficiencies between 9.0 and 9.5 EER can no longer be made available and will have to be produced with efficiencies equal to at least the new minimum efficiency level of 9.5 EER.

2.3.1.2 Usage

Usage is expressed as hours of operation per year and is shown in Table 2.3. Table 2.3 shows that usage is projected to increase 4% from 1981 to 1993, and 16% from 1993 to 2030. Usage is a function of operating expense and income.

Table 2.3 Projected Average Usage of Room Air Conditioners

Year	Hours/Year
1981	531
1993	554
1996	577
1999	589
2030	641

Source: LBL-REM.

2.3.2 Annual U.S. Appliance Installations

The market for appliances is seen as having two segments: new construction and existing housing. All new households are considered eligible to purchase each appliance. The pool of potential purchasers among existing households each year is defined as households that retired a unit that year, plus a fraction of households that did not previously own the product.

The initial (1980) fraction of new (and of existing) households expected to purchase each product and fuel type is specified as input to LBL-REM. LBL-REM produces projected fractions, for each year, of new households (and of existing households) that purchase the product. The projection is based on market share elasticities with respect to income, equipment price, and annual operating expense. Market share elasticities are given in Appendix B.

The projection for the period 1981-1990 is calibrated to reasonable agreement with available data, including domestic shipments (from published trade association data) and surveys of appliance ownership, e.g., from DOE/EIA RECS (4) and the Bureau of the Census.

Annual installations of new room air conditioners are projected to increase from 3.5 million in 1993 to 5.6 million in 2030. Installations of central air conditioners and heat pumps also increase. Tables 2.4 and 2.5 show the significant trends in the installation and saturation of these products.

Table 2.4 Annual Installations of New Air Conditioners in U.S. Households (Millions)

Year	Room A/C	Central A/C	Heat Pump	Total
1981	3.47	2.15	0.44	6.05
1993	3.47	2.52	0.64	6.63
1996	4.03	2.92	0.72	7.66
1999	4.40	3.18	0.76	8.34
2030	5.51	4.42	1.18	11.11

Table 2.5 Percent of Occupied U.S. Housing Units Having Air Conditioners

Year	Room A/C	Central A/C	Heat Pump	Total
1980	32	21	3	56
1993	29	35	8	72
1996	29	37	9	75
1999	29	39	9	77
2030	32	46	12	90

Source: LBL-REM.

2.3.3 U.S. Residential Energy Consumption

U.S. residential energy consumption for this product is calculated each year as the product of: number of occupied households; fraction of households owning the appliance; average unit energy consumption; and usage behavior factor.

Table 2.6 shows the projected U.S. energy consumption, expressed in quadrillion Btu of primary energy using a conversion factor for electricity of one kWh per 11,500 Btu. Energy consumption for room air conditioners increases from 0.37 Quads in 1993 to 0.54 Quads in 2030. Total energy for residential air conditioning increases from 1.58 Quads in 1993 to 2.59 Quads in 2030.

Table 2.6 U.S. Residential Energy Consumption for Air Conditioners (Quadrillion Btu, Primary Energy)

Year	Room A/C	Central A/C	Heat Pump	Total
1981	0.45	0.59	0.11	1.15
1993	0.37	0.93	0.27	1.58
1996	0.37	0.98	0.29	1.64
1999	0.38	1.02	0.31	1.70
2030	0.54	1.55	0.50	2.59

Source: LBL-REM.

2.3.4 Price of Purchased Appliances

Prices of new units increase over time (even without imposed efficiency levels) as energy efficiency improvements are incorporated. Table 2.7 shows projected shipment-weighted average prices.

Table 2.7 Average Price of New Room Air Conditioners in U.S. Households (1990 dollars)

Year	Room A/C
1981	490
1993	507
1996	507
1999	507
2030	519

Source: LBL-REM.

2.4 SENSITIVITY ANALYSIS OF THE BASE CASE

The sensitivity cases selected are defined as follows:

1. *Lower Equipment Price*. The price of the baseline unit and the incremental price associated with each engineering level is decreased by the estimated uncertainty interval.

2. *Higher Equipment Price*. The price of the baseline unit and the incremental price associated with each engineering level is increased by the estimated uncertainty interval.

3. *Lower Energy Price*. Assume lower energy prices. Starting from 1992 to 2030, electricity prices are 3% lower while gas and distillate prices are 5% lower than those in the AEO 1995 (5) forecast.

4. *Higher Energy Price*. Assume higher energy prices. Starting from 1992 to 2030, electricity prices are 3% higher while gas and distillate prices are 5% higher than those in the AEO 1995 forecast.

5. *High Equipment Efficiency*. Assume continuing future improvement in appliance efficiencies at a rate of 2% per year.

6. *Market Discount Rates Decline*. Assume that market discount rates used to determine future efficiency choices are declining over time by 2% per year, i.e., efficiency improvements appear in the marketplace sooner.

The impact of these six sensitivity cases on the average purchase price and the average efficiency of new room air conditioners is presented in the following tables. Tables 2.8 shows how the average price varies. Tables 2.9 shows the differences in efficiency. The first line of these tables give the results of the reference case described in the previous section; the rest of the lines give the corresponding results of the sensitivity cases listed above.

Table 2.8 Average Purchase Price of New Room Air Conditioners (1990 Dollars)

Year:	1981	1993	1996	1999	2030
Reference	490	507	507	507	519
1	450	464	475	475	479
2	530	549	549	549	561
3	490	507	507	507	518
4	490	507	516	516	519
5	490	507	541	615	1002
6	490	507	517	518	531

Table 2.9 Average Efficiency (EER) of New Room Air Conditioners

Year:	1981	1993	1996	1999	2030
Reference	7.03	9.05	9.11	9.11	9.30
1	7.03	9.05	9.30	9.30	9.38
2	7.03	9.05	9.11	9.11	9.25
3	7.03	9.05	9.11	9.11	9.26
4	7.03	9.05	9.25	9.25	9.30
5	7.03	9.05	9.62	10.22	12.01
6	7.03	9.05	9.25	9.26	9.47

Source: LBL-REM.

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CHAPTER 3. PROJECTED NATIONAL IMPACTS OF ALTERNATIVE EFFICIENCY LEVELS: ROOM AIR CONDITIONERS

The LBNL Residential Energy Model (LBNL-REM) projects a number of economic and energy-use variables that are used to assess the impact of alternative energy efficiency levels on consumers, electric utilities, and appliance manufacturers. This chapter presents projections from the model, which assume various alternative energy efficiency levels.

The principal outputs from the LBNL-REM for each year are:

- unit equipment price and operating expense by product,
- projected annual shipments of residential appliances,
- energy consumption by end use and fuel, and
- differences in these quantities between a base case and each efficiency level case.

These outputs are calculated for each year and accumulated over a period of time, i.e., 1999-2030. Energy savings are calculated for each year from implementation of alternative efficiency levels to the end of the period. Net present value of the alterative efficiency levels is evaluated for each regulated product and for the end use(s) comprising the regulated and competing products.

Section 3.1 presents the alternative efficiency levels analyzed. Section 3.2 presents the historical and projected energy consumption, including unit energy consumption (UEC) for new purchases, and total national energy consumption. Section 3.3 presents historical and projected annual installations. Section 3.4 presents purchase prices and Section 3.5 presents net present value.

An overview of the general LBNL-REM methodology and demographic assumptions is in Volume 1 of this report. Product-specific input data are described in Appendix C, herein.

3.1 ALTERNATIVE EFFICIENCY LEVELS

Table 3.1 shows the correspondence between the alternative energy efficiency levels, the engineering design levels, and the associated energy efficiency ratios.

Table 3.1 Alternative Efficiency Levels for Room Air Conditioners

	Efficiency Level				
	1	2	3	4	5
Engineering design option:					
Room A/C up to 6 kBtu/hr with louvers	2	3	4	5	7
Room A/C 6 to 8 kBtu/hr with louvers	2	3	4	5	7
Room A/C 8 to 14 kBtu/hr with louvers	1	2	3	4	6
Room A/C 14 to 20 kBtu/hr with louvers	1	2	3	3	8
Room A/C over 20 kBtu/hr with louvers	1	1	2	3	7
Room A/C 6 to 8 kBtu/hr w/o louvers	1	1	2	2	5
Room A/C 8 to 14 kBtu/hr w/o louvers	Base	1	2	2	5
Heat pump with reversing valve with louvers	1	1	2	2	5
Heat pump with reversing valve w/o louvers	Base	Base	1	1	4
Minimum EER:					
Room A/C up to 6 kBtu/hr with louvers	9.32	9.71	10.00	10.38	11.74
Room A/C 6 to 8 kBtu/hr with louvers	9.38	9.66	9.91	10.33	11.67
Room A/C 8 to 14 kBtu/hr with louvers	9.71	9.85	10.11	10.97	12.39
Room A/C 14 to 20 kBtu/hr with louvers	9.70	9.98	10.15	10.15	12.77
Room A/C over 20 kBtu/hr with louvers	8.39	8.39	8.51	8.88	11.14
Room A/C 6 to 8 kBtu/hr w/o louvers	9.10	9.10	9.23	9.23	11.52
Room A/C 8 to 14 kBtu/hr w/o louvers	8.80	9.05	9.12	9.12	11.08
Heat pump with reversing valve with louvers	9.05	9.05	9.27	9.27	11.16
Heat pump with reversing valve w/o louvers	8.72	8.72	8.86	8.86	10.87

3.2 ENERGY CONSUMPTION

Table 3.2 shows the past and projected average energy use of new room air conditioners, based on AEO 1995 fuel price projections. The weighted average is obtained by taking the product of the UEC for each class and a class-specific weighting factor (based on shipments), then summing over the classes. The weighting factors are:

Room A/C up to 6 kBtu/hr with louvers	.267
Room A/C 6 to 8 kBtu/hr with louvers	.144
Room A/C 8 to 14 kBtu/hr with louvers	.328
Room A/C 14 to 20 kBtu/hr with louvers	.131
Room A/C over 20 kBtu/hr with louvers	.063
Room A/C 6 to 8 kBtu/hr without louvers	.021
Room A/C 8 to 14 kBtu/hr without louvers	.021
Heat pump with reversing valve with louvers	.021
Heat pump with reversing valve without louvers	.005

Table 3.2 Unit Energy Consumption for New Room Air Conditioner (Weighted Average kWh/year)[1]

		Efficiency Level				
Year	Base	1	2	3	4	5
1981	920					
1993	686					
1996	672					
1999	666	636	623	611	585	504
2015	654	630	619	607	582	503
2030	652	630	618	607	583	505

Source: LBNL-REM.

Tables 3.3a to 3.3d present projections of total energy savings for: (a) room air conditioners, (b) central air conditioners, (c) heat pumps (cooling), and (d) total residential air conditioning. Alternative efficiency levels (affecting only room air conditioners) are projected to produce cumulative energy savings ranging from 0.36 Quads for efficiency level 1 to 0.96 Quads for efficiency level 4, during the period 1999-2030. At efficiency level 5, the cumulative energy savings decrease to 0.72 Quads.

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[1] Table 3.2 is updated for the supplemental efficiency level to show sensitivity to various fuel prices, equipment prices, and efficiency trends. With regard to fuel prices, calculations for the supplemental level were made using electricity rates based on fuel price projections from AEO 1995, AEO 1997 and GRI 1996. In addition, sensitivities for the supplemental level based on the use of AEO 1997 electricity rates were performed for a low equipment price case, a high equipment price case and a high efficiency trend case. See Supplemental Sensitivity Analysis Subsection of the Supplemental Analysis.

Table 3.3a U.S. Electricity Consumption for Room Air Conditioners (Quadrillion Btu, Primary)[2]

		Efficiency Level				
Year	Base	1	2	3	4	5
1981	0.45					
1993	0.37					
1996	0.37					
1999	0.38	0.37	0.37	0.37	0.37	0.36
2015	0.46	0.44	0.44	0.43	0.41	0.31
2030	0.54	0.53	0.52	0.51	0.49	0.37
1999-2030	14.63	14.23	14.04	13.84	13.29	10.53
Cumulative Savings:		0.39	0.59	0.79	1.34	4.10
Percent of Base:		2.7%	4.0%	5.4%	9.1%	28.0%

Table 3.3b U.S. Electricity Consumption for Central Air Conditioner (not Heat Pump) (Quadrillion Btu, Primary)

		Efficiency Level				
Year	Base	1	2	3	4	5
1981	0.59					
1993	0.93					
1996	0.98					
1999	1.02	1.02	1.02	1.02	1.02	1.03
2015	1.27	1.27	1.27	1.27	1.28	1.38
2030	1.55	1.56	1.56	1.56	1.57	1.67
1999-2030	40.56	40.59	40.61	40.65	40.88	43.39
Cumulative Savings:		-0.03	-0.05	-0.09	-0.32	-2.83
Percent of Base:		-0.1%	-0.1%	-0.2%	-0.8%	-7.0%

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[2] Table 3.3a is updated for the supplemental efficiency level to show sensitivity to various fuel prices, equipment prices, and efficiency trends. With regard to fuel prices, calculations for the supplemental level were made using electricity rates based on fuel price projections from AEO 1995, AEO 1997 and GRI 1996. In addition, sensitivities for the supplemental level based on the use of AEO 1997 electricity rates were performed for a low equipment price case, a high equipment price case and a high efficiency trend case. See Supplemental Sensitivity Analysis Subsection of the Supplemental Analysis.

Table 3.3c U.S. Electricity Consumption for Heat Pump (Cooling Portion) (Quadrillion Btu, Primary) (Includes Individual Units)

		Efficiency Level				
Year	Base	1	2	3	4	5
1981	0.11					
1993	0.27					
1996	0.29					
1999	0.31	0.31	0.31	0.31	0.31	0.31
2015	0.39	0.39	0.39	0.39	0.39	0.41
2030	0.50	0.50	0.50	0.50	0.50	0.52
1999-2030	12.44	12.44	12.45	12.45	12.50	12.99
Cumulative Savings:		-0.01	-0.01	-0.02	-0.06	-0.55
Percent of Base:		0.0%	-0.1%	-0.1%	-0.5%	-4.4%

Table 3.3d Total U.S. Electricity Consumption for Residential Air Conditioning (Quadrillion Btu, Primary)[3]

		Efficiency Level				
Year	Base	1	2	3	4	5
1981	1.15					
1993	1.58					
1996	1.64					
1999	1.70	1.70	1.70	1.70	1.70	1.70
2015	2.11	2.10	2.10	2.09	2.08	2.09
2030	2.59	2.58	2.57	2.56	2.55	2.56
1999-2030	67.62	67.26	67.10	66.93	66.66	66.90
Cumulative Savings:		0.36	0.52	0.69	0.96	0.72
Percent of Base:		0.5%	0.8%	1.0%	1.4%	1.1%

Source: LBNL-REM.

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[3] Table 3.3d is updated for the supplemental efficiency level to show sensitivity to various fuel prices, equipment prices, and efficiency trends. With regard to fuel prices, calculations for the supplemental level were made using electricity rates based on fuel price projections from AEO 1995, AEO 1997 and GRI 1996. In addition, sensitivities for the supplemental level based on the use of AEO 1997 electricity rates were performed for a low equipment price case, a high equipment price case and a high efficiency trend case. See Supplemental Sensitivity Analysis Subsection of the Supplemental Analysis.

3.3 ANNUAL INSTALLATIONS

As shown in Table 3.4, installations[4] of cooling equipment are affected by the implementation of alternative efficiency levels. This result is a function of the change in operating expense, change in equipment price, and market share elasticities. The projection shows a difference of between no change and a 16% decrease from base for the various efficiency levels for cumulative shipments of room air conditioners from 1999 to 2030. The 16% decrease in room air conditioner installations at efficiency level 5 is a result of the dramatic increase in room air conditioner equipment price. As a result of the increase in room air conditioner equipment price, a significant number of households are projected to switch to central air conditioners. Thus, installations of central air conditioners significantly increase at efficiency level 5.

Table 3.4 Cumulative Installations of Room Air Conditioners (Millions)

		Efficiency Level				
1999-2030	Base	1	2	3	4	5
Room AC	154.44	154.40	154.32	154.10	152.20	129.21
Central AC	118.96	119.07	119.20	119.27	120.08	128.86
Heat Pumps	29.80	29.82	29.83	29.85	29.98	31.43
TOTAL	303.20	303.29	303.35	303.22	302.26	289.50
Change from Base:						
Room AC		-0.04	-0.12	-0.34	-2.24	-25.23
Central AC		0.11	0.24	0.31	1.12	9.90
Heat Pumps		0.02	0.03	0.05	0.18	1.63
TOTAL		0.09	0.15	0.02	-0.94	-13.70
Percent Change:						
Room AC		-0.03%	-0.08%	-0.22%	-1.45%	-16.34%
Central AC		0.09%	0.16%	0.26%	0.94%	8.32%
Heat Pumps		0.06%	0.10%	0.17%	0.61%	5.45%
TOTAL		0.03%	0.05%	0.01%	-0.31%	-4.52%

Source: LBNL-REM.

3.4 APPLIANCE PRICES

Projections of the purchase prices for new room air conditioners in 1990 dollars are shown in Table 3.5. The prices typically increase when efficiency levels come into effect.

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[4] If there are no imports or exports, annual installations are equivalent to domestic shipments. Domestic shipments can be calculated as annual installations, less imports, plus exports.

Table 3.5 Average Purchase Price for New Room Air Conditioner (1990 dollars per unit)[5]

		Efficiency Level				
Year	Base	1	2	3	4	5
1981	490					
1993	507					
1996	507					
1999	507	512	516	523	565	1002
2015	517	522	525	531	573	1002
2030	519	523	526	532	573	1002

3.5 NET PRESENT VALUE

The net present value (NPV) of alternative efficiency levels for any product is calculated by first determining the difference in present value of unit life-cycle costs between the base case and efficiency level case each year. That difference is then multiplied by the shipments for the efficiency level case for the year. The NPV for the period (1999-2030) is the sum over the years of the annual values. A positive NPV of an efficiency level results when the new units in the efficiency level case has a lower present value of life-cycle cost than do new units in the base case. It should be noted that the NPV does not include the benefits of peak power reductions. (Refer to Chapter 6 (herein) on details regarding the impacts of alternative efficiency levels on peak power.) Table 3.6a to Table 3.6c show the NPV (based on AEO 1995 fuel price projections) discounted at 4%, 7% and 10% real for the various efficiency levels. For NPVs discounted at 7% real, the NPV increases from $0.40 billion at efficiency level 1 to $0.59 billion at efficiency level 3. The NPV then decreases to negative values for efficiency levels 4 and 5.

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[5] Table 3.5 is updated for the supplemental efficiency level to show sensitivity to various fuel prices, equipment prices, and efficiency trends. With regard to fuel prices, calculations for the supplemental level were made using electricity rates based on fuel price projections from AEO 1995, AEO 1997 and GRI 1996. In addition, sensitivities for the supplemental level based on the use of AEO 1997 electricity rates were performed for a low equipment price case, a high equipment price case and a high efficiency trend case. See Supplemental Sensitivity Analysis Subsection of the Supplemental Analysis.

Table 3.6a Net Present Value to Consumers for Room Air Conditioners Purchased from 1999-2030 (Billion 1990$ Discounted to 1990 at 4% Real)[6]

	Efficiency Level				
	1	2	3	4	5
Fuel costs savings:					
BENEFIT (energy):	1.13	1.66	2.20	3.32	5.90
Equipment costs:					
COST (equipment):	0.27	0.48	0.86	3.37	24.87
NET = benefit - cost					
NET PRESENT VALUE:	0.86	1.18	1.34	-0.04	-18.97
RATIO: benefit/cost	4.14	3.47	2.56	0.99	0.24

Source: LBNL-REM.

Table 3.6b Net Present Value to Consumers for Room Air Conditioners Purchased from 1999-2030 (Billion 1990$ Discounted to 1990 at 7% Real)[7]

	Efficiency Level				
	1	2	3	4	5
Fuel costs savings:					
BENEFIT (energy):	0.55	0.81	1.07	1.61	2.83
Equipment costs:					
COST (equipment):	0.16	0.27	0.48	1.87	13.75
NET = benefit - cost					
NET PRESENT VALUE:	0.40	0.54	0.59	-0.26	-10.92
RATIO: benefit/cost	3.56	3.00	2.22	0.86	0.21

Source: LBNL-REM.

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[6] Normalized to efficiency level case shipments.

[7] Table 3.6b is updated for the supplemental efficiency level to show sensitivity to various fuel prices, equipment prices, and efficiency trends. With regard to fuel prices, calculations for the supplemental level were made using electricity rates based on fuel price projections from AEO 1995, AEO 1997 and GRI 1996. In addition, sensitivities for the supplemental level based on the use of AEO 1997 electricity rates were performed for a low equipment price case, a high equipment price case and a high efficiency trend case. See Supplemental Sensitivity Analysis Subsection of the Supplemental Analysis.

Table 3.6c Net Present Value to Consumers for Room Air Conditioners Purchased from 1999-2030 (Billion 1990$ Discounted to 1990 at 10% Real)

	Efficiency Level				
	1	2	3	4	5
Fuel costs savings:					
BENEFIT (energy):	0.30	0.43	0.57	0.85	1.49
Equipment costs:					
COST (equipment):	0.10	0.16	0.29	1.12	8.18
NET = benefit - cost					
NET PRESENT VALUE:	0.20	0.27	0.28	-0.27	-6.69
RATIO: benefit/cost	3.11	2.63	1.95	0.76	0.18

Source: LBNL-REM.

CHAPTER 4. LIFE-CYCLE COSTS AND PAYBACK PERIODS: ROOM AIR CONDITIONERS

The effect of energy efficiency levels on individual consumers includes a change in operating expense (usually decreased) and a change in purchase price (usually increased). The net effect is analyzed by calculating the life-cycle cost, using the engineering data (Chapter 1) for energy consumption and equipment price, and assuming the energy price projected for 1999. Section 4.1 presents the life-cycle costs (LCC) for each design option. The results are displayed as graphs and as tables of values. Sections 4.2 through 4.4 show the impacts of efficiency levels on consumers. Section 4.5 presents the effect of different assumptions on the life-cycle cost calculations.

The *difference* due to energy efficiency levels is calculated (Sections 4.2 to 4.4) after a base case forecast is made (see Chapter 2). The base case forecast accounts for market-based shifts in efficiency and usage that are projected to occur independently of efficiency levels. Then only those appliance purchasers who are impacted by efficiency levels (i.e., those who would have chosen a design eliminated by levels) are included in calculating the impact of efficiency levels on consumers. The impact of energy efficiency levels is expressed by three measures:

- Section 4.2: Payback Period (PBP),
- Section 4.3: Change in Life-Cycle Cost (LCC), and
- Section 4.4: Cost of Conserved Energy (CCE).

4.1 LIFE-CYCLE COST FOR DESIGN OPTIONS

The LCC is the sum of the installed consumer cost (*ICC*) and the present value of operating expenses (*OE*) discounted over the lifetime (*N*) of the appliance.

$$\mathrm{LCC} = \mathrm{ICC} + \sum_{t=1}^{N} \frac{\mathrm{OE}_t}{(1 + r)^t} \tag{4.1}$$

If operating expenses are constant over time, Eq. 4.1 simplifies to:

$$\mathrm{LCC} = \mathrm{ICC} + \mathrm{PWF}\cdot\mathrm{OE}, \tag{4.2}$$

where we have defined the present worth factor:

$$\mathrm{PWF} = \sum_{t=1}^{N} \frac{1}{(1 + r)^t} = \frac{1}{r}\left[1 - \frac{1}{(1 + r)^N}\right] \tag{4.3}$$

The LCC is calculated for each class in the year levels are imposed, using a discount rate, *r*.

4.1.1 LCC Data Inputs

The installed consumer cost is composed of a retail price—based on factory costs (from the Engineering Analysis, Chapter 1) and factory, distributor, and retail markups (from LBNL-MAM, Chapter 5)—plus installation costs (where applicable). Operating expenses include energy expenditures and maintenance costs. Annual energy consumption is the average unit energy consumption in the field (from LBNL-REM). Annual energy expense to the consumer is annual energy consumption times energy price. Energy price is the projected 1999 average residential energy price from DOE/EIA's *Annual Energy Outlook 1995* (1) times an end-use factor of 0.99 derived from DOE/EIA's 1990 *Residential Energy Consumption Survey* (2). Annual operating expenses are discounted to the year of purchase (1999) and summed over the average life of the product (from LBNL-REM) to obtain a present value. For the residential sector, the discount rate is 6% real, with sensitivity analyses performed at 2% and 15% real.

4.1.2 LCC Results

Figures 4.1 to 4.9 show the LCCs by design option. The values used to produce these figures are presented in Tables 4.1 to 4.9. Revised Tables 4.1-4.9 for LCC results, which include the supplemental efficiency level, calculated using both AEO 95 and GRI 96 energy price forecasts are found in the Supplemental Analysis Section.

Figure 4.1 Life-Cycle Costs for Room A/C < 6,000 Btu/hr (with louvered sides)

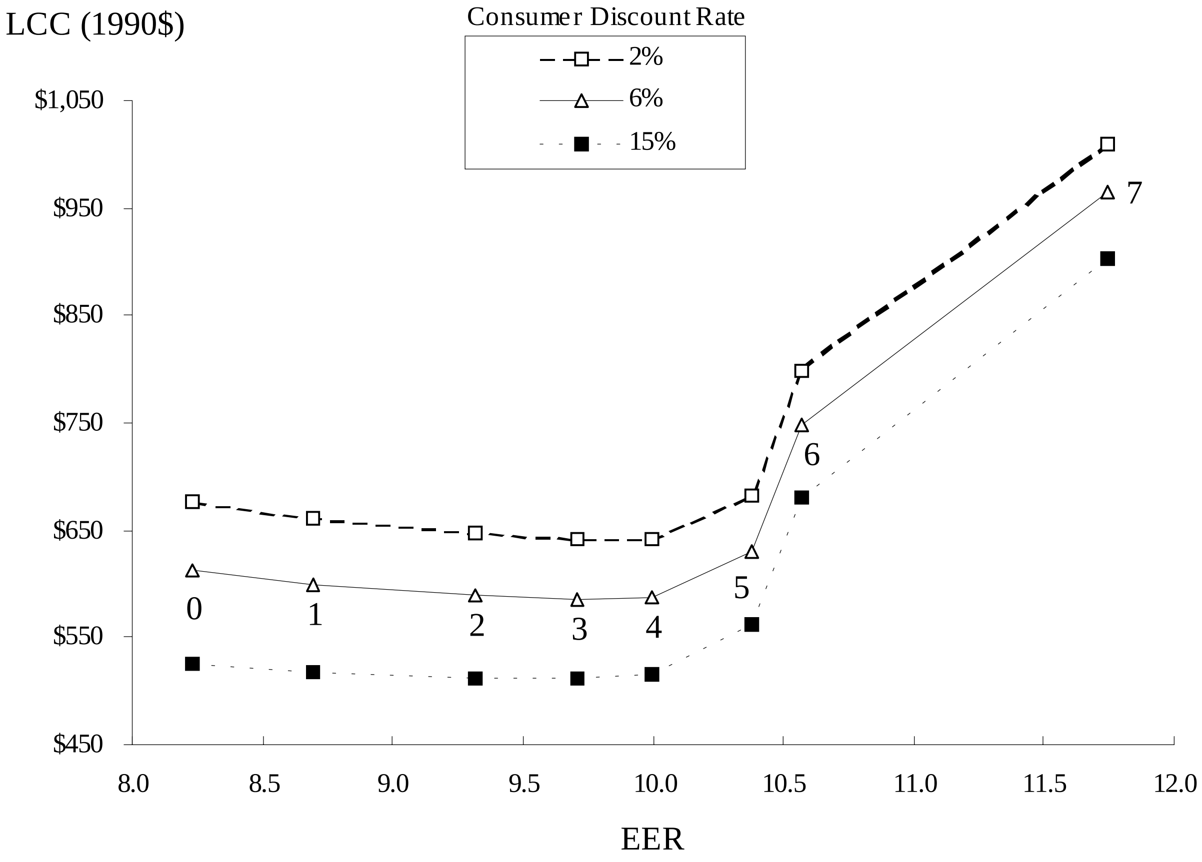

Table 4.1 Life-Cycle Costs for Room A/C < 6,000 Btu/h (with louvered sides)

Efficiency Level	Design No.	Design Option	EER Btu/W-hr	Retail Price	Installation Cost	Installed Consumer Cost	Annual Maintenance Cost (@6%)	Annual Elec. Use kWh	Annual Energy Expense	Life-Cycle Costs		
										2%	6%	15%
	0	Baseline	8.23	$372	$0	$372	$0	379	$28	$677	$612	$525
	1	0 + Evap/Cond Enhanced Fins	8.70	$373	$0	$373	$0	358	$26	$661	$600	$518
1	2	1 + PSC Fan Motor	9.32	$378	$0	$378	$0	334	$25	$647	$589	$513
2	3	2 + Evap/Cond Grooved Tubes	9.71	$383	$0	$383	$0	321	$24	$641	$586	$512
3	4	3 + Add Subcooler	10.00	$390	$0	$390	$0	312	$23	$641	$587	$516
4	5	4 + Increase Evap/Cond Coil Area	10.38	$440	$0	$440	$0	300	$22	$682	$630	$562
	6	5 + Brushless D.C. Fan Motor	10.57	$560	$0	$560	$0	295	$22	$798	$747	$680
5	7	6 + **Variable Speed Compressor	11.74	$796	$0	$796	$0	265	$20	$1,010	$964	$904

** Design options incorporating variable-speed compressors are rated with a SEER.
All dollar values in 1990$
Electricity price = 0.0735 $/kWh
Lifetime = 12.5 years.

Figure 4.2 Life-Cycle Costs for Room A/C 6,000 to 7,999 Btu/hr (with louvered sides)

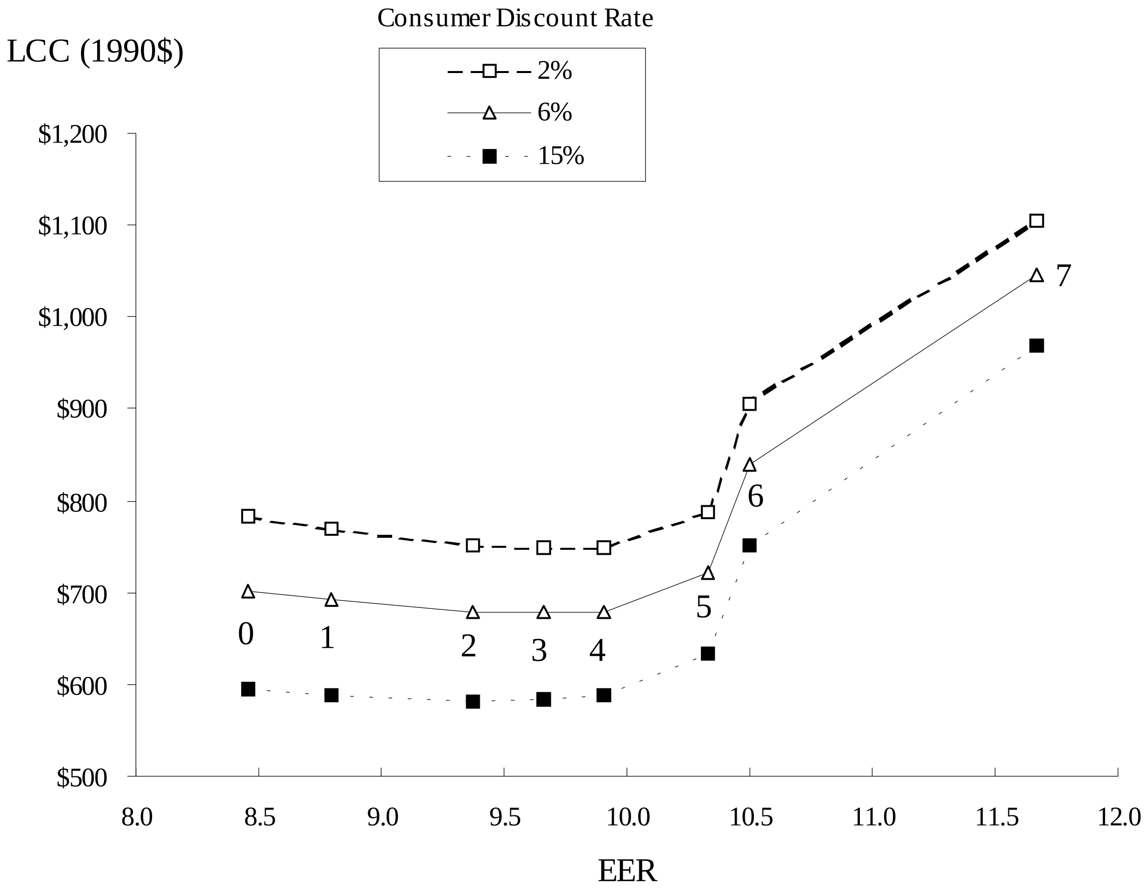

Table 4.2 Life-Cycle Costs for Room A/C 6,000 to 7,999 Btu/h (with louvered sides)

Efficiency Level	Design No.	Design Option	EER	Retail Price	Installation Cost	Installed Consumer Cost	Annual Maintenance Cost	Annual Elec. Use	Annual Energy Expense	Life-Cycle Costs		
			Btu/W-hr				(@6%)	*kWh*		2%	6%	15%
	0	Baseline	8.46	$404	$0	$404	$0	471	$35	$783	$702	$594
	1	0 + Evap/Cond Enhanced Fins	8.80	$405	$0	$405	$0	453	$33	$770	$692	$588
1	2	1 + PSC Fan Motor	9.38	$410	$0	$410	$0	425	$31	$753	$679	$582
2	3	2 + Add Subcooler	9.66	$417	$0	$417	$0	412	$30	$749	$678	$584
3	4	3 + Evap/Cond Grooved Tubes	9.91	$425	$0	$425	$0	402	$30	$749	$679	$587
4	5	4 + Increase Evap/Cond Coil Area	10.33	$478	$0	$478	$0	386	$28	$789	$722	$634
	6	5 + Brushless D.C. Fan Motor	10.50	$599	$0	$599	$0	379	$28	$904	$839	$752
5	7	6 + **Variable Speed Compressor	11.67	$830	$0	$830	$0	341	$25	$1,106	$1,047	$969

** Design options incorporating variable-speed compressors are rated with a SEER.
All dollar values in 1990$
Electricity price = 0.0735 $/kWh
Lifetime = 12.5 years.

Figure 4.3 Life-Cycle Costs for Room A/C 6,000 to 7,999 Btu/hr (without louvered sides)

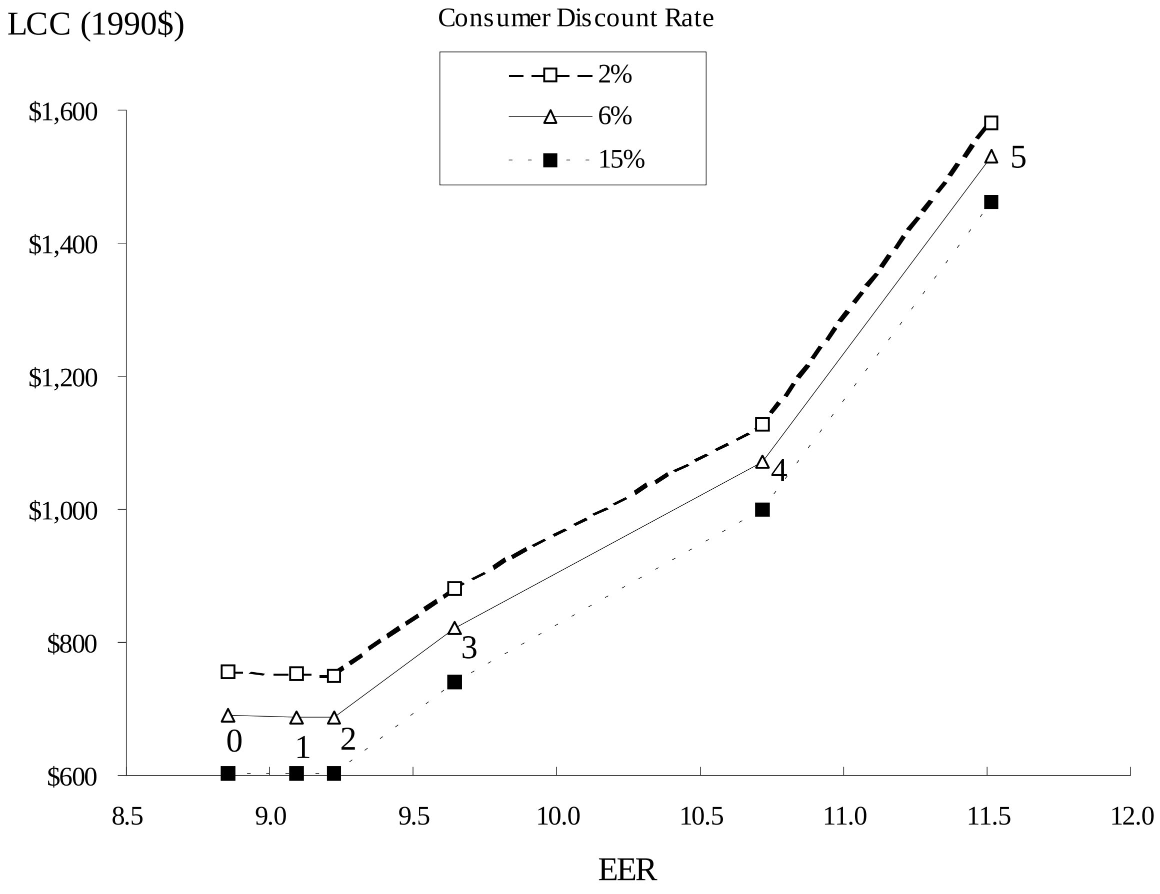

Table 4.3 Life-Cycle Costs for Room A/C 6,000 to 7,999 Btu/hr (without louvered sides)

Eficiency Level	Design No.	Design Option	EER Btu/W-hr	Retail Price	Installation Cost	Installed Consumer Cost	Annual Maintenance Cost (@6%)	Annual Elec. Use kWh	Annual Energy Expense	Life-Cycle Costs 2%	6%	15%
	0	Baseline	8.86	$447	$0	$447	$0	382	$28	$755	$689	$602
1,2	1	0 + Incr Compressor EER to 10.76	9.10	$452	$0	$452	$0	372	$27	$752	$688	$603
3,4	2	1 + Add Subcooler	9.23	$456	$0	$456	$0	367	$27	$751	$688	$604
	3	2 + Brushless D.C. Fan Motor	9.65	$599	$0	$599	$0	351	$26	$882	$822	$741
	4	3 + **Variable Speed Compressor	10.72	$873	$0	$873	$0	316	$23	$1,127	$1,073	$1,001
5	5	4 + **Increase Evap/Cond Coil Area	11.52	$1,014	$331	$1,345	$0	294	$22	$1,582	$1,531	$1,464

** Design options incorporating variable-speed compressors are rated with a SEER.
All dollar values in 1990$
Electricity price = 0.0735 $/kWh
Lifetime = 12.5 years.

Figure 4.4 Life-Cycle Costs for Room A/C 8,000 to 13,999 Btu/hr (with louvered sides)

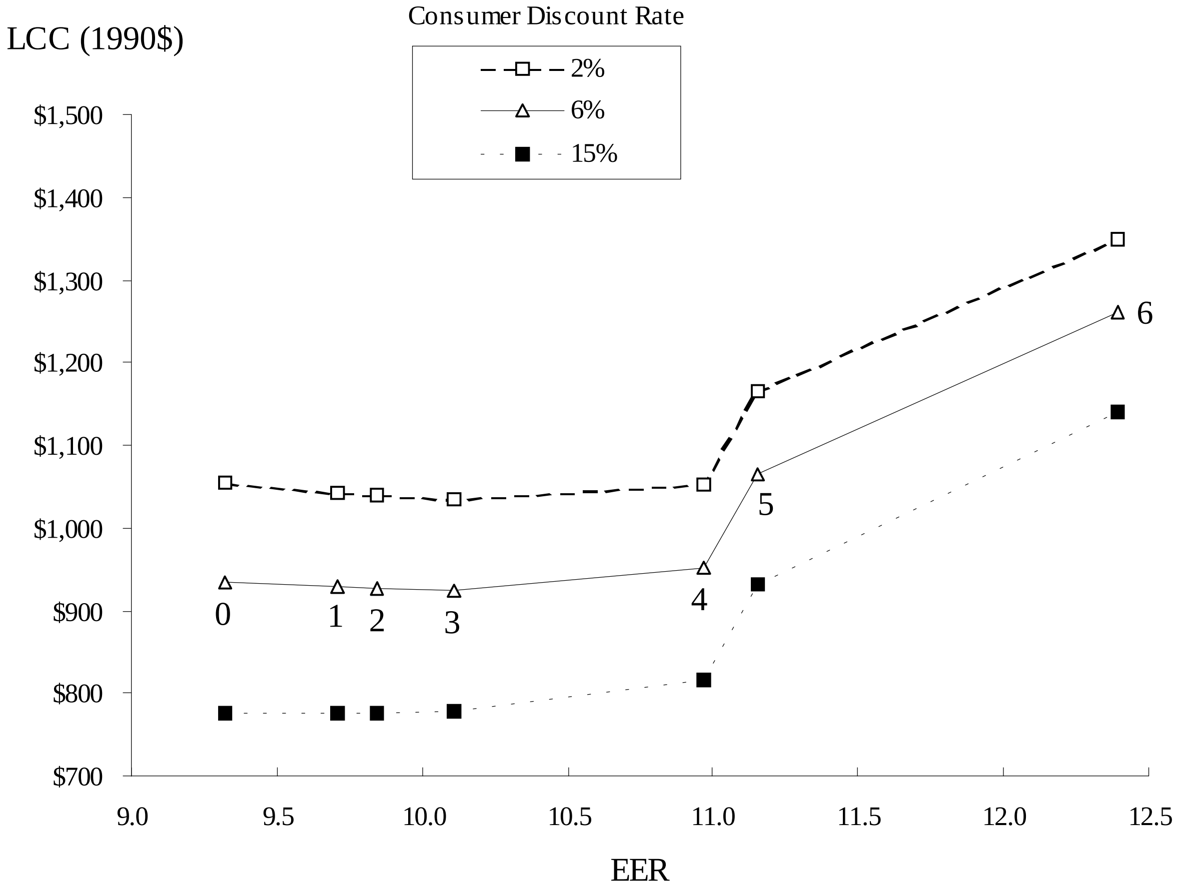

Table 4.4 Life-Cycle Costs for Room A/C 8,000 to 13,999 Btu/hr (with louvered sides)

Efficiency Level	Design No.	Design Option	EER Btu/W-hr	Retail Price	Installation Cost	Installed Consumer Cost	Annual Maintenance Cost (@6%)	Annual Elec. Use kWh	Annual Energy Expense	Life-Cycle Costs		
										2%	6%	15%
	0	Baseline	9.32	$495	$0	$495	$0	694	$51	$1,054	$935	$776
1	1	0 + Incr Compressor EER to 10.82	9.71	$506	$0	$506	$0	666	$49	$1,043	$928	$775
2	2	1 + Add Subcooler	9.85	$510	$0	$510	$0	657	$48	$1,039	$926	$776
3	3	2 + Evap/Cond Grooved Tubes	10.11	$518	$0	$518	$0	640	$47	$1,034	$924	$777
4	4	3 + Increase Evap/Cond Coil Area	10.97	$577	$0	$577	$0	590	$43	$1,052	$951	$815
	5	4 + Brushless D.C. Fan Motor	11.15	$697	$0	$697	$0	580	$43	$1,165	$1,065	$932
5	6	5 + **Variable Speed Compressor	12.39	$929	$0	$929	$0	522	$38	$1,350	$1,260	$1,141

** Design options incorporating variable-speed compressors are rated with a SEER.
All dollar values in 1990$
Electricity price = 0.0735 $/kWh
Lifetime = 12.5 years.

Figure 4.5 Life-Cycle Costs for Room A/C 8,000 to 13,999 Btu/hr (without louvered sides)

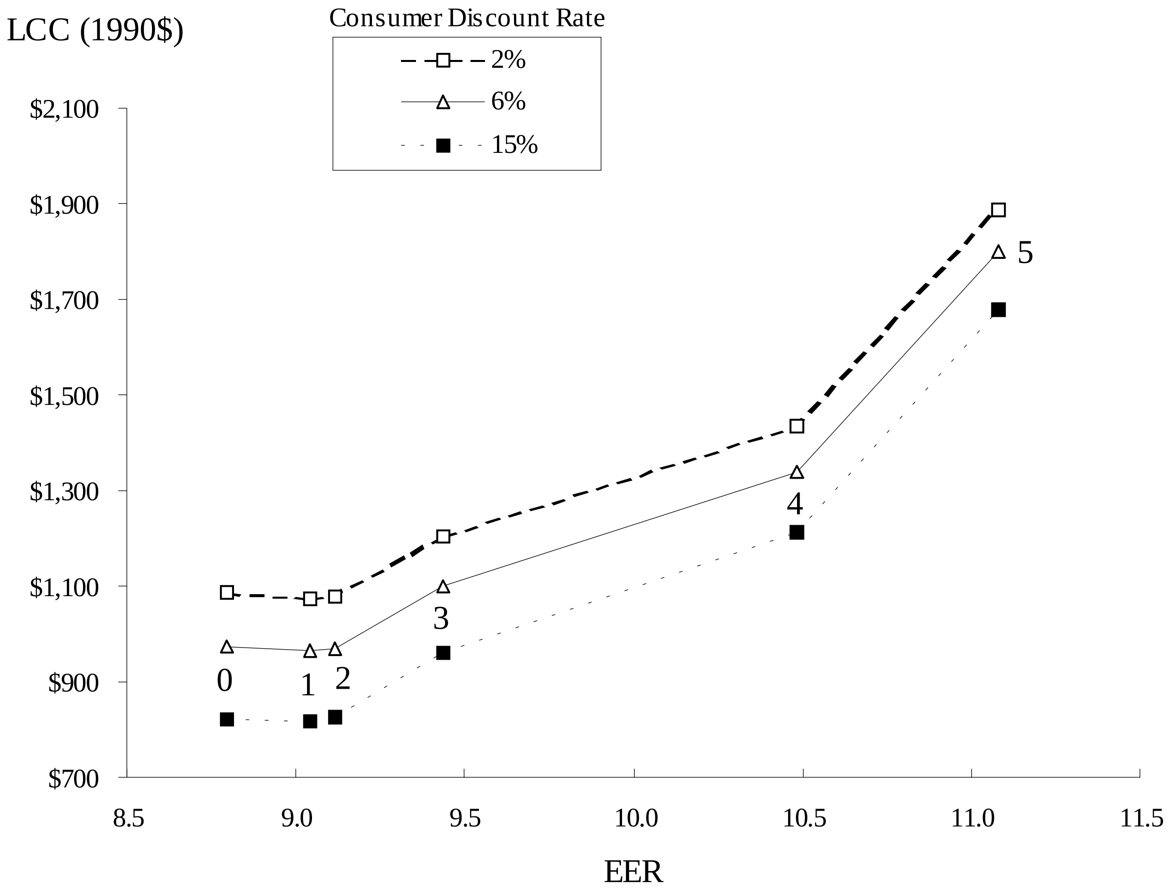

Table 4.5 Life-Cycle Costs for Room A/C 8,000 to 13,999 Btu/hr (without louvered sides)

Efficiency Level	Design No.	Design Option	EER *Btu/W-hr*	Retail Price	Installation Cost	Installed Consumer Cost	Annual Maintenance Cost (@6%)	Annual Elec. Use *kWh*	Annual Energy Expense	Life-Cycle Costs 2%	 6%	 15%
1	0	Baseline	8.80	$558	$0	$558	$0	654	$48	$1,086	$973	$823
2	1	0 + Add Subcooler	9.05	$562	$0	$562	$0	636	$47	$1,075	$965	$819
3,4	2	1 + Incr Compressor EER to 11.09	9.12	$569	$0	$569	$0	632	$46	$1,078	$969	$825
	3	2 + Brushless D.C. Fan Motor	9.44	$714	$0	$714	$0	610	$45	$1,205	$1,100	$961
	4	3 + **Variable Speed Compressor	10.49	$992	$0	$992	$0	549	$40	$1,435	$1,340	$1,214
5	5	4 + **Increase Evap/Cond Coil Area	11.08	$1,139	$331	$1,470	$0	519	$38	$1,888	$1,799	$1,680

** Design options incorporating variable-speed compressors are rated with a SEER.
All dollar values in 1990$
Electricity price = 0.0735 $/kWh
Lifetime = 12.5 years.

Figure 4.6 Life-Cycle Costs for Room A/C 14,000 to 19,999 Btu/hr (with louvered sides)

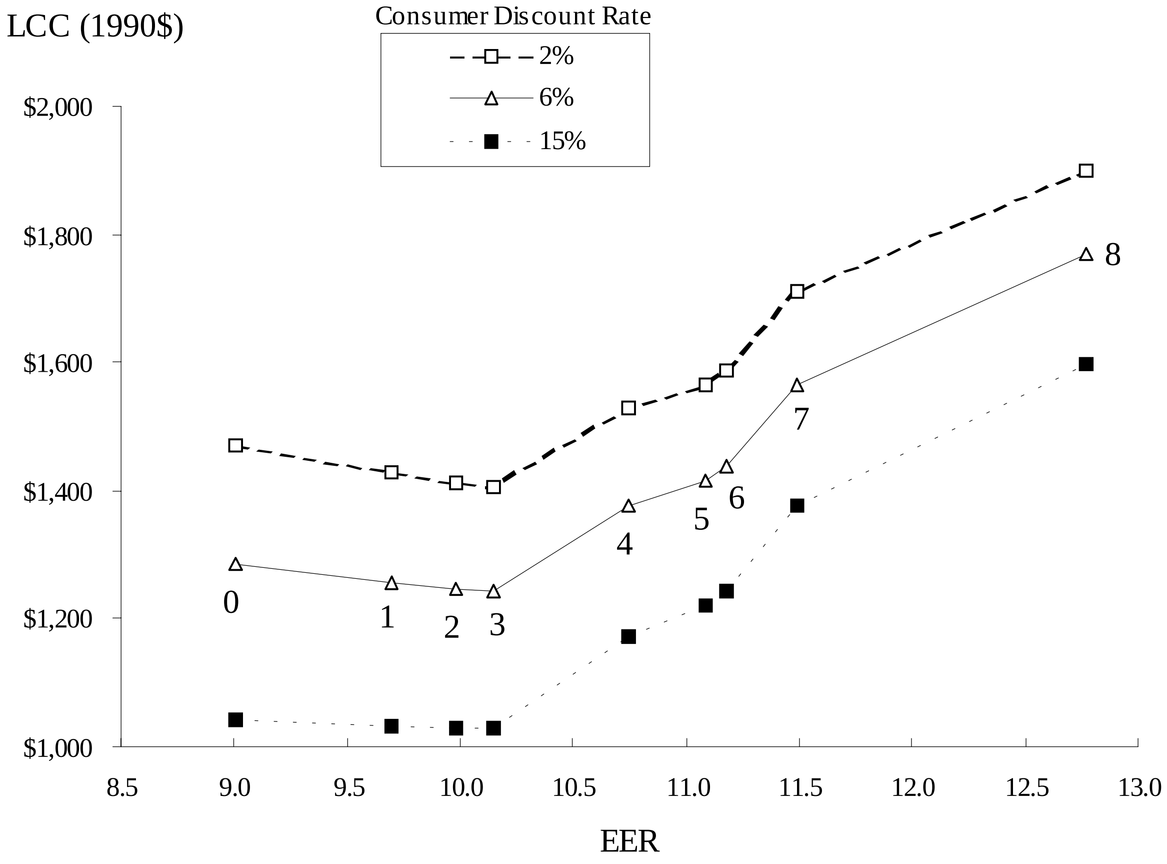

Table 4.6 Life-Cycle Costs for Room A/C 14,000 to 19,999 Btu/hr (with louvered sides)

Efficiency Level	Design No.	Design Option	EER	Retail Price	Installation Cost	Installed Consumer Cost	Annual Maintenance Cost	Annual Elec. Use	Annual Energy Expense	Life-Cycle Costs		
			Btu/W-hr				(@6%)	*kWh*		2%	6%	15%
	0	Baseline	9.00	$613	$0	$613	$0	1063	$78	$1,469	$1,286	$1,043
1	1	0 + Incr Compressor EER to 10.78	9.70	$632	$0	$632	$0	987	$73	$1,428	$1,258	$1,032
2	2	1 + Condenser Grooved Tubes	9.98	$640	$0	$640	$0	959	$70	$1,412	$1,247	$1,028
3,4	3	2 + Add Subcooler	10.15	$648	$0	$648	$0	943	$69	$1,407	$1,245	$1,029
	4	3 + Increase Evap/Cond Coil Area	10.74	$812	$0	$812	$0	891	$65	$1,530	$1,376	$1,172
	5	4 + Incr Compressor EER to 11.3	11.09	$870	$0	$870	$0	863	$63	$1,566	$1,417	$1,219
	6	5 + Incr Compressor EER to 11.4	11.18	$897	$0	$897	$0	856	$63	$1,587	$1,440	$1,244
	7	6 + Brushless D.C. Fan Motor	11.50	$1,039	$0	$1,039	$0	832	$61	$1,709	$1,566	$1,375
5	8	7 + **Variable Speed Compressor	12.77	$1,295	$0	$1,295	$0	749	$55	$1,898	$1,769	$1,598

** Design options incorporating variable-speed compressors are rated with a SEER.
All dollar values in 1990$
Electricity price = 0.0735 $/kWh
Lifetime = 12.5 years.

