NBSIR 80-1993

Economic Analysis of Improved Efficiency for Central Air Conditioners

Stephen R. Petersen
Building Economics and Regulatory Technology Division

George E. Kelly and David A. Didion
Building Thermal and Service Systems Division

Center for Building Technology
National Engineering Laboratory
National Bureau of Standards
U.S. Department of Commerce
Washington, D.C. 20234

June 1980

for:
Office of Building and Community Systems
U.S. Department of Energy

NBSIR 80-1993

ECONOMIC ANALYSIS OF IMPROVED EFFICIENCY FOR CENTRAL AIR CONDITIONERS

Stephen R. Petersen
Building Economics and Regulatory Technology Division

George E. Kelly and David A. Didion
Building Thermal and Service Systems Division

Center for Building Technology
National Engineering Laboratory
National Bureau of Standards
U.S. Department of Commerce
Washington, D.C. 20234

June 1980

for:
Office of Building and Community Systems
U.S. Department of Energy

PREFACE

The work in this report has been conducted as an interdisciplinary research project by the Building Economics and Regulatory Technology Division and the Building Thermal and Service Systems Division within the Center for Building Technology, National Engineering Laboratory, at the National Bureau of Standards. This effort has been supported by the Consumer Product Efficiency Branch in the Office of Buildings and Community Systems, at the U. S. Department of Energy.

The methodology outlined in this report employs a parametric analysis technique. The numerical values resulting from this analysis are valid only for the set of parameters specified. The NBS analysis and selection of parameters covers only a few of the many factors that DoE is required by law to consider in setting minimum efficiency standards.

ACKNOWLEDGEMENTS

The authors wish to thank all those persons who helped contribute to this report, either in providing useful information in its early stages, or in assisting in the review process. Mr. Ben Sienkiewicz of the Air-Conditioning and Refrigeration Institute was particularly helpful in collecting current cost data from manufacturers for use in this study. Dr. Harold Marshall, Dr. Stephen Weber, Mr. Michael McCabe, Mr. Clinton Phillips and Mrs. Kimberly Barnes all made many useful comments in reviewing the draft report.

ABSTRACT

The Department of Energy is in the process of developing minimum energy efficiency standards for central air conditioners (CAC's) that provide for maximum savings in energy while being economically justified. These standards will specify the minimum seasonal energy performance ratio (SEER, Btu per hour output/watt input) for all newly manufactured CAC's in the United States. This report analyzes criteria for economic justification based on life-cycle costs to consumers, provides a methodology for determining maximum economic levels of SEER for CAC's, and empirically determines these levels for CAC output capacities ranging from 24,000 to 60,000 Btu per hour. Since energy and corresponding dollar operating savings from increased efficiency vary widely by region and operating schedules, minimum SEER levels were selected which could be economically justified in the great majority of installations. Minimum SEER levels of 8.0 for split-system CAC's (7.5 for package CAC's) with output capacities ranging from 28,000 to 52,000 Btu per hour were selected, with SEER levels slightly lower for larger and smaller units, based on current retail cost data. A further cost-engineering analysis suggests that these minimum SEER's can be increased by approximately one half SEER unit by 1985 and still be economically justified in the majority of applications.

Key words: Central air conditioners; economic analysis; life-cycle cost analysis; minimum efficiency standards; minimum energy-efficiency levels; seasonal energy efficiency ratios.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

List of Figures (continued) Page

SI CONVERSION

Because the energy analysis in this report is based directly on the DoE Test Procedure for Central Air Conditioners [2] and on the capacities of central air conditioners as typically rated by U.S. manufacturers, compatable U.S. units of measurement are used throughout this report. Since the United States is a signatory to the Eleventh General Conference on Weights and Measures, which defined and gave official status to the Metric SI system, the following conversion factors are provided to assist users of SI units.

Energy: 1 Btu = 1.055×10^3 joule
Power: 1 Btu = 0.293 watt
Temperature: 1°F = 9/5 °C + 32

1. INTRODUCTION

1.1 LEGISLATIVE BACKGROUND

The Energy Policy and Conservation Act (EPCA), as amended by the National Energy Conservation Policy Act, requires that the Department of Energy (DoE) prescribe energy efficiency standards for central air conditioners and eight other types of consumer products by December 1980. EPCA defines energy efficiency standards as performance standards which establish the minimum energy efficiency level required to be achieved by each unit of a product, but which do not prescribe the methods, designs, processes, or materials to be used to achieve that efficiency level. The standards apply to all units manufactured after the effective date of the standards.

The energy efficiency standards for each product are to be designed to achieve the maximum improvement in energy efficiency which the DoE determines to be technologically feasible and economically justified. Economic justification requires that the benefits of the standard exceed its "burdens," based on the following factors, as outlined in the DoE Federal Register notice of January 2, 1979[1]:

(1) the economic impact of the standard on both manufacturers and consumers,

(2) life-cycle savings and costs,

(3) life-cycle energy savings,

(4) a lessening of utility or performance in the product due to the imposition of the standard,

(5) effect on competition,

(6) the national need to conserve energy, and

(7) any other factors DoE considers relevant.

1.2 PURPOSE AND SCOPE

The purpose of this report is to provide a methodology, some relevant data, and tentative recommendations for establishing minimum efficiency standards for central air conditioners[1] based on the assumptions stated. The results of this report are based primarily on the second of the above referenced factors related to economic justification, i.e., life-cycle savings and costs associated with improvements in energy efficiency. The position taken in this report is that the impact on consumers of improvements in efficiency is best quantified in terms of life-cycle cost rather than in

---

[1] Heat pumps in the air conditioning mode are not considered in this report.

terms of increased first cost because life-cycle costs represent all of the costs incurred in providing central air conditioning in housing. Furthermore, it is recommended that the analysis of potential impacts on manufacturers due to minimum performance standards for new central air conditioning should not be undertaken until an initial analysis is completed to determine the maximum level of efficiency which can be justified from the consumer standpoint, rather than simultaneously with that initial analysis as has been recommended by DoE.

For the purpose of this report, central air conditioners (CAC) are defined as air conditioners ranging from 18,000 to 65,000 Btu per hour (Btuh) capacities, connected to a central air distribution system (ductwork) and intended primarily for residential usage. There are two distinct types of CAC's: single package systems, and split systems consisting of an outdoor and an indoor unit. Since single package systems are inherently less efficient than split systems[1], slightly different minimum standards will be economically justified for this type of system. The efficiency of a CAC is generally defined in terms of an energy efficiency ratio, or EER (Btuh output per watt), under prescribed operating conditions. The most relevant EER for purposes of economic analysis is the seasonal energy efficiency ratio (SEER) which measures the average efficiency of the CAC over the entire cooling season. The Department of Energy, with the assistance of the National Bureau of Standards, has established a test procedure to be used by manufacturers in order to determine the SEER of each of their production models on a uniform basis with all other manufacturers of similar equipment [2,3]. This test procedure also provides a uniform method of calculating the energy and dollar savings resulting from improvements in the SEER.

An important aspect of the energy efficiency standards program, as outlined by the initial legislation and subsequent notice in the Federal Register [1] is that the minimum efficiency standard will be the same for all geographic regions of the United States. However, the savings potential from increases in energy efficiency, in terms of both energy and dollars, will vary by over an order of magnitude between consumers in different climate zones. If a given minimum efficiency standard is to be economically justifiable in the great majority of installations, it must be economically justified in regions with considerably less than average cooling requirements. Since the standard is meant to be a minimum constraint on energy efficiency, it does not preclude the manufacture of higher efficiency units for sale in regions where they would be economically advantageous. Appliance labeling, information programs, and building energy performance standards would encourage the purchase of such higher efficiency equipment in many regions of the U.S.

---

[1] This conclusion is based on an analysis of both systems performed by Murphy and Goldschmidt [7].

2. APPROACH

2.1 THE VALUE OF ECONOMIC ANALYSIS IN THE DEVELOPMENT OF STANDARDS

Economic analysis has become increasingly useful and accepted as a tool for the development of new standards for energy conservation in the design of buildings and related subsystems. Life-cycle economic analysis provides a relatively objective framework for evaluating both benefits and costs on a time-equivalent basis, and is especially valuable when applied to questions related to "how far," rather than just "go" or "no-go." While it is sometimes criticized on the grounds that many of the necessary assumptions are weak (e.g., projections of future energy costs) and that consumers do not consider life-cycle benefits in making market-place decisions, it has the following distinct advantages over alternative approaches: (1) It can provide a consistent methodology for the development of all standards related to national energy conservation policy, using the same data bases and operational criteria where appropriate. (2) It can relate the effects of differences in energy types, climates, and procurement costs on a common basis. (3) Sensitivity to critical assumptions can be easily computed. (4) It provides a consistent framework for periodically updating energy standards as energy costs change and/or technological improvements reduce conservation costs. (5) Life-cycle costs and benefits are closely related to long-term societal costs and benefits even if they are not always considered by individual consumers in their marketplace behavior.

2.2 THE LIFE-CYCLE COST MODEL

Life-cycle cost analysis provides a systematic method for evaluating all quantifiable benefits and costs incurred over the life of a building or a building system being considered on a time equivalent basis. This requires that future benefits and costs be discounted to present value so that they can be compared with initial benefits and costs. Where two or more alternative levels of performance are achievable, the alternative with the greatest net benefits (life-cycle benefits less life-cycle costs) is "optimal." In general, only incremental benefits and costs associated with improved performance need be identified to determine the optimal performance level. This is because greater net benefits are possible only as long as any increase in performance generates greater incremental benefits than incremental costs. Net benefits are therefore maximized at the point where any further increase in performance has incremental costs greater than incremental savings. This "optimal" performance level can be used as a benchmark for establishing minimum performance standards.

Performance levels for central air conditioners are specified in terms of a seasonal energy efficiency ratio (SEER), the ratio of annual output energy in Btu to input energy in watt-hours used for air conditioning. The incremental costs associated with an increase in SEER are primarily first costs, as maintenance costs are generally not considered to increase with efficiency improvements.[1] The incremental benefits associated with an increase in SEER

---

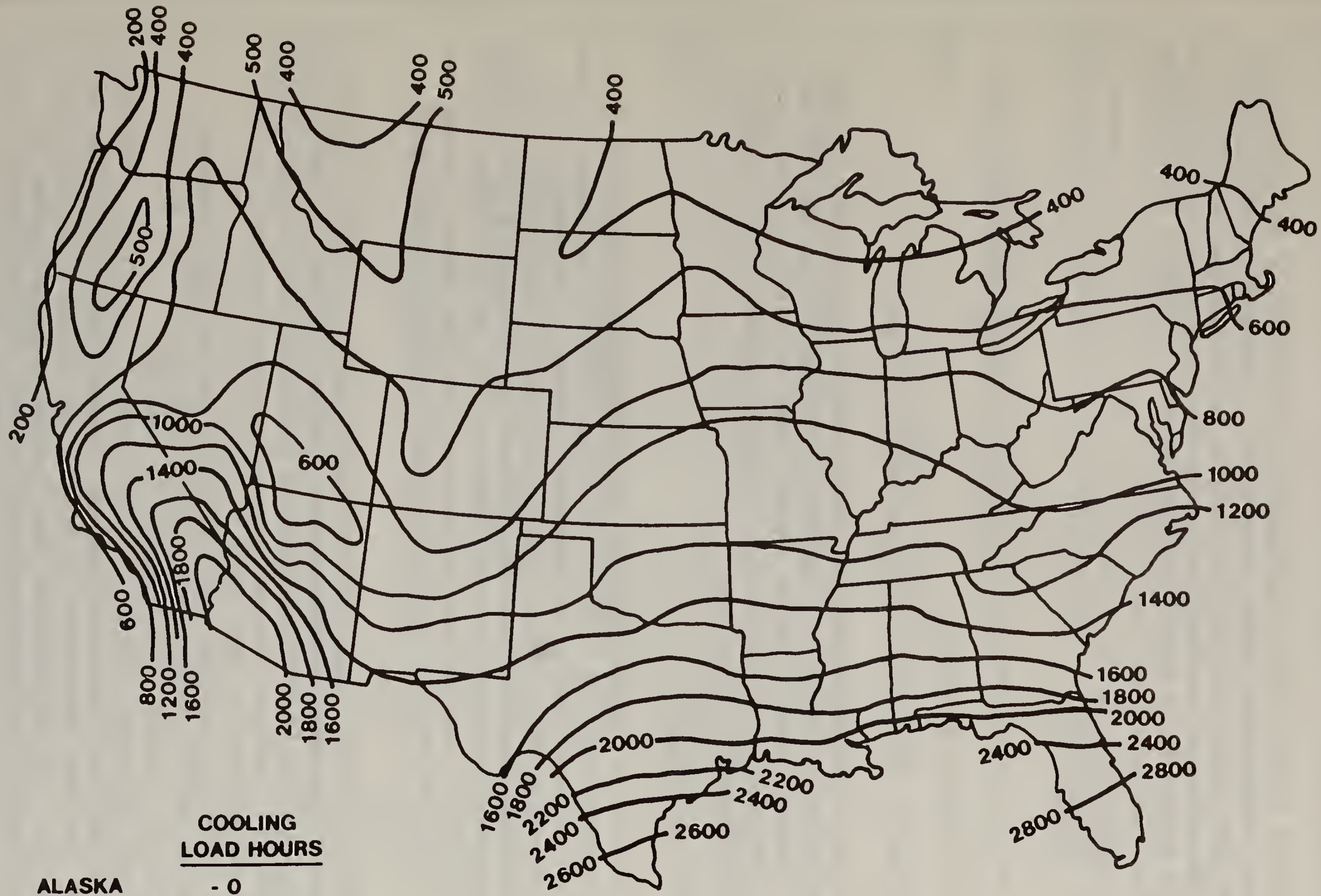
[1] For example, the annual cost of the CAC maintenance agreement offered by a major department store chain is the same for its "good," "better," and "best" systems. This maintenance agreement can be renewed for up to ten years.

are primarily reductions in electricity consumption and the resulting reduction in electricity billings to the consumer. DoE price projections (1975-1990) for residential electric rates [5], based on average utility rates, are used to calculate the present value of the energy saved due to improved CAC efficiency. Reductions in peak power demand and the true incremental cost of the electricity saved due to improved CAC performance should also be considered in such an analysis. However, such data is not presently available from DoE.