Figure 4.7 Life-Cycle Costs for Room A/C ≥ 20,000 Btu/hr (with louvered sides)

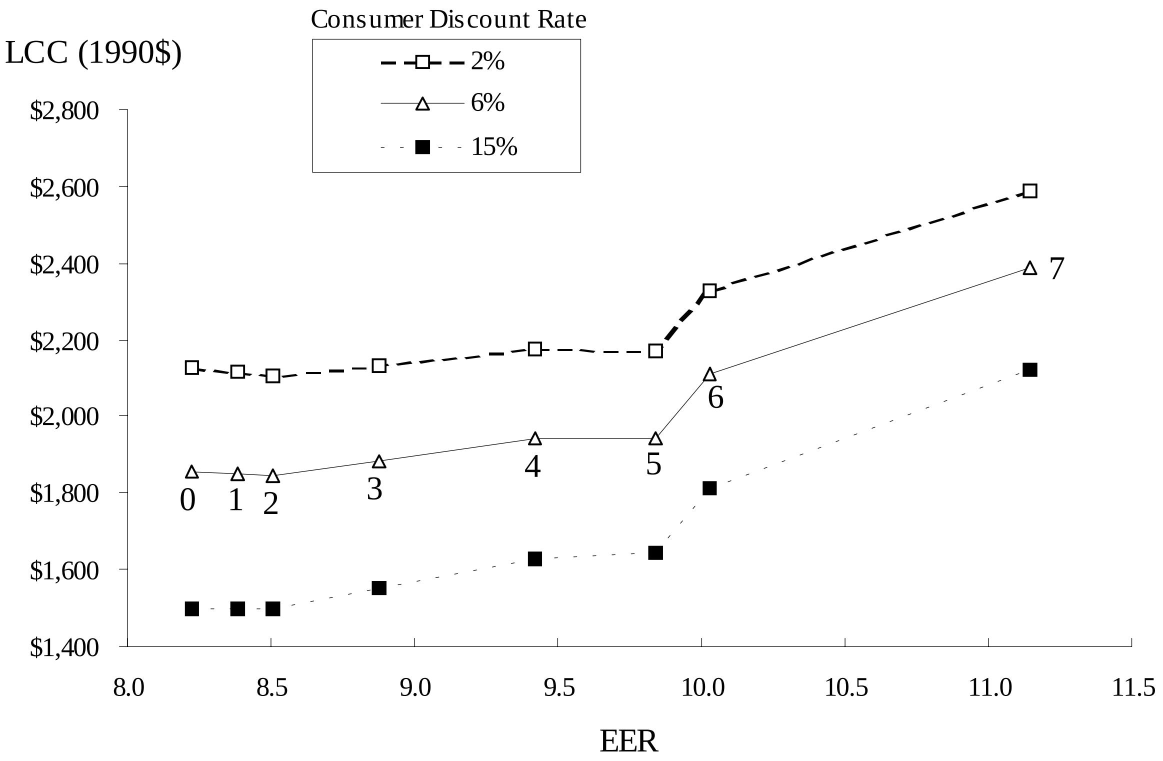

Table 4.7 Life-Cycle Costs for Room A/C > 20,000 Btu/hr (with louvered sides)

Efficiency Level	Design No.	Design Option	EER	Retail Price	Installation Cost	Installed Consumer Cost	Annual Maintenance Cost	Annual Elec. Use	Annual Energy Expense	Life-Cycle Costs		
			Btu/W-hr				(@6%)	*kWh*		2%	6%	15%
	0	Baseline	8.22	$859	$0	$859	$0	1573	$116	$2,127	$1,856	$1,496
1,2	1	0 + Incr Compressor EER to 10.89	8.39	$871	$0	$871	$0	1543	$113	$2,114	$1,849	$1,495
3	2	1 + Add Subcooler	8.51	$880	$0	$880	$0	1520	$112	$2,106	$1,844	$1,495
4	3	2 + Incr Compressor EER to 11.5	8.88	$960	$0	$960	$0	1457	$107	$2,134	$1,884	$1,550
	4	3 + Increase Evap/Cond Coil Area	9.42	$1,071	$0	$1,071	$0	1373	$101	$2,178	$1,941	$1,627
	5	4 + Incr Compressor EER to 11.7	9.84	$1,112	$0	$1,112	$0	1315	$97	$2,171	$1,945	$1,644
	6	5 + Brushless D.C. Fan Motor	10.03	$1,291	$0	$1,291	$0	1290	$95	$2,330	$2,108	$1,813
5	7	6 + **Variable Speed Compressor	11.14	$1,653	$0	$1,653	$0	1161	$85	$2,588	$2,389	$2,123

** Design options incorporating variable-speed compressors are rated with a SEER.
All dollar values in 1990$
Electricity price = 0.0735 $/kWh
Lifetime = 12.5 years.

Figure 4.8 Life-Cycle Costs for Room A/C with Reverse Cycle (with louvered sides)

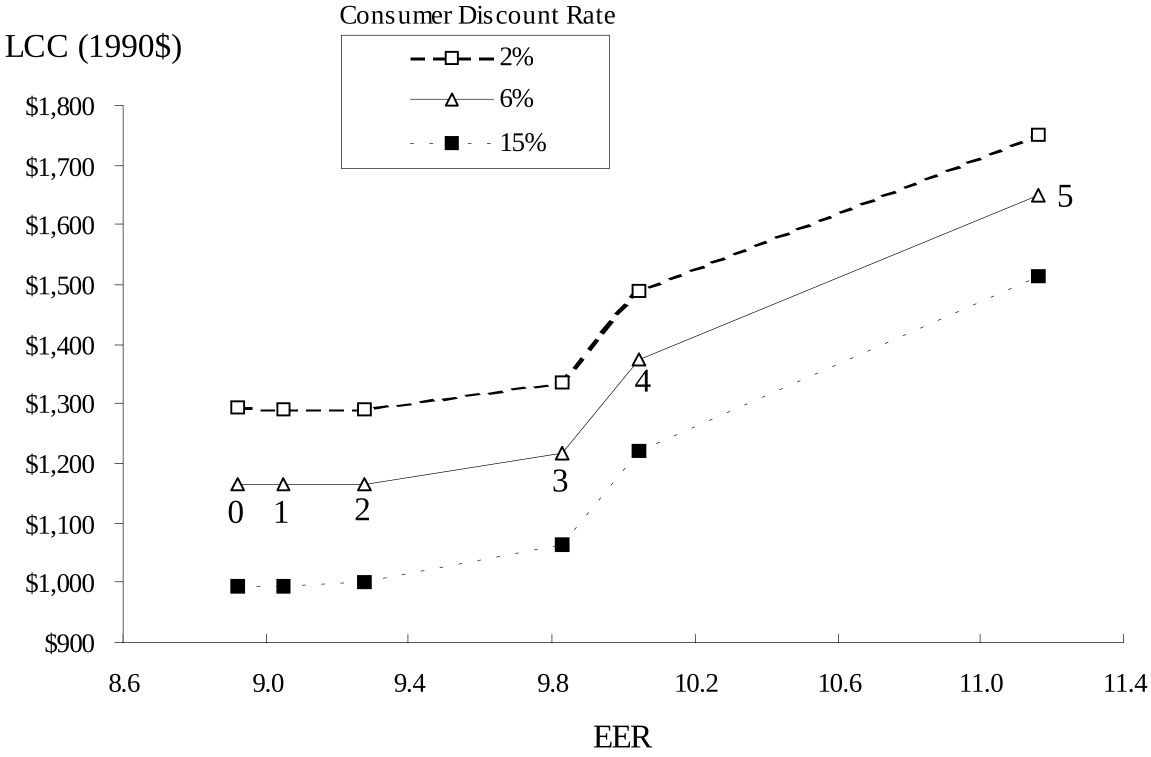

Table 4.8 Life-Cycle Costs for Room A/C with Reverse Cycle (with louvered sides)

Efficiency Level	Design No.	Design Option	EER	Retail Price	Installation Cost	Installed Consumer Cost	Annual Maintenance Cost	Annual Elec. Use	Annual Energy Expense	Life-Cycle Costs		
			Btu/W-hr				(@6%)	*kWh*		2%	6%	15%
	0	Baseline	8.92	$690	$0	$690	$0	750	$55	$1,294	$1,165	$993
1,2	1	0 + Add Subcooler	9.05	$695	$0	$695	$0	739	$54	$1,291	$1,164	$994
3,4	2	1 + Incr Compressor EER to 10.82	9.27	$708	$0	$708	$0	722	$53	$1,289	$1,165	$999
	3	2 + Increase Evap/Cond Coil Area	9.83	$788	$0	$788	$0	681	$50	$1,336	$1,219	$1,063
	4	3 + Brushless D.C. Fan Motor	10.05	$952	$0	$952	$0	666	$49	$1,489	$1,374	$1,222
5	5	4 + **Variable Speed Compressor	11.16	$1,270	$0	$1,270	$0	600	$44	$1,753	$1,650	$1,512

** Design options incorporating variable-speed compressors are rated with a SEER.
All dollar values in 1990$
Electricity price = 0.0735 $/kWh
Lifetime = 12.5 years.

Figure 4.9 Life-Cycle Costs for Room A/C with Reverse Cycle (without louvered sides)

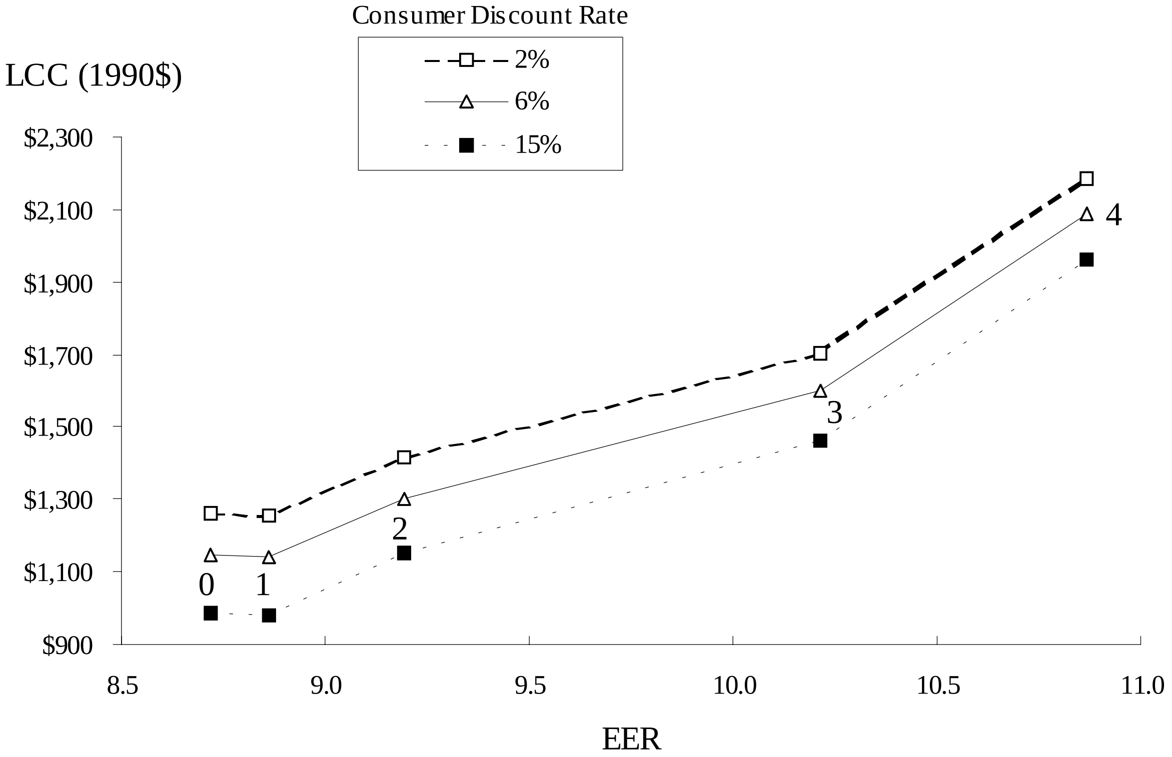

Table 4.9 Life-Cycle Costs for Room A/C with Reverse Cycle (without louvered sides)

Efficiency Level	Design No.	Design Option	EER Btu/W-hr	Retail Price	Installation Cost	Installed Consumer Cost	Annual Maintenance Cost (@6%)	Annual Elec. Use kWh	Annual Energy Expense	Life-Cycle Costs 2%	6%	15%
1,2	0	Baseline	8.72	$704	$0	$704	$0	694	$51	$1,263	$1,144	$985
3,4	1	0 + Condenser Enhanced Fins	8.86	$707	$0	$707	$0	683	$50	$1,257	$1,140	$983
	2	1 + Brushless D.C. Fan Motor	9.20	$884	$0	$884	$0	658	$48	$1,414	$1,300	$1,150
	3	2 + **Variable Speed Compressor	10.22	$1,225	$0	$1,225	$0	592	$44	$1,702	$1,600	$1,465
5	4	3 + **Increase Evap/Cond Coil Area	10.87	$1,405	$331	$1,736	$0	557	$41	$2,184	$2,088	$1,961

** Design options incorporating variable-speed compressors are rated with a SEER.
All dollar values in 1990$
Electricity price = 0.0735 $/kWh
Lifetime = 12.5 years.

4.2 PAYBACK PERIODS BY ENERGY EFFICIENCY LEVEL

The payback period (PBP) measures the amount of time needed to recover the additional consumer investment in increased efficiency through lower operating costs. PBP is found by solving the equation:

$$\Delta PC + \sum_{t=1}^{PAY} \Delta OC_t = O \qquad \textbf{(4.4)}$$

for *PAY.* In general, *PAY* is found by interpolating between the two years when the expression in Eq. 4.4 changes sign. If the operating cost is constant, the equation has the simple solution:

$$PAY = -\frac{\Delta PC}{\Delta OC} \qquad \textbf{(4.5)}$$

Numerically, the PBP is the ratio of the increase in purchase (and installation) price from the base to the efficiency levels cases to the decrease in annual operating expenditures (including maintenance). PBPs are expressed in years. A PBP of three years means that the increased purchase price is equal to three times the value of reduced operating expenses achieved in the year of purchase, or that the increased purchase price is recovered in approximately three years because of lower operating expenses. PBPs greater than the life of the product mean that the increased purchase price is not recovered in reduced operating expenses.

4.2.1 PBP Data Inputs

The data inputs are the same as in Section 4.1.1, except that, in addition, a distribution of design options is projected (by LBNL-REM) in the base case. Only those designs that are eliminated by the efficiency level are included in the calculation of impacts. Consumers whose base case choice is eliminated by efficiency levels are assumed to purchase the design option corresponding to the minimum compliance with the efficiency level.

4.2.2 PBP Results

The PBPs by efficiency level shown in Tables 4.10 through 4.18 are the weighted averages. They compare that portion of the projected distribution of designs in the base case which are less efficient than the efficiency level to the design at the efficiency level. Designs with energy consumption at or below the efficiency level are not affected by the efficiency level, and so are excluded from the calculation of impacts. Revised Tables 4.10-4.18 for payback results, which include the supplemental efficiency level, calculated using both AEO 1995 and GRI 1996 energy price forecasts are found in the Supplemental Analysis Section.

Tables 4.10 to 4.18 show the calculation of LCC differences, payback, and CCE. The tables are composed of several parts. Part a summarizes for each design option the installed consumer cost, annual electric use and operating expense, LCC (at 6% consumer discount rate), and the distribution of units sold in 1999, according to the base case forecast. Part b applies the weights from the distributions listed in the last column of Part a to the values in each preceding column in order to obtain weighted average values. It should be emphasized that only those distributions from Part a that precede the efficiency level of interest are used to calculate the weighted average values in Part b. For example, to arrive at the value of the installed consumer cost in Table 4.10b for which efficiency level 1 is being compared, only the installed costs from design numbers 0 (baseline) and 1 in Table 4.10a are used. The distributions of 70.9% and 9.6% for design numbers 0 and 1, respectively, are first normalized and then multiplied by their respective installed costs of $372.03 and $372.64. Adding the weighted installed costs for design numbers 0 and 1 together results in the installed cost of $372.10 for efficiency level 1 found in Table 4.10b. Finally, Part c shows the resulting LCC differences, PBPs, and CCE. In Part c, PBPs are presented which are based upon energy use data determined both from the existing DOE test procedure and recent field measurements. As discussed in Chapter 1 (Engineering Analysis), recent field data indicates that the annual use of room air conditioners is approximately 29% lower than that determined with DOE procedure calculations based on an annual hours of operation value of 750. Because the field data indicates a lower energy use, “field-based” PBPs are always greater than those determined with the existing test procedure.

4.3 CHANGE IN LIFE-CYCLE COSTS DUE TO ENERGY EFFICIENCY LEVELS

The impact of efficiency levels is calculated as the difference in LCC, base case minus efficiency levels case. If the LCC difference is greater than zero (positive savings), the efficiency level provides a net decrease in expenses to the consumer. That is, the present value of decreased operating expenses offsets the increased purchase price. Conversely, if the LCC difference is negative, the efficiency level causes a net increase in expenses to the consumer.

4.3.1 Data Inputs for Change in LCC

The data inputs are the same as in Section 4.1.1, except that, in addition, a distribution of design options is projected (by LBNL-REM) in the base case. Only those designs that are eliminated by the efficiency level are included in the calculation of impacts. Consumers whose base case choice is eliminated by efficiency levels are assumed to purchase the design option corresponding to the minimum compliance with the efficiency level.

4.3.2 Results for Change in LCC

Tables 4.10 through 4.18 show the LCC differences by efficiency level, one table for each class. The results are the weighted average of LCC differences comparing that portion of the projected distribution of designs in the base case that are less efficient than the efficiency level to the design at the efficiency level. Designs with energy consumption at or below the efficiency level are not affected by the efficiency level, so these are excluded from the calculation of impacts. These LCCs are calculated at a 6% discount rate; a higher discount rate (e.g., 15%) gives a smaller difference.

Tables 4.10c to 4.18c show lower LCC (positive LCC difference) for efficiency levels 1 to 3 for all classes. Efficiency level four demonstrates a higher LCC (negative LCC difference) in four classes, and standard level five shows a higher LCC in all classes.

4.4 COST OF CONSERVED ENERGY (CCE) DUE TO ENERGY EFFICIENCY LEVELS

The CCE is the increase in purchase price amortized over the lifetime of the appliance at the consumer discount rate divided by the annual energy savings:

$$\mathrm{CCE} = -\frac{\mathrm{CRF}\cdot\Delta\mathrm{PC}}{\Delta\mathrm{E}}, \qquad \mathbf{(4.6)}$$

where the capital recovery factor *CRF (*i.e., *1/PWF)* is used to annualize the capital costs. Note that although the CCE can be measured in cents per kWh, it does not depend on current or future energy prices. The consumer will benefit whenever the cost of conserved energy is less than the price of energy for that end use.

4.4.1 CCE Data Inputs

The data inputs are the same as in Section 4.1.1, except that, in addition, a distribution of design options is projected (by LBNL-REM) in the base case. Only those designs that are eliminated by the efficiency level are included in the calculation of impacts. Consumers whose base case choice is eliminated by efficiency levels are assumed to purchase the design option corresponding the minimum compliance with the efficiency level.

4.4.2 CCE Results

Tables 4.10 through 4.18 show the CCE energy (site) of the efficiency levels as compared to the base case. Note that the projected (1998) average residential electricity price is 7.94 cents per kWh (3). This is equivalent to 23.27 dollars per million Btu, where one kWh is taken as 3,412 Btu site energy.

Efficiency levels with CCEs less than projected costs of energy supply include:

All classes: efficiency levels 1 through 3.

8,000 to 13,999 Btu/hr without side louvers: efficiency level 4.

14,000 to 19,999 Btu/hr with side louvers: efficiency level 4.

Reverse Cycle with side louvers: efficiency level 4.

Reverse Cycle without side louvers: Efficiency level 4.

Efficiency levels with CCEs greater than projected costs of energy supply include:

All classes: efficiency level 5.

Less than 6,000 Btu/hr with side louvers: efficiency level 4.

6,000 to 7,999 Btu/hr with side louvers: efficiency level 4.

6,000 to 7,999 Btu/hr without side louvers: efficiency level 4.

8,000 to 13,999 Btu/hr with side louvers: efficiency level 4.

Greater than 20,000 Btu/hr with side louvers: efficiency level 4.

Revised CCE calculations, which include the supplemental efficiency level, using AEO 95 and GRI 96 energy price forecasts are found in Supplemental Tables 4.10-4.18. The CCE's calculated for the Supplemental Efficiency Level are less than the energy prices projected by either the EIA (AEO 95 and AEO 97)(4) or GRI (GRI 96).(5)

Table 4.10a Cost (1990$) and Energy-Use (Field Usage) Summary of Room Air Conditioners, Less than 6,000 Btu/hr, with Louvered Sides

Efficiency Level	Design No.	Installed Consumer Cost	Annual Elec. Use	Annual Operating Cost	Life-Cycle Cost	1999 Distribution
		(1990$)	*kWh/yr*	(1990$)	(1990$)	
	0	372.03	378.51	27.82	611.89	70.9%
	1	372.64	358.31	26.34	599.70	9.6%
1	2	377.57	334.43	24.58	589.50	9.0%
2	3	382.55	320.90	23.59	585.90	6.2%
3	4	389.51	311.69	22.91	587.02	2.7%
4	5	440.24	300.19	22.06	630.47	1.6%
	6	560.46	294.85	21.67	747.30	0.0%
5	7	796.18	265.36	19.50	964.34	0.0%

Table 4.10b Weighted Average of Units Sold below Efficiency Levels, Room Air Conditioners, Less than 6,000 Btu/hr, with Louvered Sides

Efficiency Level	1	2	3	4	5
Installed Consumer Cost (1990 $)	372.10	372.65	373.29	373.74	374.83
Annual Operating Cost (1990 $)	27.64	27.34	27.09	26.98	26.90
Life-Cycle Cost at 6% (1990 $)	610.44	608.34	606.89	606.34	606.74
Energy Use (*kWh/yr*)	376.11	371.93	368.63	367.07	365.97

Table 4.10c Life-Cycle Cost Difference (1990$), Payback Periods (years) and Costs of Conserved Energy (@6%) of Room Air Conditioners, Less Than 6,000 Btu/hr, with Louvered Sides

Efficiency Level	1	2	3	4	5
LCC Difference	20.94	22.44	19.87	-24.12	-357.60
Payback (years)					
Field	1.8	2.6	3.9	13.5	57.0
Existing Test Proc.	1.3	1.9	2.8	9.6	40.5
CCE (*cent/kWh*)	1.5	2.2	3.3	11.5	48.6

Table 4.11a Cost (1990$) and Energy-Use (Field Usage) Summary of Room Air Conditioners, 6,000 to 7,999 Btu/hr, with Louvered Sides

Efficiency Level	Design No.	Installed Consumer Cost	Annual Elec. Use	Annual Operating Cost	Life-Cycle Cost	1999 Distribution
		(1990$)	*kWh/yr*	(1990$)	(1990$)	
	0	403.82	471.06	34.62	702.33	48.5%
	1	405.25	452.75	33.28	692.15	14.8%
1	2	410.13	424.89	31.23	679.38	23.5%
2	3	416.89	412.31	30.30	678.17	11.2%
3	4	424.73	402.03	29.55	679.50	0.7%
4	5	477.78	385.68	28.35	722.19	0.4%
	6	598.82	379.26	27.88	839.15	0.9%
5	7	830.48	341.33	25.09	1046.78	0.0%

Table 4.11b Weighted Average of Units Sold below Efficiency Levels, Room Air Conditioners, 6,000 to 7,999 Btu/hr, with Louvered Sides

Efficiency Level	1	2	3	4	5
Installed Consumer Cost (1990 $)	404.15	405.77	407.04	407.18	409.11
Annual Operating Cost (1990 $)	34.31	33.47	33.11	33.09	33.02
Life-Cycle Cost at 6% (1990 $)	699.94	694.38	692.52	692.43	693.80
Energy Use (*kWh/yr*)	466.77	455.44	450.50	450.14	449.26

Table 4.11c Life-Cycle Cost Difference (1990$), Payback Periods (years) and Costs of Conserved Energy (@6%) of Room Air Conditioners, 6,000 to 7,999 Btu/hr, with Louvered Sides

Efficiency Level	1	2	3	4	5
LCC Difference	20.57	16.21	13.03	-29.76	-352.98
Payback (years)					
Field	1.9	3.5	5.0	14.9	53.1
Existing Test Proc.	1.4	2.5	3.5	10.6	37.7
CCE (*cent/kWh*)	1.7	3.0	4.2	12.7	45.3

Table 4.12a Cost (1990$) and Energy-Use (Field Usage) Summary of Room Air Conditioners, 6,000 to 7,999 Btu/hr, without Louvered Sides

Efficiency Level	Design No.	Installed Consumer Cost	Annual Elec. Use	Annual Operating Cost	Life-Cycle Cost	1999 Distribution
		(1990$)	*kWh/yr*	(1990$)	(1990$)	
	0	447.01	382.02	28.08	689.09	53.9%
1,2	1	452.23	371.94	27.34	687.92	9.8%
3,4	2	455.96	366.62	26.95	688.28	11.1%
	3	599.35	350.65	25.77	821.56	25.2%
	4	872.95	315.59	23.20	1072.94	0.0%
5	7	1344.94	293.75	21.59	1531.09	0.0%

Table 4.12b Weighted Average of Units Sold below Efficiency Levels, Room Air Conditioners, 6,000 to 7,999 Btu/hr, without Louvered Sides

Efficiency Level	1	2	3	4	5
Installed Consumer Cost (1990 $)	447.01	447.01	447.82	447.82	486.92
Annual Operating Cost (1990 $)	28.08	28.08	27.96	27.96	27.30
Life-Cycle Cost at 6% (1990 $)	689.09	689.09	688.91	688.91	722.28
Energy Use (*kWh/yr*)	382.02	382.02	380.46	380.46	371.41

Table 4.12c Life-Cycle Cost Difference (1990$), Payback Periods (years) and Costs of Conserved Energy (@6%) of Room Air Conditioners, 6,000 to 7,999 Btu/hr, without Louvered Sides

Efficiency Level	1	2	3	4	5
LCC Difference	1.17	1.17	0.63	0.63	-808.80
Payback (years)					
Field	7.0	7.0	8.0	8.0	150.3
Existing Test Proc.	5.0	5.0	5.7	5.7	106.7
CCE (*cent/kWh*)	4.5	4.5	4.6	10.9	23.8

Table 4.13a Cost (1990$) and Energy-Use (Field Usage) Summary of Room Air Conditioners, 8,000 to 13,999 Btu/hr, with Louvered Sides

Efficiency Level	Design No.	Installed Consumer Cost	Annual Elec. Use	Annual Operating Cost	Life-Cycle Cost	1999 Distribution
		(1990$)	*kWh/yr*	(1990$)	(1990$)	
	0	495.06	694.12	51.02	934.92	52.0%
1	1	505.83	666.46	48.98	928.16	18.0%
2	2	509.76	657.19	48.30	926.21	10.8%
3	3	518.17	640.03	47.04	923.75	12.4%
4	4	576.63	590.02	43.37	950.52	4.4%
	5	697.06	580.28	42.65	1064.78	0.5%
5	6	929.44	522.25	38.39	1260.39	1.9%

Table 4.13b Weighted Average of Units Sold below Efficiency Levels, Room Air Conditioners, 8,000 to 13,999 Btu/hr, with Louvered Sides

Efficiency Level	1	2	3	4	5
Installed Consumer Cost (1990 $)	495.06	497.82	499.42	501.91	506.29
Annual Operating Cost (1990 $)	51.02	50.50	50.20	49.78	49.46
Life-Cycle Cost at 6% (1990 $)	934.92	933.19	932.25	931.12	932.68
Energy Use (*kWh/yr*)	694.12	687.03	683.03	677.31	672.87

Table 4.13c Life-Cycle Cost Difference (1990$), Payback Periods (years) and Costs of Conserved Energy (@6%) of Room Air Conditioners, 8,000 to 13,999 Btu/hr, with Louvered Sides

Efficiency Level	1	2	3	4	5
LCC Difference	6.76	6.97	8.50	-19.40	-327.71
Payback (years)					
Field	5.3	5.4	5.9	11.6	38.2
Existing Test Proc.	3.8	3.9	4.2	8.3	27.1
CCE (*cent/kWh*)	4.5	4.6	5.1	9.9	32.6

Table 4.14a Cost (1990$) and Energy-Use (Field Usage) Summary of Room Air Conditioners, 8,000 to 13,999 Btu/hr, without Louvered Sides

Efficiency Level	Design No.	Installed Consumer Cost	Annual Elec. Use	Annual Operating Cost	Life-Cycle Cost	1999 Distribution
		(1990$)	*kWh/yr*	(1990$)	(1990$)	
1	0	558.35	654.42	48.10	973.05	60.7%
2	1	561.89	636.48	46.78	965.22	9.7%
3,4	2	569.09	631.59	46.42	969.33	12.2%
	3	713.85	610.04	44.84	1100.43	17.1%
	4	992.19	549.04	40.35	1340.11	0.2%
5	7	1469.75	519.39	38.18	1798.88	0.0%

Table 4.14b Weighted Average of Units Sold below Efficiency Levels, Room Air Conditioners, 8,000 to 13,999 Btu/hr, without Louvered Sides

Efficiency Level	1	2	3	4	5
Installed Consumer Cost (1990 $)	N/A	558.35	558.84	558.84	587.61
Annual Operating Cost (1990 $)	N/A	48.10	47.92	47.92	47.19
Life-Cycle Cost at 6% (1990 $)	N/A	973.05	971.97	971.97	994.48
Energy Use (*kWh/yr*)	N/A	654.42	651.94	651.94	642.05

Table 4.14c Life-Cycle Cost Difference (1990$), Payback Periods (years) and Costs of Conserved Energy (@6%) of Room Air Conditioners, 8,000 to 13,999 Btu/hr, without Louvered Sides

Efficiency Level	1	2	3	4	5
LCC Difference	N/A	7.83	2.65	2.65	-804.41
Payback (years)					
Field	N/A	2.7	6.9	6.9	97.8
Existing Test Proc.	N/A	1.9	4.9	4.9	69.5
CCE (*cent/kWh*)	N/A	2.3	5.8	5.8	83.4

Table 4.15a Cost (1990$) and Energy-Use (Field Usage) Summary of Room Air Conditioners, 14,000 to 19,999 Btu/hr, with Louvered Sides

Efficiency Level	Design No.	Installed Consumer Cost	Annual Elec. Use	Annual Operating Cost	Life-Cycle Cost	1999 Distribution
		(1990$)	*kWh/yr*	(1990$)	(1990$)	
	0	612.76	1062.76	78.11	1286.23	60.3%
1	1	632.48	986.80	72.53	1257.81	16.2%
2	2	639.63	958.91	70.48	1247.28	8.8%
3,4	3	647.54	942.93	69.31	1245.07	12.5%
	4	811.82	890.62	65.46	1376.20	2.3%
	5	870.27	863.06	63.43	1417.18	0.0%
	6	897.30	856.11	62.92	1439.81	0.0%
	7	1038.75	832.28	61.17	1566.16	0.0%
5	8	1294.53	749.05	55.06	1769.20	0.0%

Table 4.15b Weighted Average of Units Sold below Efficiency Levels, Room Air Conditioners, 14,000 to 19,999 Btu/hr, with Louvered Sides

Efficiency Level	1	2	3	4	5
Installed Consumer Cost (1990 $)	612.76	616.93	619.27	619.27	627.15
Annual Operating Cost (1990 $)	78.11	76.93	76.27	76.27	75.16
Life-Cycle Cost at 6% (1990 $)	1286.23	1280.22	1276.82	1276.82	1275.11
Energy Use (*kWh/yr*)	1062.76	1046.71	1037.64	1037.64	1022.52

Table 4.15c Life-Cycle Cost Difference (1990$), Payback Periods (years) and Costs of Conserved Energy (@6%) of Room Air Conditioners, 14,000 to 19,999 Btu/hr, with Louvered Sides

Efficiency Level	1	2	3	4	5
LCC Difference	28.42	32.94	31.75	31.75	-494.09
Payback (years)					
Field	3.5	3.5	4.1	4.1	33.2
Existing Test Proc.	2.5	2.5	2.9	2.9	23.6
CCE (*cent/kWh*)	3.0	3.0	3.5	3.5	28.3

Table 4.16a Cost (1990$) and Energy-Use (Field Usage) Summary of Room Air Conditioners, Greater than 20,000 Btu/hr, with Louvered Sides

Efficiency Level	Design No.	Installed Consumer Cost	Annual Elec. Use	Annual Operating Cost	Life-Cycle Cost	1999 Distribution
		(1990$)	*kWh/yr*	(1990$)	(1990$)	
	0	859.47	1572.75	115.60	1856.11	60.3%
1,2	1	871.31	1542.55	113.38	1848.81	16.2%
3	2	880.29	1520.43	111.75	1843.77	8.8%
4	3	960.00	1457.38	107.12	1883.53	12.5%
	4	1071.41	1372.63	100.89	1941.24	2.3%
	5	1111.79	1314.73	96.63	1944.92	0.0%
	6	1291.24	1289.56	94.78	2108.42	0.0%
5	7	1653.06	1160.60	85.30	2388.53	0.0%

Table 4.16b Weighted Average of Units Sold below Efficiency Levels, Room Air Conditioners, Greater than 20,000 Btu/hr, with Louvered Sides

Efficiency Level	1	2	3	4	5
Installed Consumer Cost (1990 $)	859.47	859.47	860.46	864.95	890.11
Annual Operating Cost (1990 $)	115.60	115.60	115.41	114.58	112.67
Life-Cycle Cost at 6% (1990 $)	1856.11	1856.11	1855.50	1852.84	1861.47
Energy Use (*kWh/yr*)	1572.75	1572.75	1570.21	1558.95	1532.86

Table 4.16c Life-Cycle Cost Difference (1990$), Payback Periods (years) and Costs of Conserved Energy (@6%) of Room Air Conditioners, Greater than 20,000 Btu/hr, with Louvered Sides

Efficiency Level	1	2	3	4	5
LCC Difference	7.30	7.30	11.72	-30.69	-527.05
Payback (years)					
Field	5.3	5.3	5.4	12.7	27.9
Existing Test Proc.	3.8	3.8	3.8	9.0	19.8
CCE (*cent/kWh*)	4.5	4.5	4.6	10.9	23.8

Table 4.17a Cost (1990$) and Energy-Use (Field Usage) Summary of Room Air Conditioners, with Reverse Cycle, with Louvered Sides

Efficiency Level	Design No.	Installed Consumer Cost	Annual Elec. Use	Annual Operating Cost	Life-Cycle Cost	1999 Distribution
		(1990$)	*kWh/yr*	(1990$)	(1990$)	
	0	689.83	750.16	55.14	1165.20	69.1%
1,2	1	695.16	739.30	54.34	1163.65	2.7%
3,4	2	707.54	721.61	53.04	1164.82	3.1%
	3	787.80	680.65	50.03	1219.12	23.1%
	4	952.26	666.15	48.96	1374.39	2.0%
5	7	1269.68	599.53	44.07	1649.60	0.0%

Table 4.17b Weighted Average of Units Sold below Efficiency Levels, Room Air Conditioners, with Reverse Cycle, with Louvered Sides

Efficiency Level	1	2	3	4	5
Installed Consumer Cost (1990 $)	689.83	689.83	690.03	690.03	718.46
Annual Operating Cost (1990 $)	55.14	55.14	55.11	55.11	53.74
Life-Cycle Cost at 6% (1990 $)	1165.20	1165.20	1165.15	1165.15	1181.83
Energy Use (*kWh/yr*)	750.16	750.16	749.76	749.76	731.21

Table 4.17c Life-Cycle Cost Difference (1990$), Payback Periods (years) and Costs of Conserved Energy (@6%) of Room Air Conditioners, with Reverse Cycle, with Louvered Sides

Efficiency Level	1	2	3	4	5
LCC Difference	1.55	1.55	0.33	0.33	-467.77
Payback (years)					
Field	6.7	6.7	8.5	8.5	57.0
Existing Test Proc.	4.7	4.7	6.0	6.0	40.4
CCE (*cent/kWh*)	5.7	5.7	7.2	7.2	48.6

Table 4.18a Cost (1990$) and Energy-Use (Field Usage) Summary of Room Air Conditioners, with Reverse Cycle, without Louvered Sides

Efficiency Level	Design No.	Installed Consumer Cost	Annual Elec. Use	Annual Operating Cost	Life-Cycle Cost	1999 Distribution
		(1990$)	*kWh/yr*	(1990$)	(1990$)	
1,2	0	704.13	693.92	51.00	1143.87	60.0%
3,4	1	706.90	682.72	50.18	1139.54	19.2%
	2	883.61	657.85	48.35	1300.49	20.8%
	3	1225.04	592.07	43.52	1600.23	0.0%
5	4	1735.77	556.54	40.91	2088.44	0.0%

Table 4.18b Weighted Average of Units Sold below Efficiency Levels, Room Air Conditioners, with Reverse Cycle, without Louvered Sides

Efficiency Level	1	2	3	4	5
Installed Consumer Cost (1990 $)	704.13	704.13	704.80	704.80	741.94
Annual Operating Cost (1990 $)	51.00	51.00	50.80	50.80	50.29
Life-Cycle Cost at 6% (1990 $)	1143.87	1143.87	1142.81	1142.81	1175.56
Energy Use (*kWh/yr*)	693.92	693.92	691.21	691.21	684.28

Table 4.18c Life-Cycle Cost Difference (1990$), Payback Periods (years) and Costs of Conserved Energy (@6%) of Room Air Conditioners, with Reverse Cycle, without Louvered Sides

Efficiency Level	1	2	3	4	5
LCC Difference	0.00	0.00	3.28	3.28	-912.88
Payback (years)					
Field	N/A	N/A	3.4	3.4	105.8
Existing Test Proc.	N/A	N/A	2.4	2.4	75.2
CCE (*cent/kWh*)	N/A	N/A	2.9	2.9	90.2

4.5 LCC SENSITIVITY ANALYSIS

The national LCC results were tested for sensitivity by varying assumptions about energy prices and equipment prices. The results of this analysis should be compared to the first set of tables in Section 4.1.

Low- and high-energy prices were defined as the minimum and maximum, respectively, of states' energy prices. State energy prices for 1992 (6), relative to the national average, were applied to the projected 1998 national average price from the *Annual Energy Outlook 1995* (7) to obtain state prices for 1998. (This represents a wider range of prices than analyzed in previous analyses, which used the average across Census regions.)

Low- and high-equipment prices were defined as one efficiency deviation below and above, respectively, the equipment prices used elsewhere in this chapter (from the Engineering Analysis). Note that the uncertainty in the baseline price is a percent of the total price, while the uncertainty in the price of other designs is applied to the incremental price of that design.

The following sensitivity cases were analyzed:

(1) low (state) energy prices;
(2) high equipment prices;
(3) low (state) energy prices and high equipment prices;
(4) high (state) energy prices;
(5) low equipment prices; and
(6) high (state) energy prices and low equipment prices;

Figure 4.10 and Table 4.19 summarize the results of the sensitivity analysis with the following:

- a graph of highest and lowest LCC sensitivity, and reference case;
- a table of LCCs for all sensitivity cases. The table also shows the number of sensitivity cases for which each design option is the minimum LCC.

A supplemental LCC sensitivity analysis was conducted for low and high state energy prices for the room air conditioners in the 8,000 -14,000 Btu/h, with side louvers, without reverse cycle class. See Supplemental Table 4.19. This analysis shows that the life-cycle cost minimums remain unchanged at high energy prices. For low State energy prices, any increase in standard above the baseline, shows a life-cycle cost increase; however, through standard level 3, this increase is less than $3.

Life cycle costs and paybacks were also calculated using energy prices calculated by the Gas Research Institute (GRI). See Supplemental Table 4.20 in the Supplemental Sensitivity Analysis. The life-cycle minimums resulting from the GRI projections remain unchanged from the analysis using the AEO price forecasts. The payback periods increase slightly, using the GRI forecasts, but remain well within the expected lifetime of the product.

Figure 4.10 Life-Cycle Cost Sensitivity Range for Room A/C < 6,000 Btu/hr (w/ louvered sides)

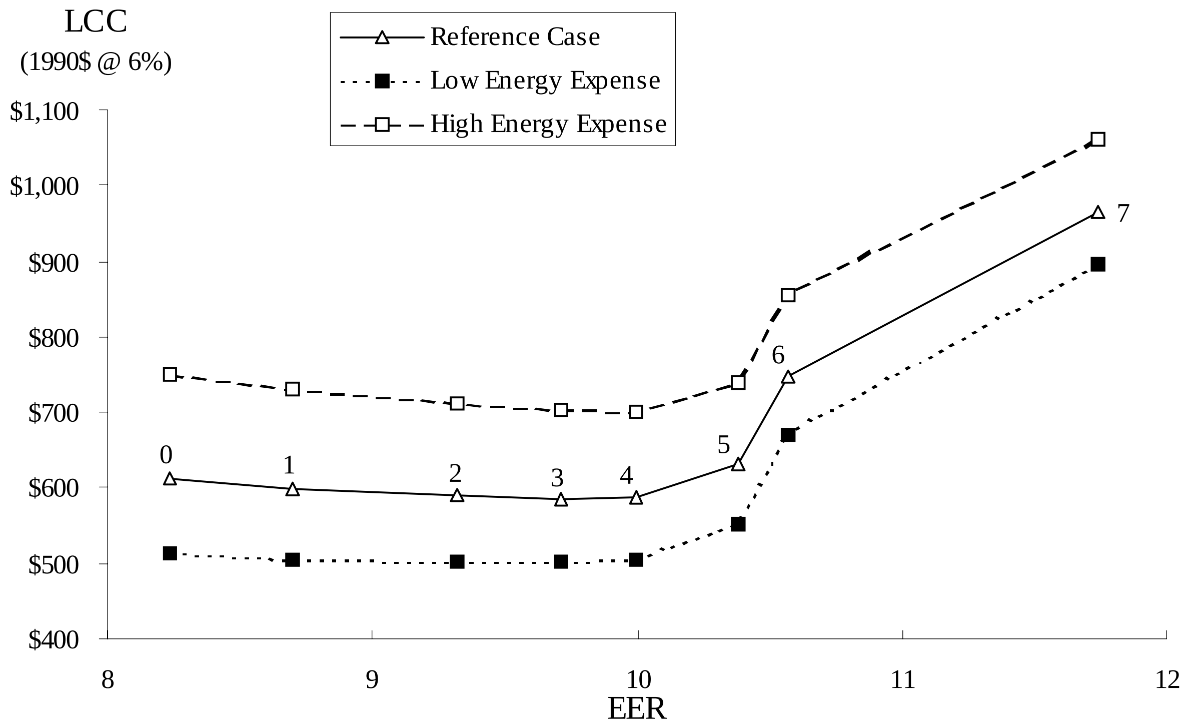

Table 4.19 Summary of LCC Sensitivities for Room A/C < 6,000 Btu/hr (w/ louvered sides)

Efficiency Level	Design No.	Sensitivity Scenarios: Reference	1	2	3	4	5	6	Number of times as min. LCC
	0	$611.89	$512.91	$630.49	$531.52	$749.77	$593.29	$731.17	
	1	$599.70	$506.01	$618.41	$524.72	$730.23	$580.99	$711.52	
1	2	$589.50	$502.05	$608.46	$521.01	$711.33	$570.54	$692.37	1
2	3	$585.90	$501.99	$605.40	$521.49	$702.80	$566.40	$683.30	4
3	4	$587.02	$505.52	$607.26	$525.76	$700.57	$566.79	$680.34	2
4	5	$630.47	$551.97	$658.73	$580.24	$739.82	$602.20	$711.55	
	6	$747.30	$670.21	$805.85	$728.76	$854.71	$688.75	$796.16	
5	7	$964.34	$894.95	$1083.32	$1013.93	$1061.01	$845.35	$942.02	

Minimum LCC values are noted with a heavy border for each sensitivity scenario.

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CHAPTER 5. IMPACTS OF ALTERNATIVE EFFICIENCY LEVELS ON THE MANUFACTURERS OF ROOM AIR CONDITIONERS

This chapter describes estimates of the impacts of alternative energy efficiency levels on manufacturers of room air conditioners. These estimates are based on the Lawrence Berkeley National Laboratory Manufacturer Analysis Model (LBNL-MAM), which consists of the former LBL-Manufacturer Impact Model and the Government Regulatory Impact Model developed by Arthur D. Little Consulting Company. The LBNL-MAM collects into one spreadsheet all calculations necessary to determine the impact of efficiency levels on an industry's profitability and scale of operation. A complete description of the LBNL-MAM is included in Appendix C of Volume 1: Methodology. The relevant inputs and outputs for the room air conditioner industry analysis is in Appendix C of this volume.

Room air conditioners were analyzed at five different energy efficiency levels. In each case it is assumed that the imposed efficiency levels would be just stringent enough to induce manufacturers to use all engineering design options up through the one listed to achieve the desired energy efficiency. For a complete description of these design options, see the Engineering Analysis in Chapter 1 of this volume.

5.1 LONG-RUN IMPACTS

The analysis shows that compared to the base case, the room air conditioner industry is likely to experience a small return on equity (ROE) decrease at efficiency levels 1 through 4, and a larger decrease in ROE at level 5. At efficiency level 1, there is approximately a 63% chance that ROE will decrease, with an expected decrease of 0.05%. At efficiency level 2, there is approximately a 64% chance ROE will decrease with a expected decrease of 0.08%. At efficiency level 3, there is approximately a 63% chance of a decrease in ROE with an expected decrease of 0.09%. At efficiency level 4, there is approximately a 71% chance of an decrease in ROE with an expected decrease of 0.59%. At efficiency level 5, there is approximately a 69% chance of a decrease in ROE with a expected decrease of 3.66%. These results are based on Table 5.1. The probabilities of change are computed from the expected change, the standard error of this estimate, and the assumption of a normal distribution.

5.1.1 Qualitative Analysis

The room air conditioner appliance manufacturing industry is characterized by economies of scale. The presence of economies of scale means that for the purpose of price determination there are fixed costs. These are estimated to be about 10% of total costs. Increases in fixed costs cannot be passed on, which implies that the markup over variable cost must be approximately 10% if the typical firm is to have a near average ROE. Because of this markup, and to the extent that implemented energy efficiency levels induce an increase in variable costs, such costs will be more than completely passed on in the form of a price increase which in itself is profitable, but which also tends to reduce profit through its effect on sales. If alternative efficiency levels induce an increase in fixed cost, this cost cannot be passed on and will negatively influence profit. Because of the mandated increase in efficiency, operating costs will necessarily decline, which will tend to increase profit (i.e., by making room air conditioners more attractive and thereby increasing demand). The model calculates that these effects, when combined, will tend to decrease typical firm's return on equity (ROE) at all efficiency levels. The model also calculates that these effects for each efficiency level will tend to increase industry net present value.

Table 5.1 Room Air Conditioners: Primary Scenario – Long-Run

Scenario= Primary			Long-Run			
	1996 Base	Lev 1	Lev 2	Lev 3	Lev 4	Lev 5
Shipments (in Mil)	0.61	0.61	0.61	0.61	0.59	0.48
% change		0.04%	-0.05%	-0.32%	-2.71%	-21.20%
S.E.		1.07%	1.37%	2.30%	3.63%	14.11%
Price	$304.35	$307.67	$309.86	$313.72	$338.27	$593.46
% change		1.09%	1.81%	3.08%	11.15%	94.99%
S.E.		1.29%	1.30%	1.88%	3.93%	27.19%
Revenue (in $M)	186.03	188.13	189.31	191.15	201.16	285.84
% change		1.13%	1.76%	2.75%	8.13%	53.65%
S.E.		1.07%	1.42%	2.06%	4.27%	30.47%
Net Income (in $M)	10.60	10.625	10.646	10.696	10.829	11.090
Difference		0.025	0.045	0.096	0.228	0.490
S.E.		0.173	0.252	0.400	1.250	11.796
ROE	10.88%	10.83%	10.80%	10.78%	10.28%	7.22%
Difference		-0.05%	-0.08%	-0.09%	-0.59%	-3.66%
S.E.		0.14%	0.21%	0.29%	1.05%	7.22%

Table 5.2 Room Air Conditioners: Industry Net Present Values

Summary Table	Pre-regulation	Post-regulation				
	Base	Level 1	Level 2	Level 3	Level 4	Level 5
Shipments (Units)	3.06	3.02	3.01	3.00	2.90	2.25
Difference		-0.04	-0.04	-0.05	-0.16	-0.80
% Change		-1.24%	-1.38%	-1.73%	-5.25%	-26.32%
Price ($ Unit)	$304.35	$318.85	$321.51	$326.24	$363.02	$698.99
Difference		14.50	17.16	21.89	58.67	394.64
% Change		4.76%	5.64%	7.19%	19.28%	129.67%
Total Revenues ($000,000)	930.17	962.39	969.07	979.82	1051.29	1573.96
Difference		32.21	38.90	49.65	121.12	643.78
% Change		3.46%	4.18%	5.34%	13.02%	69.21%
Profit after Tax ($000,000)	35.72	41.00	42.06	43.98	70.25	198.66
Difference		5.28	6.34	8.26	34.53	162.94
% Change		14.78%	17.75%	23.13%	96.67%	456.19%
Net Cash Flow ($000,000)	$28.74	$28.54	$28.47	$28.56	$42.68	$82.24
Difference		-0.20	-0.27	-0.18	13.94	53.50
% Change		-0.69%	-0.95%	-0.63%	48.50%	186.14%
Industry Value ($000,000)	239.52	245.37	245.97	247.44	251.97	211.23
Difference		5.85	6.45	7.92	12.45	-28.29
% Change		2.44%	2.69%	3.31%	5.20%	-11.81%

5.1.2 Quantitative Analysis

Table 5.1 is referred to as the long-run output table and it summarizes the essential outputs from the LBNL-MAM using the primary scenario for room air conditioners. Three other scenarios are summarized and discussed in the sensitivity analysis, Section 5.4. The first column in the output table gives the value of the output variables in the base case. This case represents the current state of the industry. Each of the next five columns shows the estimated state of the industry if one of the five alternative efficiency levels were to be implemented.

Each column of an output table gives the estimated values of the five most important output variables of the LBNL-MAM. Under each of these five values are two percentages. The upper percentage tells how much the variable has changed from the base case, while the lower percentage gives the standard error (S.E.) of the variable's estimated value. For all variables except ROE and net income, the change is given as a percentage change. For ROE and net income a simple difference is given.

Table 5.2 presents the results of industry net present value analysis using an industry net cash flow model. Industry net present value is an alternate method of analyzing the impact of alternative efficiency levels. The two measures of ROE and industry net present value are theoretically identical, although in practice small differences may arise.

Once the above interpretations are understood, the results of the model concerning the long-run impact of imposed efficiency levels on the room air conditioning industry can be read from the various output tables. However, two points should be noted. First, higher alternative efficiency levels may tend to increase profitability because higher efficiency levels generally entail higher costs which, depending on their nature, may increase markups by more than the incremental increase in costs. Second, uncertainty in the output variables increases at higher efficiency levels, approximately in proportion to the size of the change.

5.2. SHORT-RUN IMPACTS

In the short run, capacity may not adjust as needed to meet the predicted long-run change in demand resulting from imposed alternative efficiency levels. This circumstance could have either of the following consequences: If implemented efficiency levels cause a decrease in demand, stiffer-than-normal short-run price competition will result and price will fall below its long-run level, lowering profits. If imposed efficiency levels cause an increase in demand, there will be less short-run price competition than normal and price and profits will increase.

The business cycle presents the room air conditioner manufacturing industry (and indeed all durable goods industries) with fairly sharp periodic fluctuations in demand that are much larger than the fluctuations predicted for any of the alternative efficiency levels. These normal demand fluctuations present the same types of opportunities for price competition that will accompany fluctuations resulting from a change in efficiency levels. Regressing price on demand and a time trend for the past 18 years shows that a 10% fall in demand typically leads to a 1.6% fall in the price of room air conditioners; a 10% demand increase has the reverse effect. This effect is taken into account as described in Section 3.3.3.2 of Volume 1: General Methodology and is used to produce a short-run version of the output table that is displayed in Table 5.3. For reasons that are explained in 3.3.3.2, the short-run change has been overestimated. Thus all values for change in Table 5.3 should be viewed as somewhat too large in absolute value. The short-run impact on profit is also displayed in the Monte Carlo module.

Table 5.3 Room Air Conditioners: Primary Scenario – Short-Run

Scenario = Primary		Short-Run				
	1996 Base	Lev 1	Lev 2	Lev 3	Lev 4	Lev 5
Shipments (in Mil)	0.611	0.612	0.611	0.610	0.596	0.488
% change		0.07%	-0.01%	-0.27%	-2.53%	-20.14%
Price	$304.35	$307.40	$309.54	$313.28	$336.60	$574.22
% change		1.00%	1.71%	2.93%	10.59%	88.67%
Revenue (in $M)	186.03	188.03	189.18	190.98	200.53	280.31
% change		1.07%	1.69%	2.66%	7.79%	50.67%
Net Income (in $M)	10.601	10.465	10.450	10.420	9.236	0.195
Difference		-0.136	-0.151	-0.181	-1.364	-10.405
ROE	10.88%	10.67%	10.60%	10.50%	8.77%	0.13%
Difference		-0.21%	-0.27%	-0.37%	-2.11%	-10.75%
S.E.	7.31%	0.34%	0.44%	0.61%	1.54%	8.99%

5.3. IMPACT AS A FUNCTION OF FIRM SIZE

As described in Chapter 4 of Volume 1: General Methodology, the room air conditioner manufacturing industry is dominated by several large firms along with a number of smaller firms that make up a very small segment of the market. Typically, in these (and other similar) industries, average cost decreases with increasing firm size. Thus, the industry has economies of scale, and large firms (to the extent that their facilities are modernized) have lower average costs than small firms. This fact, coupled with increasing competitive pressures of the national market (e.g., foreign competition, etc.), probably accounts for the continuing consolidation that has been occurring for several decades. The fact that the consolidation has been producing larger firms strongly corroborates the finding that large firms have a cost advantage.

A principal implication of consolidation is that the smaller of the major firms will be, on average, in more danger of failing or being bought out than will the larger firms. Because smaller firms tend to have less resources and capacity to weather economic adversity, any decrease in average profitability is more likely to seriously affect a smaller firm, and an increase in average profitability is more likely to mean the difference between success and failure for a smaller firm.

From the standpoint of competitiveness, a decrease in average profitability could speed up the consolidation process, further reducing the number of firms. An increase in average profitability could help maintain the current level of competition. Either effect may well be temporary because in the long run the number of firms should be determined by the industry's cost structure and the relationship between a single firm's elasticity of demand and the number of competing firms.

5.4. SENSITIVITY ANALYSIS FOR ROOM AIR CONDITIONERS

The three following subsections discuss different aspects of the sensitivity analysis conducted by LBNL-MAM. The first subsection shows three alternative scenarios that are of interest and deserve a more detailed analysis than those generated by chance in Monte Carlo runs. The subsection on sensitivity charts shows the implications of the uncertainty of each control variable for the prediction of ROE. The last subsection shows the use of Monte Carlo runs to find combinations of standard errors that would cause the change in ROE to be considerably more negative than is predicted. For a more complete explanation, see Section 3.3.3.4 and Appendix C.2.1 in Volume 1: General Methodology.

5.4.1 Alternative Scenarios

For each appliance class and hypothetical efficiency level, hundreds of different scenarios are run for the Monte Carlo analysis described in the following section. However, a few scenarios that involve different demand elasticities (i.e., industry price elasticity and consumer discount rate, a proxy for industry operating cost elasticity) are singled out for special attention.

The sensitivity analysis shows that price elasticity and the consumer discount rate play significant roles in determining the output of the model. The price elasticity is an industry elasticity as opposed to a single-firm elasticity, that means it measures the effect on demand of a change in price by all firms for all room air conditioners. The estimates of standard errors which are calculated by the Monte Carlo analysis fully acknowledge the uncertainties of these two variables. However, in order to show in detail all of the ramifications of changing one or both of them, three alternative scenarios have been run..

The industry price elasticity in the primary analysis case is -0.35 and the consumer discount rate is 64%. For the sensitivity analysis, the three scenarios are:

1. The "high industry price elasticity" scenario where the industry price elasticity (IPE) is -1 and the consumer discount rate is unchanged.

2. The "low industry price elasticity" scenario where IPE is 0 and the consumer discount rate is unchanged.

3. The "low discount rate scenario" where the discount rate at 10% of its value in the primary scenario (a "high discount rate" case is not run because for consumer discount rates greater than approximately 60%, a significant increase in the discount rate will have an immaterial effect because consumers will have already significantly discounted the value of future energy savings).

Tables 5.4, 5.5, and 5.6 show the results of running these scenarios for the room air conditioner industry, respectively.

Table 5.4 Room Air Conditioners: High IPE Scenario

Scenario = Hi IPE		Long-Run				
	1996 Base	Lev 1	Lev 2	Lev 3	Lev 4	Lev 5
Shipments (in Mil)	0.60	0.60	0.60	0.60	0.56	0.30
% change		0.11%	-0.15%	-0.95%	-7.92%	-51.07%
S.E.		1.28%	1.53%	1.67%	3.33%	7.32%
Price	$304.35	$307.67	$309.86	$313.72	$338.27	$593.45
% change		1.09%	1.81%	3.08%	11.15%	94.99%
S.E.		1.22%	1.47%	1.62%	3.77%	27.72%
Revenue (in $M)	183.65	185.86	186.69	187.50	187.95	175.21
% change		1.20%	1.66%	2.10%	2.34%	-4.60%
S.E.		0.09%	0.12%	0.14%	0.41%	7.23%
Net Income (in $M)	10.31	10.351	10.331	10.256	9.099	-6.294
Difference		0.040	0.020	-0.054	-1.211	-16.604
S.E.		0.126	0.151	0.183	0.793	6.050
ROE	10.71%	10.67%	10.62%	10.53%	9.15%	-5.01%
Difference		-0.04%	-0.09%	-0.18%	-1.56%	-15.72%
S.E.		0.09%	0.11%	0.14%	0.80%	4.44%

Table 5.5 Room Air Conditioners: Low IPE Scenario

Scenario = Low IPE		Long-Run				
	1996 Base	Lev 1	Lev 2	Lev 3	Lev 4	Lev 5
Shipments (in Mil)	0.62	0.62	0.62	0.62	0.62	0.62
% change		0.00%	0.00%	0.00%	0.00%	-0.01%
S.E.		0.00%	0.00%	0.00%	0.00%	0.00%
Price	$304.35	$307.67	$309.86	$313.72	$338.27	$593.46
% change		1.09%	1.81%	3.08%	11.15%	94.99%
S.E.		1.13%	1.53%	1.79%	3.76%	25.63%
Revenue (in $M)	187.24	189.28	190.63	193.00	208.10	365.07
% change		1.09%	1.81%	3.08%	11.14%	94.98%
S.E.		1.13%	1.53%	1.79%	3.76%	25.63%
Net Income (in $M)	10.75	10.763	10.805	10.920	11.738	23.540
Difference		0.017	0.058	0.173	0.992	12.793
S.E.		0.200	0.297	0.332	1.056	10.610
ROE	10.96%	10.91%	10.89%	10.91%	10.83%	13.55%
Difference		-0.05%	-0.07%	-0.05%	-0.13%	2.59%
S.E.		0.15%	0.23%	0.25%	0.86%	5.49%

Table 5.6 Room Air Conditioners: Low Discount Rate Scenario

Scenario = Low Disc Rate		Long-Run				
	1996 Base	Lev 1	Lev 2	Lev 3	Lev 4	Lev 5
Shipments (in Mil)	0.63	0.66	0.67	0.68	0.69	0.59
% change		4.28%	5.96%	7.62%	8.67%	-7.25%
S.E.		0.45%	0.56%	0.76%	1.47%	7.56%
Price	$302.98	$305.13	$306.79	$309.98	$331.97	$563.95
% change		0.71%	1.26%	2.31%	9.57%	86.13%
S.E.		1.11%	1.35%	1.77%	3.45%	24.94%
Revenue (in $M)	191.42	201.03	205.37	210.75	227.91	330.46
% change		5.02%	7.29%	10.10%	19.06%	72.64%
S.E.		0.71%	0.86%	1.13%	2.10%	7.65%
Net Income (in $M)	10.81	11.311	11.515	11.736	12.129	9.751
Difference		0.503	0.707	0.928	1.321	-1.057
S.E.		0.210	0.289	0.308	0.625	3.566
ROE	10.75%	10.75%	10.73%	10.69%	10.18%	5.76%
Difference		0.00%	-0.02%	-0.06%	-0.57%	-4.99%
S.E.		0.21%	0.28%	0.30%	0.54%	2.22%

5.4.2 Sensitivity Charts

Table 5.7 lists the sensitivities of ROE to the control panel inputs. The tables are constructed by first setting each control variable to its normal value; then one is increased in absolute value by one standard error, and the change in profit is recorded. Next, that variable is returned to its normal value, and the next variable is tested. Since each variable has its own standard error, the sensitivity reported in the table measures both how sensitive the model is to a change in the variable and how uncertain the variable's value is. Note that the change in profit is simply the difference between long-run ROE and base-case ROE.

The comparison of the various inputs' contributions to the uncertainty in ROE focuses attention on the parts of the model that should be examined most closely to determine their accuracy and on the parts where improvement in the certainty of input variables would have the greatest payoff. Because of the differences in the sensitivities among input variables, it will generally be found that one to three of the inputs will dominate the model's uncertainty, in the sense that perfecting all the rest of the inputs would make only a negligible difference to the model's accuracy.

Table 5.7 RAC: Sensitivity of ROE to a 1 S.E. Change in Control Variables

Scenario = Primary

Control Variables			Efficiency Levels				
Name	Value	Changed	1	2	3	4	5
IPE	-0.350	-0.805	0.01%	-0.01%	-0.06%	-0.62%	-7.96%
RD	0.640	1.471	0.07%	0.11%	0.15%	0.29%	1.17%
ECC	0.068	0.075	-0.00%	-0.00%	-0.00%	-0.04%	-0.30%
EP	0.041	0.051	-0.01%	-0.01%	-0.01%	-0.04%	-0.11%
FCA	0.100	0.160	-0.00%	0.00%	0.03%	0.27%	1.97%
F1X	0.200	0.348	-0.00%	-0.02%	-0.05%	-0.55%	-1.82%
CC.N	4.138	5.044	-0.02%	-0.02%	-0.03%	-0.18%	-1.13%
dVC.N	9.970	13.371	0.07%	0.08%	0.10%	0.13%	-0.05%
ro.N	0.000	0.144	0.00%	-0.00%	-0.02%	-0.21%	-1.93%

As can be seen from the tables, three control variables account for nearly all of the uncertainty in the determination of ROE. These are 1) the industry elasticity of demand with respect to price (IPE), 2) the consumer discount rate of appliance energy savings (RD), and 3) the current proportion of long-run fixed costs (FCA). No variable may be singled out as most important because importance varies with the alternative efficiency level. Why these three variables are important and why their importance changes from one level to the next is discussed below.

The industry price elasticity (IPE) determines consumer reaction to the price increase imposed by alternative efficiency levels. This variable gains its importance not through any effect on pricing (which is determined only by the single-firm price elasticity) but rather because it translates a price increase into a decrease in sales, and any change in sales directly influences profit. Because of fixed costs, a fall in demand causes a greater reduction in revenue than in variable costs and, consequently, a loss in profit. Probably the most important reason for the model's high sensitivity to IPE is IPE's uncertainty.[1] Because the estimates were made quite some time ago, we view the estimated value of IPE as being highly uncertain and as a result, we assigned it an uncertainty of 100%.[2]

The consumer discount rate (RD) shows a large sensitivity for exactly the same reason as IPE. In both cases, this sensitivity changes from efficiency level to efficiency level because price increases and operating cost decreases change from level to level. The percent of long-run fixed costs (FCA) is important because of its role in the model and the uncertainty of its measurement. It determines LBNL-MAM's estimate of the firm's markup over variable cost which, in turn, determines the firm's ability to pass on various mixtures of fixed and variable costs. For similar reasons, the fixed part of one-times costs (F1X) is closely correlated with FCA and hence displays similar results.

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[1] The original source of elasticities was Oak Ridge National Laboratory and are documented in DOE/CE-0029, *Consumer Products Efficiency Standards Economic Analysis Document*, U.S. Department of Energy, March 1982. These estimates were further checked against historical shipments by the LBNL-REM analysis.

[2] This means its standard error equals its mean value.

5.4.3 Monte Carlo Analysis

The Monte Carlo approach is described in Section 3.3.3.4 in Chapter 3, Volume 1: General Methodology, and the standard errors it generates are reported in the output tables. Output uncertainty is most directly addressed by the Monte Carlo analysis. This analysis assigns an uncertainty to each of the nine control-panel input variables and then chooses a value for each based on this uncertainty. The model is then solved using these randomly chosen variables. All of the important outputs are tabulated on the Monte Carlo page of the model. These outputs are changes from the base case of price, shipments, revenue, net income, long-run ROE, and short-run ROE. Next, new values of the input variables are drawn from the same distribution. The model is run again and the new outputs recorded. This cycle can be repeated as many as 400 times. After a sufficient number of runs, the mean and standard deviations of each output variable are computed. This section examines two runs in more detail.

Table 5.8 shows the control panel from two Monte Carlo runs for room air conditioners which were selected because they showed a decrease in long-run ROE. (The Monte Carlo runs were done for efficiency level 3.) For the first run, the decrease in ROE was due to a sharp fall in the discount rate. The second Monte Carlo run shows a similar decrease in long-run ROE, due to a low discount rate combined with a high value for FCA.

Table 5.8 Room Air Conditioner Monte Carlo Runs: Searching for Low ROE

ROOM AIR CONDITIONERS	Run 1	Input		Vari-	Program	
CONTROL FACTORS		Value	Cntrl	ation	Value	Name
Price Elasticity		-0.350	-1.37	100%	-0.112	IPE
Consumer Discount Rate		64.00%	-1.84	100%	0.138	RD
Equity Cost of Capital		0.068	-0.61	10%	0.064	ECC
Economic Profit		0.041	1.69	1%	0.058	EP
L-R Fixed Part of Costs & Assets		0.100	1.62	50%	0.215	FCA
L-R Fixed Part of 1-X Cap. Cost		0.200	1.55	60%	0.471	F1X
One-Time Capital Costs		7.114	1.04	20%	8.746	CC.N
Unit Variable Cost Increase		$14.90	-1.57	30%	9.385	dVC.N
Elasticity Curve Parameter		0.000	-0.45	14%	-0.065	ro.N
Short Run Price Response to Demand		0.157	-0.74	76%	0.095	SRPR

	NAECA	NEW		PREVIOUS	NEW
SUMMARY	BASE	L-RUN	CHANGE	CHANGE	S-RUN
Shipments	0.62	0.62	1.23%	-0.32%	0.62
Price	$302.59	$302.05	-0.18%	3.08%	$302.48
Revenue (in $M)	186.64	188.60	1.05%	2.75%	188.83
Net Income	11.39	10.16	-1.23	0.10	10.12
ROE	11.59%	10.10%	-1.49%	-0.09%	10.06%
Operating Cost Elasticity	-0.15				
			Trys =	465.00	

ROOM AIR CONDITIONERS	Run 2	Input		Vari-	Program	
CONTROL FACTORS		Value	Cntrl	ation	Value	Name
Price Elasticity		-0.350	0.62	100%	-0.350	IPE
Consumer Discount Rate		64.00%	-0.79	100%	0.331	RD
Equity Cost of Capital		0.068	1.59	10%	0.080	ECC
Economic Profit		0.041	0.41	1%	0.045	EP
L-R Fixed Part of Costs & Assets		0.100	2.92	50%	0.396	FCA
L-R Fixed Part of 1-X Cap. Cost		0.200	-0.59	60%	0.144	F1X
One-Time Capital Costs		7.114	-1.19	20%	5.615	CC.N
Unit Variable Cost Increase		$14.90	-1.14	30%	10.676	dVC.N
Elasticity Curve Parameter		0.000	-1.95	14%	-0.281	ro.N
Short Run Price Response to Demand		0.157	0.53	76%	0.226	SRPR

	NAECA	NEW		PREVIOUS	NEW
SUMMARY	BASE	L-RUN	CHANGE	CHANGE	S-RUN
Shipments	0.61	0.62	1.70%	-0.32%	0.62
Price	$305.53	$304.23	-0.43%	3.08%	$305.00
Revenue (in $M)	187.10	189.46	1.26%	2.75%	189.76
Net Income	12.43	11.19	-1.25	0.10	11.38
ROE	12.73%	11.18%	-1.55%	-0.09%	11.37%
Operating Cost Elasticity	-0.19				
			Trys =	1171.00	

CHAPTER 6. IMPACTS OF ALTERNATIVE EFFICIENCY LEVELS ON ELECTRIC UTILITIES: ROOM AIR CONDITIONERS

6.1 INTRODUCTION

The implementation of appliance efficiency levels have four principal effects on electric utilities: 1) they allow utilities to avoid fuel energy and other operating costs because less electricity needs to be generated, 2) they may allow utilities to defer construction of new generating capacity, 3) they may allow utilities to defer construction of new or upgraded transmission and distribution (T&D) capacity, and 4) they reduce revenues from electricity sales. The second section of this chapter presents the results of the avoided cost calculations. The third section presents the expected peak load and reliability savings for the analyzed efficiency levels. The fourth section presents the results of the revenue loss calculation. The fifth section presents the results of the sensitivity analysis. More details on methodology may be found in Appendix E of Volume 1 of this report.

6.2 AVOIDED ENERGY AND AVOIDED CAPACITY COSTS

Table 6.1 shows avoided energy and capacity costs for electricity savings from room air conditioners (RACs).[1] As explained in Appendix E of Volume 1, this component implicitly contains the costs avoided when power plants are deferred or canceled, and it also contains avoided T&D capital costs. These avoided costs represent a simple summary of the utility analysis and they are a measure of the societal benefit of the electricity saved in each year.

Table 6.1 Avoided Cost Rate for Selected Years

Avoided Cost Rates (1990$/MMBtu[2])				
Year	Avoided Energy Cost Rate	Avoided Capacity Cost Rate	Avoided Transmission and Distribution Cost Rate	Total Avoided Cost Rate
1998	2.30	2.82	0.67	5.79
2000	2.39	4.01	0.89	7.28
2005	2.60	4.01	0.90	7.51
2010	2.81	4.01	0.92	7.74
2015	3.02	4.01	0.94	7.96
2020	3.24	4.01	0.95	8.19
2025	3.45	4.01	0.97	8.42
2030	3.66	4.01	0.98	8.65

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[1] Fuel price forecasts for the period 1990 to 2010 are taken from the DOE/EIA *Annual Energy Outlook 1995 with Projections to 2010* EIA-0383(95)). The forecasts for years after 2010 were linearly extrapolated.

[2] MM used to designate millions.

6.3 PEAK LOAD AND CAPACITY REDUCTIONS

Table 6.2 shows peak load reductions for RACs for all of the alternative efficiency levels. Table 6.3 shows capacity savings for RACs for the relevant efficiency levels. The base case peak load in the second column of Table 6.2 represents coincident peak load of all such appliances in the residential sector.

Table 6.2 Peak Demand Reductions (GW) - RACs

		PEAK DEMAND SAVINGS (GW)				
Year	**Peak Load**	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
2000	26.95	0.22	0.29	0.36	0.58	0.58
2001	27.35	0.29	0.43	0.51	0.79	0.79
2002	27.82	0.43	0.58	0.72	1.01	1.08
2003	28.23	0.58	0.79	0.94	1.30	1.30
2004	28.63	0.58	0.79	1.08	1.44	1.44
2005	28.97	0.58	0.87	1.08	1.59	1.59
2006	29.30	0.72	1.01	1.23	1.81	1.81
2007	29.57	0.72	1.08	1.44	2.02	1.95
2008	29.84	0.79	1.16	1.59	2.17	2.10
2009	30.11	0.94	1.37	1.73	2.46	2.24
2010	30.38	0.94	1.30	1.81	2.46	2.24
2011	30.71	0.94	1.37	1.81	2.53	2.24
2012	31.12	1.01	1.44	1.88	2.60	2.24
2013	31.52	0.94	1.37	1.88	2.60	2.17
2014	31.92	1.01	1.44	1.88	2.67	2.10
2015	32.40	0.94	1.44	1.88	2.67	2.17
2016	32.80	0.94	1.44	1.88	2.67	2.24
2017	33.27	1.01	1.44	1.88	2.67	2.31
2018	33.74	0.94	1.37	1.88	2.67	2.38
2019	34.21	1.08	1.52	1.95	2.82	2.53
2020	34.61	1.01	1.44	1.95	2.82	2.53
2021	35.02	1.08	1.52	2.02	2.89	2.67
2022	35.42	1.01	1.59	2.02	2.89	2.75
2023	35.76	1.08	1.59	2.10	2.96	2.82
2024	36.09	1.08	1.52	2.10	2.96	2.82
2025	36.49	1.08	1.59	2.17	2.96	2.89
2026	36.83	1.01	1.59	2.10	2.96	2.96
2027	37.23	1.01	1.52	2.10	3.03	2.96
2028	37.64	1.01	1.52	2.10	3.03	2.96
2029	38.04	1.16	1.66	2.17	3.11	3.11
2030	38.51	1.08	1.59	2.17	3.11	3.11

Table 6.3 Capacity Savings (GW) - RACs

	CAPACITY SAVINGS (GW)				
Year	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
2000	0.26	0.35	0.43	0.69	0.69
2001	0.35	0.52	0.61	0.95	0.95
2002	0.52	0.69	0.87	1.21	1.30
2003	0.69	0.95	1.13	1.56	1.56
2004	0.69	0.95	1.30	1.73	1.73
2005	0.69	1.04	1.30	1.91	1.91
2006	0.87	1.21	1.47	2.17	2.17
2007	0.87	1.30	1.73	2.43	2.34
2008	0.95	1.39	1.91	2.60	2.51
2009	1.13	1.65	2.08	2.95	2.69
2010	1.13	1.56	2.17	2.95	2.69
2011	1.13	1.65	2.17	3.03	2.69
2012	1.21	1.73	2.25	3.12	2.69
2013	1.13	1.65	2.25	3.12	2.60
2014	1.21	1.73	2.25	3.21	2.51
2015	1.13	1.73	2.25	3.21	2.60
2016	1.13	1.73	2.25	3.21	2.69
2017	1.21	1.73	2.25	3.21	2.77
2018	1.13	1.65	2.25	3.21	2.86
2019	1.30	1.82	2.34	3.38	3.03
2020	1.21	1.73	2.34	3.38	3.03
2021	1.30	1.82	2.43	3.47	3.21
2022	1.21	1.91	2.43	3.47	3.29
2023	1.30	1.91	2.51	3.55	3.38
2024	1.30	1.82	2.51	3.55	3.38
2025	1.30	1.91	2.60	3.55	3.47
2026	1.21	1.91	2.51	3.55	3.55
2027	1.21	1.82	2.51	3.64	3.55
2028	1.21	1.82	2.51	3.64	3.55
2029	1.39	1.99	2.60	3.73	3.73
2030	1.30	1.91	2.60	3.73	3.73

The total peak demand and the savings are calculated using the appropriate conservation load factor, a T&D loss factor of 7.5%, and estimates of energy consumption calculated using the LBNL-REM. Capacity savings are peak load savings in regions that need additional capacity, multiplied by 1.2 to account for reserve margin needed for adequate reliability. The amount of capacity saved can be somewhat less than the peak demand savings in years before 1999 (the year in which new energy efficiency levels are assumed to take effect) because capacity savings are only counted in regions that need capacity. After 1998, capacity savings consistently exceed peak load savings by the reserve margin of 20%.

Peak demand reductions from the energy efficiency levels for RACs range from .22 to .58 GW in 2000, and from 1.08 to 3.11 GW in 2030. Capacity savings for RACs range from .26 to .69 GW in 2000, and from 1.30 to 3.73 GW in 2030.

6.4 REVENUE LOSSES

The implementation of appliance efficiency levels allow utilities to avoid the variable costs of generating electricity, but imposed efficiency levels also reduce electricity sales. In a Public Utilities Commission rate case, the utility and the regulators agree on the revenue requirements and rates based on some estimate of future sales. If the effects of appliance efficiency levels are not included in this forecast, actual sales will be less than forecasted sales, which implies that the utility will not be able to recover some of the fixed costs that were included in the original revenue requirements calculation. This effect can be eliminated if electric utilities and regulators, when calculating rates, correctly forecast the impacts of imposed appliance efficiency levels.

Utilities routinely petition regulators for changes in rates. In the course of such a petition the utility's forecasted sales can be adjusted to account for the appliance efficiency levels and hence eliminate these "lost" revenues. Those revenues lost as a result of time lags in regulation are not a true economic cost, but are a transfer payment from the utility to utility customers. The size of this transfer payment depends on regulatory behavior and on the net change in revenues, that is, lost revenue minus avoided cost.

Since the magnitude of these losses is dependent on assumptions about regulatory behavior, and because this behavior is so varied among states, it is difficult to perform this calculation for the nation. An additional complication is that unanticipated sales growth from other sectors may compensate for the revenue shortfall. Two cases are presented here, one which assumes that regulators adjust the rates to reflect the reduced sales in five years, and one which assumes that they never adjust the rates. These cases also assume that there is no unanticipated compensating sales growth. These results are presented both on a year-by-year and a present-value basis.

It is possible that the regulators could adjust the rates in anticipation of the new alternative efficiency levels, in which case there would be no revenue impact at all. It is also possible that the regulators would not grant rate relief for several years after the efficiency levels go into effect, which is approximated by the five-year-lag case. While it is unlikely that regulators would never adjust the rates to reflect the post-efficiency level sales forecast, this case is included as an absolute upper bound. Figure 6.1 shows annual revenue losses and avoided costs over time for all 5 efficiency levels, and Table 6.4 shows net revenue losses for all alternative efficiency levels. Note that negative revenue losses signify net *increases* in utility revenues. Cumulative net revenue increases for RACs range from $ .4 to 4.1 billion.

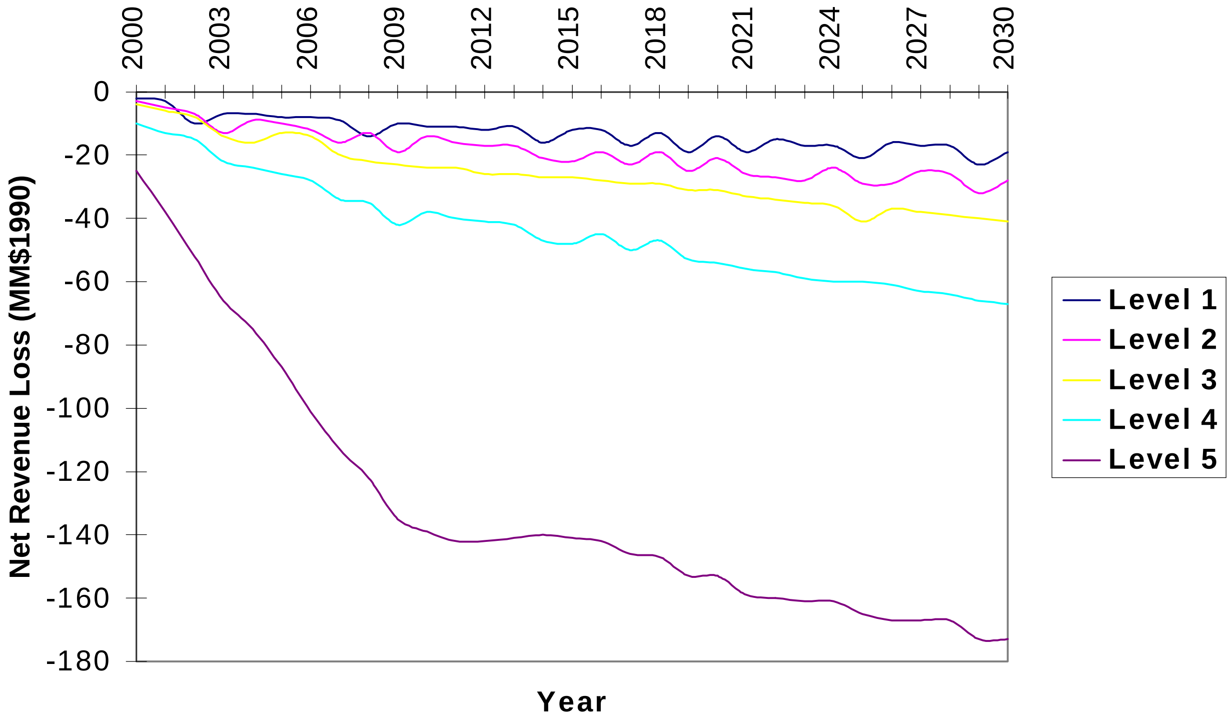

Figure 6.1 Net Electric Utility Revenue Loss

Table 6.4 Net Revenue Losses - RACs

	NET REVENUE LOSS (MM 1990$)				
Year	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
2000	-2	-3	-4	-10	-25
2001	-3	-5	-6	-13	-38
2002	-5	-7	-8	-15	-52
2003	-10	-13	-14	-22	-66
2004	-7	-9	-16	-24	-75
2005	-7	-10	-13	-26	-87
2006	-8	-12	-14	-28	-101
2007	-8	-16	-20	-34	-113
2008	-9	-13	-22	-35	-122
2009	-14	-19	-23	-42	-135
2010	-10	-14	-24	-38	-139
2011	-11	-16	-24	-40	-142
2012	-12	-17	-26	-41	-142
2013	-11	-17	-26	-42	-141
2014	-16	-21	-27	-47	-140
2015	-12	-22	-27	-48	-141
2016	-12	-19	-28	-45	-142
2017	-17	-23	-29	-50	-146
2018	-13	-19	-29	-47	-147
2019	-19	-25	-31	-53	-153
2020	-14	-21	-31	-54	-153
2021	-19	-26	-33	-56	-159
2022	-15	-27	-34	-57	-160
2023	-17	-28	-35	-59	-161
2024	-17	-24	-36	-60	-161
2025	-21	-29	-41	-60	-165
2026	-16	-29	-37	-61	-167
2027	-17	-25	-38	-63	-167
2028	-17	-26	-39	-64	-167
2029	-23	-32	-40	-66	-173
2030	-19	-28	-41	-67	-173
Total	**-401**	**-595**	**-816**	**-1367**	**-4053**

The values in Table 6.4 show changes in utility revenues, assuming no regulatory adjustment. Because the avoided costs for RACs are higher than the lost revenues, net utility revenues will actually increase, thereby *decreasing* rates. When regulators adjust rates to reflect these higher net revenues, rates will decrease over the base case forecast, and utilities will no longer gain revenue. Total residential rates would decrease 0% and 0.1% (0¢/kWh and 0.01¢/kWh) in 2000 and 2005, respectively, if RACs are subject to level 5 efficiency levels and regulators only change residential rates to compensate for any increase in revenue. Residential rate decreases for any given year are calculated by taking the net gain in revenues due to the imposition of new energy efficiency levels and dividing it by total electricity sales.

Table 6.5 shows the present value of net revenue losses at a 5% real utility discount rate for all alternative efficiency levels and for the two assumptions about regulatory behavior. This discount rate is based on an assumed average utility capital structure and current rates of return.

Table 6.5 Cumulative Present Value of Revenue Losses - RACs

CUMULATIVE PRESENT VALUE OF LOST REVENUES (MM$1990)					
Regulatory Lag	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
None	0	0	0	0	0
1998-2002	-6	-9	-10	-21	-66
1998-2030	-88	-128	-176	-299	-921

For RACs, the present value of net gained revenues may range from $6 to 66 million for a five-year lag, and, if regulators did not adjust rates, utilities would actually receive increased revenues of as much as $.9 billion. The present values over the period 1998 to 2030 also represent the rate decreases needed over this period to compensate for increased revenues, assuming that regulators adjust them immediately.

CHAPTER 7: ENVIRONMENTAL EFFECTS: ROOM AIR CONDITIONERS

7.1 INTRODUCTION

The environmental effects from a range of candidate alternative energy efficiency levels for room air conditioners are presented here. The results are presented for each alternative efficiency level. Each measure of possible environmental change is an alternative action, and it is compared to what is expected to happen if no new efficiency levels for room air conditioners were implemented, i.e., the "no action" alternative.

The environmental concern addressed is emissions from fossil-fueled electricity generation and from in-house combustion. All of the design options for room air conditioners result in decreased electricity use and, therefore, a reduction in power plant emissions. Implementing the alternative efficiency levels will decrease air pollution by decreasing future energy demand. The greatest decreases in air pollution will be for sulfur oxides, listed in equivalent weight of sulfur dioxide, or SO_2. Reductions of nitrogen oxides and carbon dioxide also occur and are listed by weight of NO_x and CO_2, respectively. CO_2 emissions from fossil-fuel burning is considered an environmental hazard because it contributes to the “greenhouse effect” by trapping heat energy from the earth that is emitted as infrared radiation. The “greenhouse effect” is expected to gradually raise the mean global temperature.

For a detailed description of the methodology that was used in estimating the environmental impacts, please refer to the Environmental Assessment in Volume 1 of this Report.

7.2 RESULTS

The following tabular results indicate what changes can be brought about in the amounts of emitted CO_2, SO_2, and NO_x by implementing efficiency levels for room air conditioners. A table is presented for each of the appliance's alternative efficiency levels. Each table details the changes that occur to each of the three emissions (i.e., CO_2, SO_2, and NO_x) through the imposition of a specific energy efficiency level. Each table includes the following information for a specific year between 1996 and 2030: the amount of emission abated from power plant generation, the amount abated from in-house generation, the net change in the emissions, and the percent the net change comprises of total U.S. power plant emissions. Also included are the cumulative changes of each pollutant (between the years 1998 and 2030).

Decreases in the amounts of CO_2, SO_2, and NO_x emitted at efficiency levels 1 through 5 are summarized in Tables 7.1 through 7.5[1]. It should be noted that in-house emissions are abated from imposed room air conditioner efficiency levels even though their direct impact is to reduce only power plant emissions. As noted in Chapter 3 (herein), because of the higher equipment prices associated with room air conditioner efficiency levels, installations of room air conditioners are projected to decrease resulting in increased installations of both central air conditioners and heat pumps. Since greater electric heat pump installations displace installations of fossil fuel-fired space heating equipment, reductions of in-house emissions are realized. The in-house emissions abated from efficiency levels 4 and 5 are significantly greater than those associated with efficiency levels 1 through 3 due to the higher room air conditioner equipment prices associated with efficiency levels 4 and 5.

7.2.1 Sulfur and Nitrogen Oxide Emissions

SO_2 emissions would be decreased by a cumulative total of up to 33 kt (37 thousand short tons) between 1998 and 2030 in the level 5 scenario. In the year 2000, decreases in SO_2 emissions will represent about .03% of the SO_2 emissions estimated to come from residential emissions in that year. In the year 2030, decreases in SO_2 emissions will represent about .10% of the SO_2 emissions estimated to come from residential emissions. Because of provisions in the Clean Air Act Amendments (Pub. L. 101-549, November 15, 1990), the possible reductions of SO_2 emissions that are caused by the implementation of energy efficiency levels can be earned as credits by the utility realizing the reductions. To the extent SO_2 credits are used for future emissions, the net effect on SO_2 emissions from implementing alternative efficiency levels would be only a postponement of those SO_2 emissions.

Level 5 design changes to room air conditioners would result in an estimated decrease in NO_x emissions of 51 kt (56 thousand short tons) between 1998 and 2030. NO_x emissions decreases would represent .03% and .12% of the NO_x emissions estimated to come from residential emissions in the years 2000 and 2030, respectively.

7.2.2 Carbon Dioxide Emissions

The cumulative reduction in CO_2 emissions from level 5 design changes is 51Mt (56 million short tons) of CO_2. For the year 2000, the estimated CO_2 emissions reduction is .55 Mt (.6 million short tons) of CO_2 or about .04% of estimated U.S. total residential CO_2 emissions in 2000. For the year 2030, the estimated CO_2 emissions reduction is 2.4 Mt (2.6 million short tons) of $CO_{2,}$ or about .15% of estimated U.S. total residential CO_2 emissions in 2030.

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[1] Also see Supplemental Tables 7.6 and 7.7 for emissions calculations for the Supplemental Efficiency level using AEO 95 and AEO 97 energy prices.

Room Air Conditioners **Table 7.1 - Level 1** **Parallel Analysis**

SO_2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	0.86	0.94	0.00	0.00	0.86	0.94	0.02
2005	1.95	2.15	0.00	0.00	1.95	2.15	0.06
2010	2.73	3.01	0.00	0.00	2.73	3.01	0.10
2015	2.19	2.42	0.00	0.00	2.19	2.42	0.09
2020	1.89	2.08	0.00	0.00	1.89	2.08	0.09
2025	1.45	1.60	0.00	0.00	1.45	1.60	0.09
2030	1.18	1.30	0.13	0.15	1.31	1.44	0.10

Cumulative SO_2 reduction (kt): 59 (short tons): 65 000

NOx

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	0.64	0.70	0.05	0.05	0.68	0.75	0.02
2005	1.57	1.73	0.00	0.00	1.57	1.73	0.06
2010	2.37	2.62	0.00	0.00	2.37	2.62	0.09
2015	2.03	2.24	0.05	0.05	2.08	2.29	0.09
2020	1.89	2.08	0.00	0.00	1.89	2.08	0.08
2025	1.59	1.75	0.00	0.00	1.59	1.75	0.08
2030	1.45	1.59	0.10	0.11	1.55	1.70	0.08

Cumulative NOxreduction (kt): 55 (short tons): 61 000

CO2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	Mt	million short tons	Mt	million short tons	Mt	million short tons	
2000	0.24	0.26	0.05	0.05	0.29	0.31	0.02
2005	0.64	0.71	0.00	0.00	0.64	0.71	0.05
2010	1.05	1.15	0.00	0.00	1.05	1.15	0.08
2015	1.04	1.15	0.05	0.05	1.09	1.20	0.08
2020	1.12	1.23	0.00	0.00	1.12	1.23	0.07
2025	1.11	1.22	0.00	0.00	1.11	1.22	0.07
2030	1.18	1.30	0.12	0.13	1.30	1.43	0.08

Cumulative CO_2 reduction (Mt): 30 (short tons): 33 000 000

Room Air Conditioners **Table 7.2 - Level 2** **Parallel Analysis**

SO_2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	1.14	1.26	0.00	0.00	1.14	1.26	0.03
2005	2.92	3.22	0.00	0.00	2.92	3.22	0.09
2010	3.78	4.17	0.00	0.00	3.78	4.17	0.13
2015	3.20	3.53	0.00	0.00	3.20	3.53	0.13
2020	2.70	2.98	0.00	0.00	2.70	2.98	0.13
2025	2.18	2.40	0.00	0.00	2.18	2.40	0.13
2030	1.72	1.90	0.13	0.15	1.86	2.05	0.14

Cumulative SO_2 reduction (kt): 86 (short tons): 95 000

NOx

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	0.85	0.94	0.05	0.05	0.89	0.99	0.03
2005	2.35	2.59	0.00	0.00	2.35	2.59	0.09
2010	3.29	3.62	0.00	0.00	3.29	3.62	0.12
2015	2.97	3.27	0.05	0.05	3.02	3.32	0.12
2020	2.70	2.98	0.00	0.00	2.70	2.98	0.12
2025	2.39	2.63	0.00	0.00	2.39	2.63	0.12
2030	2.12	2.34	0.10	0.11	2.22	2.45	0.12

Cumulative NOxreduction (kt): 80 (short tons): 89 000

CO2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	Mt	million short tons	Mt	million short tons	Mt	million short tons	
2000	0.32	0.35	0.05	0.05	0.37	0.40	0.03
2005	0.96	1.06	0.00	0.00	0.96	1.06	0.07
2010	1.45	1.60	0.00	0.00	1.45	1.60	0.11
2015	1.52	1.68	0.05	0.05	1.57	1.73	0.11
2020	1.60	1.76	0.00	0.00	1.60	1.76	0.11
2025	1.66	1.83	0.00	0.00	1.66	1.83	0.11
2030	1.73	1.90	0.12	0.13	1.85	2.03	0.11

Cumulative CO_2 reduction (Mt): 44 (short tons): 48 000 000

SO_2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	1.43	1.57	0.00	0.00	1.43	1.57	0.04
2005	3.65	4.02	0.00	0.00	3.65	4.02	0.12
2010	5.04	5.56	0.00	0.00	5.04	5.56	0.18
2015	4.22	4.65	0.00	0.00	4.22	4.65	0.17
2020	3.51	3.87	0.00	0.00	3.51	3.87	0.17
2025	2.91	3.20	0.00	0.00	2.91	3.20	0.17
2030	2.27	2.50	0.13	0.15	2.41	2.65	0.18

Cumulative SO_2 reduction (kt): 111 (short tons): 122 000

NOx

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	1.06	1.17	0.05	0.05	1.11	1.22	0.04
2005	2.94	3.24	0.00	0.00	2.94	3.24	0.11
2010	4.38	4.83	0.00	0.00	4.38	4.83	0.16
2015	3.91	4.31	0.05	0.05	3.95	4.36	0.16
2020	3.51	3.87	0.00	0.00	3.51	3.87	0.16
2025	3.18	3.51	0.05	0.05	3.23	3.56	0.16
2030	2.79	3.08	0.10	0.11	2.90	3.19	0.15

Cumulative NOxreduction (kt): 104 (short tons): 115 000

CO2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	Mt	million short tons	Mt	million short tons	Mt	million short tons	
2000	0.40	0.44	0.05	0.05	0.44	0.49	0.04
2005	1.20	1.32	0.00	0.00	1.20	1.32	0.09
2010	1.93	2.13	0.00	0.00	1.93	2.13	0.14
2015	2.01	2.21	0.05	0.05	2.05	2.26	0.14
2020	2.08	2.29	0.00	0.00	2.08	2.29	0.14
2025	2.22	2.44	0.05	0.05	2.26	2.49	0.15
2030	2.28	2.51	0.12	0.13	2.40	2.64	0.15

Cumulative CO_2 reduction (Mt): 57 (short tons): 63 000 000

Room Air Conditioners **Table 7.4 - Level 4** **Parallel Analysis**

SO_2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	2.00	2.20	0.00	0.00	2.00	2.20	0.06
2005	4.87	5.36	0.00	0.00	4.87	5.36	0.16
2010	6.52	7.18	0.13	0.15	6.65	7.33	0.23
2015	5.56	6.13	0.13	0.15	5.70	6.28	0.24
2020	4.73	5.21	0.13	0.15	4.86	5.36	0.24
2025	3.84	4.23	0.13	0.15	3.97	4.38	0.24
2030	3.06	3.37	0.13	0.15	3.19	3.52	0.23

Cumulative SO_2 reduction (kt): 149 (short tons): 164 000

NOx

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	1.49	1.64	0.05	0.05	1.53	1.69	0.05
2005	3.92	4.32	0.09	0.10	4.01	4.42	0.15
2010	5.66	6.24	0.15	0.16	5.81	6.40	0.22
2015	5.16	5.69	0.19	0.21	5.35	5.90	0.22
2020	4.73	5.21	0.15	0.16	4.87	5.37	0.22
2025	4.21	4.63	0.19	0.21	4.40	4.84	0.21
2030	3.76	4.14	0.19	0.21	3.95	4.35	0.21

Cumulative NOxreduction (kt): 141 (short tons): 156 000

CO2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	Mt	million short tons	Mt	million short tons	Mt	million short tons	
2000	0.56	0.61	0.05	0.05	0.60	0.67	0.05
2005	1.60	1.77	0.09	0.10	1.70	1.87	0.13
2010	2.50	2.75	0.17	0.18	2.66	2.94	0.19
2015	2.65	2.92	0.21	0.24	2.86	3.15	0.20
2020	2.80	3.08	0.17	0.18	2.96	3.27	0.20
2025	2.93	3.23	0.21	0.24	3.14	3.46	0.20
2030	3.06	3.37	0.21	0.24	3.27	3.61	0.20

Cumulative CO_2 reduction (Mt): 79 (short tons): 88 000 000

Table 7.5 - Level 5

SO_2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	0.86	0.94	0.13	0.15	0.99	1.09	0.03
2005	0.73	0.80	0.40	0.44	1.13	1.25	0.04
2010	0.00	0.00	0.81	0.89	0.81	0.89	0.03
2015	-0.34	-0.37	0.81	0.89	0.47	0.52	0.02
2020	0.14	0.15	0.94	1.04	1.08	1.19	0.05
2025	0.42	0.46	0.94	1.04	1.36	1.50	0.08
2030	0.47	0.52	0.94	1.04	1.41	1.56	0.10

Cumulative SO_2 reduction (kt): 33 (short tons): 37 000

NOx

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	0.64	0.70	0.28	0.31	0.92	1.01	0.03
2005	0.59	0.65	0.84	0.93	1.43	1.58	0.05
2010	0.00	0.00	1.42	1.56	1.42	1.56	0.05
2015	-0.31	-0.34	1.51	1.66	1.20	1.32	0.05
2020	0.14	0.15	1.56	1.72	1.70	1.87	0.08
2025	0.45	0.50	1.65	1.82	2.11	2.32	0.10
2030	0.58	0.64	1.74	1.92	2.32	2.56	0.12

Cumulative NOxreduction (kt): 51 (short tons): 56 000

CO2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	Mt	million short tons	Mt	million short tons	Mt	million short tons	
2000	0.24	0.26	0.31	0.34	0.55	0.60	0.04
2005	0.24	0.26	0.93	1.02	1.17	1.29	0.09
2010	0.00	0.00	1.57	1.73	1.57	1.73	0.11
2015	-0.16	-0.18	1.66	1.83	1.50	1.66	0.10
2020	0.08	0.09	1.74	1.91	1.82	2.00	0.12
2025	0.32	0.35	1.83	2.02	2.15	2.37	0.14
2030	0.47	0.52	1.93	2.12	2.40	2.64	0.15

Cumulative CO_2 reduction (Mt): 51 (short tons): 56 000 000

APPENDIX A. ENGINEERING ANALYSIS - SUPPORTING DOCUMENTATION

A.1 ROOM AIR CONDITIONER SIMULATION MODEL

A.1.1 Introduction

The room air conditioner simulation model is a modified version of the Oak Ridge Heat Pump Design Model, Mark III version (1) (2). The Oak Ridge model is a comprehensive program for the simulation of an electrically driven, air-source heat pump. The simulation model is divided into two main parts; the high side and the low side. The high side includes models for the compressor, the condenser, and the expansion device. The low side includes only a model for the evaporator. The flow chart in Figure A.1 presents the solution logic of the Oak Ridge model. The model first performs a high-side balance based on calculating a mass flow rate through the expansion device that matches the one through the compressor. Once a high-side balance is achieved, a low-side balance is performed in which the evaporator model seeks an air inlet temperature that ensures the previous balance at the high side. Modifications were made to the simulation model in order to simulate the performance of room air conditioners (3). These modifications included the following: addition of routines to model subcoolers and condensate spray, elimination of the reversing valve model, modification of the capillary tube model, and addition of adjustment factors to model rifled (grooved) tubing. For further details on the simulation model and the modifications made to it, consult the references cited above. The remainder of this section will focus on the additional modifications incorporated into the simulation model in order to better predict the performance of room air conditioners.

A.1.2 Simulation Model Modifications

There were several additional modifications made to the simulation model. Several of the modifications consisted of adding additional inputs to the simulation model so that quantities such as the compressor power, refrigerant mass flow rate, and air-side heat-transfer coefficients could be adjusted to equal measured test values. Minor modifications were also made to include additional values in the output. More involved changes were required of the compressor model and condensate spray routine. The following are the changes that were made to the modified Mark III version of the Oak Ridge Heat Pump Design Model.

Compressor Model

The compressor model is a map-based model. It is based on the use of compressor manufacturer data (compressor maps) for a specific compressor. The model has built-in corrections to adjust for levels of refrigerant superheat in reciprocating compressors which are different from those for which the maps were generated. The original authors of the simulation model contend that, although the model was written for reciprocating compressors, it should be easy to modify for use with rotary, screw, or centrifugal compressors.

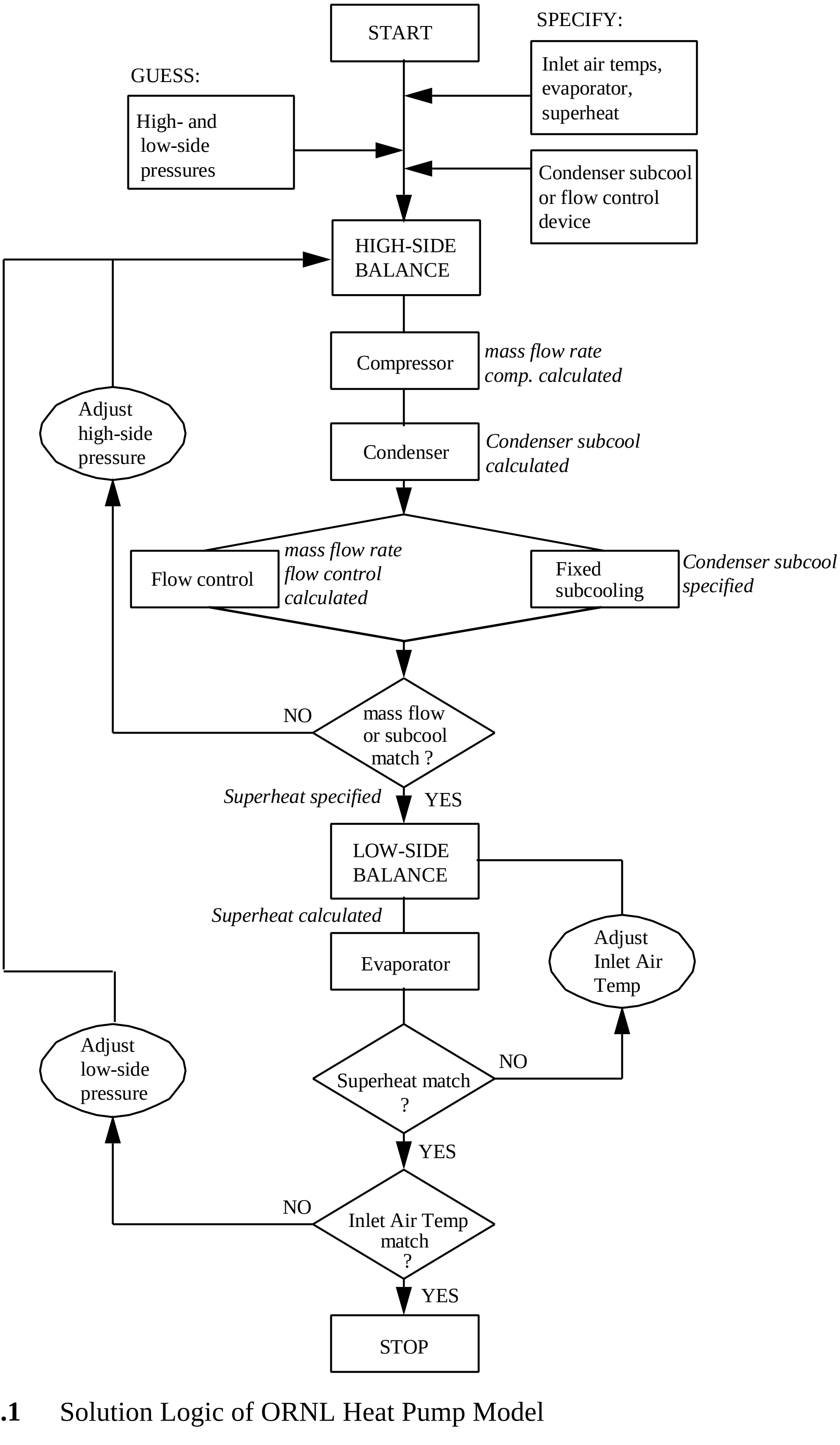

Figure A.1 Solution Logic of ORNL Heat Pump Model

Upon review of the compressor model, the built-in corrections for superheat were found to be inadequate for compressors other than reciprocating types. The correction equations were specifically derived to model a low-side cooled reciprocating compressor. They were based on calculating the enthalpy change from the compressor shell inlet to the compressor suction port. Since room air conditioners primarily use high-side cooled rotary compressors with an accumulator, the superheat correction scheme was modified. Modifications consisted of two primary changes: 1) calculation of map and actual suction port conditions directly from assumed temperature and pressure increases across the accumulator, and 2) calculation of the refrigerant mass flow rate correction factor based solely on the ratio of the map-to-actual specific volumes.

To incorporate temperature and pressure increases across the accumulator into the compressor model, compressor shell inlet conditions were assumed to exist at the accumulator inlet. In a high-side cooled rotary compressor, the suction port is practically located at the inlet to the compressor shell. Due to this condition, the suction port conditions were assumed to exist at the compressor shell inlet. Temperature and pressure increases of 5°F and 1 psi across the accumulator were used. These values were determined by compressor manufacturers and provided by the Association of Home Appliance Manufacturers (AHAM). The temperature and pressure values were input into the simulation model through the DATAIN subroutine and given the variable names TACCM and PACCM. To calculate the map and actual port conditions, the accumulator temperature and pressure increases were simply added to the pre-adjusted temperature and pressure values.

The refrigerant mass flow rate correction factor originally took the form:

$$XMRCOR = \frac{m_{actual}}{m_{map}} = 1.0 + (\frac{v_{map}}{v_{actual}} - 1.0) \cdot F_v \qquad \textbf{(A.1)}$$

where *XMRCOR* is the refrigerant mass flow rate correction factor, m_{actual} is the refrigerant mass flow rate at actual conditions, m_{map} is the refrigerant mass flow rate at map conditions, v_{actual} is the specific volume of the refrigerant at actual conditions, v_{map} is the specific volume of the refrigerant at map conditions, and F_v is a volumetric efficiency correction factor. The new correction factor is based on the following expression for the refrigerant mass flow rate:

$$m = \frac{D \cdot S_{oper} \cdot \eta_{vol}}{v} \qquad \textbf{(A.2)}$$

where m is the refrigerant mass flow rate, D is the piston displacement, S_{oper} is the motor speed, η_{vol} is the volumetric efficiency, and v is the specific volume. With the mass flow rate represented in this manner, the new correction factor takes the form:

$$XMRCOR = \frac{m_{actual}}{m_{map}} = \frac{D_{actual} \cdot v_{map} \cdot \eta_{vol,actual} \cdot S_{oper,actual}}{D_{map} \cdot v_{actual} \cdot \eta_{vol,map} \cdot S_{oper,map}} \qquad \textbf{(A.3)}$$

Assuming that 1) there is no difference between the actual and map piston displacements and 2) the ratio of the actual-to-map volumetric efficiency and motor speed product is one, the correction factor simply becomes the ratio of the map-to-actual specific volumes. Thus, the new correction factor equation becomes:

$$XMRCOR = \frac{m_{actual}}{m_{map}} = \frac{v_{map}}{v_{actual}} \qquad \textbf{(A.4)}$$

The ratio of the actual-to-map volumetric efficiency and motor speed product was assumed to be one because no other data was provided to indicate otherwise. Upon conferring with manufacturers, this assumption seemed to be reasonable.

Figures A.2 and A.3 contain listings of the original and modified versions of SUPCOR, the subroutine used for calculating the compressor power and refrigerant mass flow rate correction factors. Program lines that appear in bold in the modified version (Figure A.3) designate the changes that were made. Also note that the modified version has deleted several program lines that were used in the original version. For definitions of the variables that appear in the listings provided in Figures A.2 and A.3, please refer to the first reference cited in the introduction to this Appendix.