2.3 COOLING LOAD HOURS

Annual cooling requirements vary significantly as a function of climate, building design, and operational conditions. Because peak air conditioning loads in residences tend to be similar throughout the country, houses of similar size and design will tend to have the same size air conditioner (in terms of output capacity), regardless of location, as long as annual cooling requirements are substantial enough to justify central air conditioning. If the CAC is properly sized with respect to the peak (or design) load, the number of cooling load hours annually will tend to remain relatively constant in any given climate, regardless of house design, provided that operational conditions (including thermostat settings) are the same. As a result, cooling load hours can provide a convenient method for estimating the effects of climate on annual cooling requirements, regardless of house design. The DoE test procedure developed by NBS includes estimates of cooling load hours, in intervals of 200 hours, for the entire U.S. This data is based on a zero cooling requirement at an outdoor dry-bulb temperature of 65°F, which corresponds to an indoor temperature in the neighborhood of 75 to 80°F. A map of the continental United States displaying the cooling load hour data is presented in figure 2.1 and shows that cooling load hours range from near zero to 2800.[1]

[1] This map was prepared by York Division, Borg-Warner Corporation, and was based on results calculated in [4].



COOLING LOAD HOURS	
ALASKA	- 0
CANAL ZONE	- 6,000
GUAM	- 6,600
HAWAII	- 2,300
PUERTO RICO	- 6,000
SAMOA	- 6,600
VIRGIN ISLAND	- 6,000

Figure 2.1 Distribution of Cooling Load Hours Throughout The United States.

3. CALCULATING LIFE-CYCLE SAVINGS FROM IMPROVED SEER

3.1 GENERAL METHODOLOGY

The calculation of annual energy requirements (Q) in kWh for the operation of a central air conditioner of any given SEER is straightforward provided that the rated capacity in Btu per hour of the air conditioner at 95°F, (CAP_{95}), and the number of cooling load hours (CLH) are known. The following calculation procedure is taken from the DoE test procedure for CAC's as developed at NBS [2,3]:

$$Q = \frac{(CLH)(CAP_{95})}{(SEER)(1000)} \tag{3.1}$$

The seasonal cost of operation (SCO) is therefore simply determined using:

$$SCO = (Q)(\text{cost per kWh}), \tag{3.2}$$

where cost per kWh is the current cost per kWh at the point of use.

Calculation of the life-cycle operating cost (LCOC) requires that the seasonal operating costs projected for each year over the life of the CAC be discounted to present value. This is accomplished by multiplying the seasonal cost of operation at the first year's energy prices by the appropriate present worth factor:

$$LCOC = (SCO)(PWF) \tag{3.3}$$

The PWF is a function of system life, the discount rate, and the rate of energy price increase over the life of the system. For the purposes of this report a ten year system lifetime is projected, based on past useful life guidelines provided by the Internal Revenue Service. A ten percent nominal (i.e., including inflation) discount rate is used in calculating the present worth factor in order to account for the time value of money.[1] While no single discount rate is appropriate to represent the time value of money for all consumers, this ten percent rate is assumed to reflect an effective

---

[1] This ten percent nominal discount rate is approximately equal to a four percent real discount rate if the long-term inflation rate is assumed to be six percent. This six percent long-term inflation rate is consistent with the projections of the consumer price index used to adjust the DoE energy price projections in real terms to include inflation. While inflation is currently running higher than six percent, the effect of higher inflation both in the discount rate and in the rate of energy price increase will cancel, resulting in the same PWF.

[2] This implies a marginal income tax bracket of approximately 15-20 percent. It is assumed that most homeowners do not use the standard deduction when paying income tax. If the homeowner has a higher marginal income tax bracket, his effective borrowing rate will be less than ten percent.

approximate upper limit on the appropriate discount rate for the majority of homeowners based on the assumption that the discount rate will not generally exceed the effective long-term borrowing rate.

The Department of Energy's "Trendlong" price projections for residential electric rates (assuming a five percent annual increase in imported oil prices) and the accompanying projection of the Consumer Price Index [5] have been used to estimate the nominal rate of price increase over the ten year system life, 1979-1989. These projections are divided into two parts, 1979-1985 and 1985-1989. For the first six years the nominal rate of increase is six percent and for the remaining four years the nominal rate of increase is projected to be three percent. The resulting PWF is calculated as follows:

$$PWF = \left(\frac{1.06}{.04}\right)\left(1 - \left(\frac{1.06}{1.1}\right)^{6}\right)$$

$$+ \left(\frac{1.06}{1.1}\right)^{6}\left(\frac{1.03}{.07}\right)\left(1 - \left(\frac{1.03}{1.1}\right)^{4}\right) = 8.01$$

Using the same DoE price projections, the estimated 1979 price per kWh on a national average basis is calculated to be \$0.042.

For a central air conditioner that is rated at 36,000 Btuh (at 95°F outdoor temperature), with an SEER of 8.0 and installed in a location with 1000 cooling load hours, the ten year life-cycle operating cost can be computed as:

$$LCOC = \frac{(1000)(36000)}{(8)(1000)}(0.042)(8.01) = \$1514.$$

The life-cycle savings attributable to a change in SEER can be determined by the difference in the LCOC for the CAC before and after the change in SEER. Since only the SEER changes, this can be formulated as:

$$\Delta LCOC = \frac{(CLH)(CAP_{95})}{1000}(\text{cost per kWh})(PWF)\left[\frac{1}{SEER} - \frac{1}{SEER'}\right],$$

where SEER and SEER$'$ are the seasonal efficiency ratios before and after the change, respectively. Thus, using the above example, the savings in LCOC due to increasing the SEER from 8.0 to 8.5 can be calculated as follows:

$$\Delta LCOC = \frac{(1000)(36000)}{1000}(\$.042)(8.01)\left[\frac{1}{8} - \frac{1}{8.5}\right] = \$89.$$

If the same unit is to be installed in a region having 600 CLH, the savings in the life-cycle operating cost due to increasing the SEER from 8.0 to 8.5 would be only \$53.

In order to estimate the incremental annual kWh and life-cycle dollar savings for 0.5 unit increases in SEER over a range of CAC capacities and annual cooling load hours, a simple computer program was coded and executed. Four capacities, ranging from 24,000 to 60,000 Btuh, and five annual cooling load hours, ranging from 600 to 2000 hours, were studied. SEER was improved, in increments of 0.5 units, from 6.0 to 10.0. This range includes the vast majority of all CAC's currently on the market.[1] The incremental kWh savings are shown numerically in table 3.1. The incremental life-cycle dollar savings are shown numerically in table 3.2 and plotted graphically at the midpoint of each 0.5 SEER interval in figures 3.1-3.4, which cover the 24,000, 36,000, 48,000, and 60,000 Btuh units, respectively.

In examining tables 3.1 and 3.2 and the corresponding figures, it is important to note that, for any given unit capacity and CLH base, equal increases in SEER provide smaller and smaller incremental savings as the value of SEER increases. In general, the incremental savings (in either dollar or kWh terms) due to improving the SEER of an air conditioner from 9.5 to 10 are only 41 percent of those due to improving the SEER from 6 to 6.5.

3.2 DETERMINATION OF SAVINGS FOR STANDARDS DEVELOPMENT

The data in table 3.1 show that the incremental savings due to improvements in SEER vary significantly with cooling load hours (CLH). Since CLH vary with geographic location throughout the U.S. (see figure 2.1), it is necessary to establish a CLH baseline in order to calculate the energy savings from improvements in SEER that will be used as the basis for developing minimum SEER standards. In order to aid in establishing this baseline, 1977 regional sales data for air conditioners were employed[2]. These data were correlated with the CLH map shown in figure 2.1 and the results are shown in table 3.3 as the cumulative percentage distribution of air conditioners by 200 CLH bands. Note that approximately 90 percent of all central air conditioner sales were in areas with greater than 600 CLH. Approximately 50 percent of all central air conditioner sales were in areas with greater than 1100 CLH.

If the CLH baseline for standards development were established at the approximate midpoint of 1100 CLH, this would lead to a minimum SEER standard that was economically justified in this region but would have incremental costs greater than savings for approximately half of all new air conditioner installations (i.e., those installations with less than average CLH). Such a cost penalty is not acceptable if the standard is to be economically justified from a consumer viewpoint in the great majority of applications. A more reasonable CLH baseline would therefore be at the 90th percentile of CAC sales distribution, or 600 CLH.

---

[1] It should be noted that the starting point of 6.0 does not affect the incremental savings between any subsequent points considered.

[2] This regional analysis was based on unpublished data provided by the Air Conditioning and Refrigeration Institute for the sales of 33 companies in 615 trading areas during 1977.

TABLE 3.1 Incremental Annual kWh Savings per 0.5 SEER Improvement

SEER	COOLING LOAD HOURS					OUTPUT CAPACITY AT 95°F (Btu)
	600	800	1000	1200	2000	
6.00	*****	*****	*****	*****	*****	
6.50	184.6	246.2	307.7	369.2	615.4	
7.00	158.2	211.0	263.7	316.5	527.5	
7.50	137.1	182.9	228.6	274.3	457.1	
8.00	120.0	160.0	200.0	240.0	400.0	24,000
8.50	105.9	141.2	176.5	211.8	352.9	
9.00	94.1	125.5	156.9	188.2	313.7	
9.50	84.2	112.3	140.4	168.4	280.7	
10.00	75.8	101.1	126.3	151.6	252.6	
6.00	*****	*****	*****	*****	*****	
6.50	276.9	369.2	461.5	553.8	923.1	
7.00	237.4	316.5	395.6	474.7	791.2	
7.50	205.7	274.3	342.9	411.4	685.7	
8.00	180.0	240.0	300.0	360.0	600.0	36,000
8.50	158.8	211.8	264.7	317.6	529.4	
9.00	141.2	188.2	235.3	282.4	470.6	
9.50	126.3	168.4	210.5	252.6	421.1	
10.00	113.7	151.6	189.5	227.4	378.9	
6.00	*****	*****	*****	*****	*****	
6.50	369.2	492.3	615.4	738.5	1230.8	
7.00	316.5	422.0	527.5	633.0	1054.9	
7.50	274.3	365.7	457.1	548.6	914.3	
8.00	240.0	320.0	400.0	480.0	800.0	48,000
8.50	211.8	282.4	352.9	423.5	705.9	
9.00	188.2	251.0	313.7	376.5	627.5	
9.50	168.4	224.6	280.7	336.8	561.4	
10.00	151.6	202.1	252.6	303.2	505.3	
6.00	*****	*****	*****	*****	*****	
6.50	461.5	615.4	769.2	923.1	1538.5	
7.00	395.6	527.5	659.3	791.2	1318.7	
7.50	342.9	457.1	571.4	685.7	1142.9	
8.00	300.0	400.0	500.0	600.0	1000.0	60,000
8.50	264.7	352.9	441.2	529.4	882.4	
9.00	235.3	313.7	392.2	470.6	784.3	
9.50	210.5	280.7	350.9	421.1	701.8	
10.00	189.5	252.6	315.8	378.9	631.6	

TABLE 3.2 Incremental Life-Cycle Dollar Savings per 0.5 SEER Improvement (4.2¢ kWh, 10 years, 10% discount rate)

SEER	COOLING LOAD HOURS					OUTPUT CAPACITY AT 95°F (Btu)
	600	800	1000	1200	2000	
6.00	******	******	******	******	******	
6.50	$62.18	$82.91	$103.64	$124.36	$207.27	
7.00	$53.00	$71.06	$88.83	$106.60	$177.66	
7.50	$46.19	$61.59	$76.99	$92.38	$153.97	
8.00	$40.42	$53.89	$67.36	$80.84	$134.73	24,000
8.50	$35.66	$47.55	$59.44	$71.33	$118.88	
9.00	$31.70	$42.27	$52.83	$63.40	$105.67	
9.50	$28.36	$37.82	$47.27	$56.73	$94.54	
10.00	$25.53	$34.04	$42.55	$51.05	$85.09	
6.00	******	******	******	******	******	
6.50	$93.27	$124.36	$155.45	$186.54	$310.91	
7.00	$79.95	$106.60	$133.25	$159.89	$266.49	
7.50	$69.29	$92.38	$115.48	$138.58	$230.96	
8.00	$60.63	$80.84	$101.04	$121.25	$202.09	36,000
8.50	$53.49	$71.33	$89.16	$106.99	$178.31	
9.00	$47.55	$63.40	$79.25	$95.10	$158.50	
9.50	$42.55	$56.73	$70.91	$85.09	$141.82	
10.00	$38.29	$51.05	$63.82	$76.58	$127.64	
6.00	******	******	******	******	******	
6.50	$124.36	$165.82	$207.27	$248.73	$414.54	
7.00	$106.60	$142.13	$177.66	$213.19	$355.32	
7.50	$92.38	$123.18	$153.97	$184.77	$307.95	
8.00	$80.84	$107.78	$134.73	$161.67	$269.45	48,000
8.50	$71.33	$95.10	$118.88	$142.65	$237.75	
9.00	$63.40	$84.53	$105.67	$126.80	$211.34	
9.50	$56.73	$75.64	$94.54	$113.45	$189.09	
10.00	$51.05	$68.07	$85.09	$102.11	$170.18	
6.00	******	******	******	******	******	
6.50	$155.45	$207.27	$259.09	$310.91	$518.18	
7.00	$133.25	$177.66	$222.08	$266.49	$444.15	
7.50	$115.48	$153.97	$192.47	$230.96	$384.93	
8.00	$101.04	$134.73	$168.41	$202.09	$336.82	60,000
8.50	$89.16	$118.88	$148.59	$178.31	$297.19	
9.00	$79.25	$105.67	$132.08	$158.50	$264.17	
9.50	$70.91	$94.54	$118.18	$141.82	$236.36	
10.00	$63.82	$85.09	$106.36	$127.64	$212.73	

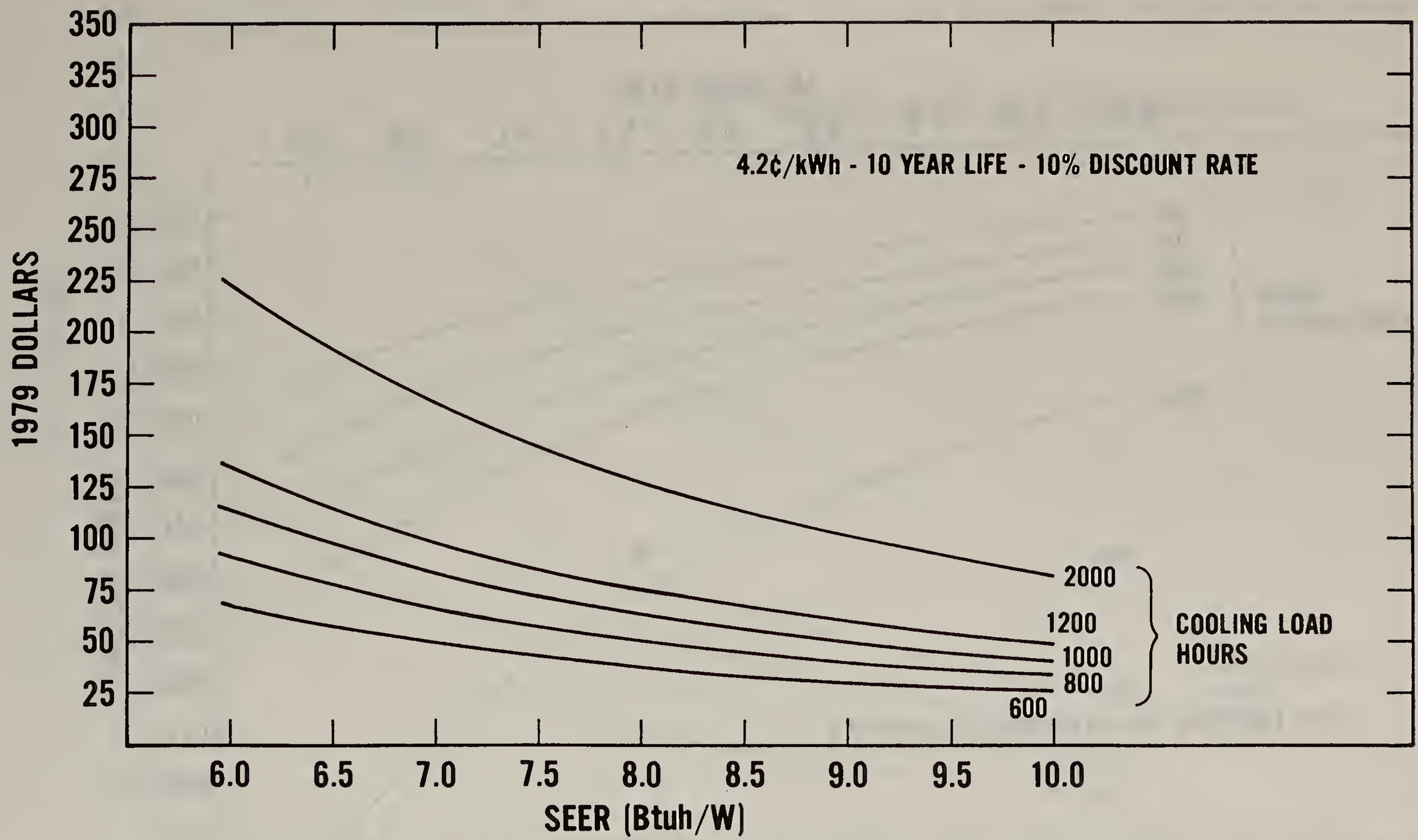


Figure 3.1 Incremental Dollar Savings per 0.5 Btu/W Improvement in SEER, 24,000 Btuh Capacity CAC.

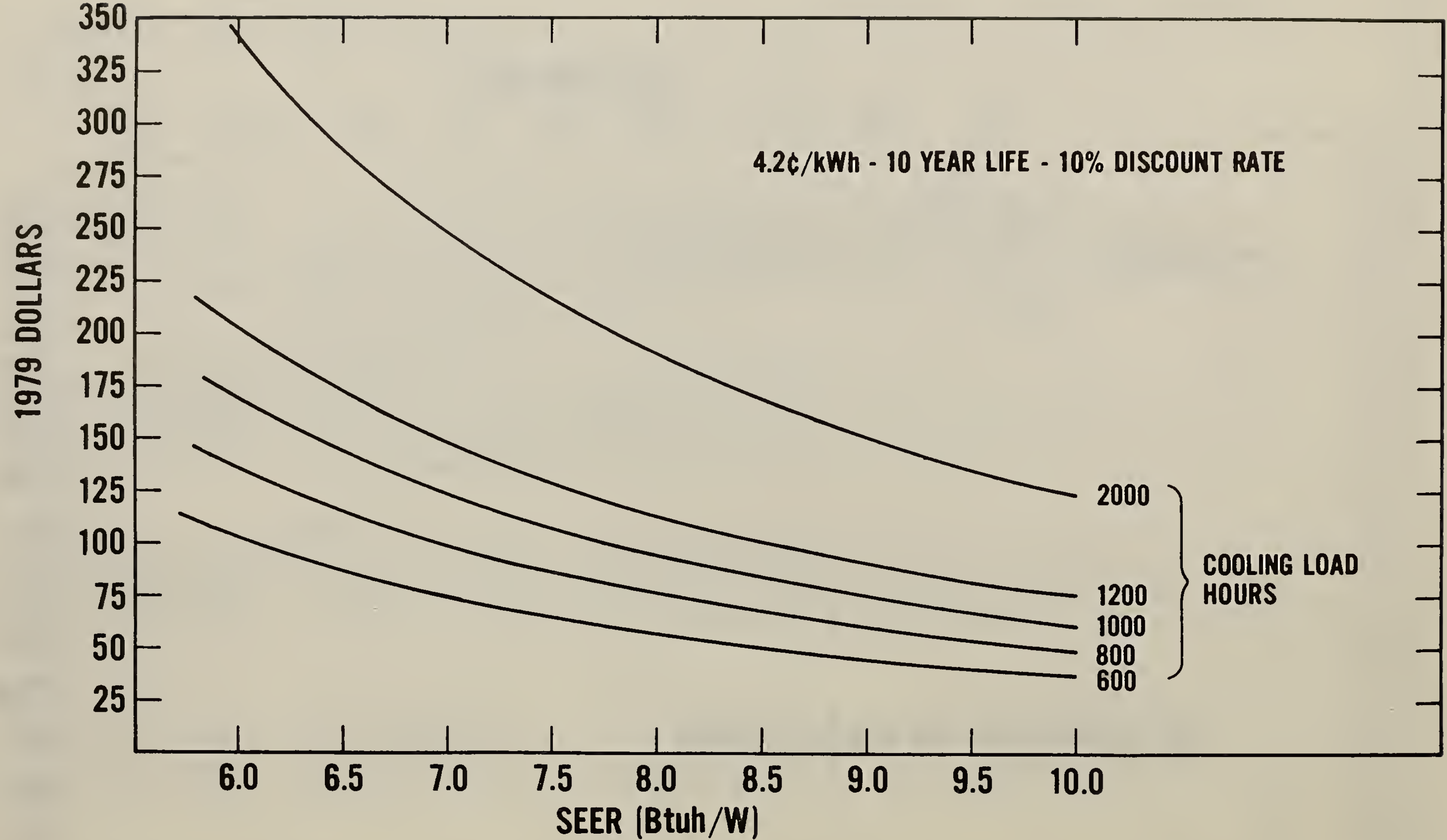


Figure 3.2 Incremental Dollar Savings per 0.5 Btu/W Improvement in SEER, 36,000 Btuh Capacity CAC.

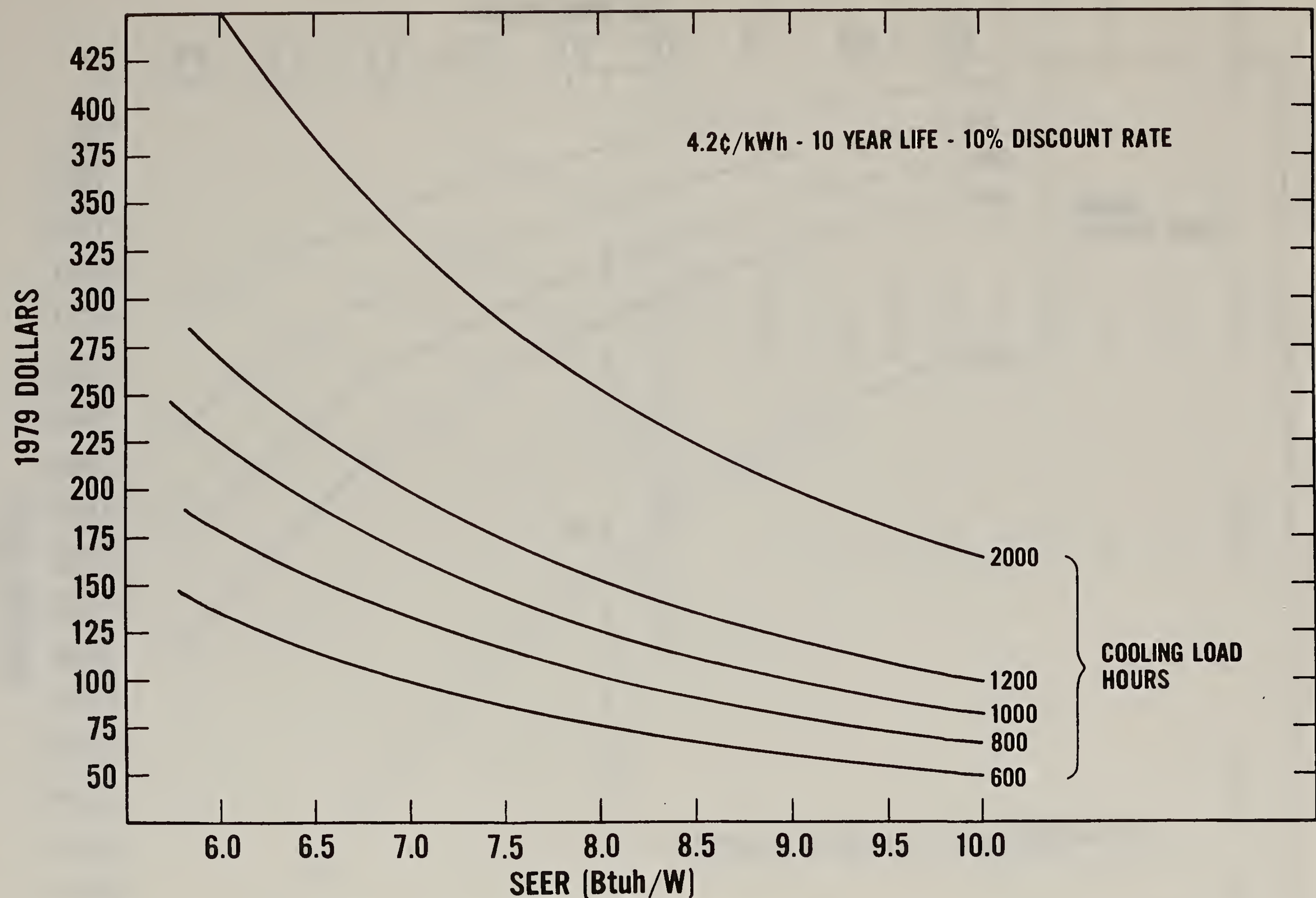


Figure 3.3 Incremental Dollar Savings per 0.5 Btu/W Improvement in SEER, 48,000 Btuh Capacity CAC.