Additional correction factors were added to the simulation model to further adjust the refrigerant mass flow rate and compressor power. After initial runs of the simulation model yielded results that differed from measured test data, additional correction factors were added to reduce the error between simulated and test results. The additional correction factors were input through the DATAIN subroutine and given the variable names COMPOWCF and XMSFLOCF. They were used to adjust the compressor power and mass flow rate directly after the original correction factors calculated by subroutine SUPCOR were already applied. Figures A.4 and A.5 provide partial listings of the original and modified versions of the subroutine CMPMAP. In CMPMAP, the compressor power and mass flow rate are calculated. Program lines that appear in bold in the modified version (Figure A.5) designate the changes that were made. Each listing contains the program line calling on subroutine SUPCOR to adjust compressor power and mass flow rate from map to actual operating conditions. For definitions of the variables that appear in the listings provided in Figures A.4 and A.5, refer to the first reference cited in the introduction to this Appendix.

```
          SUBROUTINE SUPCOR(SUCFAC,VOLFAC,TOLH,TOLS,TSICMP,
     &                TSOCMP, HINCMP, SUPERB,POWPXM,POWCOR,XMRCOR)
C
C*** PURPOSE: TO CORRECT RECIPROCATING COMPRESSOR MAP-VALUES OF
C*** POWER CONSUMPTION AND MASS FLOW RATE TO ACCOUNT FOR SUCTION
C*** SUPERHEAT LEVELS DIFFERENT FROM THOSE FOR WHICH THE MAP
C*** WAS GENERATED.
C
          INTEGER FLAG
          TRICMB=TSICMP+SUPERB
          IF(SUPERB.LT.0.0) TRICMB=-SUPERB
          CALL SATPRP(TSICMP,PINCMP,VF,VG,HF,HFG,HG,SF,SG,FLAG)
          CALL VAPOR(TRICMB,PINCMP,X,HINBSE,Y,IERROR)
          DELHSP=SUCFAC*POWPXM
          DO 1 I=1,2
          HSUP=HINBSE
          IF(I.EQ.2) HSUP=HINCMP
          HSP=HSUP+DELHSP
          IF(HSP.GT.HG) GO TO 2
          XSP=(HSP-HF)/HFG
          SSP=SF+XSP*(SG-SF)
          VSP=VF+XSP*(VG-VF)
          TSP=TSICMP
          GO TO 3
2         CONTINUE
          CALL TRIAL(TSICMP,50.,PINCMP,3,HSP,TOLH,VSP,HSP,SSP,TSP,IERROR)
3         CONTINUE
          CALL SATPRP(TSOCMP,POUCMP,X,Y,HFO,HFGO,Z,SFO,SGO,FLAG)
          IF(SSP.GT.SGO) GO TO 4
          XOUT=(SSP-SFO)/(SGO-SFO)
          HOUISN=HFO+XOUT*HFGO
          GO TO 5
4         CONTINUE
          CALL TRIAL(TSOCMP,50.,POUCMP,4,SSP,TOLS,X,HOUISN,Y,Z,IERROR)
5         CONTINUE
          DELISN=HOUISN-HSP
          IF(I.NE.1) GO TO 1
          DELHSV=DELISN
          VSPSV=VSP
1         CONTINUE
          XMRCOR=1.+(VSPSV/VSP-1.)*VOLFAC
          POWCOR=XMRCOR*DELISN/DELHSV
          RETURN
          END
```

Figure A.2 Subroutine SUPCOR: Original Version

```
      SUBROUTINE SUPCOR(TACCM,PACCM,TOLH,TOLS,TSICMP,
     &          TSOCMP,TRICMP,SUPERB,POWPXM,POWCOR,XMRCOR)
C
C*** PURPOSE: TO CORRECT RECIPROCATING COMPRESSOR MAP-VALUES OF
C*** POWER CONSUMPTION AND MASS FLOW RATE TO ACCOUNT FOR SUCTION
C*** SUPERHEAT LEVELS DIFFERENT FROM THOSE FOR WHICH THE MAP
C*** WAS GENERATED.
C
      INTEGER FLAG
      TRICMB=TSICMP+SUPERB
      IF(SUPERB.LT.0.0) TRICMB=-SUPERB
      CALL SATPRP(TSICMP,PINCMP,VF,VG,HF,HFG,HG,SF,SG,FLAG)
      TSP=TRICMB+TACCM
      PSP=PINCMP+PACCM
      DO 1 I=1,2
      IF(I.EQ.2) GO TO 6
      GO TO 7
6     TSP=TRICMP+TACCM
7     CALL VAPOR(TSP,PSP,VSP,HSP,SSP,IERROR)
      IF(HSP.GT.HG) GO TO 3
      XSP=(HSP-HF)/HFG
      SSP=SF+XSP*(SG-SF)
      VSP=VF+XSP*(VG-VF)
      TSP=TSICMP
3     CONTINUE
      CALL SATPRP(TSOCMP,POUCMP,X,Y,HFO,HFGO,Z,SFO,SGO,FLAG)
      IF(SSP.GT.SGO) GO TO 4
      XOUT=(SSP-SFO)/(SGO-SFO)
      HOUISN=HFO+XOUT*HFGO
      GO TO 5
4     CONTINUE
      CALL TRIAL(TSOCMP,50.,POUCMP,4,SSP,TOLS,X,HOUISN,Y,Z,IERROR)
5     CONTINUE
      DELISN=HOUISN-HSP
      IF(I.NE.1) GO TO 1
      DELHSV=DELISN
      VSPSV=VSP
1     CONTINUE
      XMRCOR=VSPSV/VSP
      POWCOR=XMRCOR*DELISN/DELHSV
      RETURN
      END
```

Figure A.3 Subroutine SUPCOR: Modified Version

```
C***    CORRECT FOR ACTUAL SUPERHEAT LEVEL
C
        POWPXM = POWB/XMRB
        POWCOR = 1.0
        XMRCOR = 1.0
        IF(SUPERB.EQ.SUPER) GO TO 75
        CALL SUPCOR(SUCFAC,VOLFAC,TOLH,TOLS, TSICMP,TSOCMP,HINCMP,
    &              SUPERB,POWPXM,POWCOR,XMRCOR)
75      CONTINUE
        POW = POWB*POWCOR*SIZFAC
        XMR = XMRB*XMRCOR*SIZFAC
        IF (CANFAC .LE. 0.0) GO TO 80
        IF (CANFAC .LE. 1.0) QCAN = CANFAC*POW
80      CONTINUE
```

Figure A.4 Subroutine CMPMAP: Partial Listing of Original Version

```
C***    CORRECT FOR ACTUAL SUPERHEAT LEVEL
C
        POWPXM = POWB/XMRB
        POWCOR = 1.0
        XMRCOR = 1.0
        IF(SUPERB.EQ.SUPER) GO TO 75
        CALL SUPCOR(TACCM,PACCM,TOLH,TOLS, TSICMP,TSOCMP,
     &             TRICMP, SUPERB, POWPXM,POWCOR,XMRCOR)
75      CONTINUE
        POW = POWB*POWCOR*SIZFAC*COMPOWCF
        XMR = XMRB*XMRCOR*SIZFAC*XMSFLOCF
        IF (CANFAC .LE. 0.0) GO TO 80
        IF (CANFAC .LE. 1.0) QCAN = CANFAC*POW
80      CONTINUE
```

Figure A.5 Subroutine CMPMAP: Partial Listing of Modified Version

Condensate Spray Routine

The condensate spray routine is called by the condenser (heat exchanger) model to determine the effects of condensate spray on the performance of the condenser. Heat transfer correlations developed by Tree *et al.* are used by the condensate spray routine to quantify the effects of the condensate spray on the condenser coil (4). The primary correlation consists of a heat-transfer coefficient for the wet coil as a function of the heat-transfer coefficient for the dry coil.

$$\frac{h_{wet}}{h} = 1 + \frac{m_{eff} \cdot h_{fg} \cdot D}{C_p \cdot \Delta T \cdot \mu \cdot A \cdot Re} \qquad \textbf{(A.5)}$$

Where h is the dry coil heat-transfer coefficient, h_{wet} is the wet coil heat-transfer coefficient, m_{eff} is the effective mass flow rate of condensate, h_{fg} is the enthalpy of vaporization of water, D is the hydraulic diameter, C_p is the specific heat of air, ΔT is the temperature difference across the condenser coil, μ is the viscosity, A is the area of the condenser coil, and Re is the Reynold's number.

Changes made to the original condensate spray routine consisted of the following: 1) ensuring that the condensate spray rate was equated to the condensation rate off the evaporator, 2) the addition of a correction factor to adjust the effect that the condensate spray has on the condenser air-side heat-transfer coefficient, and 3) the addition of a "check" on the condenser exiting air temperature to ensure that the condensate spray routine used the same exiting air temperature as the condenser (heat exchanger) model.

A listing of the condensate spray routine is provided in Figure A.6. The condensate spray rate is a function of the number of evaporator parallel circuits (NSECTE) and the condensation rate off the evaporator per circuit (XMM). The product of these two variables is the total condensation rate off the evaporator. The condensate spray rate (SPRYRT) is set equal to the total condensation rate (first program line that appears in bold print in Figure A.6).

The correction factor that has been added to the condensate spray routine is used to adjust the effect that the condensate spray has on the condenser air-side heat-transfer coefficient (the second line that appears in bold print in Figure A.6). The correction factor is input through the DATAIN subroutine and given the variable name CONDCORR. Variable TEMP1 is the variable that quantifies the effect of the condensate spray and is a function of many variables including PERC. (The equation used to calculate TEMP1 is the same as Eq. A.5 but in a different form.) PERC is the effective percentage of condensate spray evaporation that is useful to the condenser. Since the effect of the condensate spray on the air-side heat-transfer coefficient is uncertain, CONDCORR has been added to increase or decrease its effect for calibration purposes.

```
      SUBROUTINE SPRAY (HAC,GA,XMUA,DEA,DELTAIR,NT,WT,XMA,FINTYP)
C
      REAL NTE,NSECTE
C
      COMMON /SPR/ SPRFLG,SPRYRT,PERC,CONDCORR
C
      COMMON / CONDSR / TAIIC,TIC,TSATCI,HIC,PIC,XIC
     &                  TAOC,TROC,TSATCO,HOC,POC,XOC
C
      COMMON / PRNT5 / WAIRI, HAIR1, HAIRO, WAIRO, TACI,  TWALLO,
     &         HWALLO,WWALLO,XMM,   QMTPL, QSTPT, STRTP, STRTOT,
     &         TWB,   RHI,   TWBO,  RHO,   WOUT, XNTUSU,XNTTPE,
     &         EXFRE, ETPE,  CSUPER,TAOSPE, TAOTPE,XMASP, XMATP
C
      COMMON / EVAPOR / DEAE,   DERE, DELTAE,    FPE, XKFE, XKTE, AAFE,
     &          NTE, NSECTE, HCONTE,    STE,    WTE,  SIGAE, PE,  ARFTE,
     &          ARHTE, ALFARE, ALFAAE,   FARE,CARE, QAE, RTBEVP, DZE,
     &          FANEFE,   RHIE, FINTYE, MUNITE,FINFXE, DWHTLOSS, RECIRCLS
C
      COMMON / CONDEN / DEAC,DERC,DELTAC,FPC,XKFC,XKTC,AAFC,NTC,NSECTC,
     &          HCONTC,STC,WTC,SIGAC,PC,ARFTC,ARHTC,ALFARC, ALFAAC,FARC,
     &          CARC,QAC,RTBCND,DZC,FANEFC,RHIC, FINTYC,MUNITC,FINFXC
C
      CPA = 0.24
      SPRYRT=XMM*NSECTE
C
C     AIR DENSITY IS CALCULATED BASED ON 1 ATM PRESSURE.
C     TEMP1 IS THE ENHANCEMENT FACTOR DUE TO WATER SPRAY.  IT IS
C     NON-DIMENSIONAL.  THE VARIABLES INCLUDED IN THE EQUATION BELOW:
C     1050.0 = ENTHALPY OF VAPORIZATION (BTU/LB)
C     SPRYRT = SPRAY RATE (LB/HR)
C     PERC = EFFECTIVE PERCENTAGE OF EVAPORATION THAT IS
C                 USEFUL TO THE CONDENSER
C     DELTAIR = OUTLET - INLET AIR TEMPERATURE DIFFERENCE
C                 IN CONDENSER (F)
C     XMA = AIR MASS FLOW RATE (LB/HR)
C     CPA = SPECIFIC HEAT OF AIR (BTU/(LB-F))
C
      TEMP1=1050.0*SPRYRT*PERC*CONDCORR/(DELTAIR*XMA*CPA)
      HAC = HAC*(1.0 + TEMP1)
      RETURN
      END
```

Figure A.6 Subroutine SPRAY: Modified Version

The "check" on the condenser-exiting air temperature is to ensure that the same temperature difference between the exiting and entering air temperatures across the condenser coil is used by both the condensate spray subroutine and the subroutine EXCH. EXCH is used to determine the heat transfer and resulting temperatures in one representative parallel circuit in the condenser, given all of the necessary inlet conditions, pressure drops, properties, and heat-transfer areas and coefficients. Figure A.7 provides a partial listing of the subroutine COND. Program lines that appear in bold designate the additions that were made. Variable DELDIFF is used for comparing the temperature differences determined by the two subroutines. To ensure that the simulation model converges to solutions that yield appropriate values for the condenser air-side heat transfer coefficient, the calculated temperature differences determined by each subroutine need to be within 1.5°F of each other. If the tolerance were any tighter, it is possible that incorrect values for the air-side heat transfer coefficient could be determined. For definitions of the variables that appear in the listings provided in Figures A.7, refer to the first reference cited in the introduction to this Appendix.

Air-Side Heat-Transfer Coefficients

The air-side heat-transfer coefficients for both the evaporator and condenser are computed by the subroutine HAIR. The simulation model assumes that the air-side heat-transfer coefficients for wavy and louvered fins can be predicted approximately by the use of an equation for smooth fins increased by a multiplicative constant (i.e., an enhancement factor). The heat-transfer coefficients determined for wavy and louvered fin surfaces are assumed to be referenced to smooth-fin surface areas; thus the multiplicative constants for wavy and louvered fins are intended to account for increases in both the heat-transfer coefficient and surface area from smooth fin values.

At the time the simulation model was first developed, data were not available to verify whether an equation for smooth fins could be used to predict the air-side heat-transfer coefficients for wavy and louvered fins. Since that time, research has been conducted to determine the performance of fin-and-tube heat exchangers incorporating wavy and enhanced/louvered fins (5) (6). Out of this research, correlations have been developed to predict the air-side heat-transfer coefficients and friction factors of heat exchangers using wavy and louvered fins. The fin-and-tube heat exchangers used in this research were of the type generally found in central air conditioners. Therefore, the limitations on the fin enhancement correlations are usually exceeded when they are applied to room air conditioners. Thus, manufacturer data were relied upon to make estimates of the enhancement factors that should be used for predicting the air-side heat-transfer coefficients of wavy and louvered fins. Although manufacturer data were used, the correlations were not abandoned entirely as they served as a check to determine if the manufacturers' estimates were reasonable.

```
C       DETERMINE AIR SIDE HEAT TRANSFER COEFFICIENT 'HAC'(BTU/H-SQ FT-F)
C
        CALL HAIR(FINTYC,CPM,PRA,XMUA,DEAC,DELTAC,FPC,STC,WTC,NTC,
     &          GA,ATAMIN,HAC,finfxc,XMAC,AAFC)
C
        DELTAIRC=TAOC-TAIC
        IF(DELTAIRC.LT.10) DELTAIRC=10.0
924     IF(SPRFLG.EQ.1)
     &  CALL SPRAY(HAC,GA,XMUA,DEAC,DELTAIRC,NTC,WTC,XMA,FINTYC)
        DELCHK1 = DELTAIRC
C
C       DETERMINE OVERALL SURFACE EFFICIENCY 'SEFFXC'
C
        CALL SEFF(XKFC,DELTAC,STC,WTC,DEAC,FARC,HAC,SEFFXC)
C
C       CHECK FOR INCONSISTENT ENTERING AIR TEMPERATURE
C
        IERR = 0
        IF(TSAVG.GT.TAIC) GO TO 325
        IERR = 1
        GO TO 900
325     CONTINUE
C
C       USE SUBROUTINE EXCH TO DETERMINE CONDENSER HEAT TRANSFER
C       PERFORMANCE AND RETURN ALL RESULTS THROUGH COMMON
C
        CALL EXCH(AOM,TSTTPI,TSTTPO,HFG,HFGO,TAIC,XMR,
     &          RTUBES,RCNCON,XNTU)
        DELCHK2 = TAOC-TAIC
        DELDIFF = ABS(DELCHK1-DELCHK2)
        IF(DELDIFF .LE. 1.5) GO TO 923
        DELTAIRC = DELCHK2
        GO TO 924
923     CONTINUE
```

Figure A.7 Subroutine COND: Partial Listing to Show “Check” on Exit Air Temperature

As mentioned previously, subroutine HAIR of the simulation model is used to calculate the air-side heat-transfer coefficients of smooth, wavy, and louvered/enhanced fin surfaces. As mentioned above, the simulation model assumes that the air-side heat-transfer coefficients for wavy and louvered fins can be predicted approximately by the use of an equation for smooth fins increased by a multiplicative constant (i.e., an enhancement factor). The original version of this subroutine contains correlations to calculate the multiplicative constant (i.e., enhancement factor) for a specific type of enhanced/louvered fin surface (7). For wavy fins, the subroutine uses a constant enhancement factor of 1.45 regardless of the type of wavy fin used (8). The simulation model was modified so that fin enhancement factors for both the evaporator and condenser could be input. The location of these variables, FINFXC for condensers and FINFXE for evaporators, in the input data file is described later in Section A.1.3 on Input Data Modifications. Subroutine HAIR was modified so that the specified evaporator and condenser fin enhancement factors were used instead of the correlations (for louvered fins) and constants (for wavy fins) specified by the original routine.

Refrigerant-Side Pressure Drop Multipliers

As previously stated in the introduction to this Appendix, the original modifications to the Oak Ridge Heat Pump model included changes to account for the effects of grooved (rifled) tubing. This change took the form of adding input variables (ERTMULT for the evaporator and CRTMULT for the condenser) to increase the refrigerant-side heat transfer coefficients if grooved tubing were present. Although the benefit of grooved tubing is to improve the heat transfer performance of a heat exchanger, it also has the adverse effect of increasing the refrigerant-side pressure drop. The original modification to the Oak Ridge Heat Pump model to account for grooved tubing did not take into consideration the effect it would have on pressure drop. Thus, additional modifications were made to the model to include input variables to adjust the refrigerant-side pressure drop. These input variables, CRTPD for condensers and ERTPD for evaporators, serve as multipliers to the refrigerant-side pressure drop, and the values for CRTPD and ERTPD are relative to the pressure drop for smooth tubing. The location of these variables in the input data file are described later in Section A.1.3 on Input Data Modifications. Subroutines COND (for the condenser) and EVAPR (for the evaporator) were modified so that the input refrigerant-side multipliers were used to adjust the refrigerant-side pressure drop calculated by the simulation model.

Divider Wall Heat Losses

Because the simulation model was originally developed to simulate the performance of central heat pumps, no provisions were made to estimate the heat losses that are unique to room air conditioners.

The divider wall is that portion of the cabinet that separates the outdoor section of the room air conditioner from the indoor section. Divider wall heat losses are composed of two parts: heat leakage and air leakage losses. Heat leakage losses are a result of the temperature difference between the two sections of the room air conditioner. The warmer outdoor section transfers heat through the divider wall to the cooler indoor section. Manufacturers usually insulate the divider wall (typically with Styrofoam) to try to limit the heat leakage through the divider wall. Air leakage losses are a result of the outdoor air that is drawn into the indoor section through cracks and open spaces in the divider wall. The total divider wall heat loss creates an additional load on the room air conditioner and reduces its capacity and efficiency.

AHAM provided test data indicating what the divider wall heat losses are for typical room air conditioners in each of the five primary product classes. These heat losses are provided in Table A.1. The representative values listed in Table A.1 were used as input to the simulation model to model the divider wall heat losses for each of the baseline units. When analyzing prospective design options, the divider wall heat losses were assumed to remain constant. Subroutines EVAPR and SUMCAL were modified to include the effect of the divider wall heat losses on the discharge air temperature and capacity of the unit, respectively.

Table A.1 Divider Wall Heat Losses

Product Class	Capacity *Btu/hour*	Total Heat Loss *Btu/hour*
Less than 6000 Btu/hr	5900	180
6000 to 7999 Btu/hr	7500	180
8000 to 13999 Btu/hr	12,000	122
14000 to 19999 Btu/hr	18,000	380
Over 20000 Btu/hr	25,000	350

Figure A.8 provides a partial listing of the modified version of subroutine EVAPR. The listing in bold print indicates the modification that was made. In order to account for the effect the divider wall heat loss has on the temperature of the exiting (discharge) air, the divider wall heat loss input variable (DWHTLOSS) is divided by the heat capacity and the mass flow rate of the exiting air and added to the average air temperature leaving the evaporator coil (TAOOE).

```
C      OPTIONS FOR ADDING FAN AND/OR COMPRESSOR HEAT TO EXITING AIR
C
       TAOOE = TAOE
       IF (NCORH .EQ. 2) GO TO 725
       EINDF = QFANE
       IF (MFANIN .EQ. 2) TAOOE = TAOOE + QFANE/(CPM*XMA)
       TAOOE = TAOOE + DWHTLOSS/(CPM*XMA)
       GO TO 750
```

Figure A.8 Partial Listing of Subroutine EVAPR: Modified Version

Figure A.9 provides a partial listing of the modified version of subroutine SUMCAL. The last line in bold print indicates the modification that was made. In order to account for the effect the heat loss has on the capacity of the unit, the divider heat loss input variable is subtracted from the calculated system capacity of the unit.

```
C       CALCULATE SYSTEM CAPACITY
C
        IF (NCORH .EQ. 2) GO TO 575
        CAPHP = QE + QSUCLN
        IF(MFANIN.EQ.2) CAPHP = CAPHP - EINDF
        CAPHP = (CAPHP - DWHTLOSS) * 0.94
```

Figure A.9 Partial Listing of Subroutine SUMCAL: Modified Version

Suction Line Heat Gain

Because the refrigerant suction line in a room air conditioner lies within the indoor section of the unit, the heat gain absorbed by the suction line from the inlet air stream should be included as part of the total capacity of the unit. Figure A.9 contains the change that was made to the simulation model so that the suction line heat gain is included into the total capacity of the unit. This change appears in the line where the capacity (CAPHP) is set equal to the total rate of heat transfer for the evaporator (QE) plus the rate of heat gain in the suction line (QSUCLN). It should be noted that although this change to the simulation model was made, during the analysis it was assumed that the suction line heat gain was equal to zero for all the baseline units and design options modeled. This assumption was based on AHAM data showing that only a very small portion of the suction line is exposed to the indoor air.

Discharge Air Recirculation Heat Losses

Some portion of the air that is discharged from a room air conditioner is immediately drawn back into the unit. This short-circuiting of the evaporator discharge air decreases the capacity and the efficiency of the room air conditioner. The conditioned discharge air that is introduced into the air being drawn into the room air conditioner reduces the heat content of the inlet air stream. Because there is less heat to be extracted from the inlet air stream, the capacity of the unit is reduced. Since the energy input to the room air conditioner essentially remains the same, the efficiency of the unit is also decreased.

AHAM provided test data on an 18000 Btu/hr unit to determine the effect of recirculation on capacity and efficiency. First the unit was tested in a calorimeter room where normal short-circuiting was allowed to occur. The unit was retested in a psychometric room where ducting was used to prevent short-circuiting. In the case of the psychometric room test, refrigerant was added to the unit so that its superheat would be equal to what was measured in the calorimeter room test (this being the point at which the unit would be balanced if there were no short-circuiting). Table A.2 lists the results.

Table A.2 Recirculation Heat Losses

	Without Recirculation	With Recirculation	Difference
Capacity, *Btu/hr*	18,476	17,331	-6.2%
Power, *watts*	2021	2028	+0.3%
EER, *Btu/W-hr*	9.14	8.55	-6.5%

The 6% decrease in the capacity and efficiency of the tested unit was assumed to be representative of the recirculation losses that exist in all room air conditioner units. Because the resultant decrease in efficiency is due almost solely to the decrease in capacity, recirculation effects are modeled by reducing the system capacity calculated by the simulation model by 6%. Figure A.9 contains the modification that was made to account for recirculation heat losses. This change appears in the last line of Figure A.9 where a factor of 0.94 is multiplied by the difference between the calculated system capacity and the divider wall heat loss.

Air Delivery System Description

Because the simulation model was developed to model the performance of central heat pumps, the air delivery system is described with two fans (one for the condenser and one for the evaporator) that are each driven by their own fan motors. In the case of room air conditioners, the evaporator and condenser fans are both driven by a single fan motor. Because of this difference, room air conditioners are difficult to describe with the simulation model's input scheme.

No attempt was made to change the simulation model so that a room air conditioner's air delivery system could be described with one fan motor instead of two. Rather, a methodology was developed so that the simulation model's input scheme could be used to describe a room air conditioner's air delivery system.

The methodology is based upon determining what percentages of the fan motors' power are dedicated to driving the evaporator fan and condenser fan. The percentages were established based on comments from room air conditioner manufacturers. For all baseline units, the evaporator fan was assumed to draw 40% of the total fan motor power while the condenser fan was assumed to draw the remaining 60%. For each of the baseline units modeled, manufacturer data were provided that indicated the power draw of the fan motor. With the assumption of the "40/60 split", the power draw of the evaporator and condenser fans could easily be determined.

As a result of retaining the simulation model's input scheme of describing two fan motors for the room air conditioner, changes to the model were required to ensure that all of the heat loss coming off the room air conditioner's fan motor was rejected to the condenser air stream. By dedicating 40% of the fan motor power use to the evaporator fan, a "phantom" fan motor is being modeled for the evaporator fan. The simulation model calculates a heat loss coming off this "phantom" fan motor. Because the room air conditioner fan motor actually resides entirely in the outdoor section of the unit, this "phantom" heat loss must be "shifted" to the condenser air stream in order to fully account for the room air conditioner's entire fan motor heat loss.

Figure A.10 shows the modifications made to subroutine COND in order to account for the entire fan motor heat loss. The listing in bold print indicates the modification that was made. The new variable called QFANEEE was created to account for the heat loss coming off the "phantom" evaporator fan motor. QFANEEE was created in subroutine EVAPR and is equal to the temperature increase to the surrounding air stream resulting from the rejected heat loss. It is added to the temperature of the air crossing the condenser (TAIC). For definitions of the other variables appearing in Figure A.10, refer to the first reference cited in the introduction to this Appendix.

```
C      OPTIONS FOR ADDING FAN AND/OR COMPRESSOR HEAT TO INCOMING AIR
C
  TAIC = TAIIC
  IF (NCORH .EQ. 2) GO TO 125
  IF (MCMPOP .EQ. 1) TAIC = TAIC + QCAN/(CPM*XMA)
  IF (MFANOU .EQ. 1) TAIC = TAIC + QFANC/(CPM*XMA)
  IF (MFANOU .EQ. 1) TAIC = TAIC + QFANEEE
```

Figure A.10 Partial Listing of Subroutine COND: Modified Version

Specifying the fan power draw of each of the fans was suitable for modeling the baseline units, but for estimating the effect of prospective design options on the energy efficiency of a room air conditioner, the combined fan and fan motor efficiency was needed to describe the performance of each of the fans. The Oak Ridge Heat Pump Model uses the following expression to define the relationship between the fan motor power draw and the combined fan and fan motor efficiency.

$$W_{fan} = \frac{11.1 \cdot CFM \cdot \Delta P_{air}}{\eta_{fan,motor}} \tag{A.6}$$

W_{fan} is the fan motor power consumption in Btu per hour, *CFM* is the volumetric flow rate in cubic feet per minute, ΔP_{air} is the air-side pressure drop across the evaporator or condenser in pounds per square inch, $\eta_{fan,motor}$ is the combined fan and fan motor efficiency, and *11.1* is a constant that is used to convert to consistent units. Thus, the above equation can be used to calculate the combined fan and fan motor efficiency if the fan motor power consumption, the volumetric flow rate, and the pressure drop are known. As stated previously, manufacturers provided the fan motor power draw for each of the baseline units that were modeled. In addition, the volumetric air flow rates for both the evaporator and condenser were also given. With both the fan motor power draw and the volumetric air flow rates specified, the simulation model was run to generate the pressure drops across the heat exchanger coils. With the pressure drops determined, Eq. A.6 was used to solve for the combined fan and fan motor efficiency for both the evaporator and condenser fans. For each of the baseline units, Table A.3 provides a listing of the evaporator and condenser fan characteristics, including the combined fan and fan motor efficiency.

Table A.3 Evaporator and Condenser Fan and Fan Motor Characteristics

	Evaporator				Condenser			
Product Class	W_{fan} *watts*	CFM *cfm*	ΔP_{air} *psi*	$\eta_{fan,mtr}$	W_{fan} *watts*	CFM *cfm*	ΔP_{air} *psi*	$\eta_{fan,mtr}$
With Louvered Sides and Without Reverse Cycle								
Less than 6000 Btu/hr	50.0	180	0.0046	5.38%	75.0	330	0.0018	2.57%
6000 to 7999 Btu/hr	52.8	210	0.0077	10.02%	79.2	380	0.0027	4.25%
8000 to 13999 Btu/hr	70.0	285	0.0071	9.45%	105.0	645	0.0049	9.78%
14000 to 19999 Btu/hr	118.8	515	0.0118	16.69%	178.2	870	0.0064	10.19%
Over 20000 Btu/hr	149.6	534	0.0081	9.46%	224.4	1231	0.0080	14.24%
Without Louvered Sides and Without Reverse Cycle								
6000 to 7999 Btu/hr	40.8	186	0.0033	4.85%	61.2	342	0.0023	4.13%
8000 to 13999 Btu/hr	56.0	293	0.0098	16.60%	84.0	328	0.0031	3.99%
With Reverse Cycle								
With Louvered Sides	78.0	356	0.0066	9.85%	117.0	707	0.0045	8.81%
Without Louvered Sides	92.0	290	0.0054	5.51%	138.0	405	0.0025	2.39%

When analyzing prospective design options (excluding options that improved the fan motor efficiency), the combined fan and fan motor efficiency that was determined for each baseline unit was assumed to remain constant.

In analyzing improvements to the fan motor efficiency, the combined fan and fan motor efficiency was multiplied by the ratio of the new fan motor efficiency to the baseline fan motor efficiency. For example, in the case of the less than 6000 Btu/hr product class, the baseline unit utilized a shaded pole fan motor with efficiency equal to 30%. Replacing the shaded pole motor with a PSC motor, the fan motor efficiency is increased to 50%. The new combined fan and fan motor efficiency is determined by multiplying the baseline combined fan and fan motor efficiency (5.38% for the evaporator fan and 2.57% for the condenser fan) by the ratio of 50%-to-30%. This yields a combined fan and fan motor efficiency of 8.97% for the evaporator fan and 4.28% for the condenser fan.

Entering Air Streams Evaluated as Moist Air

For both the evaporator and condenser, the simulation model evaluates the density and, in turn, the mass flow rate of the entering air stream without correctly accounting for the moisture contained within the air. The following equation was used by the simulation model to determine the density of the entering air stream.

$$\rho = \frac{R \cdot T}{p} \qquad \textbf{(A.7)}$$

where ρ is the density of the moist air, R is the universal gas constant, T is the temperature of the moist air, and p is the pressure of the moist air. The above equation essentially obeys the perfect gas equation of state. In order to correctly account for the moisture within the entering air stream, the following equation, provided by the *1989 ASHRAE Fundamentals Handbook* (9), was substituted for equation A.7 in the simulation model.

$$\rho = \left(\frac{R \cdot T}{p}\right) \cdot (1 + 1.6078 \cdot W) \qquad \textbf{(A.8)}$$

where W is the moist air's humidity ratio. In the simulation model, subroutines EVAPR (for the evaporator) and COND (for the condenser) contain the expressions for calculating the density and mass flow rate of the entering air stream. In the subroutines, the expression for calculating the density of the entering air stream was changed to include the effects of the moisture content of the air (i.e., Eq. A.8).

A.1.3 Input Data Modifications

The modifications made to the Oak Ridge Heat Pump Design Model have required that changes be made to the input data. Most of the changes have consisted of adding additional input variables. These new input variables are necessary for modeling the effects that are unique to room air conditioners. Some of the new input variables were a result of the original modifications that were made to the Heat Pump Design Model in order to simulate the performance of room air conditioners (10). The remainder of the new input variables were added as a result of the additional revisions necessary for modeling the affects described in this Appendix.

A description of the input data is provided below. Most of the input data can be described by referring to the original Mark III program documentation, Appendix A (11). When the original documentation can be used, the number of the appropriate card that contains the description is given. All new input variables are fully described. An annotated listing of a sample input data file is provided in Figure A.11.

Input Data Descriptions

Input Line 1
Same as Card #1 in Mark III Program Documentation, Appendix A.

Input Line 2
Same as Card #2 in Mark III Program Documentation, Appendix A.

Input Line 3
Same as Card #3 in Mark III Program Documentation, Appendix A.

Input Line 4
ICAPFLAG Switch for specifying the capacity of the room air conditioner.
= 0, system capacity is not specified.
= 1, system capacity is specified by input variable CAPACITY.

CAPACITY	if ICAPFLAG = 1, the simulation model will vary the displacement of the compressor until the system capacity equals the value of CAPACITY (Btu/h).
EPSILON	if ICAPFLAG = 1, the value of EPSILON specifies the tolerance on CAPACITY for which the simulation model will stop iterating (Btu/h).

Input Line 5

Same as Card #4 in Mark III Program Documentation, Appendix A.

Input Line 6

No Subcooler

ISUB	= 0, no subcooler present.

Tube-in-Condensate Subcooler

ISUB	= 1, for the tube-in-condensate subcooler.
INDIA	The inner diameter of the refrigerant tube (inches).
OUTDIA	The outer diameter of the refrigerant tube (inches).
LENGTH	The length of the subcooler refrigerant tube (inches).
TCOND	The temperature of the condensate pool (°F).

Tube-in-Tube Subcooler

ISUB	= 2, for the tube-in-tube subcooler.
INDIA	The diameter of the inner tube (inches).
OUTDIA	The diameter of the outer tube (inches).
LENGTH	The length of the subcooler (inches).
RIDGE	Ridge height on inside tube outer surface (inches).

Input Line 7

Modification of an existing input line for specifying the type of flow control device. Input data descriptions for specifying fixed condenser subcooling, a thermostatic expansion valve, and a short tube orifice are the same as Card #5 in Mark III Program Documentation, Appendix A. For specifying a capillary tube the following input data description are used.

IREFC	= 2, or a capillary tube expansion device.
CAPLEN	The capillary tube length (inches).
CAPDIA	The capillary tube diameter (inches).
NCAP	The number of capillary tubes in parallel.

Input Line 8

Modification of an existing input line. The input data descriptions for the first two input variables on this input line (TSICMP and TSOCMP) are the same as Card #6 in Mark III Program Documentation, Appendix A. The third and fourth input variables on the input line are used when an accumulator is present. The fifth and sixth input variables on the input line are used to adjust the calculated compressor power and refrigerant mass flow rate.

TACCM	The temperature increase across the accumulator (°F).
PACCM	The pressure drop across the accumulator (psi).

COMPOWCF	Correction factor for adjusting the compressor power. Values less than one decrease the calculated compressor power. Values greater than one increase the calculated compressor power.
XMSFLOCF	Correction factor for adjusting the refrigerant mass flow rate. Values less than one decrease the calculated mass flow rate. Values greater than one increase the calculated mass flow rate.

Input Line 9

Same as Card #7 in Mark III Program Documentation, Appendix A.

Input Line 10

Same as Card #8 in Mark III Program Documentation, Appendix A.

Input Line 11

Same as Card #9 in Mark III Program Documentation, Appendix A.

Input Line 12

ERTFLG	Switch for specifying grooved (rifled) refrigerant tubing in the evaporator. = 0, specify smooth tubing. = 1, specify grooved tubing.
ERTMULT	Multiplier for the increase in the refrigerant-side heat transfer coefficient due to the grooved tubing. The value is relative to the heat transfer coefficient for smooth tubing.
ERTPD	Multiplier for the increase in the refrigerant-side pressure drop due to the grooved tubing. The value is relative to the pressure drop for smooth tubing

Input Line 13

Same as Card #10 in Mark III Program Documentation, Appendix A, with the exception that an additional input variable has been added to the end on the input line to specify the heat losses associated with the divider wall.

DWHTLOSS	The heat loss associated with the divider wall. This represents the heat loss due to both heat transfer and air leakage (Btu/h).

Input Line 14

Same as Card #11 in Mark III Program Documentation, Appendix A. (Input variables DDUCT and FIXCAP have no effect on the simulation model.)

Input Line 15

Same as Card #12 in Mark III Program Documentation, Appendix A, with the exception that an additional input variable has been added to the end of the input line to specify the effects of different fin types on the performance of the evaporator.

FINFXE	Multiplier for the increase in the air-side heat-transfer coefficient due to high performance fins (i.e., wavy, louvered, enhanced (slit)). The value is relative to the heat-transfer coefficient for flat fins.

Input Line 16

Same as Card #13 in Mark III Program Documentation, Appendix A.

Input Line 17

CRTFLG	Switch for specifying grooved (rifled) refrigerant tubing in the condenser. = 0, specify smooth tubing. = 1, specify grooved tubing.
CRTMULT	Multiplier for the increase in the refrigerant-side heat transfer coefficient due to the grooved tubing. The value is relative to the heat transfer coefficient for smooth tubing.
CRTPD	Multiplier for the increase in the refrigerant-side pressure drop due to the grooved tubing. The value is relative to the pressure drop for smooth tubing.

Input Line 18

SPRFLG	Switch for specifying whether condensate is sprayed on to the condenser. = 0, specifies that no condensate is sprayed. = 1, specifies that condensate spray is utilized.
PERC	Effective percentage of condensate spray evaporation that is useful to the condenser.
CONDCORR	Correction factor for adjusting the effect that the condensate spray has on the condenser's air-side heat-transfer coefficient. Values less than one decrease the heat transfer coefficient. Values greater than one increase the heat transfer coefficient.

Input Line 19

Same as Card #14 in Mark III Program Documentation, Appendix A.

Input Line 20

Same as Card #15 in Mark III Program Documentation, Appendix A.

Input Line 21

Same as Card #16 in Mark III Program Documentation, Appendix A with the exception that an additional input variable has been added to the end of the input line to specify the effects of different fin types on the performance of the condenser.

FINFXC	Multiplier for the increase in the air-side heat transfer coefficient due to high performance fins (i.e., wavy, louvered, enhanced (slit)). The value is relative to the heat transfer coefficient for flat fins.

Input Line 22

Same as Card #17 in Mark III Program Documentation, Appendix A.

Input Line 23
Same as Card #18 in Mark III Program Documentation, Appendix A.

Input Line 24
Same as Card #19 in Mark III Program Documentation, Appendix A.

Input Line 25

DLL	Inside diameter of the liquid line (inches).
XLEQLL	Equivalent length of the liquid line (feet).
DSL	Inside diameter of the suction line (inches).
XLEQSL	Equivalent length of the suction line (feet).
DDL	Inside diameter of the discharge line (inches).
XLEQDL	Equivalent length of the discharge line (feet).

```
ITITLE
COMPANY Q, LESS THAN 6000 BTUH
      LPRINT
           1

       NCORH
           1

    ICAPFLAG    CAPACITY     EPSILON
           0     5950.00         3.0

      ICHRGE       SUPER
           0        16.0

        ISUB       INDIA      OUTDIA      LENGTH       TCOND
           1      0.2880      0.3125        17.3       85.00

       IREFC      CAPLEN      CAPDIA        NCAP
           2       42.50      0.0460         1.0

      TSICMP      TSOCMP       TACCM       PACCM    COMPOWCF    XMSFLOCF
       40.50      132.00        5.00        1.00       0.988        1.00

       ICOMP       DISPL        SYNC        QCAN      CANFAC
           2       0.580     3450.00       749.0        0.00

     CPOW(1)     CPOW(2)     CPOW(3)     CPOW(4)     CPOW(5)     CPOW(6)      DISPLB      SUPERB
   1.667E-05  -6.933E-04  -8.750E-05   9.500E-04   6.500E-05   1.818E-01   0.580E+00  -9.500E+01

     CXMR(1)     CXMR(2)     CXMR(3)     CXMR(4)     CXMR(5)     CXMR(6)
  -4.367E-03   1.163E+00   1.263E-02   1.542E+00  -6.430E-03  -4.392E+01

      ERTFLG     ERTMULT       ERTPD
           0       2.500       1.000

       TAIII         RHI    DWHTLOSS
        74.0       0.600       180.0

         QAI      FANEFI       DDUCT      FIXCAP
       180.0      0.0541        8.00     19000.0

        AAFI         NTI      NSECTI         WTI         STI        RTBI      FINFXE
      0.8700         2.0         1.0       0.625         1.0        19.0       1.690

      FINTYI        FPFI      DELTAI        DEAI        DERI        XKFI        XKTI      HCONTI
         2.0        14.0      0.0060      0.3750      0.3510       128.3       225.0       100.0

      CRTFLG     CRTMULT       CRTPD
           0       2.000       1.000

      SPRFLG        PERC    CONDCORR
           1        0.95        1.00

       TAIIO         RHO
        95.0       0.400

         QAO      FANEFO      MFANFT
       330.0      0.0258           0

        AAFO         NTO      NSECTO         WTO         STO        RTBO      FINFXC
      1.6000         2.0         1.0       0.625         1.0        27.0       1.660

      FINTYO         FPO      DELTAO        DEAO        DERO        XKFO        XKTO      HCONTO
         2.0        18.0      0.0050      0.3125      0.2880       128.3       225.0       100.0

      MCMPOP      MFANIN      MFANOU
           1           0           1

      QSUCLN      QDISLN      QLIQLN
       000.0       100.0       100.0

         DLL      XLEQLL         DSL      XLEQSL         DDL      XLEQDL
      0.2880      00.007      0.3190       3.333      0.1940        3.00
```

Figure A.11 Annotated Listing of a Sample Input Data File

Baseline Unit Descriptions

Figures A.12 through A.20 provide listings of the input data files for the baseline units that were modeled for each of the nine product classes for which an engineering analysis was performed.

```
 COMPANY Q, LESS THAN 6000 BTUH
           1
           1
           0     5950.00         3.0
           0        16.0
           1      0.2880      0.3125        17.3       85.00
           2       42.50      0.0460       1.0
       40.50      132.00        5.00        1.00       0.943       1.030
           2       0.580     3450.00       749.0        0.00
  -2.048E-05   9.140E-03  -3.900E-05  -2.300E-03   5.350E-05  -3.545E-01   0.580E+00  -9.500E+01
  -1.809E-03   4.929E-01   1.394E-02   1.346E+00  -5.744E-03   1.869E+00
           0       2.500       1.000
        80.0       0.500       180.0
       180.0     0.05383        8.00     19000.0
      0.8700         2.0         1.0       0.625         1.0        19.0       1.690
         2.0        14.0      0.0060      0.3750      0.3510       128.3       225.0       100.0
           0       2.000       1.000
           1        0.95        1.00
        95.0       0.400
       330.0     0.02566           0
      1.6000         2.0         1.0       0.625         1.0        27.0       1.660
         2.0        18.0      0.0050      0.3125      0.2880       128.3       225.0       100.0
           1           0           1
       000.0       100.0       100.0
      0.2880      00.007      0.3190       3.333      0.1940        3.00
```

Figure A.12 Baseline Input Data Description - Room Air Conditioners Without Reverse Cycle and With Louvered Sides, Less Than 6000 Btu/hr

```
COMPANY R, 6000 TO 7999 BTUH
          1
          1
          0     7550.00         3.0
          0         3.4
          1      0.2880      0.3125        34.5       85.00
          2       45.00      0.0523         1.0
      38.50      130.00        5.00         1.0       1.030       1.003
          2       0.700     3450.00       643.0        0.00
  1.500E-05   1.062E-03  -1.000E-05  -5.200E-04   3.500E-05   1.873E-01   0.700E+00    2.00E+01
 -2.466E-04  -6.443E-02   1.203E-02   1.190E+00  -7.443E-04   5.801E+01
          0       2.500       1.000
       80.0       0.500       180.0
      210.0     0.10016        8.00     19000.0
     0.8700         3.0         1.0       0.625         1.0        29.0       1.480
        2.0        14.0      0.0060      0.3750      0.3510       128.3       225.0       100.0
          0       2.000       1.000
          1        0.95         1.0
       95.0       0.400
      380.0     0.04246           0
     1.6000         3.0         1.0       0.625         1.0        41.0       1.490
        2.0        16.0      0.0050      0.3125      0.2880       128.3       225.0       100.0
          1           0           1
      000.0       100.0       100.0
     0.2880       0.007      0.3190       3.333      0.3750       3.000
```

Figure A.13 Baseline Input Data Description - Room Air Conditioners Without Reverse Cycle and With Louvered Sides, 6000 to 7999 Btu/hr

```
COMPANY Z, 8000 TO 13,999 BTUH
           1
           1
           0    12000.00         3.0
           0         9.0
           1      0.2885      0.3125        37.2       85.00
           2       33.00      0.0468         2.0
        40.5      132.00        5.00         1.0       0.936       1.184
           2       1.120     3450.00       907.5        0.00
   4.850E-05  -3.929E-03  -1.115E-04   1.927E-03   8.745E-05   5.626E-01   1.120E+00  -9.500E+01
  -3.518E-03   3.453E-01   2.113E-02   1.531E+00   1.463E-03   6.851E+01
           0       2.500       1.000
        80.0       0.500       122.0
       285.0     0.09454        8.00     19000.0
      1.0600         3.0        1.83       0.625         1.0        29.0       1.920
         3.0        14.0      0.0045      0.3125      0.2885       128.3       225.0       100.0
           0       2.000       1.000
           1        0.95         1.0
        95.0       0.400
       645.0     0.09776           0
      1.7200         3.0         1.0       0.625         1.0        41.0       1.950
         3.0        14.0      0.0045      0.3125      0.2885       128.3       225.0       100.0
           1           0           1
       000.0       100.0       100.0
      0.3125       0.500      0.5000       4.000      0.6250       3.167
```

Figure A.14 Baseline Input Data Description - Room Air Conditioners Without Reverse Cycle and With Louvered Sides, 8000 to 13999 Btu/hr

```
COMPANY J, 14,000 TO 19,999 BTUH
           1
           1
           0    17900.00         3.0
           0         9.6
           1      0.3640      0.3920        45.8       85.00
           2       38.00      0.0735         1.0
       40.50      132.00        5.00         1.0       0.947       1.046
           2       1.540     3450.00      1449.0        0.00
   5.291E-05  -4.066E-03  -3.129E-04   2.221E-02   7.202E-05   6.415E-01   1.540E+00  -9.500E+01
  -2.030E-03  -1.166E-01   3.080E-02   2.776E+00  -3.829E-04   1.011E+02
           1        2.25       1.410
        80.0       0.500       380.0
       515.0     0.16690        8.00     19000.0
      1.5600         3.0         3.0       0.866         1.0        33.0       1.880
         3.0        13.0      0.0045      0.3920      0.3640       128.3       225.0       100.0
           0       1.720       1.850
           1        0.95         1.0
        95.0       0.400
       870.0     0.10185           0
      2.4200         3.0        1.63       0.866         1.0        46.0       1.890
         3.0        15.0      0.0045      0.3920      0.3640       128.3       225.0       100.0
           1           0           1
       000.0       100.0       100.0
      0.3190       1.000      0.4440       4.167      0.3190       3.000
```

Figure A.15 Baseline Input Data Description - Room Air Conditioners Without Reverse Cycle and With Louvered Sides, 14000 to 19999 Btu/hr

```
COMPANY K, GREATER THAN 20,000 BTUH
           1
           1
           0    24200.00         3.0
           0        18.0
           1      0.3640      0.3920        45.8       85.00
           2       40.00      0.0855        1.00
       40.50      132.00        5.00        1.00       0.948       0.931
           2       2.180     3450.00      2640.0        0.00
   3.821E-05   1.439E-02  -1.800E-04   9.918E-03   1.080E-04  -4.508E-01   2.180E+00  -9.500E+01
   1.014E-02  -2.901E+00   5.955E-02   4.149E+00  -1.143E-02   3.682E+02
           1       2.050       1.410
        80.0       0.500       350.0
       534.0    0.094640        8.00     19000.0
      2.0400         3.0         3.0       0.866         1.0        33.0       1.850
         3.0        14.0      0.0045      0.3920      0.3640       128.3       225.0       100.0
           1       1.610       1.850
           1        0.95         1.0
          95       0.400
      1231.0    0.142400           0
      2.7200         3.0        1.64       0.866         1.0        52.0       1.920
         3.0        12.0      0.0045      0.3920      0.3640       128.3       225.0       100.0
           1           0           1
       000.0       100.0       100.0
      0.3190       1.000      0.5550       5.000      0.3190       3.833
```

Figure A.16 Baseline Input Data Description - Room Air Conditioners Without Reverse Cycle and With Louvered Sides, Greater than 20000 Btu/hr

```
 COMPANY X, 6000 TO 7999 BTUH
           1
           1
           0     6300.00         3.0
           0         9.3
           1      0.2880      0.3125        17.3       85.00
           2       45.00      0.0518        1.00
       40.50      132.00        5.00        1.00       0.956      0.9620
           2       0.580     3450.00       749.0        0.00
  -1.191E-06   4.748E-03  -6.500E-05   2.300E-03   3.750E-05  -1.538E-01   0.580E+00  -9.500E+01
  -9.208E-04   1.422E-02   2.114E-02   1.973E-01  -1.842E-03   6.303E+01
           1       2.200       1.410
        80.0       0.500       180.0
       186.0     0.04851        8.00     19000.0
      1.0300         2.0         1.0       0.866         1.0        18.0       1.890
         3.0        14.0      0.0044      0.3750      0.3480       128.3       225.0       100.0
           1       1.910       1.850
           1        0.95         1.0
          95       0.400
       342.0     0.04133           0
      1.3500         2.0         1.0       0.692         0.8        31.0       1.930
         3.0        15.0      0.0044      0.3125      0.2855       128.3       225.0       100.0
           1           0           1
       000.0       100.0       100.0
      0.3125       1.317      0.3125       5.267      0.2500       7.242
```

Figure A.17 Baseline Input Data Description - Room Air Conditioners Without Reverse Cycle and Without Louvered Sides, 6000 to 7999 Btu/hr

```
 COMPANY Y, 8000 TO 13999 BTUH
           1
           1
           0    10700.00         3.0
           0         5.9
           1      0.2885      0.3125        37.2       85.00
           2       40.00      0.0610        1.00
       40.50      132.00        5.00        1.00       0.872       1.082
           2       1.000     3450.00      1200.0        0.00
  -1.429E-05   8.479E-03  -5.000E-05  -8.100E-03   1.100E-04   8.931E-04   1.000E+00  -9.500E+01
  -3.800E-04  -2.516E-02   3.217E-02   1.318E+00  -7.975E-03   8.662E+01
           1       2.270       1.410
        80.0       0.500       122.0
       293.0     0.16599        8.00     19000.0
      1.0300         3.0         2.0       0.866         1.0        29.0       1.860
         3.0        14.0      0.0044      0.3750      0.3480       128.3       225.0       100.0
           1       1.690       1.850
           1        0.95         1.0
          95       0.400
       328.0     0.03986           0
      1.3500         3.0         1.0       0.692         0.8        47.0       1.840
         3.0        15.0      0.0044      0.3125      0.2855       128.3       225.0       100.0
           1           0           1
       000.0       100.0       100.0
      0.2500       1.267      0.4375       8.433      0.2500       8.079
```

Figure A.18 Baseline Input Data Description - Room Air Conditioners Without Reverse Cycle and Without Louvered Sides, 8000 to 13999 Btu/hr

```
 COMPANY H, 8000 TO 13999 BTUH
           1
           1
           0    12400.00         3.0
           0        18.4
           1      0.3640      0.3920        20.0       85.00
           2       40.00      0.0615        1.00
       40.50      132.00        5.00        1.00      0.9248      1.0087
           2       1.120     3450.00      1200.0        0.00
   5.144E-05  -5.344E-03  -1.115E-04   4.459E-05   1.029E-04   6.820E-01   1.120E+00  -9.500E+01
  -5.665E-03   8.177E-01   1.716E-02   1.856E+00   1.608E-03   3.587E+01
           1       2.210       1.410
        80.0       0.500       122.0
       356.0    0.098496        8.00     19000.0
      1.3800         2.0         1.9       0.866         1.0        20.0       1.930
         3.0        16.0      0.0045      0.3920      0.3640       128.3       225.0       100.0
           1       1.920       1.850
           1        0.95         1.0
          95       0.400
       707.0    0.088138           0
      2.0300         2.0         1.9       0.866         1.0        29.0       1.960
         3.0        16.0      0.0045      0.3920      0.3640       128.3       225.0       100.0
           1           0           1
       000.0       100.0       100.0
      0.3190       1.000      0.4440       4.000      0.3190       4.167
```

Figure A.19 Baseline Input Data Description - Room Air Conditioners With Reverse Cycle and With Louvered Sides

```
COMPANY KK, 8000 TO 13999 BTUH
          1
          1
          0    11300.00         3.0
          0         2.5
          1      0.3190      0.3750        35.0       90.00
          2       40.00      0.0855        1.00
      40.50      132.00        5.00        1.00       0.868      1.0626
          2        0.99     3450.00      1100.0        0.00
  2.333E-05   1.262E-03  -1.200E-05  -4.200E-04   4.500E-05   2.761E-01   0.990E+00   2.000E+01
 -2.717E-04  -1.141E-01   1.734E-02   1.725E+00  -1.087E-03   8.496E+01
          1       2.180       1.410
       80.0       0.500       122.0
      290.0    0.055098        8.00     19000.0
     1.2600         3.0         1.8       0.750         1.0        30.0       1.840
        3.0        12.0      0.0045      0.3750      0.3342       128.3       225.0       100.0
          1       2.140       1.850
          1        0.95         1.0
         95       0.400
      405.0    0.023861           0
     1.7700         4.0        3.20       0.750         1.0        57.0       1.520
        2.0        12.0      0.0045      0.3750      0.3342       128.3       225.0       100.0
          1           0           1
      000.0       100.0       100.0
     0.3190       0.001      0.4440       3.586      0.2565       2.521
```

Figure A.20 Baseline Input Data Description - Room Air Conditioners Without Reverse Cycle and Without Louvered Sides

A.1.4 Map-Based Compressor Model Input Data

As mentioned previously in this appendix, the compressor model used in the analysis of room air conditioners is a map-based model. The map-based compressor model uses empirical performance curves obtained from compressor calorimeter measurements conducted by compressor manufacturers. These performance curves provide compressor motor power input, refrigerant mass flow rate, and/or refrigerating capacity as functions of "evaporator" saturation temperature (i.e., at the compressor shell inlet) for four to six "condenser" saturation temperatures (i.e., at the the compressor shell outlet).

The Oak Ridge Heat Pump Design Model also provides a second type of compressor model; a loss and efficiency model. The loss and efficiency compressor model (which uses a more general routine than the map-based model) attempts to simulate the internal energy balances in a reciprocating compressor using user-supplied heat loss and internal efficiency values. Because the loss and efficiency model cannot predict compressor performance as accurately over the same range of operating conditions as the map-based model, the map-based model was selected and used to model the compressor.

The routine in the map-based compressor model uses curve fits to the compressor motor power input (watts) and the refrigerant mass flow rate (lbm/hr) as functions of compressor shell inlet and outlet saturation temperatures to model the published performance data. The user must provide sets of coefficients for bi-quadratic functions of the form given by Eq. A.9 for the power input and mass flow rate as functions of the inlet and outlet saturation temperatures.

$$f(T_{outlet},T_{inlet}) = C_1 T_{outlet}^2 + C_2 T_{outlet} + C_3 T_{inlet}^2 + C_4 T_{inlet} + C_5 T_{outlet} T_{inlet} + C_6 \qquad \textbf{(A.9)}$$

These coefficients are input on line numbers 8 and 9 of the input data (refer to input data description). A short computer program that uses a least squares algorithm to compute these coefficients is provided with the Oak Ridge Heat Pump Design Model. There are two versions of this computer program. One version is used with compressor map data that are based on a return gas temperature of 95°F. The other version is used with map data based on a superheat temperature of 20°F.