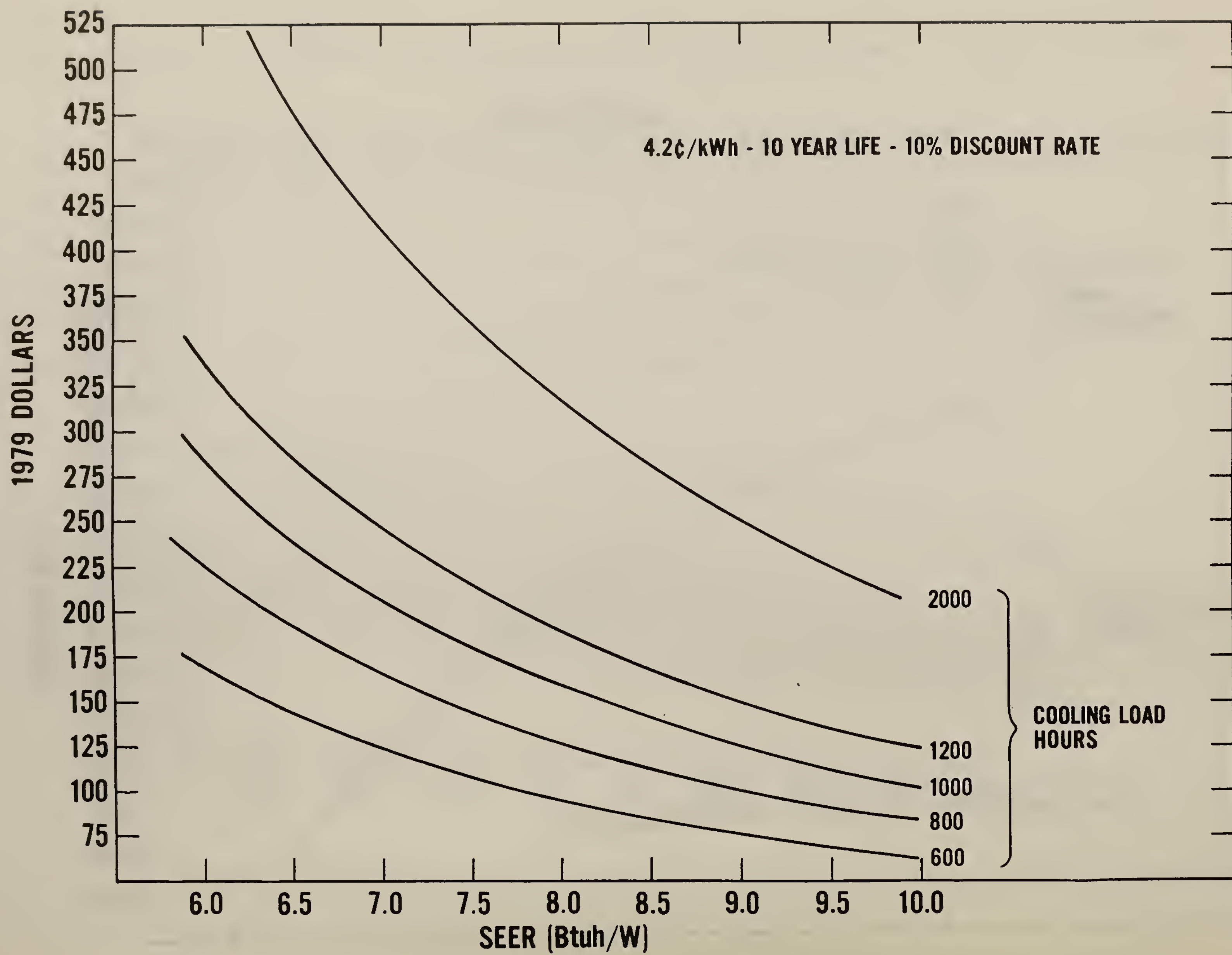


Figure 3.4 Incremental Dollar Savings per 0.5 Btu/W Improvement in SEER, 60,000 Btuh Capacity CAC.

Table 3.3 Cumulative Percentages of Central Air Conditioner[a] Sales[b] by Cooling Zone

COOLING HOURS	1977 SALES	PERCENT	CUMULATIVE PERCENT
> 1400	627,692	35.6	35.6
1200-1400	161,770	9.2	44.8
1000-1200	212,100	12.0	56.9
800-1000	207,501	11.8	68.6
600-800	363,385	20.6	89.3
400-600	181,980	10.3	99.6
< 400	7,108	0.4	100.0
TOTAL	1,761,539		

[a] Includes both split-system and single package units.

[b] Based on 1977 data from [6] adjusted to remove heat pump sales.

Even in this case, the percentage of consumers incurring incremental costs greater than benefits will more likely be in the neighborhood of 20 percent (instead of ten percent) because many consumers, especially in the north, turn their air conditioners off and use natural ventilation during the milder parts of the cooling season.[1] Since the purpose of the standard is primarily to establish minimum SEER requirements, the standard can be voluntarily exceeded in the regions where it is economically justifiable to do so.

Based on the ARI data and CLH map, the 600 CLH baseline would appear to be a reasonable basis for economic analysis of minimum efficiency standards for central air conditioners. This baseline will be employed in the analysis thoughout the remainder of this report and is the basis for the efficiency standards developed in section 5.

---

[1] This partial usage question was not addressed in the DoE/NBS test procedure for central air conditioners because of the lack of information available on this subject and because of the apparent impossibility of defining a "typical" usage pattern applicable to most consumers. Thus, equation (3.1) and the percentiles cited in table 3.3 are based on a central air conditioner satisfying the entire seasonal cooling load on a house in a particular geographical region.

4. ESTIMATES OF INCREMENTAL CENTRAL AIR CONDITIONER COSTS AND OPTIMAL SEER LEVELS

It has been shown that the incremental savings from improvements in central air conditioners decrease as the SEER increases. Conversely, one would expect the incremental costs of equal unit improvements in SEER to increase because of the increasingly cost-intensive design changes required to achieve higher performance ratings. A number of analyses of incremental costs have shown this to be true, although the exact relationship is difficult to determine.

Two distinct approaches to the determination of the increased costs corresponding to improvements in SEER are possible. The first approach is to examine actual or suggested retail prices corresponding to different levels of SEER, without regard to the technical design changes giving rise to the increased efficiency. The second approach is based on a cost engineering analysis of CAC design. Both of these approaches have advantages and disadvantages which make them useful for slightly different purposes.

A cost analysis based on retail price data to estimate the incremental costs of improvements in SEER has the advantage of being able to accurately predict the near-term effects of higher SEER requirements on CAC prices. It implicitly assumes that the higher efficiency models currently marketed are designed to achieve their rated level of efficiency at minimum manufacturing cost (at least in the short run), that they are competitively priced with other CAC models in the same SEER range, and that reasonably high production rates allow development and tooling costs to be amortized over a large number of units. One disadvantage of the retail cost approach is that the higher SEER models often have other design features (better paint, chrome, safety controls, etc.) which are seen as desirable on premium cost units but do not affect SEER. In addition, the highest SEER units available are usually low production volume models which also tends to raise their price, since development and tooling costs are spread over fewer units. These problems may be reduced or eliminated over time if manufacturers were required by minimum standards to replace their present lower efficiency lines with higher SEER units.

The engineering cost analysis method of determining the incremental costs associated with improvements in the SEER of CAC's should theoretically provide more reliable results than the retail cost analysis method. This is because the analyses can be limited to design modifications which are specifically related to improvements in SEER. In actual practice, however, the engineering cost analysis has a major shortcoming in that it is difficult to forsee the effects of competition on manufacturing and retail costs.

Given the advantages and problems associated with these two approaches, the retail cost approach appears to be the preferred method for obtaining near term (less than two or three years) estimates of incremental costs, provided one does not try to extrapolate the data to such high levels of performance that the assumptions of competitive pricing and reasonably high production rates break down. Conversely, the engineering analysis approach is more appropriate for predicting long term incremental costs, since continuously changing market conditions will invalidate today's retail cost data within a few years. This is the approach which has been adopted in this report. Analysis to determine economically justifiable intermediate minimum standards for central air conditioners is based on current (1979) retail cost data, while the analysis for tentative 1985 minimum standards is based on an engineering analysis of incremental costs. It is suggested that the Department of Energy also consider this approach with the following modification. In the year that the intermediate standard applies (e.g., 1981, 1982 or 1983), DoE should use the new retail cost data for that year to re-evaluate the final minimum efficiency standards for CAC's for cost effectiveness. The current recommendations for 1985 standards could then be revised upward or downward if the then existing retail prices indicate that the 1979 engineering analysis gave results which are no longer valid.

4.1 RETAIL COST METHOD AND INTERMEDIATE MINIMUM STANDARDS FOR SPLIT SYSTEMS

In carrying out an analysis of incremental cost vs. incremental changes in SEER for CAC's based on today's retail prices, two distinct sets of cost data have been used. The first set is based upon actual retail cost data from the 1979 Montgomery Ward and Sears, Roebuck and Co. catalogs together with some retail cost data recently supplied to DoE and NBS by Rheem Manufacturing Company and Carrier Air Conditioning. These data provide information on three distinct levels of Energy Efficiency Ratios[1] (EER), consistent with "competitive," "better," and "best" models, over a range of output capacities from 18,000 to 60,000 Btuh. Since these data are more comprehensive and better identified, they have been handled separately. They will be referred to as "list price" data to simplify identification.

The second set of data has been collected for the same EER ranges and output capacities by ARI from some of its member companies on a voluntary basis. This was done specifically for this study and provides incremental cost data that are based on wholesale prices which are not identified in any way with the manufacturer submitting it. A 40 percent markup to approximate retail cost was added to this data by NBS. Although data from eight manufacturers are included in this sample, only one or two models are represented in the 48,000-60,000 Btuh output capacity range. However, in the 24,000 and 36,000 Btuh ranges there are a useful number of observations. Because of the scattered coverage and anonymity, lesser credibility will be given to this ARI data set than the retail cost data set.

While there is sufficient data from both sets to estimate with reasonable confidence the average incremental costs associated with incremental changes in performance at moderate SEER's, this data does not clearly indicate the shape of the incremental cost curve at high SEER's. Using good engineering

---

[1] At present, manufacturer's data on EER is more readily available than on SEER. EER is generally calculated at 95°F outdoor temperature and 75°F indoor temperature and therefore does not reflect seasonal performance. Conversion of EER to SEER is discussed on the next page.

judgment, one must assume that the incremental cost curve is either linear[1] or bending upwards with SEER. Since no evidence from the retail cost data indicates that the incremental cost curve is bending upwards, a straight-line least-squares regression line was drawn through the data to indicate the average increase in retail cost for a 0.5 change in SEER at SEER intervals from 6.0 to approximately 10.0. Since only EER data were available from the manufacturers, the following formula was used to convert retail EER to SEER:

$$SEER = 1.237 + 0.885\ EER \tag{4.1}$$

This formula is based on an analysis of data collected by Purdue University [10] under contract to NBS and represents an average relationship between EER and SEER for the 148 units on which data were reported.

Figures 4.1 and 4.2 show the data for the two data sets, plotted as the incremental cost per 0.5 SEER improvement at the midpoint of each 0.5 incremental change in SEER for the 36,000 Btuh unit. A least-squares fitting of a line in both cases provides very similar results, although the result for the second set of data is not statistically significant by itself.[2] Figure 4.3 shows the least-squares, incremental cost lines superimposed on the incremental savings curve for the 36,000 Btuh unit. The intersection of incremental cost and savings for 600 CLH occurs at an SEER of approximately 7.9. This implies that the half unit increase in SEER with midpoint at 7.9 is the last such increment that can be economically justified. This half-unit increase would cover an SEER change from 7.65 to 8.15. Any further increase in SEER would have incremental costs greater than incremental savings. If smaller than half unit increments were examined, the maximum cost-effective level of efficiency would converge on the 7.9 value.

Figures 4.4-4.6 show the same type of analysis for the 24,000 Btuh case. Here the trend is for the ARI data to show a steeper incremental cost curve than the list price data. However, the least-squares fit for the ARI data is more statistically significant than that for the list price data. The intersection of the ARI curve with the 600 CLH incremental savings curve occurs at an SEER of approximately 7.7. The intersection of the list-price curve with the 600 CLH incremental savings curve occurs at an SEER of approximately 7.75. A half unit change in SEER based on a midpoint of 7.75 is from 7.5-8.0. This is slightly lower than that for the 36,000 Btuh unit.

Cost data for the 48,000 and 60,000 Btuh units are limited and somewhat inconsistent. Insufficient ARI data are available and only one data point (the difference between the "better" and "best" model) is available for Sears' and Ward's models. However, least-squares fitting of the data avail-

---

[1] A linear increase in incremental costs implies that total costs (the integration of incremental costs) are increasing in quadratic form.

[2] The R^2 (coefficient of determination, or square of the correlation coefficients, R) and t ratio (the slope estimator, β, divided by the standard error) are shown for all regressions on the corresponding figure.

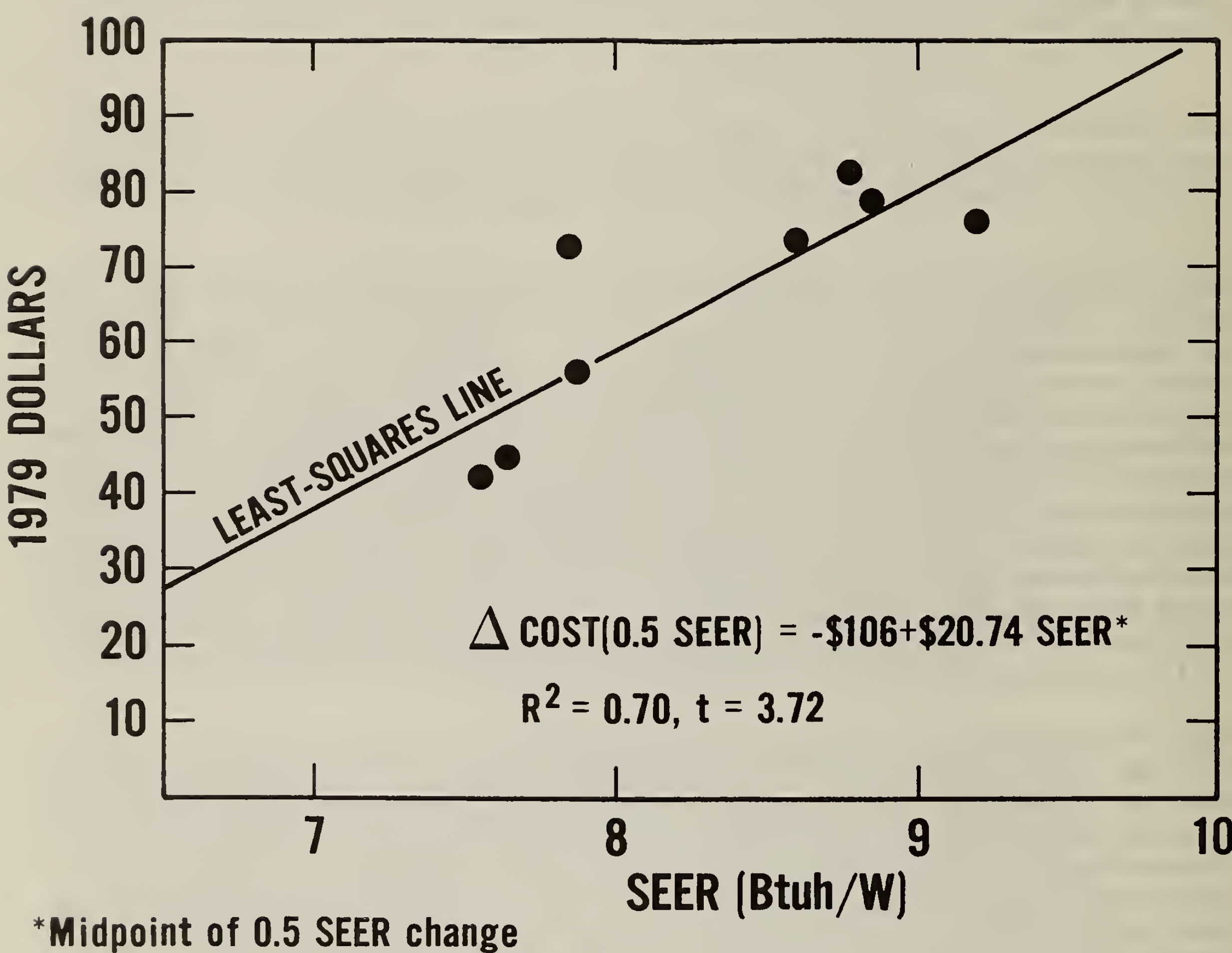


Figure 4.1 Incremental Cost per 0.5 Btu/W Improvement in SEER, List Price Data, 36,000 Btuh CAC.

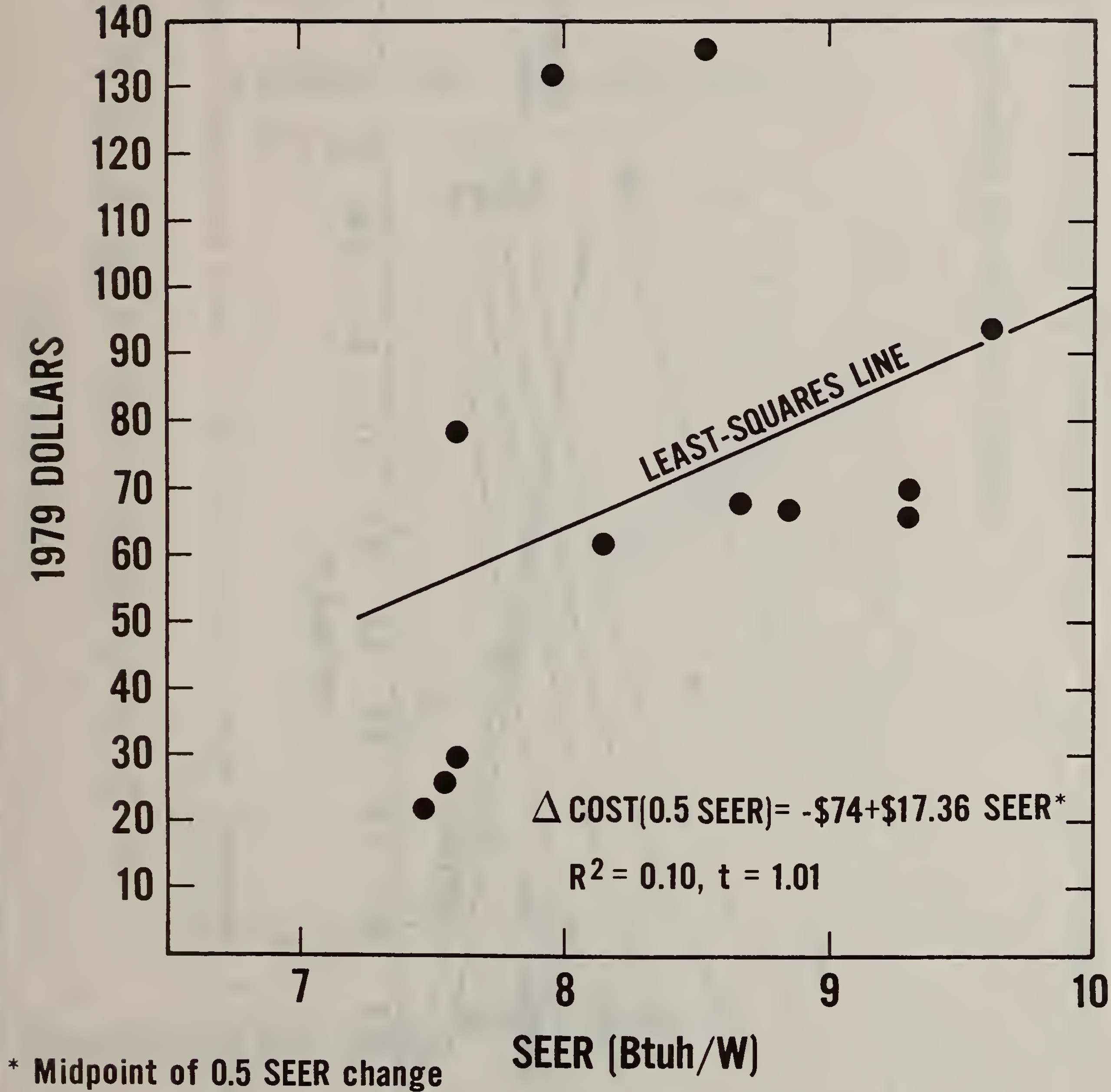


Figure 4.2 Incremental Cost per 0.5 Btu/W Improvement in SEER, ARI Sample, 36,000 Btuh CAC.

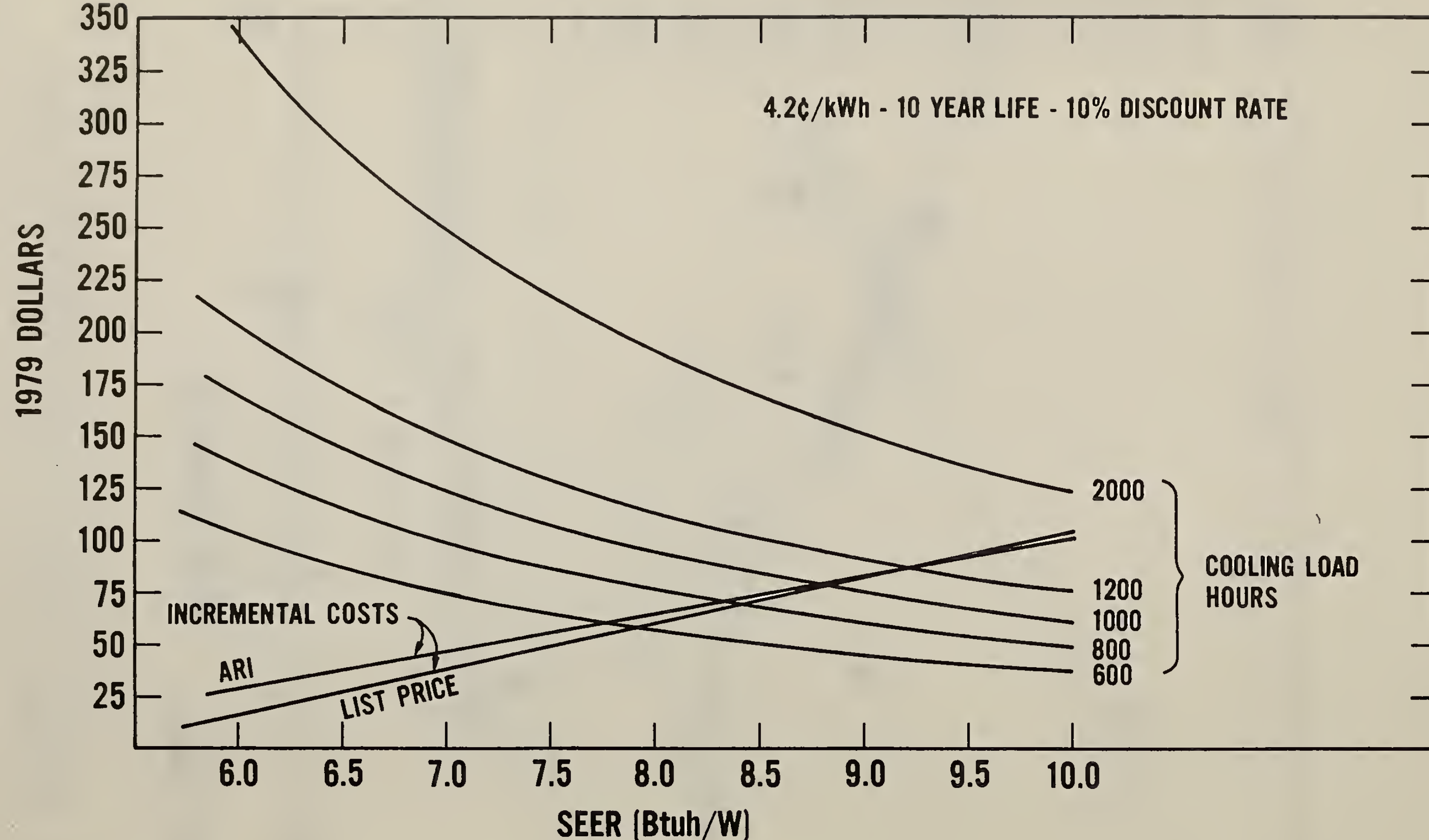


Figure 4.3 Incremental Dollar Savings and Cost per 0.5 Btu/W Improvement in SEER, 36,000 Btuh CAC.