A description of the input data for the computer program is provided below. An annotated listing of a sample input data file is provided in Figure A.21.

Input Data Description for Map-Based Compressor Computer Program

Input Line 1a

ANSI	= POWR, designates that the following data pertains to the compressor motor input.

Input Line 2a

TITLE	Descriptive title for the compressor described by this set of data.

Input Line 3a

Variables that designate the number of compressor map points that will be used to determine the coefficients for the bi-quadratic function for compressor motor power.

XNX	Specifies the number of condenser saturation temperatures.
XNY	Specifies the number of evaporator saturation temperatures.

Input Line 4a

SUPER1	Depending on the version of the computer program that is being used, this variable specifies the return gas temperature or the amount of superheat. If the compressor map data is based on a return gas temperature, enter the negative of the value (e.g. -95° F). If the compressor map data is based on a value of superheat, enter the superheat value (e.g. 20° F).
SUBCOL1	Specifies the amount of subcooling the compressor map data is based upon (°F).
DISPL1	Specifies the compressor displacement that the compressor map data is based upon (cubic inches).
RPM1	Specifies the rpm of the compressor that the compressor map data is based upon (rpm).

Input Line 5a

TSATC1(XNX)	Specifies the condenser saturation temperatures that will be used to determine the coefficients for the bi-quadratic function for the compressor motor power (°F). The number of temperatures provided on this Input Line must equal the number specified by the input variable XNX. For example, if four temperatures are entered on this Input Line, XNX equals four.

Input Line 6a

TSATE1(XNY)	Specifies the evaporator saturation temperatures that will be used to determine the coefficients for the bi-quadratic function for the compressor motor power (°F). The number of temperatures provided on this Input Line must equal the number specified by the input variable XNY. For example, if

three temperatures are entered on this Input Line, XNY equals three. Input Lines for Compressor Power (The number of Input Lines used for specifying the motor input values corresponds to the number of condenser saturation temperatures entered on Input Line 5a.)

POWER(XNY,XNX)	Specifies the compressor motor input values at the above specified condenser and evaporator saturation temperatures (watts). The first Input Line consists of motor input values at the evaporator saturation temperatures entered on Input Line 6a and the first condenser saturation temperature entered on Input Line 5a. The subsequent Input Lines are for the remaining condenser saturation temperatures entered on Input Line 5a.

Input Lines for Weighting the Compressor Power (The number of Input Lines for Weighting are equal to the number of Input Lines used for entering the Compressor Power data.)

WGHT1(XNY,XNX)	The values entered here are the "weighting" factors for the compressor motor input data entered on the above Input Lines. In general, the values here should all be 100 (100%) which indicates that all power values should be given equal weight when calculating the coefficients for the curve fitting "power" equation.

Input Line 1b

ANS1	Specifies the second type of compressor map data. = CAPA if the following data pertains to refrigerating capacity. = MASS if the following data pertains to mass flow rate data.

Input Line 2b

TITLE	Same data description as Input Line 2a.

Input Line 3b

XNX	Same description as XNX on Input Line 3a except data pertains to capacity or mass flow rate.
XNY	Same description as XNY on Input Line 3a except data pertains to capacity or mass flow rate.

Input Line 4b

SUPER2	Same description as SUPER1 on Input Line 4a.
SUBCL2	Same description as SUBCL1 on Input Line 4a.
DISPL2	Same description as DISPL1 on Input Line 4a.
RPM2	Same description as RPM1 on Input Line 4a.

Input Line 5b

TSATC2(XNX)	Same description as TSATC1 on Input Line 5a except data pertains to capacity or mass flow rate.

Input Line 6b

TSATE2(XNY) Same description as TSATE1 on Input Line 6a except data pertains to capacity or mass flow rate.

Input Lines for Capacity or Mass Flow Rate (The number of Input Lines used for specifying the capacity or mass flow rate corresponds to the number of condenser saturation temperatures entered on Input Line 5b.)

XMR(XNY,XNX) Same descriptions as Input Lines for Compressor Power except that the data pertains to capacity (kBtu/h) or mass flow rate (lbm/hr).

Input Lines for Weighting the Capacity or Mass Flow Rate (The number of Input Lines for Weighting are equal to the number of Input Lines used for entering the Capacity or Mass Flow Rate data.

WGHT1(XNY,XNX) The values entered here are the "weighting" factors for the capacity or mass flow rate data entered on the above Input Lines. In general, the values here should all be 100 (100%) which indicates that all capacity or mass flow rate values should be given equal weight when calculating the coefficients for the curve fitting "mass flow rate" equation.

```
ANS1
POWR
TITLE
COMPANY Q
                     XNX               XNY
                    4.00              3.00
                  SUPER1            SUBCL1            DISPL1              RPM1
                  -95.00             15.00              0.58            3450.0
               TSATC1(1)         TSATC1(2)         TSATC1(3)         TSATC1(4)
                  110.00            120.00            130.00            140.00
               TSATE1(1)         TSATE1(2)         TSATE1(3)
                   34.00             44.00             54.00
              POWER(1,1)        POWER(2,1)        POWER(3,1)
                   480.0             490.0             490.0
              POWER(1,2)        POWER(2,2)        POWER(3,2)
                   540.0             560.0             560.0
              POWER(1,3)        POWER(2,3)        POWER(3,3)
                   590.0             610.0             620.0
              POWER(1,4)        POWER(2,4)        POWER(3,4)
                   650.0             690.0             700.0
              WGHT1(1,1)        WGHT1(2,1)        WGHT1(3,1)
                   100.0             100.0             100.0
              WGHT1(1,2)        WGHT1(2,2)        WGHT1(3,2)
                   100.0             100.0             100.0
              WGHT1(1,3)        WGHT1(2,3)        WGHT1(3,3)
                   100.0             100.0             100.0
              WGHT1(1,4)        WGHT1(2,4)        WGHT1(3,4)
                   100.0             100.0             100.0
ANS1
CAPA
TITLE
COMPANY Q
                     XNX               XNY
                    4.00              3.00
                  SUPER2            SUBCL2            DISPL2              RPM2
                  -95.00             15.00              0.58            3450.0
               TSATC2(1)         TSATC2(2)         TSATC2(3)         TSATC2(4)
                  110.00            120.00            130.00            140.00
               TSATE2(1)         TSATE2(2)         TSATE2(3)
                   34.00             44.00             54.00
                XMR(1,1)          XMR(2,1)          XMR(3,1)
                   6.000             7.400             8.900
                XMR(1,2)          XMR(2,2)          XMR(3,2)
                   5.650             7.000             8.450
                XMR(1,3)          XMR(2,3)          XMR(3,3)
                   5.300             6.550             7.950
                XMR(1,4)          XMR(2,4)          XMR(3,4)
                   5.000             6.000             7.250
              WGHT2(1,1)        WGHT2(2,1)        WGHT2(3,1)
                   100.0             100.0             100.0
              WGHT2(1,2)        WGHT2(2,2)        WGHT2(3,2)
                   100.0             100.0             100.0
              WGHT2(1,3)        WGHT2(2,3)        WGHT2(3,3)
                   100.0             100.0             100.0
              WGHT2(1,4)        WGHT2(2,4)        WGHT2(3,4)
                   100.0             100.0             100.0
```

Figure A.21 Annotated Listing of a Sample Input Data File for Map-Based Compressor Computer Program

Compressor Baseline Unit Descriptions

Figures A.22 through A.30 provide listings of the compressor input data files for each of the baseline units that were modeled.

```
POWR
COMPANY Q, MATSHUSHITA 2R10S3R126A-6A
            5.00        3.00
          -95.00       15.00        0.58      3450.0
          100.00      110.00      120.00      130.00      140.00
           35.00       45.00       55.00
           413.0       410.0       410.0
           482.0       485.0       478.0
           546.0       555.0       554.0
           603.0       620.0       626.0
           655.0       679.0       692.0
           100.0       100.0       100.0
           100.0       100.0       100.0
           100.0       100.0       100.0
           100.0       100.0       100.0
           100.0       100.0       100.0
CAPA
COMPANY Q, MATSHUSHITA 2R10S3R126A-6A
            5.00        3.00
          -95.00       15.00        0.58      3450.0
          100.00      110.00      120.00      130.00      140.00
           35.00       45.00       55.00
           6.450       7.960       9.690
           6.110       7.500       9.080
           5.810       7.120       8.590
           5.450       6.670       8.050
           5.040       6.160       7.430
           100.0       100.0       100.0
           100.0       100.0       100.0
           100.0       100.0       100.0
           100.0       100.0       100.0
           100.0       100.0       100.0
```

Figure A.22 Compressor Baseline Input Data Description - Room Air Conditioners Without Reverse Cycle and With Louvered Sides, Less Than 6000 Btu/hr

```
POWR
COMPANY R, TECUMSEH RK5480E, 115V
                5.00          3.00
               20.00         15.00          0.70        3450.0
              100.00        110.00        120.00        130.00        140.00
               35.00         45.00         55.00
               535.0         557.0         578.0
               590.0         615.0         638.0
               648.0         676.0         702.0
               708.0         740.0         770.0
               770.0         807.0         841.0
               100.0         100.0         100.0
               100.0         100.0         100.0
               100.0         100.0         100.0
               100.0         100.0         100.0
               100.0         100.0         100.0
CAPA
COMPANY R, TECUMSEH RK5480E, 115V
                5.00          3.00
               20.00         15.00          0.70        3450.0
              100.00        110.00        120.00        130.00        140.00
               35.00         45.00         55.00
               7.876         9.583        11.511
               7.454         9.090        10.940
               7.032         8.597        10.367
               6.609         8.100         9.790
               6.183         7.599         9.208
               100.0         100.0         100.0
               100.0         100.0         100.0
               100.0         100.0         100.0
               100.0         100.0         100.0
               100.0         100.0         100.0
```

Figure A.23 Compressor Baseline Input Data Description - Room Air Conditioners Without Reverse Cycle and With Louvered Sides, 6000 to 7999 Btu/hr

```
POWR
COMPANY Z, MATSUSHITA 2P19C3R126A-1B
            5.00          3.00
          -95.00         15.00          1.12        3450.0
          104.00        113.00        122.00        131.00        140.00
           32.00         42.80         53.60
           910.0         950.0         955.0
          1005.0        1040.0        1040.0
          1100.0        1135.0        1165.0
          1200.0        1245.0        1275.0
          1295.0        1370.0        1405.0
           100.0         100.0         100.0
           100.0         100.0         100.0
           100.0         100.0         100.0
           100.0         100.0         100.0
           100.0         100.0         100.0
CAPA
COMPANY Z, MATSUSHITA 2P19C3R126A-1B
            5.00          3.00
          -95.00         15.00          1.12        3450.0
          104.00        113.00        122.00        131.00        140.00
           32.00         42.80         53.60
          11.699        14.475        17.608
          11.064        13.721        16.695
          10.311        12.928        15.882
           9.597        12.175        14.990
           8.883        11.302        13.959
           100.0         100.0         100.0
           100.0         100.0         100.0
           100.0         100.0         100.0
           100.0         100.0         100.0
           100.0         100.0         100.0
```

Figure A.24 Compressor Baseline Input Data Description - Room Air Conditioners Without Reverse Cycle and With Louvered Sides, 8000 to 13999 Btu/hr

```
POWR
COMPANY J, MATSUSHITA 2K25C3R236A-6A
          5.00        3.00
        -95.00       15.00        1.54      3450.0
        104.00      113.00      122.00      131.00      140.00
         32.00       42.80       53.60
        1420.0      1485.0      1485.0
        1510.0      1585.0      1585.0
        1605.0      1695.0      1700.0
        1705.0      1795.0      1800.0
        1825.0      1915.0      1950.0
         100.0       100.0       100.0
         100.0       100.0       100.0
         100.0       100.0       100.0
         100.0       100.0       100.0
         100.0       100.0       100.0
CAPA
COMPANY J, MATSUSHITA 2K25C3R236A-6A
          5.00        3.00
        -95.00       15.00        1.54      3450.0
         104.0       113.0       122.0       131.0       140.0
         32.00       42.80       53.60
        15.347      19.749      24.468
        14.316      18.559      23.080
        13.483      17.449      22.009
        12.631      16.458      20.701
        11.580      15.228      19.392
         100.0       100.0       100.0
         100.0       100.0       100.0
         100.0       100.0       100.0
         100.0       100.0       100.0
         100.0       100.0       100.0
```

Figure A.25 Compressor Baseline Input Data Description - Room Air Conditioners Without Reverse Cycle and With Louvered Sides, 14000 to 19999 Btu/hr

```
POWR
COMPANY K, MATSUSHITA 2J39C3R236B-1A
          5.00          3.00
        -95.00         15.00          2.40        3450.0
        100.00        110.00        120.00        130.00        140.00
         35.00         45.00         55.00
        1950.0        1925.0        1880.0
        2180.0        2180.0        2160.0
        2410.0        2435.0        2450.0
        2645.0        2700.0        2745.0
        2875.0        2965.0        3045.0
         100.0         100.0         100.0
         100.0         100.0         100.0
         100.0         100.0         100.0
         100.0         100.0         100.0
         100.0         100.0         100.0
CAPA
COMPANY K, MATSUSHITA 2J39C3R236B-1A
          5.00          3.00
        -95.00         15.00          2.40        3450.0
        100.00        110.00        120.00        130.00        140.00
         35.00         45.00         55.00
        28.435        34.145        40.445
        27.225        32.830        38.980
        25.770        31.255        37.240
        24.040        29.400        35.200
        22.035        27.250        32.850
         100.0         100.0         100.0
         100.0         100.0         100.0
         100.0         100.0         100.0
         100.0         100.0         100.0
         100.0         100.0         100.0
```

Figure A.26 Compressor Baseline Input Data Description - Room Air Conditioners Without Reverse Cycle and With Louvered Sides, Greater Than 20000 Btu/hr

```
POWR
COMPANY X, MATSUSHITA 2R10B3R126C-6A
                5.00                3.00
              -95.00               15.00                0.58              3450.0
              100.00              110.00              120.00              130.00              140.00
               35.00               45.00               55.00
               440.0               450.0               450.0
               500.0               505.0               505.0
               565.0               575.0               580.0
               610.0               635.0               640.0
               670.0               700.0               705.0
               100.0               100.0               100.0
               100.0               100.0               100.0
               100.0               100.0               100.0
               100.0               100.0               100.0
               100.0               100.0               100.0
CAPA
COMPANY X, MATSUSHITA 2R10B3R126C-6A
                5.00                3.00
              -95.00               15.00                0.58              3450.0
              100.00              110.00              120.00              130.00              140.00
               35.00               45.00               55.00
               6.800               8.200               9.850
               6.300               7.700               9.200
               5.950               7.150               8.650
               5.500               6.600               8.050
               5.000               6.050               7.500
               100.0               100.0               100.0
               100.0               100.0               100.0
               100.0               100.0               100.0
               100.0               100.0               100.0
               100.0               100.0               100.0
```

Figure A.27 Compressor Baseline Input Data Description - Room Air Conditioners Without Reverse Cycle and Without Louvered Sides, 6000 to 7999 Btu/hr

```
POWR
COMPANY Y, MATSUSHITA 2P17S3R236A-1B
          5.00          3.00
        -95.00         15.00          1.00        3450.0
        100.00        110.00        120.00        130.00        140.00
         35.00         45.00         55.00
         745.0         735.0         715.0
         840.0         840.0         830.0
         930.0         940.0         940.0
        1020.0        1040.0        1050.0
        1100.0        1135.0        1160.0
         100.0         100.0         100.0
         100.0         100.0         100.0
         100.0         100.0         100.0
         100.0         100.0         100.0
         100.0         100.0         100.0
CAPA
COMPANY Y, MATSUSHITA 2P17S3R236A-1B
          5.00          3.00
        -95.00         15.00          1.00        3450.0
        100.00        110.00        120.00        130.00        140.00
         35.00         45.00         55.00
        11.530        13.995        16.900
        10.770        13.105        15.865
        10.040        12.220        14.830
         9.335        11.350        13.785
         8.660        10.495        12.745
         100.0         100.0         100.0
         100.0         100.0         100.0
         100.0         100.0         100.0
         100.0         100.0         100.0
         100.0         100.0         100.0
```

Figure A.28 Compressor Baseline Input Data Description - Room Air Conditioners Without Reverse Cycle and Without Louvered Sides, 8000 to 13999 Btu/hr

```
POWR
COMPANY H, MATSUSHITA 2P19C3R236A-1B
          5.00           3.00
        -95.00          15.00           1.12         3450.0
        104.00         113.00         122.00         131.00         140.00
         32.00          42.80          53.60
         905.0          940.0          945.0
        1000.0         1030.0         1035.0
        1085.0         1125.0         1150.0
        1195.0         1245.0         1260.0
        1280.0         1355.0         1405.0
         100.0          100.0          100.0
         100.0          100.0          100.0
         100.0          100.0          100.0
         100.0          100.0          100.0
         100.0          100.0          100.0
CAPA
COMPANY H, MATSUSHITA 2P19C3R236A-1B
          5.00           3.00
        -95.00          15.00           1.12         3450.0
        104.00         113.00         122.00         131.00         140.00
         32.00          42.80          53.60
        11.698         14.554         17.607
        11.024         13.800         16.675
        10.311         12.967         15.882
         9.597         12.135         14.950
         8.764         11.183         13.880
         100.0          100.0          100.0
         100.0          100.0          100.0
         100.0          100.0          100.0
         100.0          100.0          100.0
         100.0          100.0          100.0
```

Figure A.29 Compressor Baseline Input Data Description - Room Air Conditioners With Reverse Cycle and With Louvered Sides

```
POWR
COMPANY KK, TECUMSEH RK5512E, 230V
           5.00          3.00
          20.00         15.00          0.99        3450.0
         100.00        110.00        120.00        130.00        140.00
          35.00         45.00         55.00
          763.0         794.0         825.0
          842.0         877.0         910.0
          924.0         963.0        1000.0
         1010.0        1055.0        1096.0
         1100.0        1151.0        1198.0
          100.0         100.0         100.0
          100.0         100.0         100.0
          100.0         100.0         100.0
          100.0         100.0         100.0
          100.0         100.0         100.0
CAPA
COMPANY KK, TECUMSEH RK5512E, 230V
           5.00          3.00
          20.00         15.00          0.99        3450.0
         100.00        110.00        120.00        130.00        140.00
          35.00         45.00         55.00
         11.382        13.850        16.633
         10.769        13.137        15.810
         10.156        12.420        14.981
          9.545        11.700        14.145
          8.935        10.979        13.304
          100.0         100.0         100.0
          100.0         100.0         100.0
          100.0         100.0         100.0
          100.0         100.0         100.0
          100.0         100.0         100.0
```

Figure A.30 Compressor Baseline Input Data Description - Room Air Conditioners With Reverse Cycle and Without Louvered Sides

A.2 MANUFACTURER COST DATA FOR ROOM AIR CONDITIONERS

The following tables show the total manufacturing costs (1990$) for several design options for twelve product classes of room air conditioners. Total costs are divided into variable and capital costs. Variable costs consist of material costs, purchased parts, labor costs, shipping costs, and a portion of indirect costs. Capital costs consist of tooling costs and a portion of indirect costs. Indirect costs include expenses such as general and administrative costs, research and development, rent, utility costs, and certification tests and fees. Since cost data were provided in total cost only, assumptions were made regarding the total cost in order to determine what percentages were variable and what were capital costs. For improved designs requiring the addition of an improved purchased part (i.e., increased compressor or fan motor efficiency), the total cost was assumed to be all variable. For design options requiring changes to components manufactured in-house (i.e., heat exchanger improvements), 85% of the total cost was assumed to be variable and 15% capital. For designs requiring substantial tooling changes (i.e., variable speed compressors and increased coil areas), a split of 60% variable cost and 40% capital cost was assumed. Cost data for the seven non-primary product classes (i.e., without side louvers or with a reversing valve) were taken directly from the cost data provided for the five primary classes (i.e., without reversing valve and with side louvers). The capacity size of the particular non-primary class dictated which primary class cost data were taken from. The variable, capital, and total incremental costs are always relative to the preceding design option, with the exception of the baseline costs. The incremental costs for each design option are per unit produced. The total costs at each design option, including the baseline, are cumulative. The estimated uncertainty (at a 95% confidence level) for the total costs are provided for each design option.

Table A.4 Total Manufacturing Costs for Room Air Conditioners (by Design Option)

Without Reverse Cycle and With Louvered Sides, Less Than 6000 Btu/hr

Level	Design No.	Design Option	Variable Cost	Capital Cost	Total Increm.	Total Cost	Uncert.
	0	Baseline	156.97	22.4	-	179.39	-
	1	0 + Evap/Cond Enhanced Fins	0.68	0.10	0.78	180.17	10%
1	2	1 + PSC Fan Motor	3.00	0.00	3.00	183.17	5%
2	3	2 + Evap/Cond Grooved Tubes	2.49	0.36	2.84	186.01	10%
3	4	3 + Add Subcooler	3.28	0.47	3.75	189.76	10%
4	5	4 + Increase Evap/Cond Coil Area	16.28	10.86	27.14	216.90	15%
	6	5 + BPM Fan Motor	60.00	0.00	60.00	276.90	25%
5	7	6 +Variable Speed Compressor	85.07	38.77	123.84	400.74	25%

Without Reverse Cycle and With Louvered Sides, 6000 to 7999 Btu/hr

Level	Design No.	Design Option	Variable Cost	Capital Cost	Total Increm.	Total Cost	Uncert.
	0	Baseline	174.41	24.92	-	199.33	-
	1	0 + Evap/Cond Enhanced Fins	0.95	0.14	1.08	200.41	10%
1	2	1 + PSC Fan Motor	3.00	0.00	3.00	203.41	5%
2	3	2 + Add Subcooler	3.28	0.47	3.75	207.16	10%
3	4	3 + Evap/Cond Grooved Tubes	3.73	0.53	4.26	211.42	10%
4	5	4 + Increase Evap/Cond Coil Area	17.45	11.63	29.08	240.50	15%
	6	5 + BPM Fan Motor	61.83	0.00	61.83	302.33	25%
5	7	6 +Variable Speed Compressor	85.80	38.77	124.57	426.90	25%

Table A.4 Total Manufacturing Costs for Room Air Conditioners (by Design Option) Cont'd

Without Reverse Cycle and With Louvered Sides, 8000 to 13999 Btu/hr

Level	Design No.	Design Option	Variable Cost	Capital Cost	Total Increm.	Total Cost	Uncert.
	0	Baseline	224.45	32.06	-	256.51	-
1	1	0 + Incr Compressor EER to 10.8	6.11	0.00	6.11	262.62	5%
2	2	1 + Add Subcooler	1.97	0.28	2.26	264.88	10%
3	3	2 + Evap/Cond Grooved Tubes	4.20	0.60	4.80	269.68	10%
4	4	3 + Increase Evap/Cond Coil Area	20.35	13.57	33.92	303.60	15%
	5	4 + BPM Fan Motor	64.58	0.00	64.58	368.18	25%
5	6	5 + Variable Speed Compressor	92.08	38.77	130.85	499.03	25%

Without Reverse Cycle and With Louvered Sides, 14000 to 19999 Btu/hr

Level	Design No.	Design Option	Variable Cost	Capital Cost	Total Increm.	Total Cost	Uncert.
	0	Baseline	286.71	40.96	-	327.67	-
1	1	0 + Incr Compressor EER to 10.8	11.51	0.00	11.51	339.18	5%
2	2	1 + Condenser Grooved Tubes	3.72	0.53	4.26	343.44	10%
3,4	3	2 + Add Subcooler	4.01	0.57	4.58	348.02	10%
	4	3 + Increase Evap/Cond Coil Area	58.16	38.77	96.93	444.94	15%
	5	4 + Incr Compressor EER to 11.3	32.51	0.00	32.51	477.45	5%
	6	5 + Incr Compressor EER to 11.4	14.98	0.00	14.98	492.44	5%
	7	6 + BPM Fan Motor	78.33	0.00	78.33	570.77	25%
5	8	7 + Variable Speed Compressor	108.95	38.77	147.72	718.48	25%

Without Reverse Cycle and With Louvered Sides, greater than 20000 Btu/hr

Level	Design No.	Design Option	Variable Cost	Capital Cost	Total Increm.	Total Cost	Uncert.
	0	Baseline	354.44	50.63	-	405.07	-
1,2	1	0 + Incr Compressor EER to 10.89	5.93	0.00	5.93	411.00	5%
3	2	1 + Add Subcooler	4.01	0.57	4.58	415.58	10%
4	3	2 + Incr Compressor EER to 11.5	39.15	0.00	39.15	454.73	5%
	4	3 + Increase Evap/Cond Coil Area	34.89	23.26	58.16	512.88	15%
	5	4 + Incr Compressor EER to 11.7	19.98	0.00	19.98	532.86	5%
	6	5 + BPM Fan Motor	87.50	0.00	87.50	620.36	25%
5	7	6 + Variable Speed Compressor	143.84	38.77	182.61	802.97	25%

Table A.4 Total Manufacturing Costs for Room Air Conditioners (by Design Option) Cont'd

Without Reverse Cycle and Without Louvered Sides, 6000 to 7999 Btu/hr

Level	Design No.	Design Option	Variable Cost	Capital Cost	Total Increm.	Total Cost	Uncert.
	0	Baseline	162.33	23.19	-	185.52	-
1,2	1	0 + Incr Compressor EER to 10.8	2.46	0.00	2.46	187.98	5%
3,4	2	1 + Add Subcooler	1.54	0.22	1.75	189.74	10%
	3	2 + BPM Fan Motor	61.83	0.00	61.83	251.57	25%
	4	3 + Variable Speed Compressor	85.07	38.77	123.84	375.41	25%
5	5	4 + Increase Evap/Cond Coil Area	17.45	11.63	29.08	404.49	15%

Without Reverse Cycle and Without Louvered Sides, 8000 to 13999 Btu/h

Level	Design No.	Design Option	Variable Cost	Capital Cost	Total Increm.	Total Cost	Uncert.
1	0	Baseline	210.08	30.01	-	240.09	-
2	1	0 + Add Subcooler	1.61	0.23	1.84	241.93	10%
3,4	2	1 + Incr Compressor EER to 11.09	3.26	0.00	3.26	245.20	5%
	3	2 + BPM Fan Motor	64.58	0.00	64.58	309.78	25%
	4	3 + Variable Speed Compressor	91.42	38.77	130.19	439.97	25%
5	5	4 + Increase Evap/Cond Coil Area	20.35	13.57	33.92	473.89	15%

With Reverse Cycle and With Louvered Sides

Level	Design No.	Design Option	Variable Cost	Capital Cost	Total Increm.	Total Cost	Uncert.
	0	Baseline	228.87	32.30	-	261.57	-
1,2	1	0 + Add Subcooler	1.97	0.28	2.26	263.83	10%
3,4	2	1 + Incr Compressor EER to 10.8	5.05	0.00	5.05	268.88	5%
	3	2 + Increase Evap/Cond Coil Area	20.35	13.57	33.92	302.80	15%
	4	3 + BPM Fan Motor	64.58	0.00	64.58	367.38	25%
5	5	4 +Variable Speed Compressor	92.08	38.77	130.85	498.23	25%

With Reverse Cycle and Without Louvered Sides

Level	Design No.	Design Option	Variable Cost	Capital Cost	Total Increm.	Total Cost	Uncert.
1,2	0	Baseline	215.95	30.85	-	246.80	-
3,4	1	0 + Condenser Enhanced Fins	0.76	0.11	0.86	247.66	10%
	2	1 + BPM Fan Motor	64.58	0.00	64.58	312.24	25%
	3	2 + Variable Speed Compressor	91.42	38.77	130.19	442.44	15%
5	4	3 + Increase Evap/Cond Coil Area	20.35	13.57	33.92	476.36	25%

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APPENDIX B. LBNL-REM INPUT DATA: AIR CONDITIONING

The complete input listing is available on electronic medium in ASCII format. The input database includes demographic, economic, and engineering data.

The following is the regular LBNL-REM input for air conditioning equipment.

For energy efficiency level cases, simply replace the input values for two variables in each class of each product regulated. The two variables are labeled: "first year for eff level" and "EER of eff level." For example, for room air conditioner energy efficiency levels taking effect in 1999, change the lines "first year for eff level = 2031" to "first year for eff level = 1999" and enter the appropiate minimum EER values in the lines "EER of eff level" for each class.

```
AIR COND.
total saturation             = 1.00
elec price multiplier        = 0.99
gas price multiplier         = 1.00
ncalc                        = 2
ndr1 (1, read drate & curve) = 0
nv1 (# of eun inputs)        = 0
nv5 (# of cap inputs)        = 0
nv2 (# of peq inputs)        = 0
nv4 (# of usage inputs)      = 0
ndis (year to forecast eff)  =11
nv3 (# of tin inputs)        = 3

--------- UEC of stock unit in base year by fuel type i (MMBTU/yr) source:HVAC Table H.9,
see cac.uec90.wk1
       1       2       3       4       5
   14.70    38.5    46.0   0.000   0.000                             ** SF **
    7.88    19.5    21.0   0.000   0.000                             ** MF **
   11.20    24.5    28.5   0.000   0.000                             ** MB **

---------- Purchase price of a reference unit ($1990) -------------------------
       1       2       3       4       5
  492.91 2326.20 2642.76    0.00    0.00                             ** SF **
  492.91 2326.20 2642.76    0.00    0.00                             ** MF **
  492.91 2326.20 2642.76    0.00    0.00                             ** MB **

---------- Relative UEC and Capacity of a reference unit to a stock unit -------
       1       2       3       4       5
   .6849   .6968   .7337    1.00    1.00                             ** re   **
  1.0000  1.0000  1.0000    1.00    1.00                             ** recap**

---------- Base Year Saturations - c70 ---------------------------------------
       1       2       3       4       5       6
   0.320   0.210   0.030   0.000   0.000   0.440                     ** SF **
   0.320   0.200   0.040   0.000   0.000   0.440                     ** MF **
   0.320   0.245   0.015   0.000   0.000   0.420                     ** MB **
```

```
---------- Marginal Saturations for Replacement Units - cn(m=1) ----------------
       1       2       3       4       5       6
   0.405   0.390   0.050   0.000   0.000   0.155                      ** SF **
   0.440   0.260   0.060   0.000   0.000   0.240                      ** MF **
   0.440   0.100   0.020   0.000   0.000   0.440                      ** MB **

---------- Marginal Saturations for New Houses - cn(m=2) -----------------------
       1       2       3       4       5       6
   0.120   0.370   0.200   0.000   0.000   0.310                      ** SF **
   0.220   0.410   0.160   0.000   0.000   0.210                      ** MF **
   0.270   0.380   0.020   0.000   0.000   0.330                      ** MB **

---------- Historical Shipments (from 1980 to 30 years back) -------------------
 1 Room Air Conditioner (source: AHAM)
   2.436   2.920   3.157   2.464   2.164   2.164   3.778   4.811   4.150   5.065
   5.492   5.017   3.641   3.722   3.011   2.651   2.480   1.751   1.422   1.350
   1.422   1.422   1.422   1.422   1.422   1.422   1.422   1.422   1.422   1.422
 2 Central Air Conditioner (source ARI)
   1.367   1.676   1.799   1.582   1.450   1.047   1.793   2.061   1.746   1.341
   1.112   1.107   0.780   0.654   0.592   0.527   0.426   0.352   0.267   0.206
   0.188   0.167   0.124   0.120   0.144   0.109   0.079   0.041   0.041   0.041
 3 Heat Pump (source ARI)
   0.354   0.482   0.486   0.418   0.251   0.128   0.097   0.087   0.080   0.067
   0.060   0.067   0.067   0.061   0.061   0.054   0.057   0.049   0.038   0.032
   0.030   0.025   0.017   0.006   0.003   0.002   0.001   0.001   0.000   0.000

---------- Retirement Function (from age 1 to 30 years) ------------------------
for i 1
   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0365   .1095
   .1645   .1895   .1895   .1645   .1095   .0365   .0000   .0000   .0000   .0000
   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000
for i 2 3           (from Weibull fit)
   .0000   .0000   .0000   .0000   .0000   .0000   .0010   .0030   .0080   .0180
   .0370   .0690   .1170   .1730   .2100   .1950   .1210   .0410   .0070   .0000
   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000

---------- Average Life Times (by fuel type i) ---------------------------------
       1       2       3       4       5
    12.5    15.0    15.0     0.0     0.0

---------- Operating Cost Elasticities (for 5 fuel types and income) -----------
       1       2       3       4       5       6
   -0.20    0.00    0.00    0.00    0.00    0.17                      ** j=1 **
    0.00   -0.40    0.00    0.00    0.00    0.00                      ** j=2 **
    0.00    0.00   -0.40    0.00    0.00    0.00                      ** j=3 **
    0.00    0.00    0.00    0.00    0.00    0.00                      ** j=4 **
    0.00    0.00    0.00    0.00    0.00    0.00                      ** j=5 **
    .599    1.20    1.20    0.00    0.00   -0.50                      ** j=6 **

---------- Interest Rate used to calculate Price Elasticities (for 5 fuel types)
       1       2       3       4       5
    0.15    0.00    0.00    0.00    0.00                              ** j=1 **
    0.00    0.12    0.00    0.00    0.00                              ** j=2 **
    0.00    0.00    0.12    0.00    0.00                              ** j=3 **
    0.00    0.00    0.00    0.00    0.00                              ** j=4 **
    0.00    0.00    0.00    0.00    0.00                              ** j=5 **

---------- Usage Elasticities (for 5 fuel types and income) --------------------
       1       2       3       4       5
   -0.20    0.00    0.00    0.00    0.00                              ** j=1 **
    0.00   -0.20    0.00    0.00    0.00                              ** j=2 **
    0.00    0.00   -0.20    0.00    0.00                              ** j=3 **
    0.00    0.00    0.00    0.00    0.00                              ** j=4 **
    0.00    0.00    0.00    0.00    0.00                              ** j=5 **
    0.30    0.30    0.30    0.00    0.00                              ** j=6 **

---------- Thermal Integrity of New Units --------------------------------------
       1       2       3       4       5
```

```
   0.989   0.987   0.975   1.000   1.000                             ** SF **
   0.998   0.997   0.986   1.000   1.000                             ** MF **
   0.990   0.980   0.935   1.000   1.000                             ** MB **

********************************************************************************
# of products in A/C         =    3

================================================================================
product type id#             =   10
product name                 =  RAC (Room A/C)
end-use id#                  =    3
fuel type id#                =    1
number of classes            =    9

---------- the 1st class -------------------------------------------------------
class id#                    =   99
class name                   = 6L   (Room A/C < 6K Btuh with louvres)
discount rate                = 2.42
last year of historical EER  = 1993
first year for eff level     = 2031
EER of eff level             =    8.23
conversion (Kwh-MMBTU&usage) = .003412          0.71

---------- Historical energy factors (AHAM scaled to baseline)
    1981    1982    1983    1984    1985    1986    1987    1988    1989    1990    1991
  1992    1993
    6.63    6.71    6.85    7.03    7.23    7.33    7.57    7.73    7.97    8.20    8.27
  8.34    8.52

---------- Adjusted volumes (1981-2015)
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0

---------- Fraction of market share (1981-2015)
l = 1 2 3
   0.276   0.276   0.276   0.276   0.276   0.276   0.276   0.276   0.276   0.271
   0.235   0.280   0.267   0.267   0.267   0.267   0.267   0.267   0.267   0.267
   0.267   0.267   0.267   0.267   0.267   0.267   0.267   0.267   0.267   0.267
   0.267   0.267   0.267   0.267   0.267

---------- UEC (Kwh) & Purchase Price ($1990) data
   Price    Kwh                                   EER
  372.03   533.0                                 8.23
  372.64   505.0                                 8.70
  377.57   471.0                                 9.32
  382.55   452.0                                 9.71
  389.51   439.0                                10.00
  440.24   423.0                                10.38
  560.46   415.0                                10.57
  796.18   374.0                                11.74

---------- Shipment Distribution (source: AHAM directory)
     EER   Units
     8.0    42.
     8.1     2.
     8.2    12.
     8.5     2.
     9.0     4.
     9.1     1.
     9.2     3.
     9.5     3.
     9.6     1.
     9.7     1.
    10.0     2.

---------- the 2nd class -------------------------------------------------------
class id#                    =   41
class name                   = 8L   (Room A/C 6K to 8K Btuh with louvres)
```

```
discount rate                 = 0.92
last year of historical EER  = 1993
first year for eff level     = 2031
EER of eff level             =    8.46
conversion (Kwh-MMBTU&usage) = .003412          0.71

---------- Historical energy factors (AHAM scaled to baseline)
    1981    1982    1983    1984    1985    1986    1987    1988    1989    1990    1991
  1992    1993
    6.82    6.89    7.04    7.22    7.43    7.53    7.78    7.95    8.19    8.43    8.50
  8.57    8.76

---------- Adjusted volumes (1981-2015)
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0

---------- Fraction of market share (1981-2015)
l = 1 2 3
   0.176   0.176   0.176   0.176   0.176   0.176   0.176   0.176   0.176   0.171
   0.151   0.137   0.144   0.144   0.144   0.144   0.144   0.144   0.144   0.144
   0.144   0.144   0.144   0.144   0.144   0.144   0.144   0.144   0.144   0.144
   0.144   0.144   0.144   0.144   0.144

---------- UEC (Kwh) & Purchase Price ($1990) data
   Price    Kwh                                     EER
  403.82  663.0                                    8.46
  405.25  638.0                                    8.80
  410.13  598.0                                    9.38
  416.89  581.0                                    9.66
  424.73  566.0                                    9.91
  477.78  543.0                                   10.33
  598.82  534.0                                   10.50
  830.48  481.0                                   11.67

---------- Shipment Distribution
     EER   Units
     8.5     21.
     8.6      1.
     8.7     11.
     9.0      5.
     9.1      1.
     9.2      3.
     9.5      9.
     9.7      6.
    10.0     18.
    10.2      1.
    10.3      1.
    11.0      1.

---------- the 3rd class ------------------------------------------------------
class id#                    =   43
class name                   = 14L  (Room A/C 8K to 14K Btuh with louvres)
discount rate                = 0.16
last year of historical EER  = 1993
first year for eff level     = 2031
EER of eff level             =    9.32
conversion (Kwh-MMBTU&usage) = .003412          0.71

---------- Historical energy factors (AHAM scaled to baseline)
    1981    1982    1983    1984    1985    1986    1987    1988    1989    1990    1991
  1992    1993
    7.51    7.59    7.75    7.96    8.19    8.30    8.57    8.75    9.02    9.29    9.36
  9.45    9.65

---------- Adjusted volumes (1981-2015)
       0       0       0       0       0       0       0       0       0       0
```

```
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0

---------- Fraction of market share (1981-2015)
l = 1 2 3
   0.296   0.296   0.296   0.296   0.296   0.296   0.296   0.296   0.296   0.317
   0.309   0.328   0.328   0.328   0.328   0.328   0.328   0.328   0.328   0.328
   0.328   0.328   0.328   0.328   0.328   0.328   0.328   0.328   0.328   0.328
   0.328   0.328   0.328   0.328   0.328

---------- UEC (Kwh) & Purchase Price ($1990) data
  Price      Kwh                                     EER
  495.06   978.0                                    9.32
  505.83   939.0                                    9.71
  509.76   926.0                                    9.87
  518.17   901.0                                   10.11
  576.63   831.0                                   10.97
  697.06   817.0                                   11.15
  929.44   736.0                                   12.39

---------- Shipment Distribution
     EER   Units
     9.0     79.
     9.1     17.
     9.2     16.
     9.3      6.
     9.5     31.
     9.6     18.
     9.7      6.
     9.9      3.
    10.0     21.
    10.2      2.
    10.3      1.
    10.4      5.
    10.5      2.
    11.0      1.
    12.0      2.
    12.5      1.
    12.6      1.

---------- the 4th class -------------------------------------------------------
class id#                    =   45
class name                   = 20L  (Room A/C 14K to 20K Btuh with louvres)
discount rate                = 0.27
last year of historical EER  = 1993
first year for eff level     = 2031
EER of eff level             =    9.00
conversion (Kwh-MMBTU&usage) = .003412          0.71

---------- Historical energy factors (AHAM scaled to baseline)
    1981    1982    1983    1984    1985    1986    1987    1988    1989    1990    1991
  1992    1993
    7.25    7.33    7.49    7.68    7.91    8.01    8.28    8.45    8.71    8.97    9.04
  9.12    9.32

---------- Adjusted volumes (1981-2015)
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0

---------- Fraction of market share (1981-2015)
l = 1 2 3
   0.131   0.131   0.131   0.131   0.131   0.131   0.131   0.131   0.131   0.120
   0.147   0.129   0.131   0.131   0.131   0.131   0.131   0.131   0.131   0.131
   0.131   0.131   0.131   0.131   0.131   0.131   0.131   0.131   0.131   0.131
   0.131   0.131   0.131   0.131   0.131

---------- UEC (Kwh) & Purchase Price ($1990) data
```

```
   Price     Kwh                                     EER
  612.76  1497.0                                    9.00
  632.48  1390.0                                    9.70
  639.63  1351.0                                    9.98
  647.54  1328.0                                   10.15
  811.82  1254.0                                   10.74
  870.27  1216.0                                   11.09
  897.30  1206.0                                   11.18
 1038.75  1172.0                                   11.50
 1294.53  1055.0                                   12.77

---------- Shipment Distribution
     EER   Units
     7.5      1.
     8.4      1.
     8.8     20.
     8.9      1.
     9.0     31.
     9.2      2.
     9.5     21.
     9.7      1.
    10.0     10.
    10.2      7.
    10.3      7.

---------- the 5th class -------------------------------------------------------
class id#                    =   47
class name                   = >20L (Room A/C over 20K Btuh with louvres)
discount rate                = 0.16
last year of historical EER  = 1993
first year for eff level     = 2031
EER of eff level             =    8.22
conversion (Kwh-MMBTU&usage) = .003412          0.71

---------- Historical energy factors (AHAM scaled to baseline)
    1981    1982    1983    1984    1985    1986    1987    1988    1989    1990    1991
  1992    1993
    6.62    6.70    6.84    7.02    7.22    7.32    7.56    7.72    7.96    8.19    8.26
  8.33    8.35

---------- Adjusted volumes (1981-2015)
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0

---------- Fraction of market share (1981-2015)
l = 1 2 3
   0.070   0.070   0.070   0.070   0.070   0.070   0.070   0.070   0.070   0.058
   0.084   0.064   0.063   0.063   0.063   0.063   0.063   0.063   0.063   0.063
   0.063   0.063   0.063   0.063   0.063   0.063   0.063   0.063   0.063   0.063
   0.063   0.063   0.063   0.063   0.063

---------- UEC (Kwh) & Purchase Price ($1990) data
   Price     Kwh                                     EER
  859.47  2215.0                                    8.22
  871.31  2173.0                                    8.39
  880.29  2141.0                                    8.51
  960.00  2053.0                                    8.88
 1071.41  1933.0                                    9.42
 1111.79  1852.0                                    9.84
 1291.24  1816.0                                   10.03
 1653.06  1635.0                                   11.14

---------- Shipment Distribution
     EER   Units
     8.2     25.
     8.3     12.
```

```
     8.5      4.
     8.7      9.
     8.8      3.
     9.0     11.
     9.1      3.
     9.2      2.
    10.0      2.

---------- the 6th class ------------------------------------------------------
class id#                    =   42
class name                   = 8N   (Room A/C 6K to 8K Btuh w/o louvres)
discount rate                = 0.10
last year of historical EER  = 1993
first year for eff level     = 2031
EER of eff level             =    8.86
conversion (Kwh-MMBTU&usage) = .003412          0.71

---------- Historical energy factors (AHAM scaled to baseline)
    1981    1982    1983    1984    1985    1986    1987    1988    1989    1990    1991
  1992    1993
    7.14    7.22    7.37    7.56    7.79    7.89    8.15    8.32    8.57    8.83    8.90
  8.98    9.00

---------- Adjusted volumes (1981-2015)
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0

---------- Fraction of market share (1981-2015)
l = 1 2 3
   0.016   0.016   0.016   0.016   0.016   0.016   0.016   0.016   0.016   0.017
   0.021   0.021   0.021   0.021   0.021   0.021   0.021   0.021   0.021   0.021
   0.021   0.021   0.021   0.021   0.021   0.021   0.021   0.021   0.021   0.021
   0.021   0.021   0.021   0.021   0.021

---------- UEC (Kwh) & Purchase Price ($1990) data
   Price     Kwh                                     EER
  447.01   538.0                                    8.86
  452.23   524.0                                    9.10
  455.96   516.0                                    9.23
  599.35   494.0                                    9.65
  872.95   444.0                                   10.72
 1334.94   414.0                                   11.52

---------- Shipment Distribution
     EER   Units
     8.5       4.
     8.7       3.
     9.1       2.
     9.5       3.
     9.6       1.

---------- the 7th class ------------------------------------------------------
class id#                    =   44
class name                   = 14N  (Room A/C 8K to 14K Btuh w/o louvres)
discount rate                = 0.38
last year of historical EER  = 1993
first year for eff level     = 2031
EER of eff level             =    8.80
conversion (Kwh-MMBTU&usage) = .003412          0.71

---------- Historical energy factors (AHAM scaled to baseline)
    1981    1982    1983    1984    1985    1986    1987    1988    1989    1990    1991
  1992    1993
    7.09    7.17    7.32    7.51    7.73    7.83    8.10    8.27    8.52    8.77    8.84
  8.92    8.95

---------- Adjusted volumes (1981-2015)
       0       0       0       0       0       0       0       0       0       0
```

```
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0

---------- Fraction of market share (1981-2015)
l = 1 2 3
   0.016   0.016   0.016   0.016   0.016   0.016   0.016   0.016   0.016   0.017
   0.021   0.021   0.021   0.021   0.021   0.021   0.021   0.021   0.021   0.021
   0.021   0.021   0.021   0.021   0.021   0.021   0.021   0.021   0.021   0.021
   0.021   0.021   0.021   0.021   0.021

---------- UEC (Kwh) & Purchase Price ($1990) data
   Price     Kwh                                   EER
  558.35   922.0                                  8.80
  561.89   896.0                                  9.05
  569.09   890.0                                  9.12
  713.85   859.0                                  9.44
  992.19   773.0                                 10.49
 1469.75   732.0                                 11.08

---------- Shipment Distribution
     EER   Units
     8.5      34.
     8.6       4.
     8.7       6.
     8.8       2.
     9.0      14.
     9.2       5.

---------- the 8th class -------------------------------------------------------
class id#                    =   49
class name                   = HPL  (Heat pump room A/C with louvres)
discount rate                = 0.12
last year of historical EER  = 1993
first year for eff level     = 2031
EER of eff level             =    8.92
conversion (Kwh-MMBTU&usage) = .003412          0.71

---------- Historical energy factors (AHAM scaled to baseline)
    1981    1982    1983    1984    1985    1986    1987    1988    1989    1990    1991
  1992    1993
    7.19    7.27    7.42    7.61    7.84    7.94    8.21    8.38    8.63    8.89    8.92
  8.92    8.92

---------- Adjusted volumes (1981-2015)
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0

---------- Fraction of market share (1981-2015)
l = 1 2 3
   0.015   0.015   0.015   0.015   0.015   0.015   0.015   0.015   0.015   0.023
   0.027   0.016   0.021   0.021   0.021   0.021   0.021   0.021   0.021   0.021
   0.021   0.021   0.021   0.021   0.021   0.021   0.021   0.021   0.021   0.021
   0.021   0.021   0.021   0.021   0.021

---------- UEC (Kwh) & Purchase Price ($1990) data
   Price     Kwh                                   EER
  689.83  1057.0                                  8.92
  695.16  1041.0                                  9.05
  707.54  1016.0                                  9.27
  787.80   959.0                                  9.83
  952.26   938.0                                 10.05
 1269.68   844.0                                 11.16

---------- Shipment Distribution
     EER   Units
```

```
     8.5     11.
     8.7      2.
     8.9      9.
     9.0      4.
     9.2      1.
     9.4      1.
    10.0      9.
    10.2      1.

---------- the 9th class -------------------------------------------------------
class id#                    =   50
class name                   = HPN  (Heat pump room A/C w/o louvres)
discount rate                = 0.40
last year of historical EER  = 1993
first year for eff level     = 2031
EER of eff level             =    8.72
conversion (Kwh-MMBTU&usage) = .003412          0.71

---------- Historical energy factors (AHAM scaled to baseline)
    1981    1982    1983    1984    1985    1986    1987    1988    1989    1990    1991
  1992    1993
    7.03    7.11    7.26    7.44    7.66    7.76    8.02    8.19    8.44    8.69    8.72
  8.72    8.72

---------- Adjusted volumes (1981-2015)
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0

---------- Fraction of market share (1981-2015)
l = 1 2 3
   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005
   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005
   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005
   0.005   0.005   0.005   0.005   0.005

---------- UEC (Kwh) & Purchase Price ($1990) data
   Price     Kwh                                     EER
  704.13   977.0                                    8.72
  706.09   962.0                                    8.86
  883.61   927.0                                    9.20
 1225.04   834.0                                   10.22
 1405.05   784.0                                   10.87

---------- Shipment Distribution
     EER   Units
     8.0      1.
     8.5      2.
     8.7      1.
     9.0      1.

================================================================================
product type id#             =   99
product name                 =  CAC (Central A/C)
end-use id#                  =    3
fuel type id#                =    2
number of classes            =    4

---------- the 1st class -------------------------------------------------------
class id#                    =   99
class name                   = SS-3 (Split System 3-ton)
discount rate                = 2.59
last year of historical SEER = 1990
first year for eff level     = 2031
EF of eff level              =   15.19
conversion (Kwh-MMBTU&usage) = .003412

---------- Historical energy factors (Source: ARI)
    1981    1982    1983    1984    1985    1986    1987    1988    1989     1990
```

```
    7.65    8.24    8.37    8.63    8.76    8.84    8.91    9.07    9.18     9.24

---------- Adjusted volumes (1981-2015)
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0

---------- Fraction of market share (1981-2015) Based on ARI
l = 1 2 3
   0.633   0.634   0.675   0.673   0.651   0.649   0.647   0.639   0.646   0.611
   0.611   0.611   0.611   0.611   0.611   0.611   0.611   0.611   0.611   0.611
   0.611   0.611   0.611   0.611   0.611   0.611   0.611   0.611   0.611   0.611
   0.611   0.611   0.611   0.611   0.611

---------- UEC (Kwh) & Purchase Price ($1990) data
   Price     Kwh                                 SEER
 1907.38 3427.31                                10.00                     4.35
 1906.07 3337.01                                10.28                     4.35
 1905.85 3296.62                                10.40                     4.35
 1916.17 3024.74                                11.34                     4.35
 1924.40 2990.08                                11.47                     3.64
 1936.37 2922.14                                11.73                     2.93
 1946.80 2815.39                                12.18                     2.93
 1956.26 2716.10                                12.62                     2.93
 1957.46 2704.23                                12.68                     2.93
 2019.50 2537.70                                13.51                     2.93
 2074.99 2381.30                                14.40                     2.93
 2144.58 2256.96                                15.19                     2.93
 2159.78 2230.41                                15.37                     2.93
 2305.21 2167.41                                15.82                     2.93
 2540.91 2090.74                                16.40                     4.39
 2673.65 2065.55                                16.60                     5.23
 2789.74 2046.86                                16.75                     5.94
 3102.75 1884.05                                18.20                     7.15
 3818.66 1845.59                                18.58                    11.25
 3644.27 1813.57                                18.91                    10.84
 3903.57 1618.74                                21.18                    11.45

---------- Shipment Distribution (source: ARI 1990)
     EFF   Units
    7.25    132.
    7.75    670.
    8.25 483083.
    8.75 179658.
    9.25 553797.
    9.75 140825.
   10.25 202053.
   10.75  15183.
   11.25  57885.
   11.75    798.
   12.00  52540.

---------- the 2nd class ----------------------------------------------------
class id#                    =   99
class name                   = SS-5 (Split System 5-ton)
discount rate                = 2.13
last year of historical SEER = 1990
first year for eff level     = 2031
EF of eff level              =   13.53
conversion (Kwh-MMBTU&usage) = .003412

---------- Historical energy factors (Source: ARI)
    1981    1982    1983    1984    1985    1986    1987    1988    1989     1990
    8.21    8.52    8.68    8.94    9.08    9.08    9.09    9.23    9.39     9.42
```

```
---------- Adjusted volumes (1981-2015) (5861.6/1000*750/365)
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0

---------- Fraction of market share (1981-2015)
l = 1 2 3
   0.146   0.137   0.178   0.183   0.188   0.196   0.204   0.206   0.214   0.231
   0.231   0.231   0.231   0.231   0.231   0.231   0.231   0.231   0.231   0.231
   0.231   0.231   0.231   0.231   0.231   0.231   0.231   0.231   0.231   0.231
   0.231   0.231   0.231   0.231   0.231

---------- UEC (Kwh) & Purchase Price ($1990) data
   Price     Kwh                                  SEER
 2998.72 5782.76                                 10.01                       4.35
 2997.39 5625.19                                 10.29                       4.35
 2997.49 5576.02                                 10.38                       4.35
 3042.11 4871.33                                 11.88                       4.35
 3053.90 4688.85                                 12.34                       4.35
 3072.59 4573.05                                 12.65                       3.64
 3087.05 4461.51                                 12.97                       3.64
 3099.30 4420.29                                 13.09                       2.93
 3102.18 4405.32                                 13.14                       2.93
 3146.78 4275.60                                 13.53                       2.93
 3178.22 4225.70                                 13.69                       2.93
 3275.78 4148.23                                 13.95                       2.93
 3458.25 4069.26                                 14.22                       2.93
 3806.47 3898.71                                 14.84                       4.39
 3958.03 3846.87                                 15.04                       5.23
 4102.99 3829.93                                 15.11                       5.94
 4475.82 3451.72                                 16.76                       7.51
 5094.41 3399.75                                 17.02                      11.92
 5292.42 3275.48                                 17.67                      12.33
 5389.71 2948.70                                 19.62                      12.54

---------- Shipment Distribution (source: ARI 1990)
     EFF   Units
    7.25     22.
    7.75      2.
    8.25 127813.
    8.75  26971.
    9.25 269897.
    9.75  41801.
   10.25 113355.
   10.75  19545.
   11.25  18786.
   11.75   4301.
   12.00  14249.

---------- the 3rd class -------------------------------------------------------
class id#                    =   99
class name                   = SP-3 (Single Package 3-ton)
discount rate                = 3.33
last year of historical SEER = 1990
first year for eff level     = 2031
EF of eff level              =   14.74
conversion (Kwh-MMBTU&usage) = .003412

---------- Historical energy factors (Source: ARI)
    1981    1982    1983    1984    1985    1986    1987    1988    1989     1990
    8.04    8.37    8.35    8.45    8.78    8.96    9.14    9.20    9.36     9.41

---------- Adjusted volumes (1981-2015) (7562.2/1000*750/365)
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0
```

```
---------- Fraction of market share (1981-2015)
l = 1 2 3
   0.103   0.101   0.091   0.088   0.097   0.095   0.093   0.100   0.088   0.097
   0.097   0.097   0.097   0.097   0.097   0.097   0.097   0.097   0.097   0.097
   0.097   0.097   0.097   0.097   0.097   0.097   0.097   0.097   0.097   0.097
   0.097   0.097   0.097   0.097   0.097

---------- UEC (Kwh) & Purchase Price ($1990) data
   Price     Kwh                                    SEER
 2639.69 3533.31                                    9.70                    4.35
 2638.64 3440.22                                    9.97                    4.35
 2638.47 3398.58                                   10.09                    4.35
 2646.77 3118.28                                   11.00                    4.35
 2653.40 3082.55                                   11.12                    3.64
 2663.04 3012.51                                   11.38                    2.93
 2671.43 2902.46                                   11.81                    2.93
 2679.05 2800.11                                   12.25                    2.93
 2680.01 2787.87                                   12.30                    2.93
 2729.96 2616.19                                   13.11                    2.93
 2777.71 2454.95                                   13.97                    2.93
 2840.01 2326.76                                   14.74                    2.93
 2853.36 2299.39                                   14.91                    2.93
 2982.99 2234.44                                   15.35                    2.93
 3172.73 2155.40                                   15.91                    4.39
 3279.59 2129.43                                   16.10                    5.23
 3373.04 2109.39                                   16.25                    5.94
 3625.02 1941.66                                   17.66                    7.15
 4201.32 1902.04                                   18.03                   11.25
 4060.93 1869.05                                   18.35                   10.84
 4269.67 1668.32                                   20.55                   11.45

---------- Shipment Distribution (source: ARI 1990)
     EFF   Units
    7.25   3699.
    7.75     24.
    8.25   5753.
    8.75  11435.
    9.25 137382.
    9.75  96980.
   10.25  13770.
```

```
---------- the 4th class -------------------------------------------------------
class id#                    =   99
class name                   = SP-5 (Single Package 5-ton)
discount rate                = 2.19
last year of historical SEER = 1990
first year for eff level     = 2031
EF of eff level              =   13.28
conversion (Kwh-MMBTU&usage) = .003412

---------- Historical energy factors (Source: ARI)
    1981    1982    1983    1984    1985    1986    1987    1988    1989     1990
    8.08    8.33    8.39    8.43    8.62    8.77    8.91    8.96    9.25     9.34

---------- Adjusted volumes (1981-2015) (7554.8/1000*750/365)
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0

---------- Fraction of market share (1981-2015)
l = 1 2 3
   0.069   0.072   0.057   0.056   0.064   0.060   0.056   0.055   0.052   0.061
   0.061   0.061   0.061   0.061   0.061   0.061   0.061   0.061   0.061   0.061
   0.061   0.061   0.061   0.061   0.061   0.061   0.061   0.061   0.061   0.061
   0.061   0.061   0.061   0.061   0.061

---------- UEC (Kwh) & Purchase Price ($1990) data
   Price     Kwh                                    SEER
 3476.02 5961.61                                    9.71                    4.35
 3474.87 5799.16                                    9.98                    4.35
 3474.96 5748.48                                   10.07                    4.35
 3514.02 5021.99                                   11.52                    4.35
 3524.35 4833.86                                   11.97                    4.35
 3540.72 4714.48                                   12.27                    3.64
 3553.38 4599.49                                   12.58                    3.64
 3564.11 4557.00                                   12.70                    2.93
 3566.62 4541.56                                   12.74                    2.93
 3606.86 4407.83                                   13.13                    2.93
 3634.39 4356.39                                   13.28                    2.93
 3723.40 4276.53                                   13.53                    2.93
 3890.09 4195.11                                   13.79                    2.93
 4194.99 4019.29                                   14.40                    4.39
 4327.71 3965.85                                   14.59                    5.23
 4454.62 3946.77                                   14.66                    5.94
 4781.07 3557.16                                   16.27                    7.51
 5322.71 3503.62                                   16.52                   11.92
 5496.09 3375.60                                   17.14                   12.33
 5581.28 3038.94                                   19.04                   12.54

---------- Shipment Distribution (source: ARI 1990)
     EFF   Units
    7.25    651.
    7.75   1067.
    8.25   2292.
    8.75  20146.
    9.25  88984.
    9.75  50611.
   10.25   5948.

================================================================================
product type id#             =   99
product name                 =  HP  (Heat Pump)
end-use id#                  =    3
fuel type id#                =    3
number of classes            =    4

---------- the 1st class -------------------------------------------------------
class id#                    =   99
class name                   = HPS3 (HP Split 3-ton)
discount rate                = 3.21
```

```
last year of historical SEER = 1990
first year for eff level     = 2031
EF of eff level              =   15.00
conversion (Kwh-MMBTU&usage) = .003412

---------- Historical energy factors (Source: ARI)
    1981    1982    1983    1984    1985    1986    1987    1988    1989     1990
    7.77    8.00    8.26    8.47    8.56    8.67    8.87    9.11    9.23     9.45

---------- Adjusted volumes (1981-2015)
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0

---------- Fraction of market share (1981-2015) Based on ARI
l = 1 2 3
   0.633   0.644   0.681   0.677   0.685   0.685   0.680   0.663   0.663   0.652
   0.652   0.652   0.652   0.652   0.652   0.652   0.652   0.652   0.652   0.652
   0.652   0.652   0.652   0.652   0.652   0.652   0.652   0.652   0.652   0.652
   0.652   0.652   0.652   0.652   0.652

---------- UEC (Kwh) & Purchase Price ($1990) data
   Price     Kwh                                   SEER
 2381.54 3651.20                                  10.00 8132.31    6.89    4.35
 2380.68 3543.91                                  10.30 8011.43    7.00    4.35
 2380.24 3499.99                                  10.43 7888.54    7.11    4.35
 2381.35 3486.22                                  10.47 7857.58    7.13    4.35
 2394.34 3406.22                                  10.72 7759.69    7.22    3.64
 2405.79 3371.62                                  10.83 7657.92    7.32    2.93
 2417.29 3268.21                                  11.17 7506.16    7.47    2.93
 2436.92 3124.79                                  11.69 7295.16    7.68    2.93
 2471.15 2941.30                                  12.41 7036.91    7.97    2.93
 2490.57 2941.30                                  12.41 6831.95    8.20    2.93
 2503.39 2869.42                                  12.73 6802.91    8.24    2.93
 2541.47 2782.21                                  13.12 6674.43    8.40    2.93
 2574.99 2665.19                                  13.70 6591.17    8.50    2.93
 2597.73 2600.18                                  14.04 6421.63    8.73    2.93
 2687.21 2470.65                                  14.78 6184.47    9.06    2.93
 2707.80 2434.04                                  15.00 6139.12    9.13    2.93
 2747.99 2415.59                                  15.12 6091.71    9.20    2.93
 2899.02 2358.59                                  15.48 6017.61    9.32    2.93
 3025.62 2342.77                                  15.59 5934.93    9.45    3.64
 3116.40 2313.09                                  15.79 5903.68    9.50    4.48
 3382.04 2232.27                                  16.36 5864.87    9.56    5.94
 3719.40 2039.78                                  17.90 5836.56    9.60    7.24
 4489.96 2001.96                                  18.24 5601.10   10.01   11.51
 4302.03 1976.41                                  18.48 5499.78   10.19   11.11
 4581.45 1752.76                                  20.83 5089.36   11.01   11.72

---------- Shipment Distribution (source: ARI 1990)
     EFF   Units
    8.25  78415.
    8.75  51675.
    9.25 175253
    9.75 119795
   10.25  44250.
   10.75  15282.
   11.25  10020.
   11.75   8570.
   12.00  14382.

---------- the 2nd class ----------------------------------------------------
class id#                    =   99
class name                   = HPS5 (HP Split 5-ton)
discount rate                = 1.85
last year of historical SEER = 1990
first year for eff level     = 2031
```

```
EF of eff level              =   14.17
conversion (Kwh-MMBTU&usage) = .003412

---------- Historical energy factors (Source: ARI)
    1981    1982    1983    1984    1985    1986    1987    1988    1989     1990
    7.69    7.97    8.34    8.46    8.66    8.89    9.12    9.23    9.35     9.58

---------- Adjusted volumes (1981-2015) (5861.6/1000*750/365)
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0

---------- Fraction of market share (1981-2015)
l = 1 2 3
   0.151   0.153   0.137   0.141   0.133   0.133   0.148   0.160   0.170   0.180
   0.180   0.180   0.180   0.180   0.180   0.180   0.180   0.180   0.180   0.180
   0.180   0.180   0.180   0.180   0.180   0.180   0.180   0.180   0.180   0.180
   0.180   0.180   0.180   0.180   0.180

---------- UEC (Kwh) & Purchase Price ($1990) data
   Price     Kwh                                    SEER
 3439.63 5797.70                                   10.00 13555.7    7.09    4.35
 3438.77 5629.33                                   10.30 13328.2    7.21    4.35
 3438.90 5583.90                                   10.38 13210.9    7.27    4.35
 3451.69 5428.82                                   10.68 12980.7    7.40    4.35
 3499.81 4715.21                                   12.30 12320.0    7.80    4.35
 3512.55 4666.48                                   12.42 12176.4    7.89    3.64
 3516.04 4652.88                                   12.46 12116.5    7.93    3.64
 3535.80 4524.88                                   12.81 11946.3    8.04    2.93
 3559.12 4524.88                                   12.81 11598.4    8.29    2.93
 3603.45 4414.52                                   13.13 11266.4    8.53    2.93
 3651.33 4291.69                                   13.51 11137.3    8.63    2.93
 3679.23 4229.44                                   13.71 11101.5    8.66    2.93
 3857.65 4093.03                                   14.17 10807.0    8.89    2.93
 3948.71 4036.05                                   14.37 10746.6    8.94    3.77
 4100.20 4014.45                                   14.44 10615.8    9.05    4.48
 4309.93 3962.81                                   14.63 10527.1    9.13    4.48
 4674.36 3777.60                                   15.35 10419.0    9.22    5.94
 5066.19 3414.65                                   16.98 10408.5    9.23    7.54
 5920.42 3377.94                                   17.16 9830.53    9.78   12.41
 5711.87 3351.92                                   17.30 9586.09   10.02   12.01
 6022.67 3025.61                                   19.16 9321.74   10.31   12.62

---------- Shipment Distribution (source: ARI 1990)
     EFF   Units
    7.75      8.
    8.25  13969.
    8.75   6547.
    9.25  60742.
    9.75  23966.
   10.25  23184.
   10.75   6625.
   11.25   3537.
   11.75   1892.
   12.00   2602.

---------- the 3rd class -------------------------------------------------------
class id#                    =   99
class name                   = HPP3 (HP package 3-ton)
discount rate                = 2.47
last year of historical SEER = 1990
first year for eff level     = 2031
EF of eff level              =   14.34
conversion (Kwh-MMBTU&usage) = .003412

---------- Historical energy factors (Source: ARI)
    1981    1982    1983    1984    1985    1986    1987    1988    1989     1990
    7.73    7.92    8.06    8.47    8.58    8.85    9.12    9.23    9.32     9.39
```

```
---------- Adjusted volumes (1981-2015) (7562.2/1000*750/365)
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0

---------- Fraction of market share (1981-2015)
l = 1 2 3
   0.146   0.137   0.126   0.125   0.126   0.126   0.117   0.115   0.106   0.105
   0.105   0.105   0.105   0.105   0.105   0.105   0.105   0.105   0.105   0.105
   0.105   0.105   0.105   0.105   0.105   0.105   0.105   0.105   0.105   0.105
   0.105   0.105   0.105   0.105   0.105

---------- UEC (Kwh) & Purchase Price ($1990) data
   Price     Kwh                                    SEER
 2550.10 3764.13                                    9.70 8378.74    6.69    4.35
 2549.31 3653.51                                    9.99 8254.20    6.79    4.35
 2548.91 3608.23                                   10.12 8127.59    6.90    4.35
 2549.93 3594.04                                   10.16 8095.69    6.92    4.35
 2561.99 3511.57                                   10.40 7994.83    7.01    3.64
 2572.62 3475.90                                   10.51 7889.98    7.10    2.93
 2583.29 3369.29                                   10.84 7733.62    7.25    2.93
 2601.50 3221.44                                   11.34 7516.22    7.46    2.93
 2633.92 3032.27                                   12.04 7250.15    7.73    2.93
 2651.95 3032.27                                   12.04 7038.98    7.96    2.93
 2663.85 2958.17                                   12.34 7009.06    8.00    2.93
 2699.85 2868.26                                   12.73 6876.69    8.15    2.93
 2730.96 2747.61                                   13.29 6790.90    8.25    2.93
 2752.06 2680.60                                   13.62 6616.22    8.47    2.93
 2837.82 2547.06                                   14.34 6371.87    8.80    2.93
 2857.44 2509.32                                   14.55 6325.15    8.86    2.93
 2894.74 2490.30                                   14.66 6276.30    8.93    2.93
 3038.95 2431.54                                   15.02 6199.97    9.04    2.93
 3156.45 2415.23                                   15.12 6114.78    9.17    3.64
 3240.70 2384.63                                   15.31 6082.58    9.22    4.48
 3487.24 2300.44                                   15.87 6041.63    9.28    5.94
 3800.37 2102.14                                   17.37 6012.48    9.32    7.24
 4515.54 2063.17                                   17.70 5769.95    9.72   11.51
 4341.12 2036.86                                   17.93 5665.60    9.89   11.11
 4600.45 1806.43                                   20.21 5242.86   10.69   11.72

---------- Shipment Distribution (source: ARI 1990)
     EFF   Units
    7.25   4870.
    7.75      4.
    8.25   1528.
    8.75   2800.
    9.25  43279.
    9.75  12180.
   10.25  18477.

---------- the 4th class -------------------------------------------------------
class id#                    =   99
class name                   = HPP5 (HP package 5-ton)
discount rate                = 1.91
last year of historical SEER = 1990
first year for eff level     = 2031
EF of eff level              =   13.74
conversion (Kwh-MMBTU&usage) = .003412

---------- Historical energy factors (Source: ARI)
    1981    1982    1983    1984    1985    1986    1987    1988    1989     1990
    7.71    7.87    8.03    8.21    8.27    8.50    8.73    8.86    9.18     9.28

---------- Adjusted volumes (1981-2015) (7554.8/1000*750/365)
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0       0       0
```

```
       0       0       0       0       0

---------- Fraction of market share (1981-2015)
l = 1 2 3
   0.070   0.067   0.056   0.057   0.056   0.056   0.055   0.063   0.061   0.063
   0.063   0.063   0.063   0.063   0.063   0.063   0.063   0.063   0.063   0.063
   0.063   0.063   0.063   0.063   0.063   0.063   0.063   0.063   0.063   0.063
   0.063   0.063   0.063   0.063   0.063

---------- UEC (Kwh) & Purchase Price ($1990) data
   Price     Kwh                                    SEER
 3223.86 5977.01                                    9.70 13966.4    6.88    4.35
 3223.14 5803.44                                    9.99 13732.0    7.00    4.35
 3223.25 5756.60                                   10.07 13611.2    7.06    4.35
 3233.96 5596.72                                   10.36 13374.0    7.19    4.35
 3274.21 4861.04                                   11.93 12693.3    7.57    4.35
 3284.89 4810.80                                   12.05 12545.4    7.66    3.64
 3287.80 4796.79                                   12.09 12483.7    7.70    3.64
 3304.33 4664.83                                   12.43 12308.3    7.81    2.93
 3323.86 4664.83                                   12.43 11949.8    8.04    2.93
 3360.95 4551.05                                   12.74 11607.8    8.28    2.93
 3402.58 4424.43                                   13.10 11474.8    8.37    2.93
 3425.92 4360.25                                   13.30 11437.9    8.40    2.93
 3583.19 4219.62                                   13.74 11134.5    8.63    2.93
 3659.39 4160.87                                   13.93 11072.3    8.68    3.77
 3786.16 4136.84                                   14.02 10935.6    8.79    4.48
 3971.05 4083.65                                   14.20 10844.3    8.86    4.48
 4276.02 3892.86                                   14.89 10732.9    8.95    5.94
 4603.91 3518.98                                   16.48 10722.2    8.96    7.54
 5318.75 3481.16                                   16.65 10126.9    9.49   12.41
 5144.23 3454.35                                   16.78 9875.09    9.73   12.01
 5404.32 3118.18                                   18.59 9602.81   10.01   12.62

---------- Shipment Distribution (source: ARI 1990)
     EFF   Units
    7.25   5111.
    7.75     50.
    8.25    387.
    8.75   7417.
    9.25  15982.
    9.75  11355.
   10.25   9978.
```

APPENDIX C. LAWRENCE BERKELEY NATIONAL LABORATORY - MANUFACTURER ANALYSIS MODEL

C.1 INPUT DATA AND DATA DEVELOPMENT

In this section, we present the Lawrence Berkeley National Laboratory - Manufacturer Analysis Model (LBNL-MAM) input data and sensitivity analysis runs for the analysis of room air conditioners.

C.1.1 Engineering Cost Data

The source of the engineering data is the Engineering Analysis described in Chapter 1 of this volume. The sources of data include manufacturers of these products, discussions with industry consultants, and other studies. The engineering data inputs used in the model consist of several components:

1. The incremental unit variable cost for each of the design options that increases the efficiency of the appliance (e.g., raw materials, direct labor, purchased parts, and increased transportation costs). The incremental variable cost is listed for each design option for each product class.

2. The annual maintenance costs associated with each design option for each product class.

3. The annual unit energy consumption (UEC) associated with each design option for each product class.

4. The installation costs for each design option and product class.

5. Some of the design options also require additional capital investment in the form of retooling, new tooling, or other capital expenditures. These expenses are listed for each design option requiring capital expenditures.

The engineering input data are also listed for each alternative energy efficiency level being analyzed (a base case and the efficiency levels which are the new levels being analyzed). The figures used are exactly the same as those used for the design options, but are calculated for alternative efficiency levels instead. The engineering data used as inputs to the LBNL-MAM are listed on the engineering data page of the model, which follows this section. The actual data are listed there rather than here since there are several tables of data.

C.1.2. Industry Market Data

Industry Shipments

These data include annual industry shipments for the base case. The base case shipments figures are based on statistics from the Association of Home Appliance Manufacturers.

Price Elasticities and Discount Rates

Price elasticities and consumer discount rates determine the effect on shipments of changes in appliance price and operating cost. The estimated price elasticity for room air conditioners was -0.35. The consumer discount rate supplied by the LBNL-REM was 64%. The source of the elasticity and discount rate is the LBNL-REM. Because these estimates are important, we perform sensitivity analyses using different elasticities and discount rates.

Product Class Market Share

Each of the product classes has a share of the total market and the market share, or unit sales, for each product class is an input to the model.

Markups

Manufacturers charge different markups over variable cost for different product classes, resulting in different profit margins for different product classes. For room air conditioners the estimated markup is 1.37. In the absence of any data from the industry, the range of markups for all the products is based on historical data collected from a previous analysis of refrigerators and freezers documented in DOE/EE-0064.[1]

Initial Prices

The baseline manufacturer's selling price is used as a base to which are added incremental costs of reaching the higher efficiency levels. The unit price quoted for each product class refers to the most inexpensive, fewest-frills model produced by the manufacturer. The source of the baseline manufacturer's price for each product class is research by LBNL.

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[1] U.S. Department of Energy, *Technical Support Document: Energy Efficiency Standards for Consumer Products: Refrigerators, Refrigerator-Freezers, and Freezers*, Washington, D.C., DOE/EE-0064, July 1995.

Energy Price

The energy price variable is the ratio of the price of a 1992 kWh to a 1999 kWh (the model is constructed to calculate the energy price variable from the price for the base year (i.e., the year which is defined as being a reference point for energy prices) and the price for the year in which new energy efficiency levels are assumed to become effective). The source is the LBNL-REM. Industry market data appear on the Cost, Sales, and Revenues page of the model.

C.1.3 Financial Input Data

Financial Inputs

The financial inputs for room air conditioners are summarized in Tables C.1 to C.4.

Table C.1 Rates of Financial Costs

Variable	Value	Source
After-tax equity cost of capital[†]	6.8%	MAM calc. from public financial data[§]
Interest rate on debt[†‡]	2.5%	MAM calc. from public financial data
Interest lost in cash[†‡]	1.0%	MAM calc. from public financial data
Rate of depreciation	17.7%	Public financial data
Tax rate[§]	36%	Tax Law

[†] Cost of capital and interest rate are *real* rather than nominal.

[‡] Public financial data include data from Value Line, Standard and Poors, Moody's, individual company annual reports, and economic reports.

[§] We adopted the 36% discount used by Arthur D. Little Inc. and the trade associations in their development of the Government Regulatory Impact Model.

Table C.2 Other Financial Data

Variable††	Value	Source
Cash	2.60%	Public financial data
Inventory and receivables	54.50%	Public financial data
Net depreciable assets	36.50%	Public financial data
General and administrative expenses	18.00%	Public financial data
Engineering expense	6.80%	Public financial data and industry sources†

† Industry sources include consultants under contract to LBNL and discussions with industry representatives.

††All variables are percentages of revenues (which is the format used by the model).

Table C.3 Fixed, Variable, and Revenue-Related Cost Split

Variable	Value	Source
Fixed part of costs and depr. assets	10%	Industry sources
Fixed part of one-time capital costs	20%	Industry sources
Economic profit	4.10%	MAM est. from financial data
Debt/equity ratio	77.20%	Public financial data
Markup on typical model:	1.37	Industry sources
Ratio of highest to lowest markup:	2	Industry sources

Table C.4 One-Time Costs

Variable	Value	Source
One-time capital cost's life	8 years	Industry sources
One-time capital cost's tax life	6 years	MAM calculation
Percent additional 1-X capital	50%	MAM estimate
Age of replaced capital	1 year	Public financial data

The expenditure schedule above lists the costs incurred over time for preparations to meet the alternative efficiency levels. A percentage of the total cost is attributed to each year before the efficiency levels go into effect since that is when these expenses will occur.

C.1.4 LBNL-MAM Inputs and Outputs Showing the Primary Scenario

Tables C.5 to C.16 contain all the data input and outputs used in the analysis of room air conditioners. Please see Appendix C of the General Methodology volume for details on the LBNL-MAM.

Table C.5 Room Air Conditioners

The Control Panel

ROOM AIR CONDITIONERS CONTROL FACTORS	Input Value	Cntrl	Variation	Program Value	Name
Price Elasticity	-0.350	0.00	100%	-0.350	IPE
Consumer Discount Rate	64.00%	0.00	100%	0.640	RD
Equity Cost of Capital	0.068	0.00	10%	0.068	ECC
Economic Profit	0.041	0.00	1%	0.041	EP
L-R Fixed Part of Costs & Assets	0.100	0.00	50%	0.100	FCA
L-R Fixed Part of 1-X Cap. Cost	0.200	0.00	60%	0.200	F1X
One-Time Capital Costs	4.138	0.00	20%	4.138	CC.N
Unit Variable Cost Increase	$9.97	0.00	30%	9.970	dVC.N
Elasticity Curve Parameter	0.000	0.00	14%	0.000	ro.N
Short Run Price Response to Demand	0.157	0.00	76%	0.157	SRPR

SUMMARY	NAECA BASE	NEW L-RUN	CHANGE	PREVIOUS CHANGE	NEW S-RUN
Shipments	0.61	0.61	0.04%	0.04%	0.61
Price	$304.35	$307.67	1.09%	1.09%	$307.40
Revenue (in $M)	186.03	188.13	1.13%	1.13%	188.03
Net Income	10.60	10.63	0.02	0.02	10.46
ROE	10.88%	10.83%	-0.05%	-0.05%	10.67%
Operating Cost Elasticity	-0.10				
			Trys =	33.00	
MIM/GRIM Cost Convergence Factor Status	0				

0 = Only MIM modules are running; 1 = MIM/GRIM cost convergence module running

GRIM NPV RESULTS	Base	NS	Diffs
Millions of dollars @ a 12% discount rate	239.52	188.75	-50.77

MIM NPV RESULTS

Flow of Profit	Base	Effcy Levels	NPVg Base	NPVg Stds	DIFFS
12% discount rate	53.00	53.13	442	443	1.03
7% discount rate			757	759	1.76
	53.00	52.77	442	440	-1.96

Effcy Level for New Effcy Level Case	1	Equity (Cal)	481
Firm equity (Efficiency level case)	98.11	Equity (base case)	487
Industry equity (Efficiency level case)	491		
IPE Variation > 2 Standard Deviations?	1		

Table C.6 Room Air Conditioners

The Monte Carlo Module

MONTE CARLO DETERMINATION OF STANDARD ERRORS OF ESTIMATES.						1
			Secnds/iteration =		0.52	time
			Iterations to go =		0.00	nn
ROOM AIR CONDITIONERS			Sample Size =		400.00	
	%dQ	%dP	%dR	dNI	dROE.N	dROE.S
Value	0.04%	1.09%	1.13%	0.02	-0.05%	-0.21%
Means	-23.75%	98.40%	50.18%	-0.67	-4.79%	-12.43%
Stnd. Dev	14.11%	27.19%	30.47%	11.80	7.22%	8.99%
History	-0.07	0.63	0.52	2.36	-0.02	-0.06
...	-0.46	0.75	-0.05	-12.40	-0.12	-0.29
Range	-0.41	1.37	0.40	-0.85	-0.05	-0.18
Name	-0.11	0.97	0.76	0.80	-0.03	-0.10
Is	-0.12	0.73	0.52	4.13	-0.01	-0.06
Carlo	-0.16	0.98	0.65	-2.07	-0.06	-0.11
	-0.40	0.92	0.15	-4.60	-0.07	-0.15
	-0.17	0.77	0.46	-1.55	-0.05	-0.11
	-0.08	2.31	2.04	73.54	0.29	0.26
	-0.24	0.73	0.31	-9.75	-0.10	-0.19
	-0.67	1.00	-0.34	-25.80	-0.24	-0.33
	-0.35	0.77	0.16	-9.64	-0.10	-0.18
	-0.25	1.11	0.58	6.82	0.01	-0.04
	-0.26	0.59	0.18	-3.00	-0.05	-0.21
	-0.09	0.64	0.49	7.41	0.02	-0.03
	-0.58	1.55	0.06	-24.80	-0.20	-0.41
	-0.13	0.67	0.45	3.49	-0.00	-0.08
	-0.29	0.73	0.22	-5.77	-0.07	-0.17
	-0.14	1.00	0.71	6.40	-0.00	-0.05
	-0.21	0.66	0.31	-4.29	-0.06	-0.12
	-0.21	1.02	0.60	21.38	0.11	0.05
	-0.21	0.63	0.29	-9.45	-0.10	-0.18
	-0.34	0.81	0.19	-8.01	-0.09	-0.18
	-0.07	1.30	1.15	8.38	0.01	-0.03
	-0.07	0.94	0.80	1.29	-0.02	-0.07
	-0.11	0.96	0.74	7.92	0.01	-0.03
	-0.18	1.43	0.99	27.98	0.13	0.07
	-0.27	1.59	0.88	4.05	-0.04	-0.09
	-0.29	1.48	0.76	5.87	-0.01	-0.10
	-0.05	1.23	1.11	17.85	0.04	-0.00
	-0.34	0.75	0.16	-14.09	-0.14	-0.23
	-0.52	1.61	0.24	-8.07	-0.09	-0.13
	-0.55	1.11	-0.05	-7.74	-0.08	-0.14
	-0.24	0.92	0.46	-4.60	-0.07	-0.20
	-0.37	0.79	0.12	-10.82	-0.11	-0.19

Table C.7 Room Air Conditioners

The Accounting Module

(All units are millions or millions of $ unless labeled with $ or %.)

	1987	BASE '96	NEW '96	CHANGE
Revenue	182.06	186.03	188.13	1.1%
Expenses				
Cost of Goods Sold	120.32	123.68	125.68	1.6%
Selling & G & A	29.51	29.41	29.44	0.1%
Engineering	1.97	1.96	1.96	0.1%
Depreciation	12.07	12.07	12.07	NA
1-X Depreciation	0.00	0.50	0.52	NA
Total Expenses	163.86	167.62	169.67	1.2%
Earnings Before Interest & Taxes	18.20	18.40	18.45	0.3%
Interest	1.82	1.81	1.82	0.7%
Earnings Before Taxes	16.37	16.59	16.63	0.2%
Taxes	5.89	6.10	6.12	0.3%
Net Income	10.48	10.49	10.51	0.2%
Gross Margin	33.91%	33.52%	33.19%	-0.3
Return on Sales	5.76%	5.64%	5.59%	-0.1
Total Assets	170.35	172.69	173.86	0.7%
Return on Assets (w/intrst taxed)	6.84%	6.75%	6.72%	-0.0
Equity	96.13	97.45	98.11	0.7%
Return on Equity	10.90%	10.77%	10.71%	-0.1

ECONOMIC ANALYSIS

	1987	BASE '96	NEW '96	CHANGE
INCOME				
Shipments	0.62	0.61	0.61	0.0%
Price	$295.93	$304.35	$307.67	1.1%
Revenue	182.06	186.03	188.13	1.1%
EXPENSE (W/ INTEREST)				
Fixed Costs	18.21	18.21	18.21	0.0%
Variable Costs (w/ Q)	147.48	150.66	152.68	1.3%
Total Expenses	165.68	168.87	170.89	1.2%
ASSETS				
Cash	4.73	4.70	4.70	0.0%
Inventories	99.26	98.62	98.66	0.0%
Depreciable	66.36	69.36	70.50	1.6%
Total Assets	170.35	172.69	173.86	0.7%

Table C.8 Room Air Conditioners

The Engineering Inputs Model

Increment in Additional UVC by Level and Class

Baseline	0	1	2	3	4	5	6	7	8
NRC/L:<6kBtu	$156.97	$0.68	$3.00	$2.49	$3.28	$16.28	$60.00	$85.07	0.0
NRC/L:6-8kBtu	$174.41	$0.95	$3.00	$3.28	$3.73	$17.45	$61.83	$85.80	0.0
NRC/L:8-14kBtu	$224.45	$6.11	$1.97	$4.20	$20.35	$64.58	$92.08	0.0	0.0
NRC/L:14-20kBtu	$286.71	$11.51	$3.72	$4.01	$58.16	$32.51	$14.98	$78.33	$108.95
NRC/L:>20kBtu	$354.44	$5.93	$4.01	$39.15	$34.89	$19.98	$87.50	$143.84	0.0
NRC/NL:6-8kBtu	$162.33	$2.46	$1.54	$61.83	$85.07	$17.45	0.0	0.0	0.0
NRC/NL:8-14kBtu	$210.08	$1.61	$3.26	$64.58	$91.42	$20.35	0.0	0.0	0.0
RC/L	$228.87	$1.97	$5.05	$20.35	$64.58	$92.08	0.0	0.0	0.0
RC/NL	$215.95	$0.76	$64.58	$91.42	$20.35	0.0	0.0	0.0	0.0

VCS.E Additional UVC. (Above Level 0 cost). Cumulative costs directly from engineering inputs.

CLS	0	1	2	3	4	5	6	7	8
0	0	$0.68	$3.68	$6.17	$9.45	$25.73	$85.73	$170.80	0.0
1	0	$0.95	$3.95	$7.23	$10.96	$28.40	$90.23	$176.03	0.0
2	0	$6.11	$8.08	$12.29	$32.64	$97.22	$189.30	0.0	0.0
3	0	$11.51	$15.23	$19.24	$77.40	$109.91	$124.89	$203.22	$312.17
4	0	$5.93	$9.93	$49.08	$83.98	$103.95	$191.45	$335.29	0.0
5	0	$2.46	$4.00	$65.83	$150.90	$168.35	0.0	0.0	0.0
6	0	$1.61	$4.88	$69.46	$160.88	$181.23	0.0	0.0	0.0
7	0	$1.97	$7.03	$27.38	$91.96	$184.04	0.0	0.0	0.0
8	0	$0.76	$65.34	$156.76	$177.11	0.0	0.0	0.0	0.0

MC.E Maintenance Costs ($/Yr) Cumulative costs directly from engineering inputs.

NRC/L:<6kBtu	0	1	2	3	4	5	6	7	8
NRC/L:6-8kBtu	0	0	0	0	0	0	0	0	0
NRC/L:8-14kBtu	0	0	0	0	0	0	0	0	0
NRC/L:14-20kBtu	0	0	0	0	0	0	0	0	0
NRC/L:>20kBtu	0	0	0	0	0	0	0	0	0
NRC/NL:6-8kBtu	0	0	0	0	0	0	0	0	0
NRC/NL:8-14kBtu	0	0	0	0	0	0	0	0	0
RC/L	0	0	0	0	0	0	0	0	0
RC/NL	0	0	0	0	0	0	0	0	0

Table C.8 (Continued)

OC.E Annual Energy Costs ($/Yr) Cumulative costs directly from engineering inputs.

OC.E	0	1	2	3	4	5	6	7	8
NRC/L:<6kBtu	$29.76	$28.18	$26.30	$25.23	$24.51	$23.61	$23.19	$20.87	$0.00
NRC/L:6-8kBtu	$37.04	$35.60	$33.41	$32.42	$31.61	$30.33	$29.82	$26.84	$0.00
NRC/L:8-14kBtu	$54.58	$52.41	$51.68	$50.33	$46.40	$45.63	$41.07	$0.00	$0.00
NRC/L:14-20kBtu	$83.57	$77.60	$75.41	$74.15	$70.04	$67.87	$67.32	$65.45	$58.90
NRC/L:>20kBtu	$123.68	$121.30	$119.56	$114.60	$107.94	$103.39	$101.41	$91.27	$0.00
NRC/NL:6-8kBtu	$30.04	$29.25	$28.83	$27.57	$24.82	$23.10	$0.00	$0.00	$0.00
NRC/NL:8-14kBtu	$51.46	$50.05	$49.67	$47.97	$43.17	$40.84	$0.00	$0.00	$0.00
RC/L	$58.99	$58.14	$56.74	$53.52	$52.38	$47.15	$0.00	$0.00	$0.00
RC/NL	$54.57	$53.69	$51.73	$46.56	$43.76	$0.00	$0.00	$0.00	$0.00

Total Operating Costs: $/Yr

KWS.E	0	1	2	3	4	5	6	7	8
NRC/L:<6kBtu	$29.76	$28.18	$26.30	$25.23	$24.51	$23.61	$23.19	$20.87	$0.00
NRC/L:6-8kBtu	$37.04	$35.60	$33.41	$32.42	$31.61	$30.33	$29.82	$26.84	$0.00
NRC/L:8-14kBtu	$54.58	$52.41	$51.68	$50.33	$46.40	$45.63	$41.07	$0.00	$0.00
NRC/L:14-20kBtu	$83.57	$77.60	$75.41	$74.15	$70.04	$67.87	$67.32	$65.45	$58.90
NRC/L:>20kBtu	$123.68	$121.30	$119.56	$114.60	$107.94	$103.39	$101.41	$91.27	$0.00
NRC/NL:6-8kBtu	$30.04	$29.25	$28.83	$27.57	$24.82	$23.10	$0.00	$0.00	$0.00
NRC/NL:8-14kBtu	$51.46	$50.05	$49.67	$47.97	$43.17	$40.84	$0.00	$0.00	$0.00
RC/L	$58.99	$58.14	$56.74	$53.52	$52.38	$47.15	$0.00	$0.00	$0.00
RC/NL	$54.57	$53.69	$51.73	$46.56	$43.76	$0.00	$0.00	$0.00	$0.00

Incremental Installation Costs ($/Yr)

INCOST.E	0	1	2	3	4	5	6	7	8
NRC/L:<6kBtu	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	0.0
NRC/L:6-8kBtu	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	0.0
NRC/L:8-14kBtu	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	0.0
NRC/L:14-20kBtu	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
NRC/L:>20kBtu	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	0.0
NRC/NL:6-8kBtu	$0.00	$0.00	$0.00	$0.00	$0.00	$330.72	0.0	0.0	0.0
NRC/NL:8-14kBtu	$0.00	$0.00	$0.00	$0.00	$0.00	$330.72	0.0	0.0	0.0
RC/L	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	0.0	0.0	0.0
RC/NL	$0.00	$0.00	$0.00	$0.00	$330.72	0.0	0.0	0.0	0.0

Cumulative Installation Costs ($/Yr)

INCOST.E	0	1	2	3	4	5	6	7	8
NRC/L:<6kBtu	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	0.0
NRC/L:6-8kBtu	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	0.0
NRC/L:8-14kBtu	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	0.0
NRC/L:14-20kBtu	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
NRC/L:>20kBtu	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	0.0
NRC/NL:6-8kBtu	$0.00	$0.00	$0.00	$0.00	$0.00	$330.72	0.0	0.0	0.0
NRC/NL:8-14kBtu	$0.00	$0.00	$0.00	$0.00	$0.00	$330.72	0.0	0.0	0.0
RC/L	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	0.0	0.0	0.0
RC/NL	$0.00	$0.00	$0.00	$0.00	$330.72	0.0	0.0	0.0	0.0

Table C.8 (Continued)

INCREMENTAL PER UNIT, DEPRECIATED INVESTMENT COSTS

Note: Capital cost includes tooling, building&equipment, and R&D.

	Capital cost / unit / 7			Depreciated Per Unit Incremental Investment Costs					
	0	1	2	3	4	5	6	7	8
NRC/L:<6kBtu	$0.00	$0.10	$0.00	$0.36	$0.47	$10.86	$0.00	$38.77	0.0
+G.Cost Inputs:B14	$0.00	$0.14	$0.00	$0.47	$0.53	$11.63	$0.00	$38.77	0.0
NRC/L:8-14kBtu	$0.00	$0.00	$0.28	$0.60	$13.57	$0.00	$38.77	0.0	0.0
NRC/L:14-20kBtu	$0.00	$0.00	$0.53	$0.57	$38.77	$0.00	$0.00	$0.00	$38.77
NRC/L:>20kBtu	$0.00	$0.00	$0.57	$0.00	$23.26	$0.00	$0.00	$38.77	0.0
NRC/NL:6-8kBtu	$0.00	$0.00	$0.22	$0.00	$38.77	$11.63	0.0	0.0	0.0
NRC/NL:8-14kBtu	$0.00	$0.23	$0.00	$0.00	$38.77	$13.57	0.0	0.0	0.0
RC/L	$0.00	$0.28	$0.00	$13.57	$0.00	$38.77	0.0	0.0	0.0
RC/NL	$0.00	$0.11	$0.00	$38.77	$13.57	0.0	0.0	0.0	0.0

CUMULATIVE PER UNIT, DEPRECIATED INVESTMENT COSTS

Capital Costs Depreciated Over 7 Years

	Capital cost / unit / 7			Depreciated Per Unit Incremental Investment Costs					
	0	1	2	3	4	5	6	7	8
NRC/L:<6kBtu	0.00	0.10	0.10	0.45	0.92	11.78	11.78	50.55	0.00
NRC/L:6-8kBtu	0.00	0.14	0.14	0.60	1.14	12.77	12.77	51.54	0.00
NRC/L:8-14kBtu	0.00	0.00	0.28	0.88	14.45	14.45	53.22	0.00	0.00
NRC/L:14-20kBtu	0.00	0.00	0.53	1.10	39.88	39.88	39.88	39.88	78.65
NRC/L:>20kBtu	0.00	0.00	0.57	0.57	23.83	23.83	23.83	62.61	0.00
NRC/NL:6-8kBtu	0.00	0.00	0.22	0.22	38.99	50.62	0.00	0.00	0.00
NRC/NL:8-14kBtu	0.00	0.23	0.23	0.23	39.00	52.57	0.00	0.00	0.00
RC/L	0.00	0.28	0.28	13.85	13.85	52.62	0.00	0.00	0.00
RC/NL	0.00	0.11	0.11	38.88	52.45	52.45	0.00	0.00	0.00

		Total Cumulative Per Unit								
CC.E		Additional CC./7 (Above Level 0 cost.):				Depreciated Per Unit Cumulative Investement Costs				
	CLS	0	1	2	3	4	5	6	7	8
	0	0.00	0.10	0.10	0.45	0.92	11.78	11.78	50.55	0.00
	1	0.00	0.14	0.14	0.60	1.14	12.77	12.77	51.54	0.00
	2	0.00	0.00	0.28	0.88	14.45	14.45	53.22	0.00	0.00
	3	0.00	0.00	0.53	1.10	39.88	39.88	39.88	39.88	78.65
	4	0.00	0.00	0.57	0.57	23.83	23.83	23.83	62.61	0.00
	5	0.00	0.00	0.22	0.22	38.99	50.62	0.00	0.00	0.00
	6	0.00	0.23	0.23	0.23	39.00	52.57	0.00	0.00	0.00
	7	0.00	0.28	0.28	13.85	13.85	52.62	0.00	0.00	0.00
	8	0.00	0.11	0.11	38.88	52.45	52.45	0.00	0.00	0.00
	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table C.8 (Continued)

ADDITIONAL CC*7 (or life): Per Firm

Note: Capital cost includes tooling, building&equipment, and R&D.

	Capital Costs UnDepreciated					(Capital cost) * 7			
	0	1	2	3	4	5	6	7	8
NRC/L:<6kBtu	0.00	0.10	0.10	0.44	0.90	11.51	11.51	49.41	49.41
NRC/L:6-8kBtu	0.00	0.10	0.10	0.46	0.87	9.73	9.73	39.28	39.28
NRC/L:8-14kBtu	0.00	0.00	0.36	1.13	18.48	18.48	68.07	68.07	68.07
NRC/L:14-20kBtu	0.00	0.00	0.30	0.63	22.67	22.67	22.67	22.67	44.71
NRC/L:>20kBtu	0.00	0.00	0.17	0.17	7.19	7.19	7.19	18.87	18.87
NRC/NL:6-8kBtu	0.00	0.00	0.02	0.02	2.69	3.49	3.49	3.49	3.49
NRC/NL:8-14kBtu	0.00	0.02	0.02	0.02	2.69	3.62	3.62	3.62	3.62
RC/L	0.00	0.02	0.02	0.89	0.89	3.40	3.40	3.40	3.40
RC/NL	0.00	0.02	0.02	8.37	11.29	11.29	11.29	11.29	11.29

TOTAL ADDITIONAL CC * 7 MATRIX

ADD.E	0	1	2	3	4	5	6	7	8
NRC/L:<6kBtu	0.00	0.10	0.10	0.44	0.90	11.51	11.51	49.41	49.41
NRC/L:6-8kBtu	0.00	0.10	0.10	0.46	0.87	9.73	9.73	39.28	39.28
NRC/L:8-14kBtu	0.00	0.00	0.36	1.13	18.48	18.48	68.07	68.07	68.07
NRC/L:14-20kBtu	0.00	0.00	0.30	0.63	22.67	22.67	22.67	22.67	44.71
NRC/L:>20kBtu	0.00	0.00	0.17	0.17	7.19	7.19	7.19	18.87	18.87
NRC/NL:6-8kBtu	0.00	0.00	0.02	0.02	2.69	3.49	3.49	3.49	3.49
NRC/NL:8-14kBtu	0.00	0.02	0.02	0.02	2.69	3.62	3.62	3.62	3.62
RC/L	0.00	0.02	0.02	0.89	0.89	3.40	3.40	3.40	3.40
RC/NL	0.00	0.02	0.02	8.37	11.29	11.29	11.29	11.29	11.29

Total Weighted Undepreciated Cumulative Investment Costs

CCEE.E	0.0	0.2	1.1	3.8	56.4	80.1	129.7	208.8	230.9

Total Updepreciated Capital Costs: Per Industry (for GRIM)

	Capital Costs UnDepreciated					(Capital cost) * 7			
	0	1	2	3	4	5	6	7	8
NRC/L:<6kBtu	0.00	0.48	0.48	2.21	4.50	57.56	57.56	247.07	0.00
NRC/L:6-8kBtu	0.00	0.52	0.52	2.30	4.33	48.66	48.66	196.42	0.00
NRC/L:8-14kBtu	0.00	0.00	1.80	5.64	92.42	92.42	340.36	0.00	0.00
NRC/L:14-20kBtu	0.00	0.00	1.51	3.14	113.33	113.33	113.33	113.33	223.53
NRC/L:>20kBtu	0.00	0.00	0.86	0.86	35.92	35.92	35.92	94.36	0.00
NRC/NL:6-8kBtu	0.00	0.00	0.08	0.08	13.43	17.44	0.00	0.00	0.00
NRC/NL:8-14kBtu	0.00	0.08	0.08	0.08	13.44	18.11	0.00	0.00	0.00
RC/L	0.00	0.09	0.09	4.47	4.47	17.00	0.00	0.00	0.00
RC/NL	0.00	0.12	0.12	41.86	56.47	56.47	0.00	0.00	0.00

Table C.8 (Continued)

TCC.E: Total Conversion Capital Costs (exc. Design/R&D costs)

	0	1	2	3	4	5	6	7	8
NRC/L:<6kBtu	0.00	0.48	0.48	2.21	4.50	57.56	57.56	247.07	0.00
NRC/L:6-8kBtu	0.00	0.52	0.52	2.30	4.33	48.66	48.66	196.42	0.00
NRC/L:8-14kBtu	0.00	0.00	1.80	5.64	92.42	92.42	340.36	0.00	0.00
NRC/L:14-20kBtu	0.00	0.00	1.51	3.14	113.33	113.33	113.33	113.33	223.53
NRC/L:>20kBtu	0.00	0.00	0.86	0.86	35.92	35.92	35.92	94.36	0.00
NRC/NL:6-8kBtu	0.00	0.00	0.08	0.08	13.43	17.44	0.00	0.00	0.00
NRC/NL:8-14kBtu	0.00	0.08	0.08	0.08	13.44	18.11	0.00	0.00	0.00
RC/L	0.00	0.09	0.09	4.47	4.47	17.00	0.00	0.00	0.00
RC/NL	0.00	0.12	0.12	41.86	56.47	56.47	0.00	0.00	0.00

Table C.9 Room Air Conditioners

The Standards Level Module

```
LevIn   prev    LEV.B    lev.N    Eng: Levels =           0 ...     30   No. of Eng. Levs.
          -1        0        1    REM: -1='87  0='96     -1 ...      5   No. of Stds Levs.
           1        1        1    1 ==> Stndrds                0 ==> Eng.
         S|E    S|E.B    S|E.N    Esc = QUIT
```

VCS.R	Additional UVC by Level and Class. (Above Base cost.)									
LEVEL -->	-1=1987	0=1996	1	2	3	4	5	6	7	8
NRC/L:<6kBtu	0.00	1.45	4.35	6.58	9.72	25.73	170.80	0.00	0.00	0.00
NRC/L:6-8kBtu	0.00	2.85	5.21	8.05	11.71	28.93	176.03	0.00	0.00	0.00
NRC/L:8-14kBtu	0.00	8.95	12.13	13.51	16.91	35.88	189.30	0.00	0.00	0.00
NRC/L:14-20kBtu	0.00	7.35	14.29	17.14	20.56	20.56	312.17	0.00	0.00	0.00
NRC/L:>20kBtu	0.00	14.31	17.60	17.60	20.03	50.67	335.29	0.00	0.00	0.00
NRC/NL:6-8kBtu	0.00	17.28	18.61	18.61	19.59	19.59	168.35	0.00	0.00	0.00
NRC/NL:8-14kBtu	0.00	13.01	13.01	13.99	16.29	16.29	181.23	0.00	0.00	0.00
RC/L	0.00	8.45	9.82	9.82	13.44	13.44	184.04	0.00	0.00	0.00
RC/NL	0.00	13.72	13.72	13.72	14.17	14.17	177.11	0.00	0.00	0.00

KWS.R	Kw Hrs /Yr									
LEVEL -->	-1=1987	0=1996	1	2	3	4	5	6	7	8
NRC/L:<6kBtu	29.76	28.78	26.14	25.19	24.50	23.61	20.87	0.00	0.00	0.00
NRC/L:6-8kBtu	37.04	35.33	33.24	32.39	31.59	30.32	26.84	0.00	0.00	0.00
NRC/L:8-14kBtu	54.58	52.69	51.56	51.05	49.96	46.29	41.07	0.00	0.00	0.00
NRC/L:14-20kBtu	83.57	80.41	76.80	75.13	74.06	74.06	58.90	0.00	0.00	0.00
NRC/L:>20kBtu	123.68	120.55	119.23	119.23	118.16	114.28	91.27	0.00	0.00	0.00
NRC/NL:6-8kBtu	30.04	29.21	28.78	28.78	28.51	28.51	23.10	0.00	0.00	0.00
NRC/NL:8-14kBtu	51.46	50.49	50.49	49.63	49.37	49.37	40.84	0.00	0.00	0.00
RC/L	58.99	57.50	56.91	56.91	55.91	55.91	47.15	0.00	0.00	0.00
RC/NL	54.57	53.81	53.81	53.81	53.28	53.28	43.76	0.00	0.00	0.00

CC.R										
LEVEL -->	-1=1987	0=1996	1	2	3	4	5	6	7	8
NRC/L:<6kBtu	0.00	0.26	0.33	0.65	1.10	11.78	50.55	0.00	0.00	0.00
NRC/L:6-8kBtu	0.00	0.29	0.36	0.76	1.29	12.77	51.54	0.00	0.00	0.00
NRC/L:8-14kBtu	0.00	1.84	1.84	2.04	2.53	15.17	53.22	0.00	0.00	0.00
NRC/L:14-20kBtu	0.00	1.09	1.09	1.49	1.98	1.98	78.65	0.00	0.00	0.00
NRC/L:>20kBtu	0.00	0.99	0.99	0.99	1.34	1.34	62.61	0.00	0.00	0.00
NRC/NL:6-8kBtu	0.00	0.08	0.08	0.08	0.22	0.22	50.62	0.00	0.00	0.00
NRC/NL:8-14kBtu	0.00	0.18	0.18	0.32	0.32	0.32	52.57	0.00	0.00	0.00
RC/L	0.00	3.50	3.69	3.69	3.69	3.69	52.62	0.00	0.00	0.00
RC/NL	0.00	0.04	0.04	0.04	0.11	0.11	52.45	0.00	0.00	0.00

Table C.9 (Continued)

ADD.R

LEVEL -->	-1=1987	0=1996	1	2	3	4	5	6	7	8
NRC/L:<6kBtu	0.00	0.26	0.33	0.64	1.07	11.51	49.41	0.00	0.00	0.00
NRC/L:6-8kBtu	0.00	0.22	0.27	0.58	0.98	9.73	39.28	0.00	0.00	0.00
NRC/L:8-14kBtu	0.00	2.36	2.36	2.61	3.23	19.41	68.07	0.00	0.00	0.00
NRC/L:14-20kBtu	0.00	0.62	0.62	0.85	1.13	1.13	44.71	0.00	0.00	0.00
NRC/L:>20kBtu	0.00	0.30	0.30	0.30	0.40	0.40	18.87	0.00	0.00	0.00
NRC/NL:6-8kBtu	0.00	0.01	0.01	0.01	0.02	0.02	3.49	0.00	0.00	0.00
NRC/NL:8-14kBtu	0.00	0.01	0.01	0.02	0.02	0.02	3.62	0.00	0.00	0.00
RC/L	0.00	0.23	0.24	0.24	0.24	0.24	3.40	0.00	0.00	0.00
RC/NL	0.00	0.01	0.01	0.01	0.02	0.02	11.29	0.00	0.00	0.00

CCEE.R

LEVEL -->	-1=1987	0=1996	1	2	3	4	5	6	7	8
Cumltv CC	0.00	0.00	0.00	0.00	0.00	0.00	0.00			
	0.00	4.01	4.14	5.25	7.11	42.48	242.15	0.00	0.00	0.00

INCOST.R

LEVEL -->	-1=1987	0=1996	1	2	3	4	5	6	7	8
NRC/L:<6kBtu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NRC/L:6-8kBtu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NRC/L:8-14kBtu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NRC/L:14-20kBtu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NRC/L:>20kBtu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NRC/NL:6-8kBtu	0.00	0.00	0.00	0.00	0.00	0.00	330.72	0.00	0.00	0.00
NRC/NL:8-14kBtu	0.00	0.00	0.00	0.00	0.00	0.00	330.72	0.00	0.00	0.00
RC/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RC/NL	0.00	0.00	0.00	0.00	0.00	0.00	330.72	0.00	0.00	0.00

	1987	1996	NEW96	1987	1996	NEW96	Cal	Base	New
	VC87	VCB	VCN	KW87	KWB	KWN	INCST87	INCSTB	INCSTN
NRC/L:<6kBtu	0.00	1.45	4.35	29.76	28.78	26.14	0.00	0.00	0.00
NRC/L:6-8kBtu	0.00	2.85	5.21	37.04	35.33	33.24	0.00	0.00	0.00
NRC/L:8-14kBtu	0.00	8.95	12.13	54.58	52.69	51.56	0.00	0.00	0.00
NRC/L:14-20kBtu	0.00	7.35	14.29	83.57	80.41	76.80	0.00	0.00	0.00
NRC/L:>20kBtu	0.00	14.31	17.60	123.68	120.55	119.23	0.00	0.00	0.00
NRC/NL:6-8kBtu	0.00	17.28	18.61	30.04	29.21	28.78	0.00	0.00	0.00
NRC/NL:8-14kBtu	0.00	13.01	13.01	51.46	50.49	50.49	0.00	0.00	0.00
RC/L	0.00	8.45	9.82	58.99	57.50	56.91	0.00	0.00	0.00
RC/NL	0.00	13.72	13.72	54.57	53.81	53.81	0.00	0.00	0.00

Table C.9 (Continued)