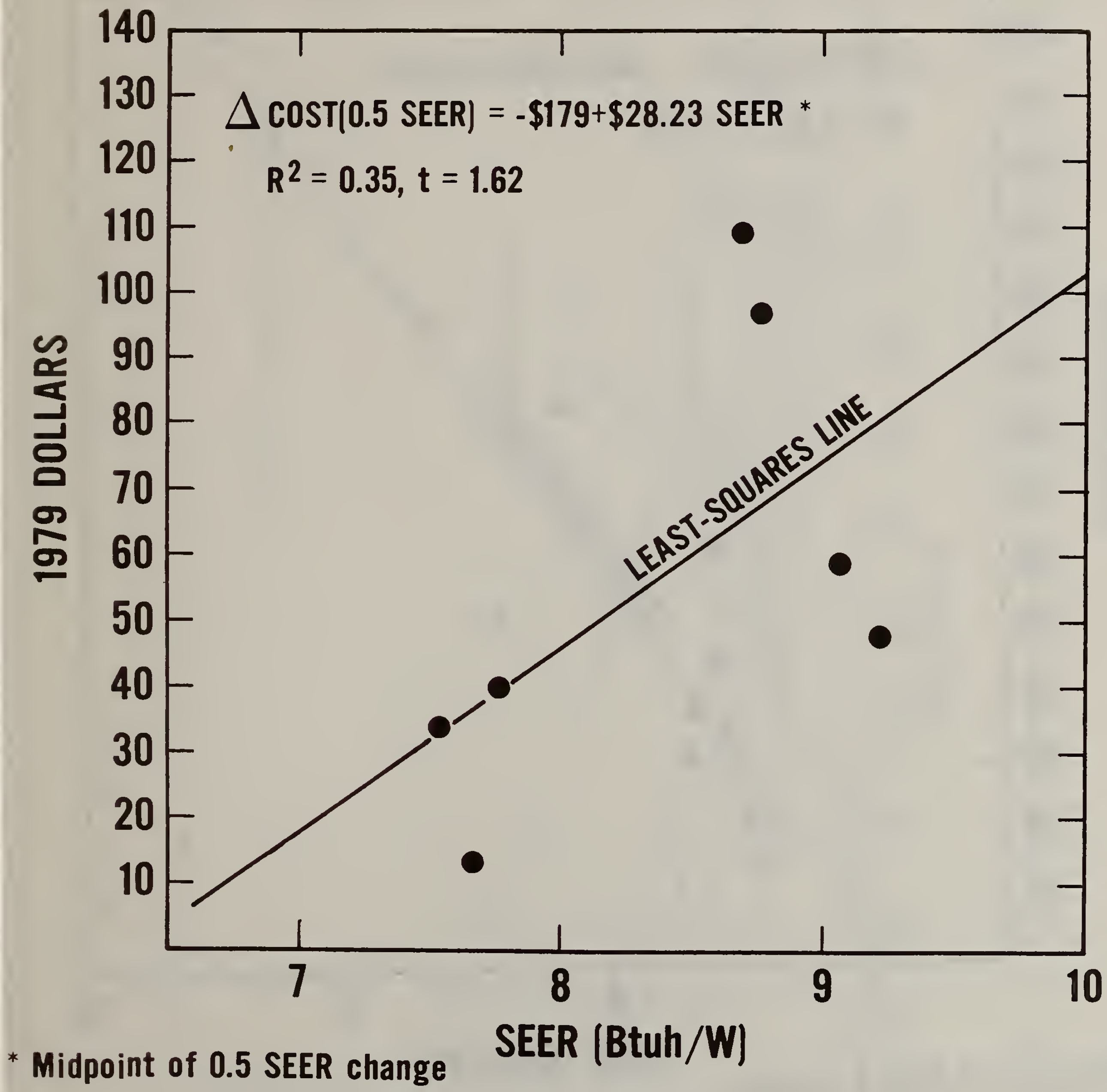
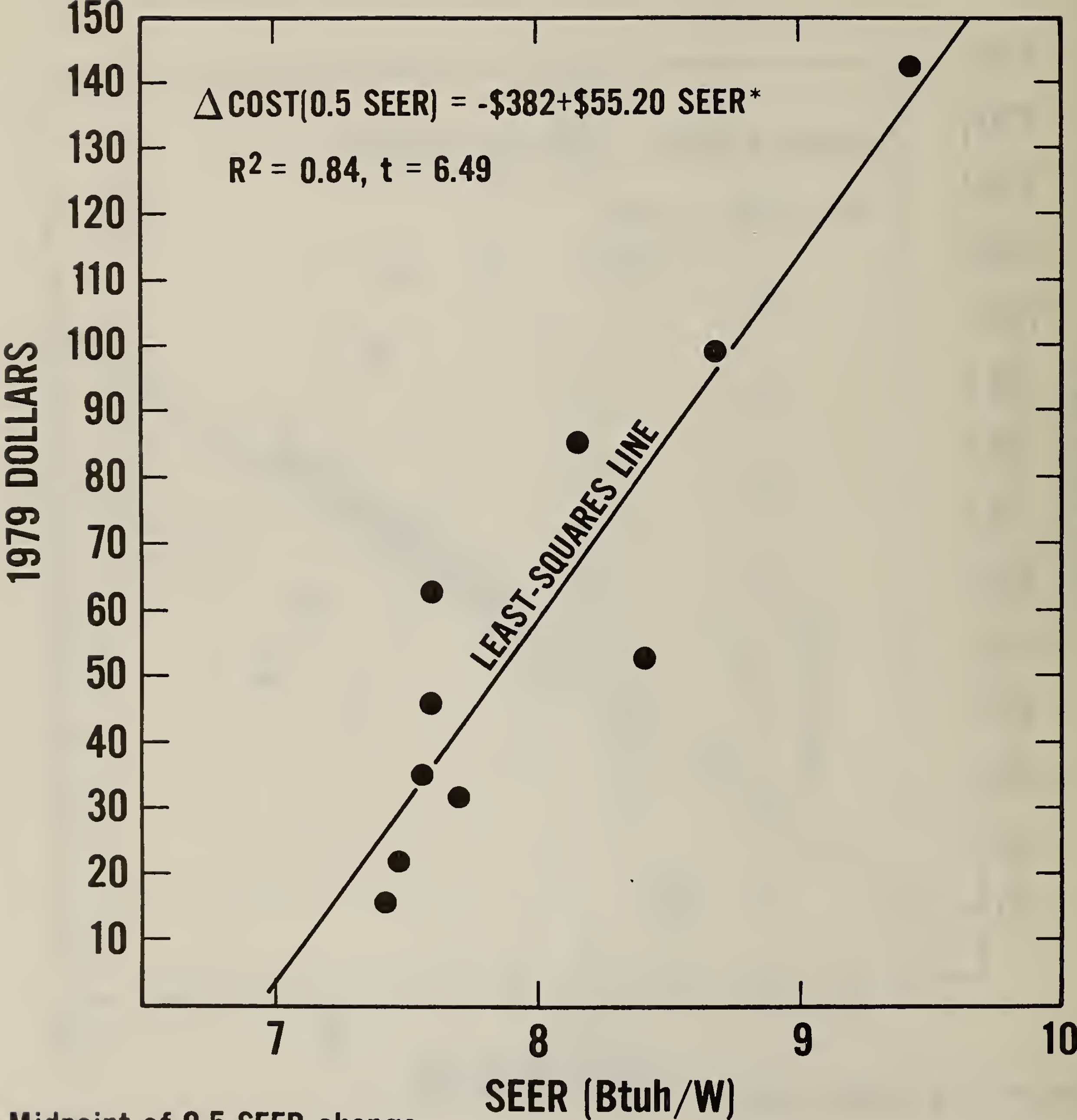


Figure 4.4 Incremental Cost per 0.5 Btu/W Improvement in SEER, List Price Data, 24,000 Btuh CAC.



* Midpoint of 0.5 SEER change

Figure 4.5 Incremental Cost per 0.5 Btu/W Improvement in SEER, ARI Sample, 24,000 Btuh CAC.

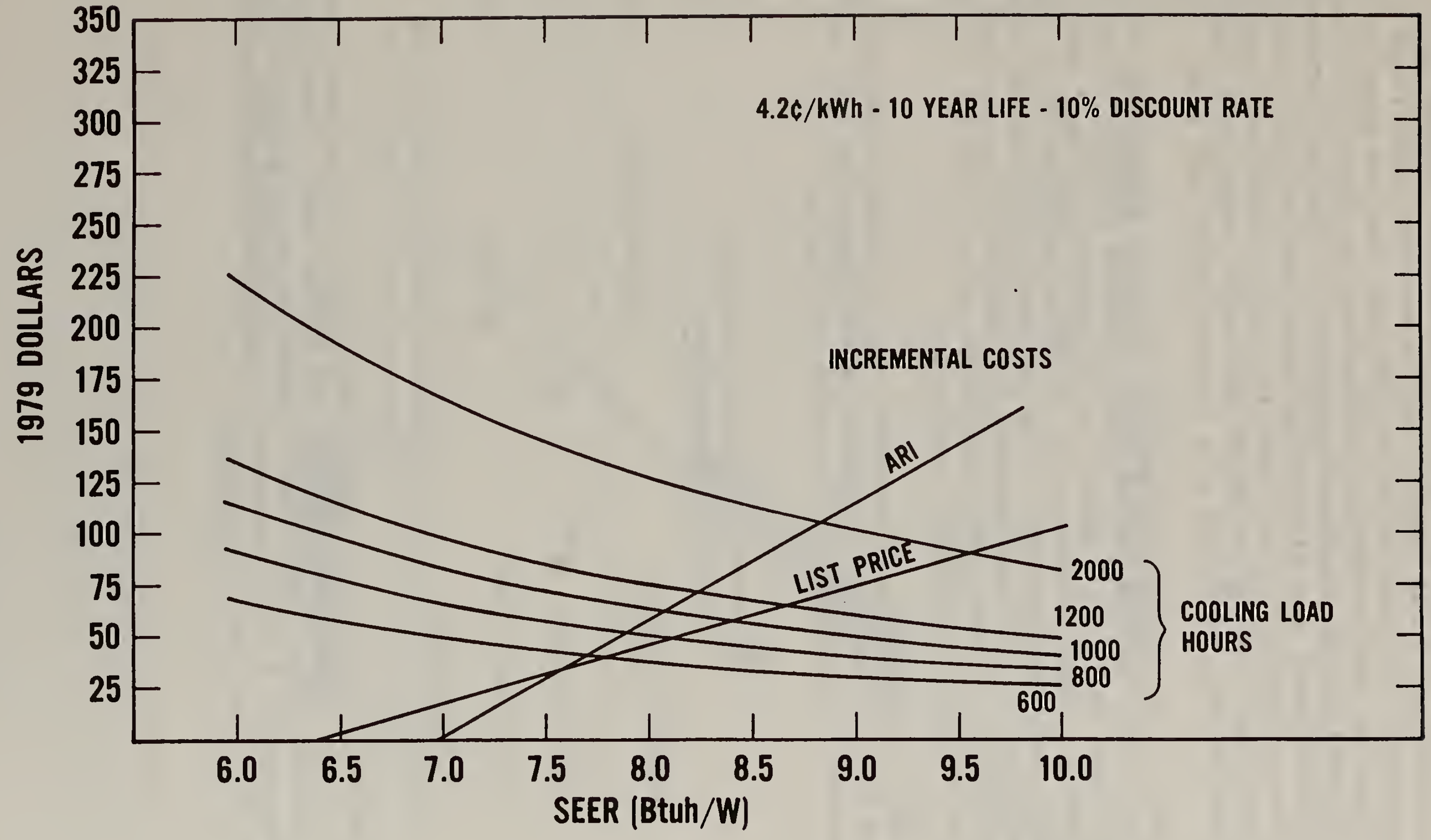


Figure 4.6 Incremental Dollar Savings and Cost per 0.5 Btu/W Improvement in SEER, 24,000 Btuh CAC.

able for each capacity can provide incremental cost lines that can be used to indicate trends. Incremental cost data for the 48,000 Btuh case are shown in figure 4.7 and are superimposed on the incremental savings data in figure 4.8. An approximate 8.1 EER results, with a half-unit SEER range of 7.85 to 8.35. Incremental cost data for the 60,000 Btuh case are shown in figure 4.9 and superimposed on the incremental savings data in figure 4.10. An approximate 7.7 EER results with a half-unit EER range of 7.45 to 7.95. These results, although based upon limited cost data, seem to imply that the 48,000 Btuh units are cost effective in a 600 CLH region at the same SEER level as the 36,000 Btuh units, while the 60,000 Btuh units behave more like the 24,000 Btuh units and are cost effective at a slightly lower SEER level.

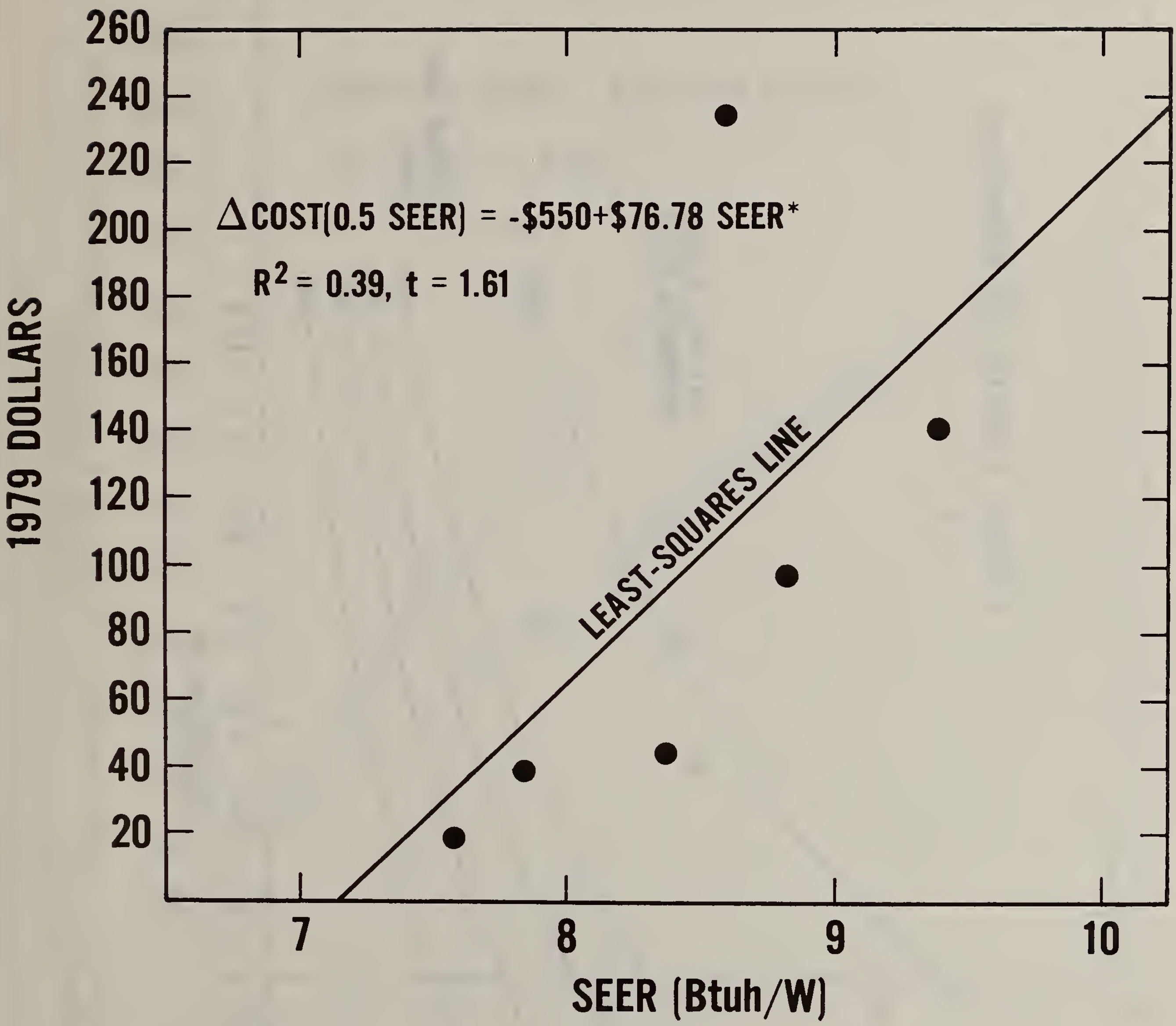
The above results, which indicate that the levels of SEER which are cost effective for 24,000 Btuh and 60,000 Btuh units are slightly lower than those for the 36,000 and 48,000 Btuh units, are in general agreement with the testimony presented by several manufacturers on the Advanced Notice of Proposed Rule Making for minimum standards. This testimony indicated that size limitations impacted the cost of manufacturing low capacity units and that both low and high capacity CACs, being low sales volume units, suffered from the unavailability of high performance compressors.

Based upon this limited economic analysis, the following intermediate minimum standards for split-system central air conditioners are cost justified for installations with approximately 600 cooling load hours.

Intermediate Minimum Standards
for Split-System CAC's

Capacity (Btuh)	Minimum SEER
Below 28,000	7.7
28,000 to 51,999	8.0
52,000-65,000	7.7

Setting intermediate standards at these levels will encourage manufacturers to concentrate their efforts on obtaining the highest SEER on their high volume, mid-capacity units. This should result in larger energy savings than achievable through a single minimum standard that is cost effective for all split systems, regardless of capacity.



* Midpoint of 0.5 SEER change

Figure 4.7 Incremental Cost per 0.5 Btu/W Improvement in SEER, List Price Data, 48,000 Btuh CAC.

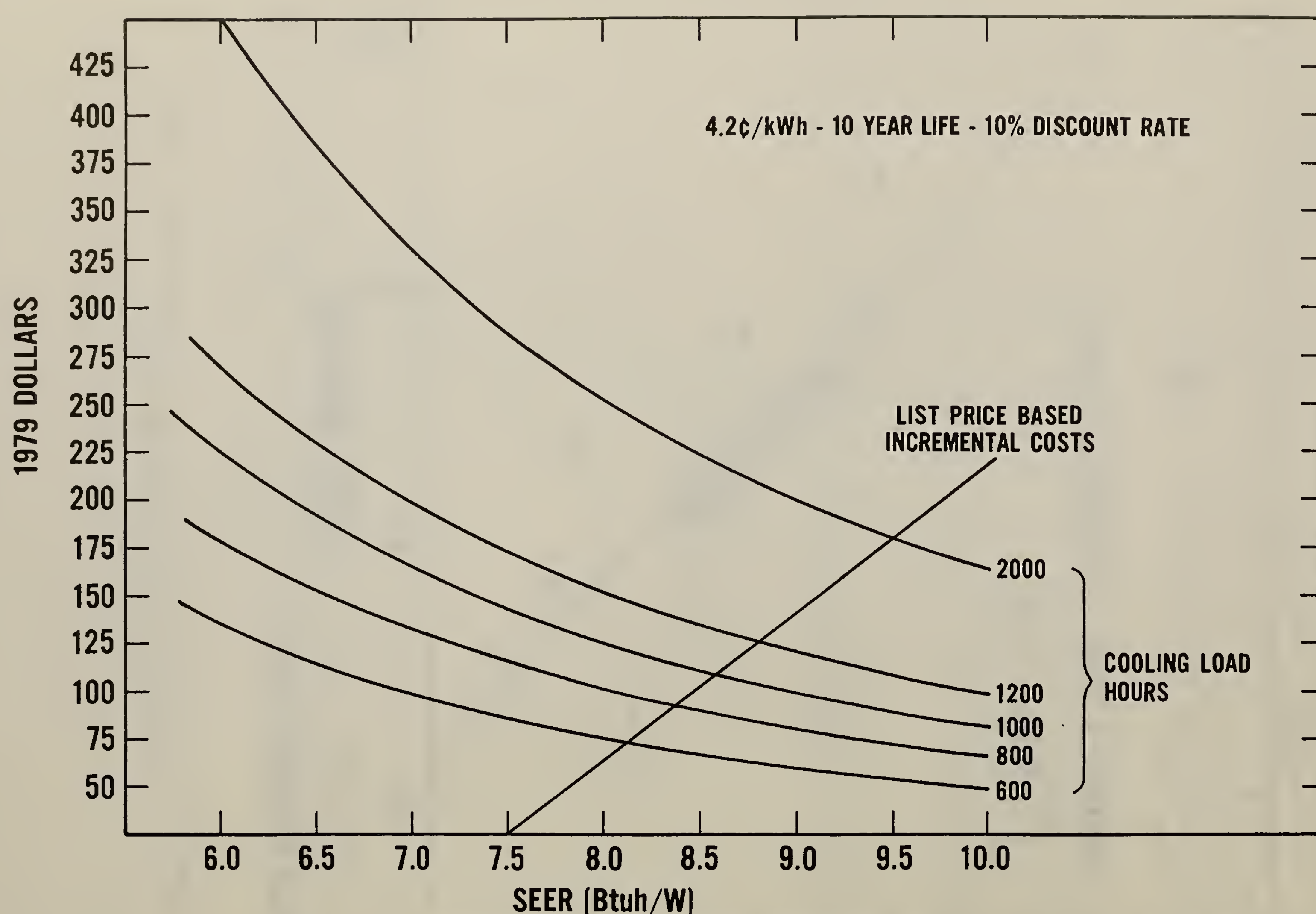


Figure 4.8 Incremental Dollar Savings and Cost per 0.5 Btu/W Improvement in SEER, 48,000 Btuh CAC.

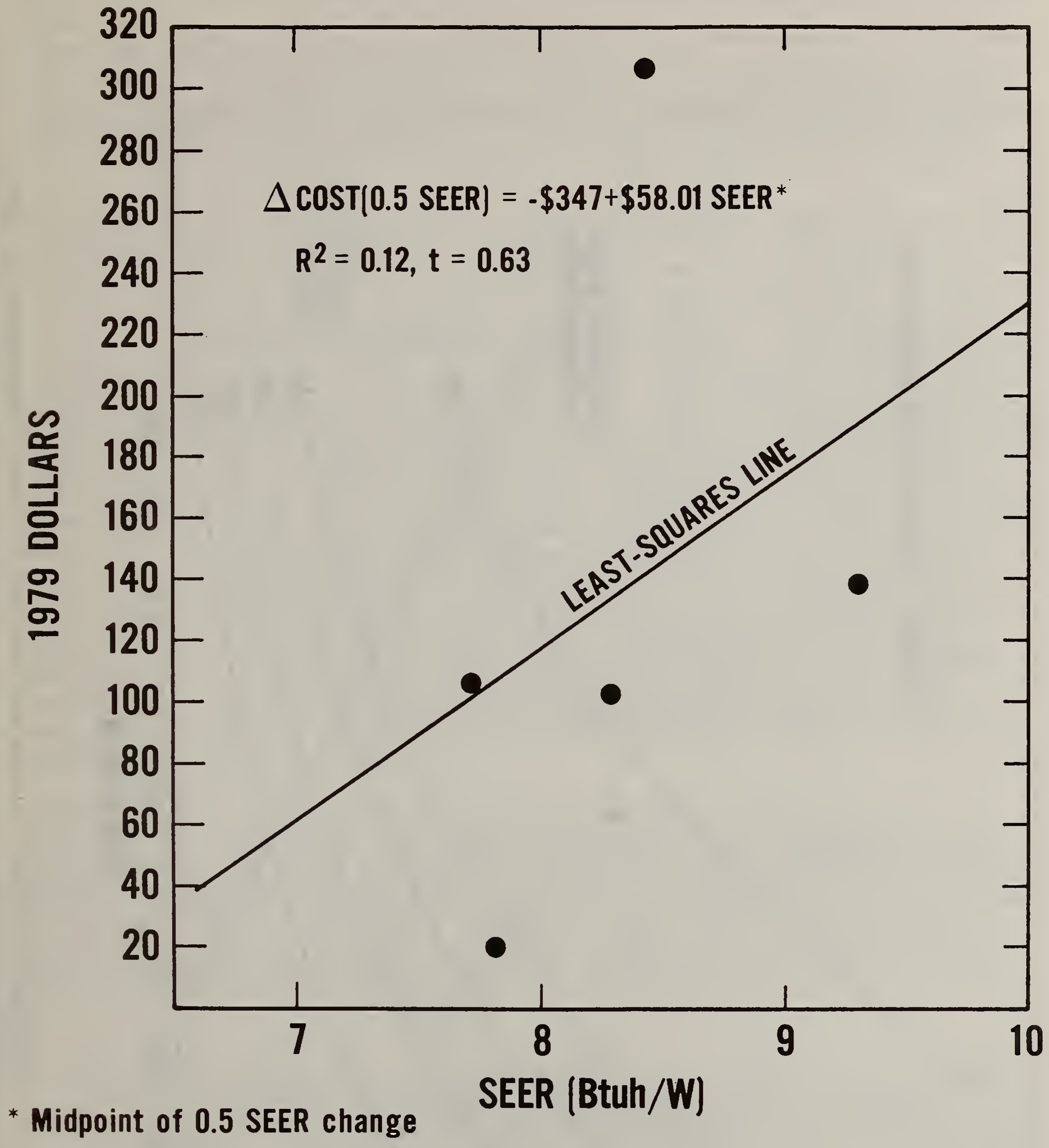


Figure 4.9 Incremental Cost per 0.5 Btu/W Improvement in SEER, List Price Data, 60,000 Btuh CAC.

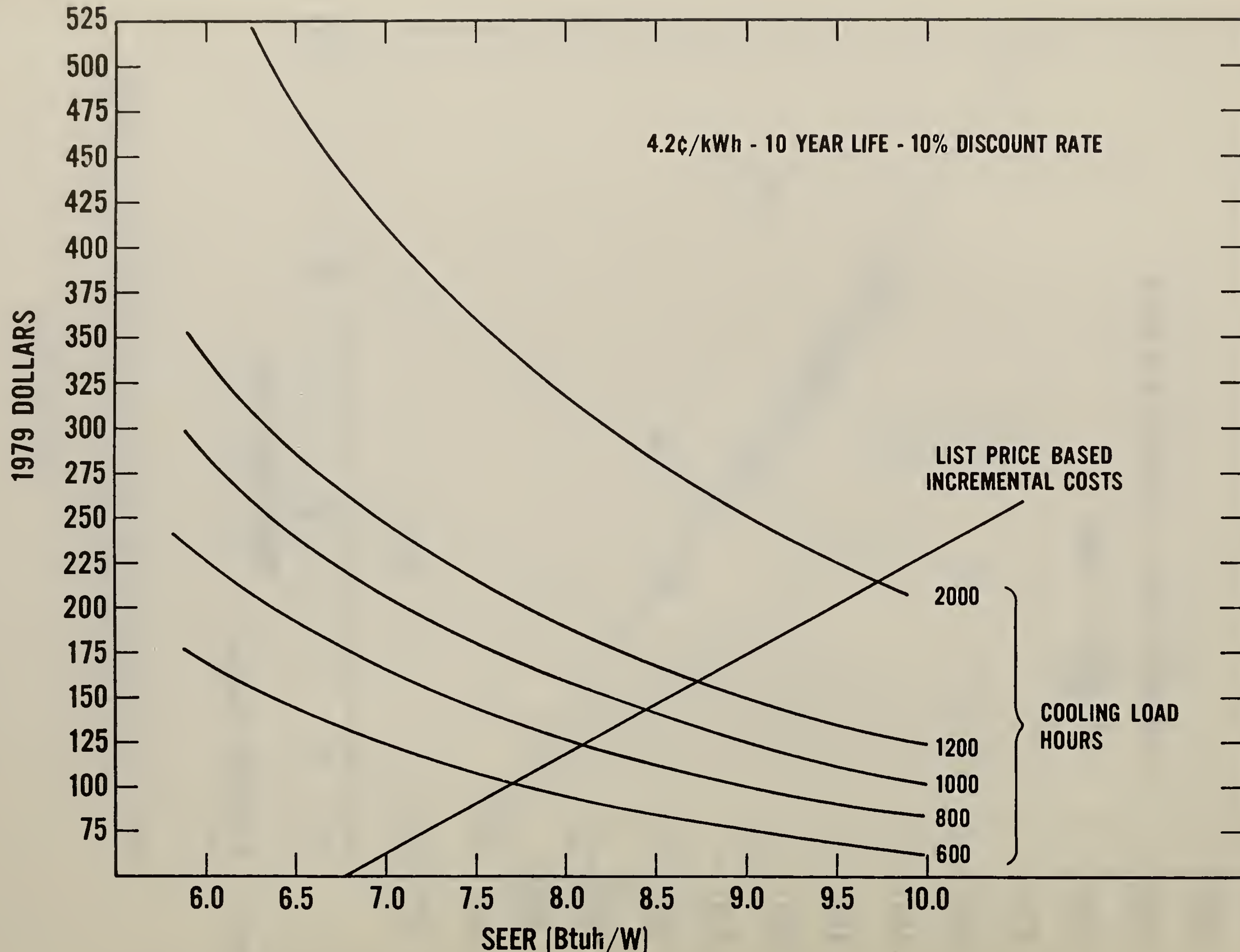


Figure 4.10 Incremental Dollar Savings and Cost per 0.5 Btu/W Improvement in SEER, 60,000 Btuh CAC.