					Base Case	New Stds	INSTALLATION COST CALCs		
	1987	1996	NEW96	Weighted	Weighted	Weighted	Cal Wgt	Base	New Stds
	CPC87	CPCB	CPCN	Op Cost	d P	d P	INST Cst	Wgt Inst. Cst	Wgt Inst. Cst
NRC/L:<6kBtu	0	0.26	0.33	6.76	0.33	0.99	0	0.00	0.00
NRC/L:6-8kBtu	0	0.29	0.36	6.56	0.50	0.92	0	0.00	0.00
NRC/L:8-14kBtu	0	1.84	1.84	16.21	2.66	3.60	0	0.00	0.00
NRC/L:14-20kBtu	0	1.09	1.09	11.03	0.97	1.89	0	0.00	0.00
NRC/L:>20kBtu	0	0.99	0.99	8.66	1.00	1.23	0	0.00	0.00
NRC/NL:6-8kBtu	0	0.08	0.08	0.48	0.28	0.30	0	0.00	0.00
NRC/NL:8-14kBtu	0	0.18	0.18	0.82	0.21	0.21	0	0.00	0.00
RC/L	0	3.50	3.69	0.88	0.13	0.15	0	0.00	0.00
RC/NL	0	0.04	0.04	2.73	0.69	0.69	0	0.00	0.00
				====	====	====	====	====	====
		Wgt Fuel Cost: F		54.13	6.76	9.97	0.00	0.00	0.00
					dVC.B0	dVC.N0	IN.87.0	IN.B.0	IN.N.0

OUTPUT

CC.87	CCB	CCN	CC.B0	CC.N0	dVC.B.CV	IN.B	IN.N
0.00	4.01	4.14	4.01	4.14	0.25	0.00	0.00

	Weighted VC:	Weighted VC:	Weighted VC:
	Cal. Case	Base	New Stds
NRC/L:<6kBtu	0.00	0.33	0.99
NRC/L:6-8kBtu	0.00	0.50	0.92
NRC/L:8-14kBtu	0.00	2.66	3.60
NRC/L:14-20kBtu	0.00	0.97	1.89
NRC/L:>20kBtu	0.00	1.00	1.23
NRC/NL:6-8kBtu	0.00	0.28	0.30
NRC/NL:8-14kBtu	0.00	0.21	0.21
RC/L	0.00	0.13	0.15
RC/NL	0.00	0.69	0.69
	====	====	====
	0.00	6.76	9.97
	WVC87	WVCB	WVCN

RD.R: Conversion Design/R&D Cost Per Unit, Cumulative for GRIM

	-1=1987	0=1996	1	2	3	4	5	6	7	8
NRC/L:<6kBtu	0	0	0	0	0	0	0	0	0	0
NRC/L:6-8kBtu	0	0	0	0	0	0	0	0	0	0
NRC/L:8-14kBtu	0	0	0	0	0	0	0	0	0	0
NRC/L:14-20kBtu	0	0	0	0	0	0	0	0	0	0
NRC/L:>20kBtu	0	0	0	0	0	0	0	0	0	0
NRC/NL:6-8kBtu	0	0	0	0	0	0	0	0	0	0
NRC/NL:8-14kBtu	0	0	0	0	0	0	0	0	0	0
RC/L	0	0	0	0	0	0	0	0	0	0
RC/NL	0	0	0	0	0	0	0	0	0	0

Table C.9 (Continued)

TCC.R: Total Capital Costs, exc. R&D Per Unit, Cumulative for GRIM

	-1=1987	0=1996	1	2	3	4	5	6	7	8
NRC/L:<6kBtu	0.00	1.29	1.63	3.18	5.37	57.56	247.07	0.00	0.00	0.00
NRC/L:6-8kBtu	0.00	1.11	1.36	2.91	4.90	48.66	196.42	0.00	0.00	0.00
NRC/L:8-14kBtu	0.00	11.79	11.79	13.05	16.16	97.03	340.36	0.00	0.00	0.00
NRC/L:14-20kBtu	0.00	3.09	3.09	4.24	5.63	5.63	223.53	0.00	0.00	0.00
NRC/L:>20kBtu	0.00	1.49	1.49	1.49	2.02	2.02	94.36	0.00	0.00	0.00
NRC/NL:6-8kBtu	0.00	0.03	0.03	0.03	0.08	0.08	17.44	0.00	0.00	0.00
NRC/NL:8-14kBtu	0.00	0.06	0.06	0.11	0.11	0.11	18.11	0.00	0.00	0.00
RC/L	0.00	1.13	1.19	1.19	1.19	1.19	17.00	0.00	0.00	0.00
RC/NL	0.00	0.05	0.05	0.05	0.12	0.12	56.47	0.00	0.00	0.00

	Wgt RD: Base	Wgt TCC: Base	Wgt RD: New Stds	Wgt TCC: New Stds
NRC/L:<6kBtu	0.00	1.29	0.00	1.63
NRC/L:6-8kBtu	0.00	1.11	0.00	1.36
NRC/L:8-14kBtu	0.00	11.79	0.00	11.79
NRC/L:14-20kBtu	0.00	3.09	0.00	3.09
NRC/L:>20kBtu	0.00	1.49	0.00	1.49
NRC/NL:6-8kBtu	0.00	0.03	0.00	0.03
NRC/NL:8-14kBtu	0.00	0.06	0.00	0.06
RC/L	0.00	1.13	0.00	1.19
RC/NL	0.00	0.05	0.00	0.05
	0.00	20.04	0.00	20.69
	RDC.B	TCCC.B	RDC.N	TCCC.N

Table C.10 Room Air Conditioners

The Cost, Sales, and Revenue Module

COSTS, SALES, and REVENUES			bb	-55
			aa	712
Ratio of highest to lowest markup:	ratio.0	2.00	ratio.cv	0.20
Typical markup over UVC	mid.0	0.38	mid.cv	0.20
Size of firm as % of industry	size.0	0.20		

CALIBRATION CASE (1987)

	Indst	Relatv		------------------ Firm --------- --------				
	Ship.	Ship.	Ship.	Price	Rev.			Weighted
	IQ	Q%	Q.1	P.1/Range	R.1	m.1	UVC.1	UVC
NRC/L:<6kBtu	0.70	22.7%	0.14	215.04	30.03	1.38	155.83	35.37
NRC/L:6-8kBtu	0.54	17.7%	0.11	238.95	26.02	1.41	169.04	29.92
NRC/L:8-14kBtu	0.91	29.7%	0.18	307.49	56.18	1.51	203.66	60.49
NRC/L:14-20kBtu	0.41	13.2%	0.08	392.79	31.90	1.63	241.03	31.82
NRC/L:>20kBtu	0.22	7.0%	0.04	485.58	20.91	1.76	275.90	19.31
NRC/NL:6-8kBtu	0.05	1.6%	0.01	222.39	2.19	1.39	159.96	2.56
NRC/NL:8-14kBtu	0.05	1.6%	0.01	287.81	2.83	1.48	194.18	3.11
RC/L	0.05	1.5%	0.01	313.56	2.89	1.52	206.51	3.10
RC/NL	0.15	5.0%	0.03	295.85	9.10	1.49	198.09	9.90
TOTAL S	3.08	20.00%	0.62	$296	182.06	1.51	20.00%	195.58
	TS.0	Q.CV	Q.0	P.0	R		P.CV	UVC

BASE CASE (1996)

	Rule-of-Thb d P	Rule-of-Thb Revenue		Pi.B	Op Cost Ratio	Weightd OpCst-R	Qi.B	Ri.B
NRC/L:<6kBtu	2.30	30.16	1	$217.26	0.97	0.22	0.1388	30.15
NRC/L:6-8kBtu	4.35	26.32	2	$242.99	0.95	0.17	0.1082	26.29
NRC/L:8-14kBtu	15.74	58.68	45	$319.16	0.97	0.29	0.1815	57.94
NRC/L:14-20kBtu	13.39	32.77	14	$403.24	0.96	0.13	0.0807	32.54
NRC/L:>20kBtu	26.59	21.91	30	$500.55	0.97	0.07	0.0428	21.42
NRC/NL:6-8kBtu	24.12	2.41	6	$236.95	0.97	0.02	0.0098	2.32
NRC/NL:8-14kBtu	19.49	3.01	4	$301.06	0.98	0.02	0.0098	2.94
RC/L	17.09	3.03	3	$325.85	0.97	0.01	0.0092	2.99
RC/NL	20.54	9.67	13	$309.46	0.99	0.05	0.0306	9.46
	0.02	187.96	117	304.4	186.03	-0.03	0.6112	186.03
	Alpha.B	Sum P (2)	Sum (3)	P.B	Sum(Ri)	OC%.B0	Q.B	R.B

Table C.10 (Continued)

EFFICIENCY LEVEL CASE (1996)	Rule-of-	Rule-of-Th b			% Chng	Weightd		
	Thb d P	Revenue		Pi.N	Op Cost	OpCst-R	Qi.N	Ri.N
NRC/L:<6kBtu	6.38	30.73	6	$220.86	0.88	0.20	0.1388	30.66
NRC/L:6-8kBtu	7.76	26.70	7	$245.87	0.90	0.16	0.1082	26.61
NRC/L:8-14kBtu	20.54	59.57	77	$322.18	0.94	0.28	0.1816	58.51
NRC/L:14-20kBtu	24.70	33.70	49	$409.04	0.92	0.12	0.0807	33.02
NRC/L:>20kBtu	32.38	22.17	45	$503.42	0.96	0.07	0.0428	21.55
NRC/NL:6-8kBtu	25.96	2.43	7	$239.01	0.96	0.02	0.0098	2.34
NRC/NL:8-14kBtu	19.49	3.01	4	$302.03	0.98	0.02	0.0098	2.96
RC/L	19.39	3.05	3	$327.74	0.96	0.01	0.0092	3.01
RC/NL	20.54	9.67	13	$310.54	0.99	0.05	0.0306	9.49
TOTAL	0.01	191.04	210	307.7	188.13	-0.08	0.6115	188.13
	Alpha.N	Sum P (2)	Sum (3)	P.N	Sum(Ri)	OC%.N0	Q.N	R.N

Table C.11 Room Air Conditioners

The One-Time Cost Amortization Module

NOTES

Economic life of existing capital	L	8.00	years
Tax life of existing capital	TL	6.00	years
Age of existing capital	AGE	1.00	years
Percent of 1X capital that is add-on (as opposed to replacement capital)	%NC	50%	

COMPUTATIONS

DESCRIPTION		NAME	VALUE	
Continuous After-Tax WACC		ATR	4.43%	
Weighted CC Lead-Time Factors	0.00	0.28	0.53	0.26
Cumulative CC Lead-Time Factors		LTC.0	1.074	
exp(-ATR*TL)		EMRT	0.766	
exp(-ATR*L)		EMRL	0.701	
Rate of tax benefit	3.30	BN	0.060	
Remaining tax life		RTL	5.00	years
Tax Benefit Rate: (1-%NC)*BN		BEN	0.030	
Discount factor: @exp(-ATR*(L-(TL-RTL)))		DIS	0.73	
Loss of tax benefit on portion of existing capital with remaining tax life		LEC1	0.135	
Loss of tax benefit on discounted existing capital expenditure in the future		LEC2	0.116	

LEVELIZED CC		GROSS CC	TAX EFF
Initial Cost		1.000	
Tax Benefit of Straight-Line Depreciation			0.316
Savings from not replacing existing Capital later		-0.367	
Loss of Tax Benefit from existing Capital			-0.250
Present Value of CC:		0.633	0.066
Adjusted for Capital Lead Time		0.680	0.071
Levelized Tax Benefit: 1-X dep. of existing Cap.			0.004
LEVELIZED CC FACTOR	CCLF	0.101	0.014
			CCLTF

AVERAGE ASSET FACTOR		
Asset Factor for Any New Cap. or Asset	AFB	0.559
Average Asset Factor for Add-on Capital	AAF	0.279

INPUT

NEW CAP. COST: 1987-96 ($000)	CC.B0	4.01
1996 CHANGE	CC.N	4.14
COEFFICIENTS OF VARIATION	CCL.CV	0.20
	CC.B.CV	0.25

Table C.11 (Continued)

OUTPUT				
	BASE CASE 1996		NEW STNDS 1996	
Levelized 1-X CC: Gross	LCC.B	0.40	LCC.N	0.4178
Levelized 1-X CC: Tax Effects	LCC.TB	0.06	LCC.TN	0.06
Levelized 1-X CC: Net	LCC.NB	0.35	LCC.NN	0.36
Levelized 1-X Assets	LA.B	1.12	LA.N	1.16

Table C.12 Room Air Conditioners

The Long-Run Model Module

1987 CASE			A.F	A.Q	A:R	A
	Assets -->		0.036	0.899	0.936	170
	Costs except taxes		TC.F	TC.Q	TC:R	TC
	and equity -->		0.100	0.810	0.910	166
			EC.F	EC.Q	EC:R	EC
	Economic costs -->		0.065	0.553	0.978	178
		Economic Income			EI:R	0.0217
		Markup (mu - 1)			mu1	0.1574
		Price Leader's elasticity of demand:				-7.4
BASE 1996			A.BF	A.BQ		A.B
	Assets		6.64	266.12		172.69
			TC.BF	TC.BQ		TC.B
	Costs except taxes		18.21	246.49		168.93
			EC.BF	EC.BQ		EC.B
	Economic costs		11.99	168.65		180.62
	Total Working Capital Correction Assets		WCA.B	2.27		
	Working Capital Correction (Per Unit EC)		WCCEC.B	0.163		
	Total Working Capital Correction (Interest)		WCCI.B	0.057		
NEW 1996			A.NF	A.NQ		A.N
	Assets		6.636	266.117		173.859
			TC.NF	TC.NQ		TC.N
	Costs except taxes		18.206	249.694		170.970
			EC.NF	EC.NQ		EC.N
	Economic costs		11.990	170.801		181.971
	Total Working Capital Correction Assets		WCA.N	3.34		
	Working Capital Correction (Per Unit EC)		WCCEC.N	0.24		
	Total Working Capital Correction (Interest)		WCCI.N	0.08		

Assets	---------1987---------		------BASE 1996-------		-------NEW 1996-------	
Shipments	Q	0.62	Q.B	0.6112	Q.N	0.61
Price	P	$295.93	P.B	$304.35	P.N	$307.67
Revenue	R	182.06	R.B	186.03	R.N	188.13
Unit Var. Cost	UVC	$195.58	UVC.B	$202.34	UVC.N	$205.54
V. Cost Goods Sold	VCGS	120.32	VCGS.B	123.68	VCGS.N	125.69
1X tax benefit			X1T.B	0.06	X1T.N	0.06
Pre-tax cost	PTC	165.68	PTC.B	169.33	PTC.N	171.39
Taxes	TAX	5.89	TAX.B	6.10	TAX.N	6.12
Net Income	NI	10.48	NI.B	10.60	NI.N	10.63
Economic Income	EI	3.94	EI.B	3.97	EI.N	3.95
Equity	EQ	96.13	EQ.B	97.45	EQ.N	98.11
Return on Equity	ROE	10.90%	ROE.B	10.88%	ROE.N	10.83%

Table C.12 (Continued)

ACCOUNTING PAGE ONLY CALCULATIONS	----------1987----------		------BASE 1996-------		--- ----NEW 1996-------	
Interest not1X	IC	1.82	IC.B	1.80	IC.N	1.81
Pre-intrst cst	PIC	163.86	PIC.B	167.63	PIC.N	169.68
1X deprciation			X1D.B	0.50	X1D.N	0.52
1X interest			X1I.B	0.01	X1I.N	0.01
1X equity cost			X1E.B	0.04	X1E.N	0.04

Table C.13 Room Air Conditioners

The Short-Run Module

SHORT-RUN ANALYSIS

Short-Run "Supply Elasticity of Price": (Q/P)*dP/dQ	SRQE.0	0.157
Standard Error of SRQE	SRQE.SD	0.120
Random Value selected for this run:	SRQE	0.157

R.S	188.03	P.N	$307.67	
UVC.S	$205.54	Q.N		0.61
VCGS.S	125.73			
TC.S	170.94		ap	bp
TAX.S	6.09	P=a+bQ	259.37	78.52
PTC.S	171.47			
NI.S	10.46			
A.S	173.86			
EQ.S	98.11	P.S	307.40	
ROE.S	10.67%	Q.S	0.61	

Short-Run Assumptions:

The industry installs the long-run optimal level of capital

The industry produces to meet demand at the low short-run price

Table C.14   Room Air Conditioners

The Charts Module

Sensitivity of ROE to 1 S.E. change in Control Variable

Scenario= Primary

Control Variables			Efficiency Levels				
Name	Value	Changed	1	2	3	4	5
IPE	-0.350	-0.805	0.01%	-0.01%	-0.06%	-0.62%	-7.96%
RD	0.640	1.471	0.07%	0.11%	0.15%	0.29%	1.17%
ECC	0.068	0.075	0.00%	0.00%	0.00%	-0.04%	-0.30%
EP	0.041	0.051	-0.01%	-0.01%	-0.01%	-0.04%	-0.11%
FCA	0.100	0.160	0.00%	0.00%	0.03%	0.27%	1.97%
F1X	0.200	0.348	0.00%	-0.02%	-0.05%	-0.55%	-1.82%
CC.N	4.138	5.044	-0.02%	-0.02%	-0.03%	-0.18%	-1.13%
dVC.N	9.970	13.371	0.07%	0.08%	0.10%	0.13%	-0.05%
ro.N	0.000	0.144	0.00%	0.00%	-0.02%	-0.21%	-1.93%
SRPR	0.157	0.309	0	0	0	0	0

Table C.15 Room Air Conditioners

The Financial Module

DESCRIPTION (FINANCE PAGE)		RANGE NAME	INPUT VALUE	RANGE NAME	C.V.
RATES OF COST					
	After Tax Equity Cost of Capital	ECC.0	6.80%	ECC.CV	10%
	Interest Rate on Debt	I.0	2.50%	I.CV	100.00%
	Interest Lost on Cash	ICash.0	1.00%	ICASH.CV	100.00%
	Rate of Depreciation	Dep.0	17.70%		
	Tax Rate	T.0	36.00%	T.CV	0.00%
	Cash	C:R.0	2.6%	C:R.CV	100.00%
	Inventory & Receivables	IR:R.0	54.5%	IR:R.CV	27.19%
	Depreciable Assets	DA:R.0	36.5%	DA:R.CV	36.89%
	G & A	G&A.0	18.0%	G&A.CV	40.00%
	Engineering	Eng	1.2%		
	Fixed Part of All Costs & Depr Assets	FCA.0	10.0%	FCA.CV	50%
	Fixed Part of 1-X Capital Cost	F1X.0	20.0%	F1X.CV	60%
	Economic Profit	EP.0	4.1%	EP.CV	1%
	Debt to Equity ratio	DER.0	77.2%	DER.CV	43%
	Markup on typical model	"mid	38.0%		
	Ratio of highest to lowest markup	"ratio	2.00		

OUTPUT		NAME	VALUE		
	Depreciation	DRR	6.6%		
	G&A to Overhead Ratio	G:O	93.8%		
	Engineering to Overhead Ratio	E:O	6.3%		
	Debt Ratio	DR	43.6%		
	Equity Ratio	ER	56.4%		
	Pre-Tax Equity Cost of Capital*	PECC	10.6%		
	Weighted Average Cost of Capital	WACC	7.1%		
	After Tax WACC	ATWACC	4.5%		
	Return on Equity	ROE	10.90%	ROE.0	10.90%

All interest rates and costs of capital are "real".

*When Pre-Tax ECC is used, all costs are counted tax exempt.

Table C.16 Room Air Conditioners

Cash Flow Analysis

ROOM AIR CONDITIONERS			Base Year 1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
GRIM Switch		0										
Price/Unit			$304	$304	$304	$304	$304	$304	$304	$304	$304	$304
Unit Sales			3.06	3.06	3.06	3.06	3.06	3.06	3.06	3.06	3.06	3.06
Revenues			930	930	930	930	930	930	930	930	930	930
	New	Base										
CGS	244.32	234.35	716	716	716	716	716	716	716	716	716	716
Labor	31.43	30.44	93	93	93	93	93	93	93	93	93	93
Material	162.92	155.22	474	474	474	474	474	474	474	474	474	474
Overhead	40.08	38.80	119	119	119	119	119	119	119	119	119	119
Depreciation	9.89	9.89	30	30	30	30	30	30	30	30	30	30
SG&A			158	158	158	158	158	158	158	158	158	158
R&D			19	19	19	19	19	19	19	19	19	19
Product Conversion			0	0	0	0	0	0	0	0	0	0
Profit Before Tax			56	56	56	56	56	56	56	56	56	56
Taxes (Rate)	36%		20	20	20	20	20	20	20	20	20	20
Net Income before Financing			36	36	36	36	36	36	36	36	36	36
Cash Flow												
Net Income			36	36	36	36	36	36	36	36	36	36
Depreciation			30	30	30	30	30	30	30	30	30	30
Change in Work Capital			0	0	0	0	0	0	0	0	0	0
Cash Flows from Operations			66	66	66	66	66	66	66	66	66	66
Capital Expenditures (Cash used in invest)			(37)	(37)	(37)	(37)	(37)	(37)	(37)	(37)	(37)	(37)
Conversion Expenditure			0	0	0	0	0	0	0	(5)	(7)	(8)
Cash Used in Investments			(37)	(37)	(37)	(37)	(37)	(37)	(37)	(42)	(44)	(45)
Net Cash Flow			29	29	29	29	29	29	29	24	22	20

Table C.16 (Continued)

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Price/Unit	$308	$308	$308	$308	$308	$308	$308	$308	$308	$308	$308	$308
Unit Sales	3.06	3.06	3.06	3.06	3.06	3.06	3.06	3.06	3.06	3.06	3.06	3.06
Revenues	941	941	941	941	941	941	941	941	941	941	941	941
CGS	748	748	748	748	748	748	748	748	748	748	748	748
Labor	96	96	96	96	96	96	96	96	96	96	96	96
Material	498	498	498	498	498	498	498	498	498	498	498	498
Overhead	123	123	123	123	123	123	123	123	123	123	123	123
Depreciation	32	32	32	32	32	32	32	32	32	32	32	32
SG&A	158	158	158	158	158	158	158	158	158	158	158	158
R&D	19	19	19	19	19	19	19	19	19	19	19	19
Product Conversion	0	0	0	0	0	0	0	0	0	0	0	0
Profit Before Tax	34	34	34	34	34	34	34	34	34	34	34	34
Taxes	12	12	12	12	12	12	12	12	12	12	12	12
Net Income before Financing	22	22	22	22	22	22	22	22	22	22	22	22
Cash Flow												
Net Income	22	22	22	22	22	22	22	22	22	22	22	22
Depreciation	32	32	32	32	32	32	32	32	32	32	32	32
Change in Work Capital	2	0	0	0	0	0	0	0	0	0	0	0
Cash Flows from Operations	52	53	53	53	53	53	53	53	53	53	53	53
Capital Expenditures (Cash used in invest)	(39)	(39)	(39)	(39)	(39)	(39)	(39)	(39)	(39)	(39)	(39)	(39)
Conversion Expenditure	0	0	0	0	0	0	0	0	0	0	0	0
Cash Used in Investments	(39)	(39)	(39)	(39)	(39)	(39)	(39)	(39)	(39)	(39)	(39)	(39)
Net Cash Flow	13	15	15	15	15	15	15	15	15	15	15	15

Supplemental Sensitivity Analysis

Supplemental Table 1: Supplemental Efficiency Level

Product class	Energy Efficiency Ratio
1. Without reverse cycle, with louvered sides, and less than 6,000 Btu/h	9.7
2. Without reverse cycle, with louvered sides, and 6,000 to 7,999 Btu/h	9.7
3. Without reverse cycle, with louvered sides, and 8,000 to 13,999 Btu/h	9.8
4. Without reverse cycle, with louvered sides, and 14,000 to 19,999 Btu/h	9.7
5. Without reverse cycle, with louvered sides, and 20,000 Btu/h or more	8.5
6. Without reverse cycle, without louvered sides, and less than 6,000 Btu/h	9.0
7. Without reverse cycle, without louvered sides, and 6,000 to 7,999 Btu/h	9.0
8. Without reverse cycle, without louvered sides, and 8,000 to 13,999 Btu/h	8.5
9. Without reverse cycle, without louvered sides, and 14,000 to 19,999 Btu/h	8.5
10. Without reverse cycle, without louvered sides, and 20,000 Btu/h or more	8.5
11. With reverse cycle, with louvered sides, and less than 20,000 Btu/h	9.0
12. With reverse cycle, without louvered sides, and less than 14,000 Btu/h	8.5
13. With reverse cycle, with louvered sides, and 20,000 Btu/h or more	8.5
14. With reverse cycle, without louvered sides, and 14,000 Btu/h or more	8.0

Supplemental Table 3.95 (based on 1995 AEO fuel price projections)

Table 3.2 Unit Energy Consumption for New Room Air Conditioners (weighted average kWh/yr)

Year	Base	Final
1981	919	919
1990	725	725
1996	672	672
2000	666	625
2015	652	620
2030	653	620

Table 3.3a U.S. Electricity Consumption for New Room Air Conditioners (quadrillion Btu, primary)

Year	Base	Final	
1981	0.452	0.452	
1990	0.374	0.374	
1996	0.368	0.368	
2000	0.380	0.376	
2015	0.456	0.436	
2030	0.543	0.520	
1999-2030	14.606	14.063	Saving 0.543

Table 3.3d U.S. Electricity Consumption for Residential Air Conditioning (quadrillion Btu, primary)

Year	Base	Final	
1981	1.145	1.145	
1990	1.503	1.503	
1996	1.641	1.641	
2000	1.717	1.713	
2015	2.112	2.095	
2030	2.592	2.572	
1999-2030	67.601	67.115	Saving 0.486

Table 3.5 Average Purchase Price for New Room Air Conditioners (1990 dollars per unit)

Year	Base	Final
1981	490	490
1990	495	495
1996	507	507
2000	507	516
2015	518	525
2030	518	525

Supplemental Table 3.97 (based on AEO 1997 fuel price projections)

Table 3.2 Unit Energy Consumption for New Room Air Conditioners (weighted average kWh/yr)

Year	Base	Final
1981	920	920
1990	726	726
1996	667	667
2000	665	625
2015	662	622
2030	666	626

Table 3.3a U.S. Electricity Consumption for New Room Air Conditioners (quadrillion Btu, primary)

Year	Base	Final	
1981	0.452	0.452	
1990	0.376	0.376	
1996	0.379	0.379	
2000	0.397	0.394	
2015	0.516	0.489	
2030	0.638	0.604	
1999-2030	16.416	15.703	Saving 0.713

Table 3.3d U.S. Electricity Consumption for Residential Air Conditioning (quadrillion Btu, primary)

Year	Base	Final	
1981	1.146	1.146	
1990	1.512	1.512	
1996	1.677	1.677	
2000	1.772	1.770	
2015	2.310	2.286	
2030	2.850	2.820	
1999-2030	73.214	72.571	Saving 0.643

Table 3.5 Average Purchase Price for New Room Air Conditioners (1990 dollars per unit)

Year	Base	Final
1981	490	490
1990	495	495
1996	507	507
2000	507	516
2015	507	516
2030	507	516

Updated Table 3.6b Net Present Value to Consumers for Room A/C purchased from 1999 to 2030 based on *1995* AEO fuel price projections (billion 1990$ discounted to 1990 at 7%)

Fuel Savings	0.76
Equipment Cost	0.25
Net Present Value	0.51

Updated Table 3.6b Net Present Value to Consumers for Room A/C purchased from 2000 to 2030 based on *1997* AEO fuel price projections (billion 1990$ discounted to 1990 at 7%)

Fuel Savings	0.74
Equipment Cost	0.29
Net Present Value	0.45

Supplemental Table 4.1 (using AEO 95 energy price projections[1])

Life Cycle Costs and Payback Periods of Room Air Conditioner, Less than 6000 Btu/h, Without Reverse Cycle and With Louvered Sides

Effc'y Level	Design No.	Design Option	EER *Btu/W-hr*	Retail Price	Install. Cost	Installed Consumer Cost	Annual Maint. Cost (@6%)	Annual Elec. Use *kWh*	Annual Energy Expense	Life-Cycle Costs 2%	6%	15%
	0	Baseline	8.23	$372	$0	$372.03	$0	378.51	$27.82	$677.04	$611.89	$525.17
	1	0 + Evap/Cond Enhanced Fins	8.70	$373	$0	$372.64	$0	358.31	$26.34	$661.38	$599.70	$517.61
1	2	1 + PSC Fan Motor	9.32	$378	$0	$377.57	$0	334.43	$24.58	$647.07	$589.50	$512.88
Suppl.	**2a**	**Supplemental Level**	**9.70**	**$382**	**$0**	**$382.41**	**$0**	**321.26**	**$23.61**	**$641.30**	**$585.99**	**$512.39**
2	3	2 + Evap/Cond Grooved Tubes	9.71	$383	$0	$382.55	$0	320.90	$23.59	$641.14	$585.90	$512.38
3	4	3 + Add Subcooler	10.00	$390	$0	$389.51	$0	311.69	$22.91	$640.68	$587.02	$515.62
4	5	4 + Increase Evap/Cond Coil Area	10.38	$440	$0	$440.24	$0	300.19	$22.06	$682.14	$630.47	$561.69
	6	5 + Brushless D.C. Fan Motor	10.57	$560	$0	$560.46	$0	294.85	$21.67	$798.06	$747.30	$679.75
5	7	6 + **Variable Speed Compressor	11.74	$796	$0	$796.18	$0	265.36	$19.50	$1,010.02	$964.34	$903.55

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[1] U.S. Department of Energy (U.S. DOE), Energy Information Administration, 1995. *Annual Energy Outlook 1995 with Projections to 2010.* Washington, D.C. DOE/EIA-0383(95), January.

Supplemental Table 4.2 (using AEO 95)

Life Cycle Costs and Payback Periods of Room Air Conditioner, 6000 to 7999 Btu/h, Without Reverse Cycle and With Louvered Sides

Effc'y Level	Design No.	Design Option	EER *Btu/W-hr*	Retail Price	Install. Cost	Installed Consumer Cost	Annual Maint. Cost (@6%)	Annual Elec. Use *kWh*	Annual Energy Expense	Life-Cycle Costs 2%	6%	15%
	0	Baseline	8.46	$404	$0	$403.82	$0	471.06	$34.62	$783.42	$702.33	$594.41
	1	0 + Evap/Cond Enhanced Fins	8.80	$405	$0	$405.25	$0	452.75	$33.28	$770.09	$692.15	$588.43
1	2	1 + PSC Fan Motor	9.38	$410	$0	$410.13	$0	424.89	$31.23	$752.52	$679.38	$582.04
2	3	2 + Add Subcooler	9.66	$417	$0	$416.89	$0	412.31	$30.30	$749.14	$678.17	$583.71
Suppl.	**3a**	**Supplemental Level**	**9.70**	**$418**	**$0**	**$418.10**	**$0**	**410.69**	**$30.19**	**$749.05**	**$678.35**	**$584.26**
3	4	3 + Evap/Cond Grooved Tubes	9.91	$425	$0	$424.73	$0	402.03	$29.55	$748.70	$679.50	$587.39
4	5	4 + Increase Evap/Cond Coil Area	10.33	$478	$0	$477.78	$0	385.68	$28.35	$788.58	$722.19	$633.83
	6	5 + Brushless D.C. Fan Motor	10.50	$599	$0	$598.82	$0	379.26	$27.88	$904.44	$839.15	$752.27
5	7	6 + **Variable Speed Compressor	11.67	$830	$0	$830.48	$0	341.33	$25.09	$1,105.54	$1,046.78	$968.58

Supplemental Table 4.3 (using AEO 95)

Life Cycle Costs and Payback Periods of Room Air Conditioner, 6000 to 7999 Btu/h, Without Reverse Cycle and Without Louvered Sides

Effc'y Level	Design No.	Design Option	EER	Retail Price	Install. Cost	Installed Consumer Cost	Annual Maint. Cost	Annual Elec. Use	Annual Energy Expense	Life-Cycle Costs		
			Btu/W-hr				(@6%)	*kWh*		2%	6%	15%
	0	Baseline	8.86	$447	$0	$447.01	$0	382.02	$28.08	$754.85	$689.09	$601.57
Suppl.	**0a**	**Supplemental Level**	**9.00**	**$450**	**$0**	**$450.17**	**$0**	**375.86**	**$27.63**	**$753.05**	**$688.35**	**$602.24**
1,2	1	0 + Incr Compressor EER to 10.76	9.10	$452	$0	$452.23	$0	371.94	$27.34	$751.95	$687.92	$602.71
3,4	2	1 + Add Subcooler	9.23	$456	$0	$455.96	$0	366.62	$26.95	$751.39	$688.28	$604.29
	3	2 + Brushless D.C. Fan Motor	9.65	$599	$0	$599.35	$0	350.65	$25.77	$881.92	$821.56	$741.22
	4	3 + **Variable Speed Compressor	10.72	$873	$0	$872.95	$0	315.59	$23.20	$1,127.26	$1,072.94	$1,000.64
5	5	4 + **Incr Evap/Cond Coil Area	11.52	$1,014	$331	$1,344.94	$0	293.75	$21.59	$1,581.65	$1,531.09	$1,463.79

Supplemental Table 4.4 (using AEO 95)

Life Cycle Costs and Payback Periods of Room Air Conditioner, 8000 to 13,999 Btu/h, Without Reverse Cycle and With Louvered Sides

Effc'y Level	Design No.	Design Option	EER *Btu/W-hr*	Retail Price	Install. Cost	Installed Consumer Cost	Annual Maint. Cost (@6%)	Annual Elec. Use *kWh*	Annual Energy Expense	Life-Cycle Costs		
										2%	6%	15%
	0	Baseline	9.32	$495	$0	$495.06	$0	694.12	$51.02	$1,054.41	$934.92	$775.90
1	1	0 + Incr Compressor EER to 10.82	9.71	$506	$0	$505.83	$0	666.46	$48.98	$1,042.89	$928.16	$775.48
Suppl.	**1a**	**Supplemental Level**	**9.80**	**$508**	**$0**	**$508.41**	**$0**	**660.34**	**$48.53**	**$1,040.54**	**$926.86**	**$775.58**
2	2	1 + Add Subcooler	9.85	$510	$0	$509.76	$0	657.19	$48.30	$1,039.35	$926.21	$775.66
3	3	2 + Evap/Cond Grooved Tubes	10.11	$518	$0	$518.17	$0	640.03	$47.04	$1,033.93	$923.75	$777.12
4	4	3 + Increase Evap/Cond Coil Area	10.97	$577	$0	$576.63	$0	590.02	$43.37	$1,052.09	$950.52	$815.35
	5	4 + Brushless D.C. Fan Motor	11.15	$697	$0	$697.06	$0	580.28	$42.65	$1,164.67	$1,064.78	$931.84
5	6	5 + **Variable Speed Compressor	12.39	$929	$0	$929.44	$0	522.25	$38.39	$1,350.29	$1,260.39	$1,140.74

Supplemental Table 4.5 (using AEO 95)

Life Cycle Costs and Payback Periods of Room Air Conditioner, 8000 to 13,999 Btu/h, Without Reverse Cycle and Without Louvered Sides

Effc'y Level	Design No.	Design Option	EER *Btu/W-hr*	Retail Price	Install. Cost	Installed Consumer Cost	Annual Maint. Cost (@6%)	Annual Elec. Use *kWh*	Annual Energy Expense	Life-Cycle Costs 2%	Life-Cycle Costs 6%	Life-Cycle Costs 15%
Suppl.	**0a**	**Supplemental Level**	**8.50**	**$554**	**$0**	**$554.10**	**$0**	**677.29**	**$49.78**	**$1,099.88**	**$983.29**	**$828.13**
1	0	Baseline	8.80	$558	$0	$558.35	$0	654.42	$48.10	$1,085.71	$973.05	$823.13
2	1	0 + Add Subcooler	9.04	$562	$0	$561.89	$0	636.48	$46.78	$1,074.79	$965.22	$819.41
3,4	2	1 + Incr Compressor EER to 11.09	9.12	$569	$0	$569.09	$0	631.59	$46.42	$1,078.05	$969.33	$824.63
	3	2 + Brushless D.C. Fan Motor	9.44	$714	$0	$713.85	$0	610.04	$44.84	$1,205.44	$1,100.43	$960.67
	4	3 + **Variable Speed Compressor	10.49	$992	$0	$992.19	$0	549.04	$40.35	$1,434.62	$1,340.11	$1,214.33
5	5	4 + **Incr Evap/Cond Coil Area	11.08	$1,139	$331	$1,469.75	$0	519.39	$38.18	$1,888.29	$1,798.88	$1,679.89

Supplemental Table 4.6 (using AEO 95)

Life Cycle Costs and Payback Periods of Room Air Conditioner, 14,000 to 19,999 Btu/h, Without Reverse Cycle and With Louvered Sides

Effc'y Level	Design No.	Design Option	EER *Btu/W-hr*	Retail Price	Install. Cost	Installed Consumer Cost	Annual Maint. Cost (@6%)	Annual Elec. Use *kWh*	Annual Energy Expense	Life-Cycle Costs 2%	6%	15%
	0	Baseline	9.00	$613	$0	$612.76	$0	1062.76	$78.11	$1,469.17	$1,286.23	$1,042.75
1	1	0 + Incr Compressor EER to 10.78	9.70	$632	$0	$632.48	$0	986.80	$72.53	$1,427.68	$1,257.81	$1,031.74
Suppl.	**1a**	**Supplemental Level**	**9.70**	**$633**	**$0**	**$632.61**	**$0**	**986.29**	**$72.49**	**$1,427.40**	**$1,257.61**	**$1,031.66**
2	2	1 + Condenser Grooved Tubes	9.98	$640	$0	$639.63	$0	958.91	$70.48	$1,412.35	$1,247.28	$1,027.60
3,4	3	2 + Add Subcooler	10.15	$648	$0	$647.54	$0	942.93	$69.31	$1,407.39	$1,245.07	$1,029.05
	4	3 + Increase Evap/Cond Coil Area	10.74	$812	$0	$811.82	$0	890.62	$65.46	$1,529.51	$1,376.20	$1,172.16
	5	4 + Incr Compressor EER to 11.3	11.08	$870	$0	$870.27	$0	863.06	$63.43	$1,565.75	$1,417.18	$1,219.46
	6	5 + Incr Compressor EER to 11.4	11.18	$897	$0	$897.30	$0	856.11	$62.92	$1,587.18	$1,439.81	$1,243.68
	7	6 + Brushless D.C. Fan Motor	11.50	$1,039	$0	$1,038.75	$0	832.28	$61.17	$1,709.43	$1,566.16	$1,375.49
5	8	7 + **Variable Speed Compressor	12.77	$1,295	$0	$1,294.53	$0	749.05	$55.06	$1,898.14	$1,769.20	$1,597.59

Supplemental Table 4.7 (using AEO 95)

Life Cycle Costs and Payback Periods of Room Air Conditioner, Greater than 20,000 Btu/h, Without Reverse Cycle and With Louvered Sides

Effc'y Level	Design No.	Design Option	EER Btu/W-hr	Retail Price	Install. Cost	Installed Consumer Cost	Annual Maint. Cost (@6%)	Annual Elec. Use kWh	Annual Energy Expense	Life-Cycle Costs 2%	6%	15%
	0	Baseline	8.22	$859	$0	$859.47	$0	1572.75	$115.60	$2,126.85	$1,856.11	$1,495.80
1,2	1	0 + Incr Compressor EER to 10.89	8.38	$871	$0	$871.31	$0	1542.55	$113.38	$2,114.35	$1,848.81	$1,495.42
Suppl.	**1a**	**Supplemental Level**	**8.50**	**$880**	**$0**	**$879.78**	**$0**	**1521.68**	**$111.84**	**$2,106.00**	**$1,844.05**	**$1,495.44**
3	2	1 + Add Subcooler	8.51	$880	$0	$880.29	$0	1520.43	$111.75	$2,105.51	$1,843.77	$1,495.45
4	3	2 + Incr Compressor EER to 11.5	8.88	$960	$0	$960.00	$0	1457.38	$107.12	$2,134.41	$1,883.53	$1,549.65
	4	3 + Increase Evap/Cond Coil Area	9.42	$1,071	$0	$1,071.41	$0	1372.63	$100.89	$2,177.52	$1,941.23	$1,626.77
	5	4 + Incr Compressor EER to 11.7	9.84	$1,112	$0	$1,111.79	$0	1314.73	$96.63	$2,171.24	$1,944.92	$1,643.72
	6	5 + Brushless D.C. Fan Motor	10.03	$1,291	$0	$1,291.24	$0	1289.56	$94.78	$2,330.41	$2,108.42	$1,812.99
5	7	6 + **Variable Speed Compressor	11.14	$1,653	$0	$1,653.06	$0	1160.60	$85.30	$2,588.32	$2,388.53	$2,122.64

Supplemental Table 4.8 (using AEO 95)

Life Cycle Costs and Payback Periods of Room Air Conditioner, With Reverse Cycle and With Louvered Sides

Effc'y Level	Design No.	Design Option	EER *Btu/W-hr*	Retail Price	Install. Cost	Installed Consumer Cost	Annual Maint. Cost (@6%)	Annual Elec. Use *kWh*	Annual Energy Expense	Life-Cycle Costs 2%	6%	15%
	0	Baseline	8.92	$690	$0	$689.83	$0	750.16	$55.14	$1,294.34	$1,165.20	$993.34
Suppl.	**0a**	**Supplemental Level**	**9.00**	**$693**	**$0**	**$693.09**	**$0**	**743.49**	**$54.65**	**$1,292.22**	**$1,164.23**	**$993.90**
1,2	1	0 + Add Subcooler	9.05	$695	$0	$695.16	$0	739.30	$54.34	$1,290.92	$1,163.65	$994.28
3,4	2	1 + Incr Compressor EER to 10.82	9.27	$708	$0	$707.54	$0	721.61	$53.04	$1,289.04	$1,164.82	$999.50
	3	2 + Increase Evap/Cond Coil Area	9.83	$788	$0	$787.80	$0	680.65	$50.03	$1,336.29	$1,219.12	$1,063.19
	4	3 + Brushless D.C. Fan Motor	10.04	$952	$0	$952.26	$0	666.15	$48.96	$1,489.07	$1,374.39	$1,221.78
5	5	4 + **Variable Speed Compressor	11.16	$1,270	$0	$1,269.68	$0	599.53	$44.07	$1,752.81	$1,649.60	$1,512.25

Supplemental Table 4.9 (using AEO 95)

Life Cycle Costs and Payback Periods of Room Air Conditioner, With Reverse Cycle and Without Louvered Sides

Effc'y Level	Design No.	Design Option	EER *Btu/W-hr*	Retail Price	Install. Cost	Installed Consumer Cost	Annual Maint. Cost (@6%)	Annual Elec. Use *kWh*	Annual Energy Expense	Life-Cycle Costs 2%	Life-Cycle Costs 6%	Life-Cycle Costs 15%
Suppl.	**0a**	**Supplemental Level**	**8.50**	**$700**	**$0**	**$699.93**	**$0**	**711.64**	**$52.31**	**$1,273.40**	**$1,150.89**	**$987.86**
1,2	0	Baseline	8.72	$704	$0	$704.13	$0	693.92	$51.00	$1,263.32	$1,143.86	$984.89
3,4	1	0 + Condenser Enhanced Fins	8.86	$707	$0	$706.90	$0	682.72	$50.18	$1,257.06	$1,139.54	$983.13
	2	1 + Brushless D.C. Fan Motor	9.20	$884	$0	$883.61	$0	657.85	$48.35	$1,413.73	$1,300.49	$1,149.77
	3	2 + **Variable Speed Compressor	10.22	$1,225	$0	$1,225.04	$0	592.07	$43.52	$1,702.15	$1,600.23	$1,464.59
5	4	3 + **Incr Evap/Cond Coil Area	10.87	$1,405	$331	$1,735.77	$0	556.54	$40.91	$2,184.25	$2,088.44	$1,960.94

Supplemental Table 4.10 (using AEO 95)
Less than 6 KBtu/h, with Louvered Sides

Cost (1990 $) and Energy-Use Summary (Field Usage)

Standard Level	Design No.	Installed Consumer Cost (1990$)	Elec. use kWh/yr	Annual Operating Exepnse (1990$)	LCC @ 6% (1990$)	1999 Distribution
	0	372.03	378.51	27.82	611.89	70.9%
	1	372.64	358.31	26.34	599.70	9.6%
1	2	377.57	334.43	24.58	589.50	9.0%
Suppl.	**Suppl.**	**382.41**	**321.26**	**23.61**	**585.99**	**1.0%**
2	3	382.55	320.90	23.59	585.90	5.2%
3	4	389.51	311.69	22.91	587.02	2.7%
4	5	440.24	300.19	22.06	630.47	1.6%
	6	560.46	294.85	21.67	747.30	0.0%
5	7	796.18	265.36	19.50	964.34	0.0%

Weighted Average of Units Sold below Standards

Standard Level	1	**Suppl.**	2	3	4	5
Installed Consumer Cost (1990 $)	372.10	**372.65**	372.75	373.29	373.74	374.83
Annual Operating Cost (1990 $)	27.64	**27.34**	27.30	27.09	26.98	26.90
Life-Cycle Cost at 6% (1990 $)	610.44	**608.35**	608.11	606.89	606.34	606.74
Energy Use (kWh./a)	376.11	**371.94**	371.40	368.62	367.06	365.97

Life-Cycle Cost Difference (1990$), Payback Periods (Years), and Costs of Conserved Energy (at 6%)

Standard Level	1	**Suppl.**	2	3	4	5
LCC Difference	20.94	**22.35**	22.20	19.86	-24.12	-357.60
Payback (year)						
Field	1.8	**2.6**	2.6	3.9	13.5	57.0
Existing Test Proc.	1.3	**1.9**	1.9	2.8	9.6	40.5
CCE (cent/kWh)	1.5	**2.2**	2.2	3.3	11.5	48.6

Supplemental Table 4.11 (using AEO 95)
6 to 8 KBtu/h, with Louvered Sides

Cost (1990 $) and Energy-Use Summary (Field Usage)

Standard Level	Design No.	Installed Consumer Cost (1990$)	Annual Elec. use kWh/yr	Annual Operating Expense (1990$)	LCC @ 6% (1990$)	1999 Distribution
	0	403.82	471.06	34.62	702.33	48.5%
	1	405.25	452.75	33.28	692.15	14.8%
1	2	410.13	424.89	31.23	679.38	23.5%
2	3	416.89	412.31	30.30	678.17	9.9%
Suppl.	**Suppl.**	**418.10**	**410.69**	**30.19**	**678.35**	**1.6%**
3	4	424.73	402.03	29.55	679.50	0.5%
4	5	477.78	385.68	28.35	722.19	0.4%
	6	598.82	379.26	27.88	839.15	0.8%
5	7	830.48	341.33	25.09	1046.78	0.0%

Weighted Average of Units Sold below Standards

Standard Level	1	2	**Suppl.**	3	4	5
Installed Consumer Cost (1990 $)	404.15	405.77	**406.91**	407.09	407.18	409.11
Annual Operating Cost (1990 $)	34.31	33.47	**33.15**	33.10	33.09	33.02
Life-Cycle Cost at 6% (1990 $)	699.94	694.38	**692.72**	692.49	692.43	693.80
Energy Use (kWh./a)	466.8	455.4	**451.0**	450.4	450.1	449.3

Life-Cycle Cost Difference (1990$), Payback Periods (Years), and Costs of Conserved Energy (at 6%)

Standard Level	1	2	**Suppl.**	3	4	5
LCC Difference	20.57	16.21	**14.37**	12.99	-29.76	-352.98
Payback (year)						
Field	1.9	3.5	**3.8**	5.0	14.9	53.1
Existing Test Proc.	1.4	2.5	**2.7**	3.5	10.6	37.7
CCE (cent/kWh)	1.7	3.0	**3.2**	4.2	12.7	45.3

Supplemental Table 4.12 (using AEO 95)
6 to 8 KBtu/h, without Louvered Sides

Cost (1990 $) and Energy-Use Summary (Field Usage)

Standard Level	Design No.	Installed Consumer Cost (1990$)	Annual Elec. use kWh/yr	Annual Operating Expense (1990$)	LCC @ 6% (1990$)	1999 Distribution
	0	447.01	382.02	28.08	689.09	53.8%
Suppl.	**Suppl.**	**450.17**	**375.86**	**27.63**	**688.35**	**0.0%**
1,2	1	452.23	371.94	27.34	687.92	9.8%
3,4	2	455.96	366.62	26.95	688.28	11.1%
	3	599.35	350.65	25.77	821.56	25.2%
	4	872.95	315.59	23.20	1072.94	0.0%
5	7	1344.94	293.75	21.59	1531.09	0.0%

Weighted Average of Units Sold below Standards

Standard Level	**Suppl.**	1	2	3	4	5
Installed Consumer Cost (1990 $)	**447.01**	447.01	447.01	447.82	447.82	486.92
Annual Operating Cost (1990 $)	**28.08**	28.08	28.08	27.96	27.96	27.30
Life-Cycle Cost at 6% (1990 $)	**689.09**	689.09	689.09	688.91	688.91	722.28
Energy Use (kWh./a)	**382.02**	382.02	382.02	380.46	380.46	371.41

Life-Cycle Cost Difference (1990$), Payback Periods (Years), and Costs of Conserved Energy (at 6%)

Standard Level	**Suppl.**	1	2	3	4	5
LCC Difference	**0.74**	1.17	1.17	0.63	0.63	-808.80
Payback (year)						
Field use	**7.0**	7.0	7.0	8.0	8.0	150.3
Existing Test Proc.	**5.0**	5.0	5.0	5.7	5.7	106.7
CCE (cent/kWh)	**5.9**	6.0	6.0	6.8	6.8	128.1

Supplemental Table 4.13 (using AEO 95)
8-14 KBtu/h, with Louvered Sides

Cost (1990 $) and Energy-Use Summary (Field Usage)

Standard Level	Design No.	Installed Consumer Cost (1990$)	Annual Elec. use kWh/yr	Annual Operating Expense (1990$)	LCC @ 6% (1990$)	1999 Distribution
	0	495.06	694.12	51.02	934.92	52.0%
1	1	505.83	666.46	48.98	928.16	14.5%
Suppl.	**Suppl.**	**508.41**	**660.34**	**48.53**	**926.86**	**6.2%**
2	2	509.76	657.19	48.30	926.21	7.9%
3	3	518.17	640.03	47.04	923.75	12.6%
4	4	576.63	590.02	43.37	950.52	4.4%
	5	697.06	580.28	42.65	1064.78	0.5%
5	6	929.44	522.25	38.39	1260.39	1.9%

Weighted Average of Units Sold below Standards

Standard Level	1	**Suppl.**	2	3	4	5
Installed Consumer Cost (1990 $)	495.06	**497.40**	498.34	499.47	501.99	506.36
Annual Operating Cost (1990 $)	51.02	**50.58**	50.40	50.20	49.77	49.44
Life-Cycle Cost at 6% (1990 $)	934.92	**933.45**	932.89	932.23	931.09	932.65
Energy Use (kWh./a)	694.12	**688.10**	685.73	682.93	677.15	672.71

Life-Cycle Cost Difference (1990$), Payback Periods (Years), and Costs of Conserved Energy (at 6%)

Standard Level	1	**Suppl.**	2	3	4	5
LCC Difference	6.76	**6.59**	6.67	8.48	-19.43	-327.74
Payback (year)						
Field	5.3	**5.4**	5.4	5.9	11.7	38.3
Existing Test Proc.	3.8	**3.8**	3.9	4.2	8.3	27.2
CCE (cent/kWh)	4.5	**4.6**	4.6	5.1	9.9	32.6

Supplemental Table 4.14 (using AEO 95)
8 to 14 KBtu/h, without Louvered Sides

Cost (1990 $) and Energy-Use Summary (Field Usage)

Standard Level	Design No.	Installed Consumer Cost (1990$)	Annual Elec. use kWh/yr	Annual Operating Expense (1990$)	LCC @ 6% (1990$)	1999 Distribution
Suppl.	**Suppl.**	**554.10**	**677.29**	**49.78**	**983.29**	**8.9%**
1	0	558.35	654.42	48.10	973.05	51.8%
2	1	561.89	636.48	46.78	965.22	9.7%
3,4	2	569.09	631.59	46.42	969.33	12.2%
	3	713.85	610.04	44.84	1100.43	17.1%
	4	992.19	549.04	40.35	1340.11	0.2%
5	7	1469.75	519.39	38.18	1798.88	0.0%

Weighted Average of Units Sold below Standards

Standard Level	**Suppl.**	1	2	3	4	5
Installed Consumer Cost (1990 $)	**N/A**	554.10	557.73	558.30	558.30	587.23
Annual Operating Cost (1990 $)	**N/A**	49.78	48.35	48.13	48.13	47.34
Life-Cycle Cost at 6% (1990 $)	**N/A**	983.29	974.56	973.27	973.27	995.39
Energy Use (kWh./a)	**N/A**	677.29	657.78	654.84	654.84	644.09

Life-Cycle Cost Difference (1990$), Payback Periods (Years), and Costs of Conserved Energy (at 6%)

Standard Level	**Suppl.**	1	2	3	4	5
LCC Difference	**N/A**	10.24	9.33	3.94	3.94	-803.49
Payback (year)						
Field use	**N/A**	2.5	2.7	6.3	6.3	96.3
Existing Test Proc.	**N/A**	1.8	1.9	4.5	4.5	68.4
CCE (cent/kWh)	**N/A**	2.2	2.3	5.4	5.4	82.1

Supplemental Table 4.15 (using AEO 95)
Room Air Conditioner, 14 to 20 KBtu/h, with Louvered Sides

Cost (1990 $) and Energy-Use Summary (Field Usage)

Standard Level	Design No.	Installed Consumer Cost (1990$)	Annual Elec. use kWh/yr	Annual Operating Expense (1990$)	LCC @ 6% (1990$)	1999 Distribution
	0	612.76	1062.76	78.11	1286.23	60.2%
1	1	632.48	986.80	72.53	1257.81	15.8%
Suppl.	**Suppl.**	**632.61**	**986.29**	**72.49**	**1257.61**	**0.5%**
2	2	639.63	958.91	70.48	1247.28	8.8%
3,4	3	647.54	942.93	69.31	1245.07	12.5%
	4	811.82	890.62	65.46	1376.20	2.3%
	5	870.27	863.06	63.43	1417.18	0.0%
	6	897.30	856.11	62.92	1439.81	0.0%
	7	1038.75	832.28	61.17	1566.16	0.0%
5	8	1294.53	749.05	55.05	1769.20	0.0%

Weighted Average of Units Sold below Standards

Standard Level	1	**Suppl.**	2	3	4	5
Installed Consumer Cost (1990 $)	612.76	**616.86**	616.96	619.30	619.30	627.17
Annual Operating Cost (1990 $)	78.11	**76.95**	76.92	76.26	76.26	75.15
Life-Cycle Cost at 6% (1990 $)	1286.23	**1280.32**	1280.18	1276.78	1276.78	1275.08
Energy Use (kWh./a)	1062.76	**1046.96**	1046.60	1037.54	1037.54	1022.43

Life-Cycle Cost Difference (1990$), Payback Periods (Years), and Costs of Conserved Energy (at 6%)

Standard Level	1	**Suppl.**	2	3	4	5
LCC Difference	28.42	**22.70**	32.90	31.71	31.71	-494.12
Payback (year)						
Field use	3.5	**3.5**	3.5	4.1	4.1	33.2
Existing Test Proc.	2.5	**2.5**	2.5	2.9	2.9	23.6
CCE (cent/kWh)	3.0	**3.0**	3.0	3.5	3.5	28.3

Supplemental Table 4.16 (using AEO 95)
>20 KBtu/h, with Louvered Sides

Cost (1990 $) and Energy-Use Summary (Field Usage)

Standard Level	Design No.	Installed Consumer Cost (1990$)	Annual Elec. use kWh/yr	Annual Operating Expense (1990$)	LCC @ 6% (1990$)	1999 Distribution
	0	859.47	1572.75	115.60	1856.11	55.5%
1,2	1	871.31	1542.55	113.38	1848.81	4.2%
Suppl.	**Suppl.**	**879.78**	**1521.68**	**111.84**	**1844.05**	**10.7%**
3	2	880.29	1520.43	111.75	1843.77	7.9%
4	3	960.00	1457.38	107.12	1883.53	18.4%
	4	1071.41	1372.63	100.89	1941.23	1.1%
	5	1111.79	1314.73	96.63	1944.92	2.2%
	6	1291.24	1289.56	94.78	2108.42	0.0%
5	7	1653.06	1160.60	85.30	2388.53	0.0%

Weighted Average of Units Sold below Standards

Standard Level	1	2	**Suppl.**	3	4	5
Installed Consumer Cost (1990 $)	859.47	859.47	**860.30**	863.27	864.98	890.18
Annual Operating Cost (1990 $)	115.60	115.60	**115.44**	114.89	114.58	112.66
Life-Cycle Cost at 6% (1990 $)	1856.11	1856.11	**1855.60**	1853.84	1852.83	1861.48
Energy Use (kWh./a)	1572.75	1572.75	**1570.63**	1563.16	1558.87	1532.75

Life-Cycle Cost Difference (1990$), Payback Periods (Years), and Costs of Conserved Energy (at 6%)

Standard Level	1	2	**Suppl.**	3	4	5
LCC Difference	7.30	7.30	**11.54**	10.06	-30.71	-527.05
Payback (year)						
Field use	5.3	5.3	**5.4**	5.4	12.7	27.9
Existing Test Proc.	3.8	3.8	**3.8**	3.8	9.0	19.8
CCE (cent/kWh)	4.5	4.5	**4.6**	4.6	10.9	23.8

Supplemental Table 4.17 (using AEO 95)
With Reverse Cycle with louvered sides

Cost (1990 $) and Energy-Use Summary (Field Usage)

Standard Level	Design No.	Installed Consumer Cost (1990$)	Annual Elec. use kWh/yr	Annual Operating Expense (1990$)	LCC @ 6% (1990$)	1999 Distribution
	0	689.83	750.16	55.14	1165.20	68.4%
Suppl.	**Suppl.**	**693.09**	**743.49**	**54.65**	**1164.23**	**1.7%**
1,2	1	695.16	739.30	54.34	1163.65	1.6%
3,4	2	707.54	721.61	53.04	1164.82	3.1%
	3	787.80	680.65	50.03	1219.12	23.1%
	4	952.26	666.15	48.96	1374.39	2.0%
5	7	1269.68	599.53	44.07	1649.60	0.0%

Weighted Average of Units Sold below Standards

Standard Level	**Suppl.**	1	2	3	4	5
Installed Consumer Cost (1990 $)	**689.83**	689.91	689.91	690.03	690.03	718.46
Annual Operating Cost (1990 $)	**55.14**	55.13	55.13	55.11	55.11	53.74
Life-Cycle Cost at 6% (1990 $)	**1165.20**	1165.18	1165.18	1165.15	1165.15	1181.83
Energy Use (kWh./a)	**750.16**	750.00	750.00	749.76	749.76	731.21

Life-Cycle Cost Difference (1990$), Payback Periods (Years), and Costs of Conserved Energy (at 6%)

Standard Level	**Suppl.**	1	2	3	4	5
LCC Difference	**0.97**	1.53	1.53	0.33	0.33	-467.77
Payback (year)						
Field use	**6.6**	6.7	6.7	8.5	8.5	57.0
Existing Test Proc.	**4.7**	4.7	4.7	6.0	6.0	40.4
CCE (cent/kWh)	**5.7**	5.7	5.7	7.2	7.2	48.6

Supplemental Table 4.18 (using AEO 95)
With Reverse Cycle without louvered sides

Cost (1990 $) and Energy-Use Summary (Field Usage)

Standard Level	Design No.	Installed Consumer Cost (1990$)	Annual Elec. use kWh/yr	Annual Operating Expense (1990$)	LCC @ 6% (1990$)	1999 Distribution
Suppl.	**Suppl.**	**699.93**	**711.64**	**52.31**	**1150.89**	**27.4%**
1,2	0	704.13	693.92	51.00	1143.86	32.6%
3,4	1	706.90	682.72	50.18	1139.54	19.2%
	2	883.61	657.85	48.35	1300.49	20.8%
	3	1225.04	592.07	43.52	1600.23	0.0%
5	4	1735.77	556.54	40.91	2088.44	0.0%

Weighted Average of Units Sold below Standards

Standard Level	**Suppl.**	1	2	3	4	5
Installed Consumer Cost (1990 $)	**N/A**	699.93	699.93	702.21	702.21	740.79
Annual Operating Cost (1990 $)	**N/A**	52.31	52.31	51.60	51.60	50.65
Life-Cycle Cost at 6% (1990 $)	**N/A**	1150.89	1150.89	1147.08	1147.08	1177.49
Energy Use (kWh./a)	**N/A**	711.64	711.64	702.02	702.02	689.14

Life-Cycle Cost Difference (1990$), Payback Periods (Years), and Costs of Conserved Energy (at 6%)

Standard Level	**Suppl.**	1	2	3	4	5
LCC Difference	**N/A**	7.03	7.03	7.54	7.54	-910.95
Payback (year)						
Field use	**N/A**	N/A	N/A	3.3	3.3	102.1
Existing Test Proc.	**N/A**	N/A	N/A	2.3	2.3	72.5
CCE (cent/kWh)	**N/A**	N/A	N/A	2.8	2.8	87.0

SUPPLEMENTAL TABLE 7.6
ELECTRICITY POLLUTANT REDUCTIONS BASED ON AEO 1995 FUEL PRICE PROJECTIONS

SO2 Emissions

Year	Abated from Power Plant kt	Abated from Power Plant short tons 000's	Abated from in House kt	Abated from in House short tons 000's	Total Reduction in Emissions kt	Total Reduction in Emissions short tons 000's	Reduction as % of Total Residential Emissions
2000	1.14	1.26	0.00	0.00	1.14	1.26	0.03
2005	2.68	2.95	0.00	0.00	2.68	2.95	0.09
2010	3.57	3.94	0.00	0.00	3.57	3.94	0.13
2015	3.04	3.35	0.00	0.00	3.04	3.35	0.13
2020	2.57	2.83	0.00	0.00	2.57	2.83	0.13
2025	1.97	2.17	0.00	0.00	1.97	2.17	0.12
2030	1.65	1.81	0.13	0.15	1.78	1.96	0.13

Cumulative SO2 reduction, 79 kt = 87,000 short tons

NOx Emissions

Year	Abated from Power Plant kt	Abated from Power Plant short tons 000's	Abated from in House kt	Abated from in House short tons 000's	Total Reduction in Emissions kt	Total Reduction in Emissions short tons 000's	Reduction as % of Total Residential Emissions
2000	0.85	0.94	0.05	0.05	0.89	0.99	0.03
2005	2.15	2.37	0.00	0.00	2.15	2.37	0.08
2010	3.10	3.42	0.00	0.00	3.10	3.42	0.12
2015	2.81	3.10	0.00	0.00	2.81	3.10	0.12
2020	2.57	2.83	0.00	0.00	2.57	2.83	0.11
2025	2.16	2.38	0.00	0.00	2.16	2.38	0.11
2030	2.02	2.23	0.10	0.11	2.12	2.34	0.11

Cumulative Nox redution, 74 kt = 82,000 short tons

CO2 Emissions

Year	Abated from Power Plant Mt	Abated from Power Plant short tons 000's	Abated from in House Mt	Abated from in House short tons 000's	Total Reduction in Emissions Mt	Total Reduction in Emissions short tons 000's	Reduction as % of Total Residential Emissions
2000	0.32	0.35	0.05	0.05	0.37	0.40	0.03
2005	0.88	0.97	0.00	0.00	0.88	0.97	0.07
2010	1.37	1.51	0.00	0.00	1.37	1.51	0.10
2015	1.44	1.59	0.00	0.00	1.44	1.59	0.10
2020	1.52	1.67	0.00	0.00	1.52	1.67	0.10
2025	1.50	1.66	0.00	0.00	1.50	1.66	0.10
2030	1.65	1.82	0.12	0.13	1.77	1.95	0.11

Cumulative CO2 reduction, 41 Mt = 45,000,000 short tons

SUPPLEMENTAL TABLE 7.7
ELECTRICITY POLLUTANT REDUCTIONS BASED ON AEO 1997 FUEL PRICE PROJECTIONS

SO2 Emissions

Year	Abated from Power Plant		Abated from in House		Total Reduction in Emissions		Reduction as % of Total
	kt	short tons 000's	kt	short tons 000's	kt	short tons 000's	Residential Emissions
2000	0.57	0.63	0.00	0.00	0.57	0.63	0.02
2005	2.68	2.95	0.00	0.00	2.68	2.95	0.08
2010	4.20	4.63	0.13	0.15	4.34	4.78	0.14
2015	4.22	4.65	0.00	0.00	4.22	4.65	0.16
2020	3.65	4.02	0.00	0.00	3.65	4.02	0.17
2025	2.91	3.20	0.13	0.15	3.04	3.35	0.17
2030	2.43	2.68	0.00	0.00	2.43	2.68	0.17

Cumulative SO2 reduction, 100 kt = 110,000 short tons

NOx Emissions

Year	Abated from Power Plant		Abated from in House		Total Reduction in Emissions		Reduction as % of Total
	kt	short tons 000's	kt	short tons 000's	kt	short tons 000's	Residential Emissions
2000	0.42	0.47	0.00	0.00	0.42	0.47	0.01
2005	2.15	2.37	0.00	0.00	2.15	2.37	0.08
2010	3.65	4.03	0.10	0.11	3.75	4.14	0.13
2015	3.91	4.31	0.00	0.00	3.91	4.31	0.15
2020	3.65	4.02	0.05	0.05	3.69	4.07	0.15
2025	3.18	3.51	0.10	0.11	3.28	3.62	0.15
2030	2.99	3.29	0.05	0.05	3.03	3.34	0.15

Cumulative Nox redution, 95 kt = 105,000 short tons

CO2 Emissions

Year	Abated from Power Plant		Abated from in House		Total Reduction in Emissions		Reduction as % of Total
	Mt	short tons 000's	Mt	short tons 000's	Mt	short tons 000's	Residential Emissions
2000	0.16	0.18	0.00	0.00	0.16	0.18	0.01
2005	0.88	0.97	0.00	0.00	0.88	0.97	0.06
2010	1.61	1.78	0.12	0.13	1.73	1.91	0.12
2015	2.01	2.21	0.00	0.00	2.01	2.21	0.13
2020	2.16	2.38	0.05	0.05	2.21	2.43	0.14
2025	2.22	2.44	0.12	0.13	2.34	2.57	0.14
2030	2.43	2.68	0.05	0.05	2.48	2.73	0.14

Cumulative CO2 reduction, 54 Mt = 59,000,000 short ton

BASED ON 1996 GRI FUEL PRICE PROJECTIONS

Table 3.2 Unit Energy Consumption for New Room Air Conditioners (weighted average kWh/yr)

Year	Base	Final
1981	920	920
1990	727	727
1996	668	668
2000	666	626
2015	664	624
2030	667	627

Table 3.3a U.S. Electricity Consumption for New Room Air Conditioners (quadrillion Btu, primary)

Year	Base	Final	
1981	0.452	0.452	
1990	0.387	0.387	
1996	0.389	0.389	
2000	0.410	0.407	
2015	0.544	0.516	
2030	0.660	0.625	
1999-2030	17.180	16.423	Saving 0.757

Table 3.3d U.S. Electricity Consumption for Residential Air Conditioning (quadrillion Btu, primary)

Year	Base	Final	
1981	1.147	1.147	
1990	1.553	1.553	
1996	1.721	1.721	
2000	1.827	1.824	
2015	2.423	2.397	
2030	2.947	2.915	
1999-2030	76.320	75.625	Saving 0.695

Table 3.5 Average Purchase Price for New Room Air Conditioners (1990 dollars per unit)

Year	Base	Final
1981	490	490
1990	495	495
1996	507	507
2000	507	516
2015	507	516
2030	507	516

BASED ON HIGH EFFICIENCY TREND (Room A/C EER improving at 2% per year from year 2000) AND 1997 AEO FUEL PRICE PROJECTIONS

Table 3.2 Unit Energy Consumption for New Room Air Conditioners (weighted average kWh/yr)

Year	Base	Final
1981	920	920
1990	726	726
1996	667	667
2000	655	621
2015	501	501
2030	504	504

Table 3.3a U.S. Electricity Consumption for New Room Air Conditioners (quadrillion Btu, primary)

Year	Base	Final	
1981	0.452	0.452	
1990	0.376	0.376	
1996	0.379	0.379	
2000	0.396	0.394	
2015	0.398	0.397	
2030	0.422	0.422	
1999-2030	12.988	12.920	Saving 0.068

Table 3.3d U.S. Electricity Consumption for Residential Air Conditioning (quadrillion Btu, primary)

Year	Base	Final	
1981	1.146	1.146	
1990	1.512	1.512	
1996	1.677	1.677	
2000	1.772	1.770	
2015	2.270	2.269	
2030	2.800	2.800	
1999-2030	72.262	72.202	Saving 0.060

Table 3.5 Average Purchase Price for New Room Air Conditioners (1990 dollars per unit)

Year	Base	Final
1981	490	490
1990	495	495
1996	507	507
2000	515	522
2015	1000	1000
2030	1003	1003

BASED ON HIGH EQUIPMENT PRICES & 1997 AEO FUEL PRICE PROJECTIONS

Table 3.2 Unit Energy Consumption for New Room Air Conditioners
(weighted average kWh/yr)

Year	Base	Final
1981	920	920
1990	726	726
1996	667	667
2000	665	625
2015	662	622
2030	666	626

Table 3.3a U.S. Electricity Consumption for New Room Air Conditioners (quadrillion Btu, primary)

Year	Base	Final	
1981	0.452	0.452	
1990	0.376	0.376	
1996	0.379	0.379	
2000	0.396	0.394	
2015	0.516	0.489	
2030	0.637	0.603	
1999-2030	16.400	15.685	Saving 0.715

Table 3.3d U.S. Electricity Consumption for Residential Air Conditioning (quadrillion Btu, primary)

Year	Base	Final	
1981	1.146	1.146	
1990	1.512	1.512	
1996	1.677	1.677	
2000	1.772	1.770	
2015	2.310	2.286	
2030	2.850	2.820	
1999-2030	73.221	72.580	Saving 0.641

Table 3.5 Average Purchase Price for New Room Air Conditioners
(1990 dollars per unit)

Year	Base	Final
1981	530	530
1990	535	535
1996	550	550
2000	550	559
2015	550	559
2030	550	559

BASED ON LOW EQUIPMENT PRICES AND 1997 AEO FUEL PRICE PROJECTIONS

Table 3.2 Unit Energy Consumption for New Room Air Conditioners (weighted average kWh/yr)

Year	Base	Final
1981	920	920
1990	726	726
1996	655	655
2000	652	620
2015	649	617
2030	654	621

Table 3.3a U.S. Electricity Consumption for New Room Air Conditioners (quadrillion Btu, primary)

Year	Base	Final	
1981	0.452	0.452	
1990	0.376	0.376	
1996	0.377	0.377	
2000	0.393	0.391	
2015	0.507	0.486	
2030	0.626	0.600	
1999-2030	16.145	15.573	Saving 0.572

Table 3.3d U.S. Electricity Consumption for Residential Air Conditioning (quadrillion Btu, primary)

Year	Base	Final	
1981	1.146	1.146	
1990	1.512	1.512	
1996	1.675	1.675	
2000	1.769	1.767	
2015	2.303	2.283	
2030	2.841	2.817	
1999-2030	73.003	72.483	Saving 0.520

Table 3.5 Average Purchase Price for New Room Air Conditioners (1990 dollars per unit)

Year	Base	Final
1981	451	451
1990	454	454
1996	474	474
2000	474	481
2015	474	481
2030	474	481

Supplemental Table 3.3 Room Air Conditioner Energy Consumption as a Percent of Total Consumption

Year	Fuel Price Projection	Total RAC Residentail Electricity Consumption (Quads)	Total Residential Electricity Consumption (Quads)	RAC Percent of Total Electricity Consumption
1995	AEO 1995	0.368	10.884	3.38%
1996	AEO 1996	0.367	10.880	3.37%
1997	AEO 1997	0.379	11.081	3.42%

Updated Table 3.6b Net Present Value to Consumers for Room A/C purchased from 1999 to 2030 based on *1996* GRI fuel price projections (billion 1990$ discounted to 1990 at 7%)

Fuel Savings	0.68
Equipment Cost	0.29
Net Present Value	0.38

Modified Table 3.6b Net Present Value to Consumers for Room A/C purchased from 1999 to 2030 based on Low Equipment Price and *1997* AEO fuel price projections (billion 1990$ discounted to 1990 at 7%)

Fuel Savings	0.60
Equipment Cost	0.21
Net Present Value	0.39

Modified Table 3.6b Net Present Value to Consumers for Room A/C purchased from 2000 to 2030 based on High Equipment Price and *1997* AEO fuel price projections (billion 1990$ discounted to 1990 at 7%)

Fuel Savings	0.74
Equipment Cost	0.31
Net Present Value	0.43

Modified Table 3.6b Net Present Value to Consumers for Room A/C purchased from 2000 to 2030 based on High Efficiency Trend and *1997* AEO fuel price projections (billion 1990$ discounted to 1990 at 7%)

Fuel Savings	0.13
Equipment Cost	0.05
Net Present Value	0.08

Life Cycle Cost and Payback calculations using GRI 96 Energy Price Projections[1]

Life Cycle Costs and Payback Periods of Room Air Conditioner, Less than 6000 Btu/h, Without Reverse Cycle and With Louvered Sides

Efficiency Level	Design No.	Design Option	EER *Btu/W-hr*	Retail Price	Installation Cost	Installed Consumer Cost	Annual Maintenance Cost (@6%)	Annual Elec. Use *kWh*	Annual Energy Expense	Life-Cycle Costs		
										2%	6%	15%
	0	Baseline	8.23	$372	$0	$372.03	$0	378.51	$25.55	$652.15	$592.31	$512.67
	1	0 + Evap/Cond Enhanced Fins	8.70	$373	$0	$372.64	$0	358.31	$24.19	$637.81	$581.16	$505.78
1	2	1 + PSC Fan Motor	9.32	$378	$0	$377.57	$0	334.43	$22.57	$625.07	$572.20	$501.83
Suppl.	**Suppl.**	**Supplemental Level**	**9.70**	**$382**	**$0**	**$382.41**	**$0**	**321.26**	**$21.69**	**$620.16**	**$569.37**	**$501.78**
2	3	2 + Evap/Cond Grooved Tubes	9.71	$383	$0	$382.55	$0	320.90	$21.66	$620.03	$569.30	$501.79
3	4	3 + Add Subcooler	10.00	$390	$0	$389.51	$0	311.69	$21.04	$620.18	$570.90	$505.32
4	5	4 + Increase Evap/Cond Coil Area	10.38	$440	$0	$440.24	$0	300.19	$20.26	$662.39	$614.94	$551.78
	6	5 + Brushless D.C. Fan Motor	10.57	$560	$0	$560.46	$0	294.85	$19.90	$778.66	$732.05	$670.02
5	7	6 + **Variable Speed Compressor	11.74	$796	$0	$796.18	$0	265.36	$17.91	$992.56	$950.61	$894.78

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[1] Holtberg, P.D., T.J. Woods, M.L. Lihn, and Nice, 1996. Baseline Projection Data Book: 1996 Edition of the GRI Baseline Projection of U.S. Energy Supply and Demand to 2015. Gas Research Institute, Baseline/Gas Resource Analytical Center. Washington, DC.

Life Cycle Costs and Payback Periods of Room Air Conditioner, 6000 to 7999 Btu/h, Without Reverse Cycle and With Louvered Sides

Efficiency Level	Design No.	Design Option	EER *Btu/W-hr*	Retail Price	Installation Cost	Installed Consumer Cost	Annual Maintenance Cost (@6%)	Annual Elec. Use *kWh*	Annual Energy Expense	Life-Cycle Costs		
										2%	6%	15%
	0	Baseline	8.46	$404	$0	$403.82	$0	471.06	$31.80	$752.43	$677.96	$578.85
	1	0 + Evap/Cond Enhanced Fins	8.80	$405	$0	$405.25	$0	452.75	$30.56	$740.31	$668.73	$573.48
1	2	1 + PSC Fan Motor	9.38	$410	$0	$410.13	$0	424.89	$28.68	$724.57	$657.40	$568.00
2	3	2 + Add Subcooler	9.66	$417	$0	$416.89	$0	412.31	$27.83	$722.02	$656.84	$570.09
Suppl.	**Suppl.**	**Supplemental Level**	**9.70**	**$418**	**$0**	**$418.10**	**$0**	**410.69**	**$27.72**	**$722.03**	**$657.11**	**$570.70**
3	4	3 + Evap/Cond Grooved Tubes	9.91	$425	$0	$424.73	$0	402.03	$27.14	$722.26	$658.70	$574.11
4	5	4 + Increase Evap/Cond Coil Area	10.33	$478	$0	$477.78	$0	385.68	$26.03	$763.21	$702.23	$621.09
	6	5 + Brushless D.C. Fan Motor	10.50	$599	$0	$598.82	$0	379.26	$25.60	$879.49	$819.53	$739.74
5	7	6 + **Variable Speed Compressor	11.67	$830	$0	$830.48	$0	341.33	$23.04	$1,083.09	$1,029.12	$957.31

Life Cycle Costs and Payback Periods of Room Air Conditioner, 8000 to 13,999 Btu/h, Without Reverse Cycle and With Louvered Sides

Efficiency Level	Design No.	Design Option	EER *Btu/W-hr*	Retail Price	Installation Cost	Installed Consumer Cost	Annual Maintenance Cost (@6%)	Annual Elec. Use *kWh*	Annual Energy Expense	Life-Cycle Costs		
										2%	6%	15%
	0	Baseline	9.32	$495	$0	$495.06	$0	694.12	$46.85	$1,008.75	$899.01	$752.97
1	1	0 + Incr Compressor EER to 10.82	9.71	$506	$0	$505.83	$0	666.46	$44.99	$999.05	$893.68	$753.47
Suppl.	**Suppl.**	**Supplemental Level**	**9.80**	**$508**	**$0**	**$508.41**	**$0**	**660.34**	**$44.57**	**$997.10**	**$892.71**	**$753.77**
2	2	1 + Add Subcooler	9.85	$510	$0	$509.76	$0	657.19	$44.36	$996.11	$892.22	$753.95
3	3	2 + Evap/Cond Grooved Tubes	10.11	$518	$0	$518.17	$0	640.03	$43.20	$991.82	$890.64	$755.98
4	4	3 + Increase Evap/Cond Coil Area	10.97	$577	$0	$576.63	$0	590.02	$39.83	$1,013.28	$920.00	$795.86
	5	4 + Brushless D.C. Fan Motor	11.15	$697	$0	$697.06	$0	580.28	$39.17	$1,126.50	$1,034.76	$912.67
5	6	5 + **Variable Speed Compressor	12.39	$929	$0	$929.44	$0	522.25	$35.25	$1,315.94	$1,233.37	$1,123.49

Life Cycle Costs and Payback Periods of Room Air Conditioner, 14,000 to 19,999 Btu/h, Without Reverse Cycle and With Louvered Sides

Efficiency Level	Design No.	Design Option	EER	Retail Price	Installation Cost	Installed Consumer Cost	Annual Maintenance Cost	Annual Elec. Use	Annual Energy Expense	Life-Cycle Costs		
			Btu/W-hr				(@6%)	*kWh*		2%	6%	15%
	0	Baseline	9.00	$613	$0	$612.76	$0	1062.76	$71.74	$1,399.26	$1,231.25	$1,007.65
1	1	0 + Incr Compressor EER to 10.78	9.70	$632	$0	$632.48	$0	986.80	$66.61	$1,362.76	$1,206.76	$999.14
Suopl.	**Suppl.**	**Supplemental Level**	**9.70**	**$633**	**$0**	**$632.61**	**$0**	**986.29**	**$66.57**	**$1,362.51**	**$1,206.59**	**$999.08**
2	2	1 + Condenser Grooved Tubes	9.98	$640	$0	$639.63	$0	958.91	$64.73	$1,349.27	$1,197.68	$995.93
3,4	3	2 + Add Subcooler	10.15	$648	$0	$647.54	$0	942.93	$63.65	$1,345.36	$1,196.29	$997.90
	4	3 + Increase Evap/Cond Coil Area	10.74	$812	$0	$811.82	$0	890.62	$60.12	$1,470.92	$1,330.13	$1,142.75
	5	4 + Incr Compressor EER to 11.3	11.09	$870	$0	$870.27	$0	863.06	$58.26	$1,508.98	$1,372.54	$1,190.96
	6	5 + Incr Compressor EER to 11.4	11.18	$897	$0	$897.30	$0	856.11	$57.79	$1,530.87	$1,395.52	$1,215.40
	7	6 + Brushless D.C. Fan Motor	11.50	$1,039	$0	$1,038.75	$0	832.28	$56.18	$1,654.68	$1,523.10	$1,348.00
5	8	7 + **Variable Speed Compressor	12.77	$1,295	$0	$1,294.53	$0	749.05	$50.56	$1,848.87	$1,730.45	$1,572.85

Life Cycle Costs and Payback Periods of Room Air Conditioner, Greater than 20,000 Btu/h, Without Reverse Cycle and With Louvered Sides

Efficiency Level	Design No.	Design Option	EER	Retail Price	Installation Cost	Installed Consumer Cost	Annual Maintenance Cost	Annual Elec. Use	Annual Energy Expense	Life-Cycle Costs		
			Btu/W-hr				(@6%)	*kWh*		2%	6%	15%
	0	Baseline	8.22	$859	$0	$859.47	$0	1572.75	$106.16	$2,023.39	$1,774.75	$1,443.85
1,2	1	0 + Incr Compressor EER to 10.89	8.39	$871	$0	$871.31	$0	1542.55	$104.12	$2,012.88	$1,769.02	$1,444.47
Suppl.	**Suppl.**	**Supplemental Level**	**8.50**	**$880**	**$0**	**$879.78**	**$0**	**1521.68**	**$102.71**	**$2,005.90**	**$1,765.34**	**$1,445.18**
3	2	1 + Add Subcooler	8.51	$880	$0	$880.29	$0	1520.43	$102.63	$2,005.49	$1,765.12	$1,445.23
4	3	2 + Incr Compressor EER to 11.5	8.88	$960	$0	$960.00	$0	1457.38	$98.37	$2,038.54	$1,808.14	$1,501.52
	4	3 + Increase Evap/Cond Coil Area	9.42	$1,071	$0	$1,071.41	$0	1372.63	$92.65	$2,087.23	$1,870.23	$1,581.44
	5	4 + Incr Compressor EER to 11.7	9.84	$1,112	$0	$1,111.79	$0	1314.73	$88.74	$2,084.76	$1,876.91	$1,600.30
	6	5 + Brushless D.C. Fan Motor	10.03	$1,291	$0	$1,291.24	$0	1289.56	$87.05	$2,245.58	$2,041.72	$1,770.40
5	7	6 + **Variable Speed Compressor	11.14	$1,653	$0	$1,653.06	$0	1160.60	$78.34	$2,511.97	$2,328.49	$2,084.30

Life Cycle Costs and Payback Periods of Room Air Conditioner, 6000 to 7999 Btu/h, Without Reverse Cycle and Without Louvered Sides

Eficiency Level	Design No.	Design Option	EER *Btu/W-hr*	Retail Price	Installation Cost	Installed Consumer Cost	Annual Maintenance Cost (@6%)	Annual Elec. Use *kWh*	Annual Energy Expense	Life-Cycle Costs 2%	6%	15%
	0	Baseline	8.86	$447	$0	$447.01	$0	382.02	$25.79	$729.72	$669.33	$588.96
Suppl.	**Suppl.**	**Supplemental Level**	**9.00**	**$450**	**$0**	**$450.17**	**$0**	**375.86**	**$25.37**	**$728.32**	**$668.90**	**$589.82**
1,2	1	0 + Incr Compressor EER to 10.76	9.10	$452	$0	$452.23	$0	371.94	$25.11	$727.48	$668.68	$590.43
3,4	2	1 + Add Subcooler	9.23	$456	$0	$455.96	$0	366.62	$24.75	$727.28	$669.32	$592.18
	3	2 + Brushless D.C. Fan Motor	9.65	$599	$0	$599.35	$0	350.65	$23.67	$858.85	$803.42	$729.64
	4	3 + **Variable Speed Compressor	10.72	$873	$0	$872.95	$0	315.59	$21.30	$1,106.50	$1,056.61	$990.21
5	5	4 + **Increase Evap/Cond Coil Area	11.52	$1,014	$331	$1,344.94	$0	293.75	$19.83	$1,562.33	$1,515.89	$1,454.09

Life Cycle Costs and Payback Periods of Room Air Conditioner, 8000 to 13,999 Btu/h, Without Reverse Cycle and Without Louvered Sides

Efficiency Level	Design No.	Design Option	EER *Btu/W-hr*	Retail Price	Installation Cost	Installed Consumer Cost	Annual Maintenance Cost (@6%)	Annual Elec. Use *kWh*	Annual Energy Expense	Life-Cycle Costs 2%	6%	15%
Suppl.	**Suppl.**	**Supplemental level**	**8.50**	**$554**	**$0**	**$554.10**	**$0**	**677.29**	**$45.72**	**$1,055.33**	**$948.25**	**$805.76**
1	0	Baseline	8.80	$558	$0	$558.35	$0	654.42	$44.17	$1,042.66	$939.20	$801.51
2	1	0 + Add Subcooler	9.05	$562	$0	$561.89	$0	636.48	$42.96	$1,032.92	$932.30	$798.39
3,4	2	1 + Incr Compressor EER to 11.09	9.12	$569	$0	$569.09	$0	631.59	$42.63	$1,036.50	$936.65	$803.77
	3	2 + Brushless D.C. Fan Motor	9.44	$714	$0	$713.85	$0	610.04	$41.18	$1,165.31	$1,068.87	$940.52
	4	3 + **Variable Speed Compressor	10.49	$992	$0	$992.19	$0	549.04	$37.06	$1,398.51	$1,311.71	$1,196.20
5	5	4 + **Increase Evap/Cond Coil Area	11.08	$1,139	$331	$1,469.75	$0	519.39	$35.06	$1,854.13	$1,772.01	$1,662.74

Life Cycle Costs and Payback Periods of Room Air Conditioner, With Reverse Cycle and With Louvered Sides

Efficiency Level	Design No.	Design Option	EER *Btu/W-hr*	Retail Price	Installation Cost	Installed Consumer Cost	Annual Maintenance Cost (@6%)	Annual Elec. Use *kWh*	Annual Energy Expense	Life-Cycle Costs 2%	Life-Cycle Costs 6%	Life-Cycle Costs 15%
	0	Baseline	8.92	$690	$0	$689.83	$0	750.16	$50.64	$1,244.99	$1,126.40	$968.57
Suppl.	**Suppl.**	**Supplemental level**	**9.00**	**$693**	**$0**	**$693.09**	**$0**	**743.49**	**$50.19**	**$1,243.31**	**$1,125.77**	**$969.35**
1,2	1	0 + Add Subcooler	9.05	$695	$0	$695.16	$0	739.30	$49.90	$1,242.29	$1,125.41	$969.86
3,4	2	1 + Incr Compressor EER to 10.82	9.27	$708	$0	$707.54	$0	721.61	$48.71	$1,241.57	$1,127.49	$975.67
	3	2 + Increase Evap/Cond Coil Area	9.83	$788	$0	$787.80	$0	680.65	$45.94	$1,291.52	$1,183.91	$1,040.71
	4	3 + Brushless D.C. Fan Motor	10.05	$952	$0	$952.26	$0	666.15	$44.96	$1,445.25	$1,339.93	$1,199.78
5	5	4 + **Variable Speed Compressor	11.16	$1,270	$0	$1,269.68	$0	599.53	$40.47	$1,713.37	$1,618.59	$1,492.45

Life Cycle Costs and Payback Periods of Room Air Conditioner, With Reverse Cycle and Without Louvered Sides

Efficiency Level	Design No.	Design Option	EER *Btu/W-hr*	Retail Price	Installation Cost	Installed Consumer Cost	Annual Maintenance Cost (@6%)	Annual Elec. Use *kWh*	Annual Energy Expense	Life-Cycle Costs 2%	Life-Cycle Costs 6%	Life-Cycle Costs 15%
Suppl.	**Suppl.**	**Supplemental Level**	**8.50**	**$700**	**$0**	**$699.93**	**$0**	**711.64**	**$48.04**	**$1,226.58**	**$1,114.08**	**$964.35**
1,2	0	Baseline	8.72	$704	$0	$704.13	$0	693.92	$46.84	$1,217.67	$1,107.97	$961.97
3,4	1	0 + Condenser Enhanced Fins	8.86	$707	$0	$706.90	$0	682.72	$46.08	$1,212.15	$1,104.22	$960.58
	2	1 + Brushless D.C. Fan Motor	9.20	$884	$0	$883.61	$0	657.85	$44.40	$1,370.46	$1,266.45	$1,128.05
	3	2 + **Variable Speed Compressor	10.22	$1,225	$0	$1,225.04	$0	592.07	$39.96	$1,663.20	$1,569.60	$1,445.03
5	4	3 + **Increase Evap/Cond Coil Area	10.87	$1,405	$331	$1,735.77	$0	556.54	$37.57	$2,147.64	$2,059.65	$1,942.56

Room Air Conditioner, Less than 6 KBtu/h, with Louvered Sides (Using GRI 96 energy price projections)[1]

Cost (1990 $) and Energy-Use Summary (Field Usage)

Standard Level	Design No.	Installed Consumer Cost (1990$)	Elec. use kWh/yr	Annual Operating Exepnse (1990$)	LCC (1990$) @ 6%	1999 Distribution
	0	372.03	378.51	25.55	592.31	70.9%
	1	372.64	358.31	24.19	581.16	9.6%
1	2	377.57	334.43	22.57	572.20	9.0%
Suppl.	**Suppl.**	**382.41**	**321.26**	**21.69**	**569.37**	**1.0%**
2	3	382.55	320.90	21.66	569.30	5.3%
3	4	389.51	311.69	21.04	570.90	2.7%
4	5	440.24	300.19	20.26	614.94	1.6%
	6	560.46	294.85	19.90	732.05	0.0%
5	7	796.18	265.36	17.91	950.61	0.0%
						100.0%

Weighted Average of Units Sold below Standards

Standard Level	1	**Suppl.**	2	3	4	5
Installed Consumer Cost (1990 $)	372.10	**372.65**	372.75	373.29	373.74	374.83
Annual Operating Cost (1990 $)	25.39	**25.11**	25.07	24.88	24.78	24.70
Life-Cycle Cost at 6% (1990 $)	590.98	**589.10**	588.89	587.82	587.35	587.81
Energy Use (kWh./a)	376.11	**371.94**	371.40	368.62	367.06	365.97

Life-Cycle Cost Difference (1990$), Payback Periods (Years), and Costs of Conserved Energy (at 6%)

Standard Level	1	**Suppl.**	2	3	4	5
LCC Difference	18.79	**19.73**	19.59	16.92	-27.58	-362.81
Payback (year)						
Field	1.9	**2.9**	2.9	4.2	14.7	62.0
Existing Test Proc.	1.4	**2.0**	2.0	3.0	10.5	44.1
CCE (cent/kWh)	1.5	**2.2**	2.2	3.3	11.5	48.6

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[1] Holtberg, P.D., T.J. Woods, M.L. Lihn, and Nice, 1996. Baseline Projection Data Book: 1996 Edition of the GRI Baseline Projection of U.S. Energy Supply and Demand to 2015. Gas Research Institute, Baseline/Gas Resource Analytical Center. Washington, DC.

Room Air Conditioner, 6 to 8 KBtu/h, with Louvered Sides (Using GRI 96)

Cost (1990 $) and Energy-Use Summary (Field Usage)

Standard Level	Design No.	Installed Consumer Cost	Annual Elec. use	Annual Operating Expense	LCC (1990$)	1999 Distribution
		(1990$)	kWh/yr	(1990$)	@ 6%	
	0	403.82	471.06	31.80	677.96	48.5%
	1	405.25	452.75	30.56	668.73	14.8%
1	2	410.13	424.89	28.68	657.40	23.5%
2	3	416.89	412.31	27.83	656.84	9.9%
Suppl.	**Suppl.**	**418.10**	**410.69**	**27.72**	**657.11**	**1.6%**
3	4	424.73	402.03	27.14	658.70	0.5%
4	5	477.78	385.68	26.03	702.23	0.4%
	6	598.82	379.26	25.60	819.53	0.9%
5	7	830.48	341.33	23.04	1029.12	0.0%

Weighted Average of Units Sold below Standards

Standard Level	1	2	**Suppl.**	3	4	5
Installed Consumer Cost (1990 $)	404.15	405.77	**406.91**	407.09	407.18	409.11
Annual Operating Cost (1990 $)	31.51	30.74	**30.44**	30.40	30.38	30.33
Life-Cycle Cost at 6% (1990 $)	675.80	670.82	**669.39**	669.19	669.14	670.56
Energy Use (kWh./a)	466.8	455.4	**451.0**	450.4	450.1	449.3

Life-Cycle Cost Difference (1990$), Payback Periods (Years), and Costs of Conserved Energy (at 6%)

Standard Level	1	2	**Suppl.**	3	4	5
LCC Difference	18.40	13.98	**12.28**	10.49	-33.09	-358.56
Payback (year)						
Field	2.1	3.8	**4.1**	5.4	16.2	57.8
Existing Test Proc.	1.5	2.7	**2.9**	3.8	11.5	41.1
CCE (cent/kWh)	1.7	3.0	**3.2**	4.2	12.7	45.3

Room Air Conditioner, 8-14 KBtu/h, with Louvered Sides

Cost (1990 $) and Energy-Use Summary (Field Usage)

Standard Level	Design No.	Installed Consumer Cost	Annual Elec. use	Annual Operating Expense	LCC (1990$)	1999 Distribution
		(1990$)	kWh/yr	(1990$)	@ 6%	
	0	495.06	694.12	46.85	899.01	52.0%
1	1	505.83	666.46	44.99	893.68	14.5%
DOE	**DOE**	**508.41**	**660.34**	**44.57**	**892.71**	**6.2%**
2	2	509.76	657.19	44.36	892.22	7.9%
3	3	518.17	640.03	43.20	890.64	12.6%
4	4	576.63	590.02	39.83	920.00	4.4%
	5	697.06	580.28	39.17	1034.76	0.5%
5	6	929.44	522.25	35.25	1233.37	1.9%
						100.0%

Weighted Average of Units Sold below Standards

Standard Level	1	**DOE**	2	3	4	5
Installed Consumer Cost (1990 $)	495.06	**497.40**	498.34	499.47	501.99	506.36
Annual Operating Cost (1990 $)	46.85	**46.45**	46.29	46.10	45.71	45.41
Life-Cycle Cost at 6% (1990 $)	899.01	**897.85**	897.41	896.90	896.06	897.85
Energy Use (kWh./a)	694.12	**688.10**	685.73	682.93	677.15	672.71

Life-Cycle Cost Difference (1990$), Payback Periods (Years), and Costs of Conserved Energy (at 6%)

Standard Level	1	**DOE**	2	3	4	5
LCC Difference	5.33	**5.15**	5.20	6.26	-23.94	-335.52
Payback (year)						
Field	5.8	**5.9**	5.9	6.5	12.7	41.7
Existing Test Proc.	4.1	**4.2**	4.2	4.6	9.0	29.6
CCE (cent/kWh)	4.5	**4.6**	4.6	5.1	9.9	32.6

Room Air Conditioner, 14 to 20 KBtu/h, with Louvered Sides (Using GRI 96)

Cost (1990 $) and Energy-Use Summary (Field Usage)

Standard Level	Design No.	Installed Consumer Cost	Annual Elec. use	Annual Operating Expense	LCC (1990$)	1999 Distribution
		(1990$)	kWh/yr	(1990$)	@ 6%	
	0	612.76	1062.76	71.74	1231.25	60.2%
1	1	632.48	986.80	66.61	1206.76	15.8%
Suppl.	**Suppl.**	**632.61**	**986.29**	**66.57**	**1206.59**	**0.5%**
2	2	639.63	958.91	64.73	1197.68	8.8%
3,4	3	647.54	942.93	63.65	1196.29	12.5%
	4	811.82	890.62	60.12	1330.13	2.3%
	5	870.27	863.06	58.26	1372.54	0.0%
	6	897.30	856.11	57.79	1395.52	0.0%
	7	1038.75	832.28	56.18	1523.10	0.0%
5	8	1294.53	749.05	50.56	1730.45	0.0%
						100.0%

Weighted Average of Units Sold below Standards

Standard Level	1	**Suppl.**	2	3	4	5
Installed Consumer Cost (1990 $)	612.76	**616.86**	616.96	619.30	619.30	627.17
Annual Operating Cost (1990 $)	71.74	**70.67**	70.65	70.03	70.03	69.01
Life-Cycle Cost at 6% (1990 $)	1231.25	**1226.16**	1226.04	1223.11	1223.11	1222.19
Energy Use (kWh./a)	1062.76	**1046.96**	1046.60	1037.54	1037.54	1022.43

Life-Cycle Cost Difference (1990$), Payback Periods (Years), and Costs of Conserved Energy (at 6%)

Standard Level	1	**Suppl.**	2	3	4	5
LCC Difference	24.49	**19.56**	28.36	26.82	26.82	-508.26
Payback (year)						
Field use	3.8	**3.8**	3.8	4.4	4.4	36.2
Existing Test Proc.	2.7	**2.7**	2.7	3.1	3.1	25.7
CCE (cent/kWh)	3.0	**3.0**	3.0	3.5	3.5	28.3

Room Air Conditioner >20 KBtu/h, with Louvered Sides (Using GRI 96)

Cost (1990 $) and Energy-Use Summary (Field Usage)

Standard Level	Design No.	Installed Consumer Cost (1990$)	Annual Elec. use kWh/yr	Annual Operating Expense (1990$)	LCC (1990$) @ 6%	1999 Distribution
	0	859.47	1572.75	106.16	1774.75	55.5%
1,2	1	871.31	1542.55	104.12	1769.02	4.2%
Suppl.	**Suppl.**	**879.78**	**1521.68**	**102.71**	**1765.34**	**10.7%**
3	2	880.29	1520.43	102.63	1765.12	7.9%
4	3	960.00	1457.38	98.37	1808.14	18.4%
	4	1071.41	1372.63	92.65	1870.23	1.1%
	5	1111.79	1314.73	88.74	1876.91	2.2%
	6	1291.24	1289.56	87.05	2041.72	0.0%
5	7	1653.06	1160.60	78.34	2328.49	0.0%
						100.0%

Weighted Average of Units Sold below Standards

Standard Level	1	2	**Suppl.**	3	4	5
Installed Consumer Cost (1990 $)	859.47	859.47	**860.30**	863.27	864.98	890.18
Annual Operating Cost (1990 $)	106.16	106.16	**106.02**	105.51	105.22	103.46
Life-Cycle Cost at 6% (1990 $)	1774.75	1774.75	**1774.35**	1772.97	1772.19	1782.19
Energy Use (kWh./a)	1572.75	1572.75	**1570.63**	1563.16	1558.87	1532.75

Life-Cycle Cost Difference (1990$), Payback Periods (Years), and Costs of Conserved Energy (at 6%)

Standard Level	1	2	**Suppl.**	3	4	5
LCC Difference	5.73	5.73	**9.01**	7.85	-35.96	-546.30
Payback (year)						
Field use	5.8	5.8	**5.9**	5.9	13.9	30.4
Existing Test Proc.	4.1	4.1	**4.2**	4.2	9.8	21.6
CCE (cent/kWh)	4.5	4.5	**4.6**	4.6	10.9	23.8

Room Air Conditioner, 6 to 8 KBtu/h, without Louvered Sides (Using GRI 96)

Cost (1990 $) and Energy-Use Summary (Field Usage)

Standard Level	Design No.	Installed Consumer Cost (1990$)	Annual Elec. use kWh/yr	Annual Operating Expense (1990$)	LCC (1990$) @ 6%	1999 Distribution
	0	447.01	382.02	25.79	669.33	53.9%
Suppl.	**Suppl.**	**450.17**	**375.86**	**25.37**	**668.90**	**0.0%**
1,2	1	452.23	371.94	25.11	668.68	9.8%
3,4	2	455.96	366.62	24.75	669.32	11.1%
	3	599.35	350.65	23.67	803.42	25.2%
	4	872.95	315.59	21.30	1056.61	0.0%
5	7	1344.94	293.75	19.83	1515.89	0.0%
						100.0%

Weighted Average of Units Sold below Standards

Standard Level	**Suppl.**	1	2	3	4	5
Installed Consumer Cost (1990 $)	**447.01**	447.01	447.01	447.82	447.82	486.92
Annual Operating Cost (1990 $)	**25.79**	25.79	25.79	25.68	25.68	25.07
Life-Cycle Cost at 6% (1990 $)	**669.33**	669.33	669.33	669.23	669.23	703.07
Energy Use (kWh./a)	**382.02**	382.02	382.02	380.46	380.46	371.41

Life-Cycle Cost Difference (1990$), Payback Periods (Years), and Costs of Conserved Energy (at 6%)

Standard Level	**Suppl.**	1	2	3	4	5
LCC Difference	**0.43**	0.65	0.65	-0.09	-0.09	-812.82
Payback (year)						
Field use	**7.6**	7.7	7.7	8.7	8.7	163.7
Existing Test Proc.	**5.4**	5.4	5.4	6.2	6.2	116.2
CCE (cent/kWh)	**5.9**	6.0	6.0	6.8	6.8	128.1

Room Air Conditioner, 8 to 14 KBtu/h, without Louvered Sides
(Using GRI 96)

Cost (1990 $) and Energy-Use Summary (Field Usage)

Standard Level	Design No.	Installed Consumer Cost	Annual Elec. use	Annual Operating Expense	LCC (1990$)	1999 Distribution
		(1990$)	kWh/yr	(1990$)	@ 6%	
Suppl.	**Suppl.**	**554.10**	**677.29**	**45.72**	**948.25**	**8.9%**
1	0	558.35	654.42	44.17	939.20	51.8%
2	1	561.89	636.48	42.96	932.30	9.7%
3,4	2	569.09	631.59	42.63	936.65	12.2%
	3	713.85	610.04	41.18	1068.87	17.1%
	4	992.19	549.04	37.06	1311.71	0.2%
5	7	1469.75	519.39	35.06	1772.01	0.0%
						100.0%

Weighted Average of Units Sold below Standards

Standard Level	**Suppl.**	1	2	3	4	5
Installed Consumer Cost (1990 $)	**N/A**	554.10	557.73	558.30	558.30	587.23
Annual Operating Cost (1990 $)	**N/A**	45.72	44.40	44.20	44.20	43.48
Life-Cycle Cost at 6% (1990 $)	**N/A**	948.25	940.53	939.39	939.39	962.07
Energy Use (kWh./a)	**N/A**	677.29	657.78	654.84	654.84	644.09

Life-Cycle Cost Difference (1990$), Payback Periods (Years), and Costs of Conserved Energy (at 6%)

Standard Level	**Suppl.**	1	2	3	4	5
LCC Difference	**N/A**	9.05	8.23	2.74	2.74	-809.94
Payback (year)						
Field use	**N/A**	2.8	2.9	6.9	6.9	104.8
Existing Test Proc.	**N/A**	2.0	2.1	4.9	4.9	74.4
CCE (cent/kWh)	**N/A**	2.2	2.3	5.4	5.4	82.1

Room Air Conditioner, with Reverse Cycle with louvered sides
(Using GRI 96)

Cost (1990 $) and Energy-Use Summary (Field Usage)

Standard Level	Design No.	Installed Consumer Cost	Annual Elec. use	Annual Operating Expense	LCC (1990$)	1999 Distribution
		(1990$)	kWh/yr	(1990$)	@ 6%	
	0	689.83	750.16	50.64	1126.40	68.4%
Suppl.	**Suppl.**	**693.09**	**743.49**	**50.19**	**1125.77**	**1.7%**
1,2	1	695.16	739.30	49.90	1125.41	1.6%
3,4	2	707.54	721.61	48.71	1127.49	3.1%
	3	787.80	680.65	45.94	1183.91	23.1%
	4	952.26	666.15	44.96	1339.93	2.0%
5	7	1269.68	599.53	40.47	1618.59	0.0%
						100.0%

Weighted Average of Units Sold below Standards

Standard Level	**Suppl.**	1	2	3	4	5
Installed Consumer Cost (1990 $)	**689.83**	689.91	689.91	690.03	690.03	718.46
Annual Operating Cost (1990 $)	**50.64**	50.63	50.63	50.61	50.61	49.36
Life-Cycle Cost at 6% (1990 $)	**1126.40**	1126.38	1126.38	1126.36	1126.36	1144.00
Energy Use (kWh./a)	**750.16**	750.00	750.00	749.76	749.76	731.21

Life-Cycle Cost Difference (1990$), Payback Periods (Years), and Costs of Conserved Energy (at 6%)

Standard Level	**Suppl.**	1	2	3	4	5
LCC Difference	**0.62**	0.97	0.97	-1.13	-1.13	-474.59
Payback (year)						
Field use	**7.2**	7.3	7.3	9.2	9.2	62.0
Existing Test Proc.	**5.1**	5.2	5.2	6.5	6.5	44.0
CCE (cent/kWh)	5.7	5.7	5.7	7.2	7.2	48.6

Room Air Conditioner, with Reverse Cycle without louvered sides (Using GRI 96)

Cost (1990 $) and Energy-Use Summary (Field Usage)

Standard Level	Design No.	Installed Consumer Cost	Annual Elec. use	Annual Operating Expense	LCC (1990$)	1999 Distribution
		(1990$)	kWh/yr	(1990$)	@ 6%	
Suppl.	**Suppl.**	**699.93**	**711.64**	**48.04**	**1114.08**	**27.4%**
1,2	0	704.13	693.92	46.84	1107.97	32.6%
3,4	1	706.90	682.72	46.08	1104.22	19.2%
	2	883.61	657.85	44.40	1266.45	20.8%
	3	1225.04	592.07	39.96	1569.60	0.0%
5	4	1735.77	556.54	37.57	2059.65	0.0%
						100.0%

Weighted Average of Units Sold below Standards

Standard Level	**Suppl.**	1	2	3	4	5
Installed Consumer Cost (1990 $)	**N/A**	699.93	699.93	702.21	702.21	740.79
Annual Operating Cost (1990 $)	**N/A**	48.04	48.04	47.39	47.39	46.52
Life-Cycle Cost at 6% (1990 $)	**N/A**	1114.08	1114.08	1110.76	1110.76	1141.84
Energy Use (kWh./a)	**N/A**	711.64	711.64	702.02	702.02	689.14

Life-Cycle Cost Difference (1990$), Payback Periods (Years), and Costs of Conserved Energy (at 6%)

Standard Level	**Suppl.**	1	2	3	4	5
LCC Difference	**N/A**	6.11	6.11	6.54	6.54	-917.81
Payback (year)						
Field use	**N/A**	N/A	N/A	3.6	3.6	111.2
Existing Test Proc.	**N/A**	N/A	N/A	2.6	2.6	78.9
CCE (cent/kWh)	**N/A**	N/A	N/A	2.8	2.8	87.0

Supplemental Table 4.19

LCC Sensitivity to 1995 State Energy Prices for Room A/C, 8000 to 13,999 Btu/hr (with louvered sides) in 1990$

			Sensitivity Scenarios	
Efficiency Level	Design No.	Reference	Low State Elect. Price	High State Elect. Price
	0	$934.92	$746.55	$1,213.59
1	1	$928.16	$747.29	$1,195.73
2	2	$926.21	$747.86	$1,190.06
3	3	$923.75	$750.06	$1,180.70
4	4	$950.52	$790.40	$1,187.40
	5	$1,064.78	$907.30	$1,297.75
5	6	$1,260.39	$1,118.66	$1,470.06

Supplemental Table 4.20

Class	Standard Level for LCC minimum		Payback Period for DOE Std Level	
	(AEO 95) Nat'l Avg Elec Price[1]	GRI Elec Price[2]	(AEO 95) Nat'l Avg Elec Price[1]	GRI Elec Price[2]
Without Reverse Cycle, With Louvered Sides				
Less than 6000 Btu/hr	2	2	2.6	2.9
6000 - 7999 Bth/hr	2	2	3.8	4.1
8000 - 13,999 Btu/hr	DOE	DOE	5.4	5.9
14,000 - 19,999 Btu/hr	3,4	3,4	3.5	3.8
20,000 Btu/hr and over	3	3	5.4	5.9
Without Reverse Cycle, Without Louvered Sides				
6000 - 7999 Bth/hr	1,2	1,2	7.0	7.6
8000 - 13,999 Btu/hr	2	2	NA	NA
With Reverse Cycle, With Louvered Sides	1,2	1,2	6.6	7.2
With Reverse Cycle, Without Louvered Sides	3,4	3,4	NA	NA

[1] 1995 AEO Nat'l Avg Elec Price in the year 1999 (1990 Dollars) = 0.0735 $/kWh

[2] GRI Electricity Price in the year 2000 (1990 Dollars) = 0.0675 $/kWh