4.2 ENGINEERING COST ANALYSIS AND 1985 MINIMUM STANDARDS FOR SPLIT SYSTEMS

The three major design modifications considered in this report for increasing the SEER of CAC's are improved compressor efficiency, improved fan motor efficiency, and increased condenser coil size. Increasing the evaporator coil size, which also improves SEER, was not considered because it leads to high sensible-to-total cooling ratios and reduced dehumidification which could result in poor comfort conditions in many regions of the country.

To analyze the cumulative effect of these modifications, NBS contracted with Purdue University to undertake a detailed engineering analysis [7] of several different types of central air conditioner systems using a sophisticated computer model developed by a major air conditioner manufacturer. In addition, a simple engineering analysis was also performed at NBS using typical values of saturated suction and discharge temperatures, return gas temperature, degrees of subcooling, fan power, etc.[1] The results of both of these analyses are shown in figure 4.11 for a split system. This figure shows the effects of improved compressor EER (horizontal axis) on system EER (vertical axis), given the condensing temperature of the system. System EER curves are shown for five condensing temperatures ranging from 130° to 110°F based on the NBS analysis. These curves include a fan motor efficiency of 66 percent. Lowering the condensing temperature, which increases the EER of the CAC, is achieved by adding more condenser coil to the outdoor condenser unit. This requires not only a larger coil, but a larger condenser unit and thus can add significantly to the cost of the CAC. System EER curves based on the Purdue University analysis for two condensing temperatures (120-115°F) are also shown in figure 4.11. The Purdue curves are somewhat steeper than the NBS curves because a 10 percent increase in fan motor efficiency (from 60 to 66 percent) is incorporated at the upper end but not at the lower end. In fact, there is a considerable degree of consistency between the two sets of data.

Information on how the cost of a split-system CAC is affected by reducing the condenser temperature (corresponding to using larger condensing units) was taken from testimony presented by the Carrier Corporation in 1976 to the California State Energy Resources Conservation and Development Commission.[8] Based upon Carrier's California testimony, figure 4.12 shows the estimated total and incremental increase in condenser coil costs, in 1979 dollars, associated with decreasing the condensing temperatures from 130°F to 110°F for a 36,000 Btuh split-system CAC.

---

[1] This simple engineering analysis was based on the following assumptions: a standard condenser fan typically uses 120 w/ton of air conditioning, while an improved condenser fan uses 10 percent less power; the evaporator fan typically uses 146 w/ton of air conditioning; the evaporating temperature is 45°F in all cases; the subcooling assumed is 20, 18, 16, 12 and 8°F for condensing temperatures of 130, 125, 120, 115 and 110°F respectively; compressor EER's are based on an evaporating temperature of 45°F and a condensing temperature of 130°F; and a 1°F drop in the condensing temperature typically increases the system EER by 1.5 percent.

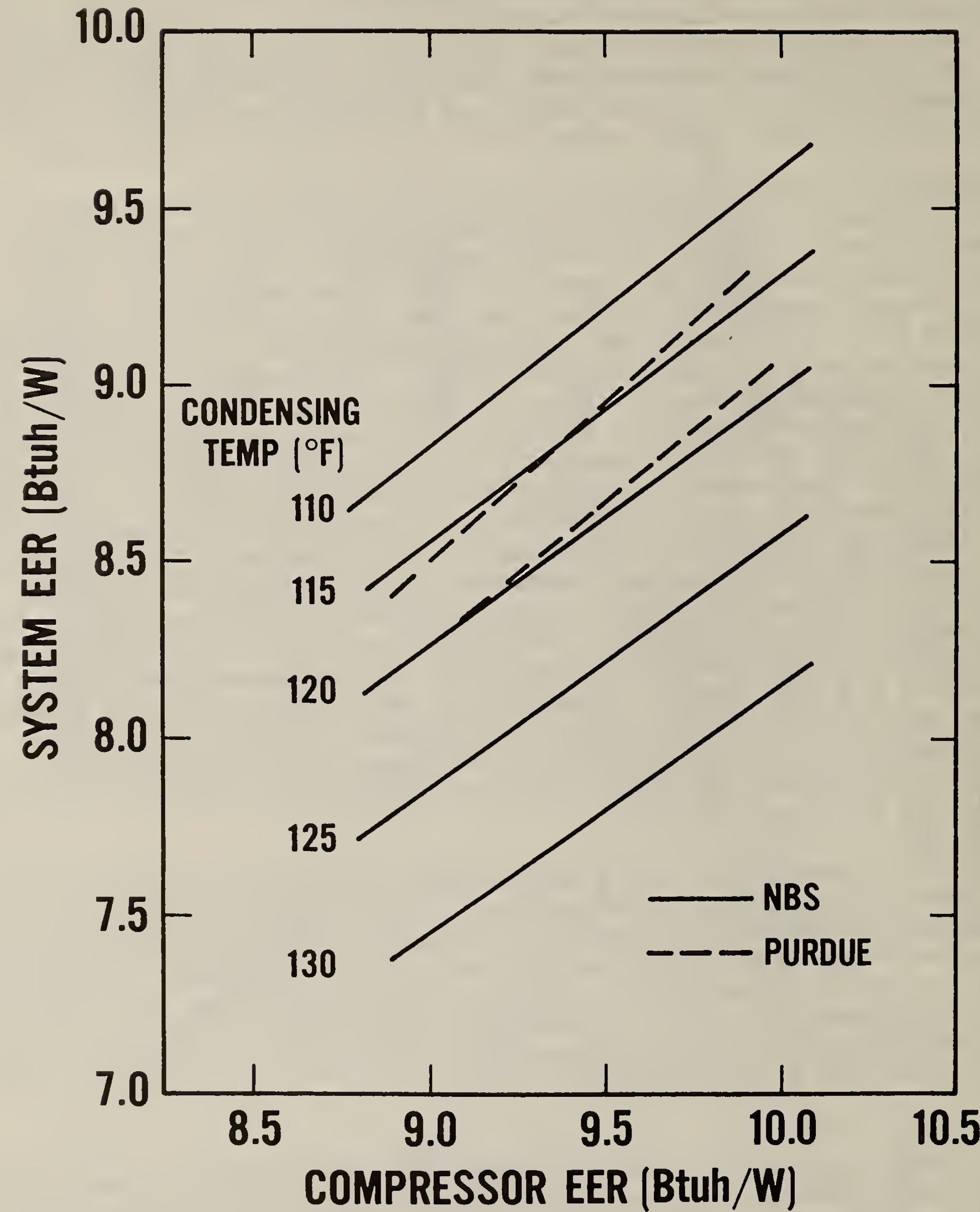


Figure 4.11 System EER as a Function of Compressor EER and Condensing Temperature.

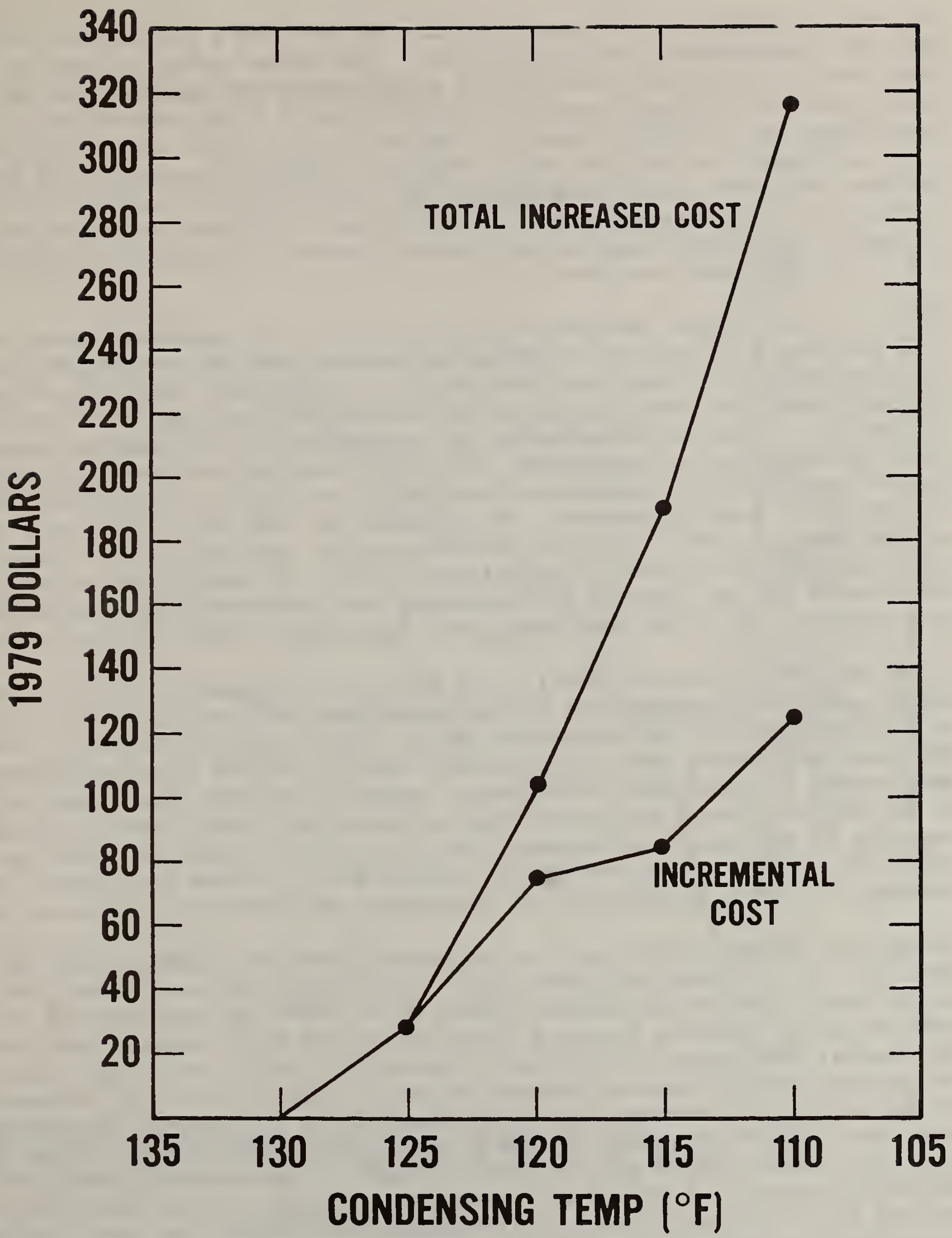


Figure 4.12 Cost Estimates for Reducing Condensing Temperatures, 36,000 Btuh CAC.

Figure 4.13 shows the estimated increase in cost for a 36,000 Btuh compressor with EER improvements from 8.8 to 10.7. This latter data is based on a relative cost factor curve provided by a major compressor manufacturer and an assumption that the base cost of a 36,000 Btuh, 8.8 EER compressor is approximately $240 at the retail level[1]. The additional retail cost of the ten percent improvement in the fan motor efficiency (from 60 percent of 66 percent) has been estimated to be less than $2.00 and is therefore assumed to be cost effective in all installations. (A 66 percent efficient fan motor has been assumed in the simple engineering analysis shown in figure 4.11 and is implicit in the following analysis.)

Using the performance data shown in figure 4.11, the cost data shown in figures 4.12 and 4.13 and the relationship between SEER and system EER presented in equation 4.1, a least-cost combination of compressor improvements and reduced condensing temperatures is established for any SEER level between 7.7 and 9.7. This is accomplished by considering the incremental costs of a small increase in the system EER, either by reducing the condensing temperature or improving the compressor efficiency, and then selecting the modification which is least expensive. For example, the EER of a 36,000 Btuh unit can be improved from 7.3 to 7.7 by reducing the condensing temperature from 130°F to 125°F at a cost of approximately $30. The same increase in system performance can be achieved by increasing the compressor EER from 8.8 to 9.3 at a cost of $10. Thus this compressor improvement would be made first.

At an EER of 7.7 (the new level), the EER can be raised to 8.1 at a cost of $30 if condensing temperature is decreased from 130°F to 125°F, or at a cost of $35 ($45-$10) if the compressor EER is raised from 9.3 to 9.95. Now the decreased condensing temperature is more cost effective than the further improvement in compressor efficiency. However, the next step, from an EER of 8.1 to 8.58, would be accomplished at least additional cost by making the increase in compressor efficiency from 9.3 to 9.95. (This has been rounded from 9.95 to 10.0 at an incremental cost of $40.) Beyond this point, the increase in EER is made solely by decreasing the condensing temperature.

The path of lowest total cost for increasing SEER, as adjusted from EER using equation 4.1, is shown in figure 4.14. From this total cost curve, an incremental cost curve can be derived, based on 0.5 SEER improvements for the same SEER intervals shown in figure 3.2 for the 36,000 Btuh system. This new incremental cost curve is plotted in figure 4.15 and is replotted along with the appropriate incremental savings curves in figure 4.16. The intersection of the incremental savings curve corresponding to 600 CLH and the incremental cost curve occurs at a point slightly below an 8.5 SEER. This implies that up to this point a half unit increase in SEER is economically justified. This half-unit increase, with 8.5 as the midpoint, would cover an SEER change from 8.25 to 8.75. If smaller than half-unit increments had been used, the maximum cost-effective level would tend to converge on an SEER of approximately 8.5.

---

[1] Based on 40 percent of the approximate $600 cost of a new 36,000 Btuh condensing unit in the lower SEER range. SAI [9] estimates that the ratio of compressor cost of condensing unit cost is typically 38 percent.

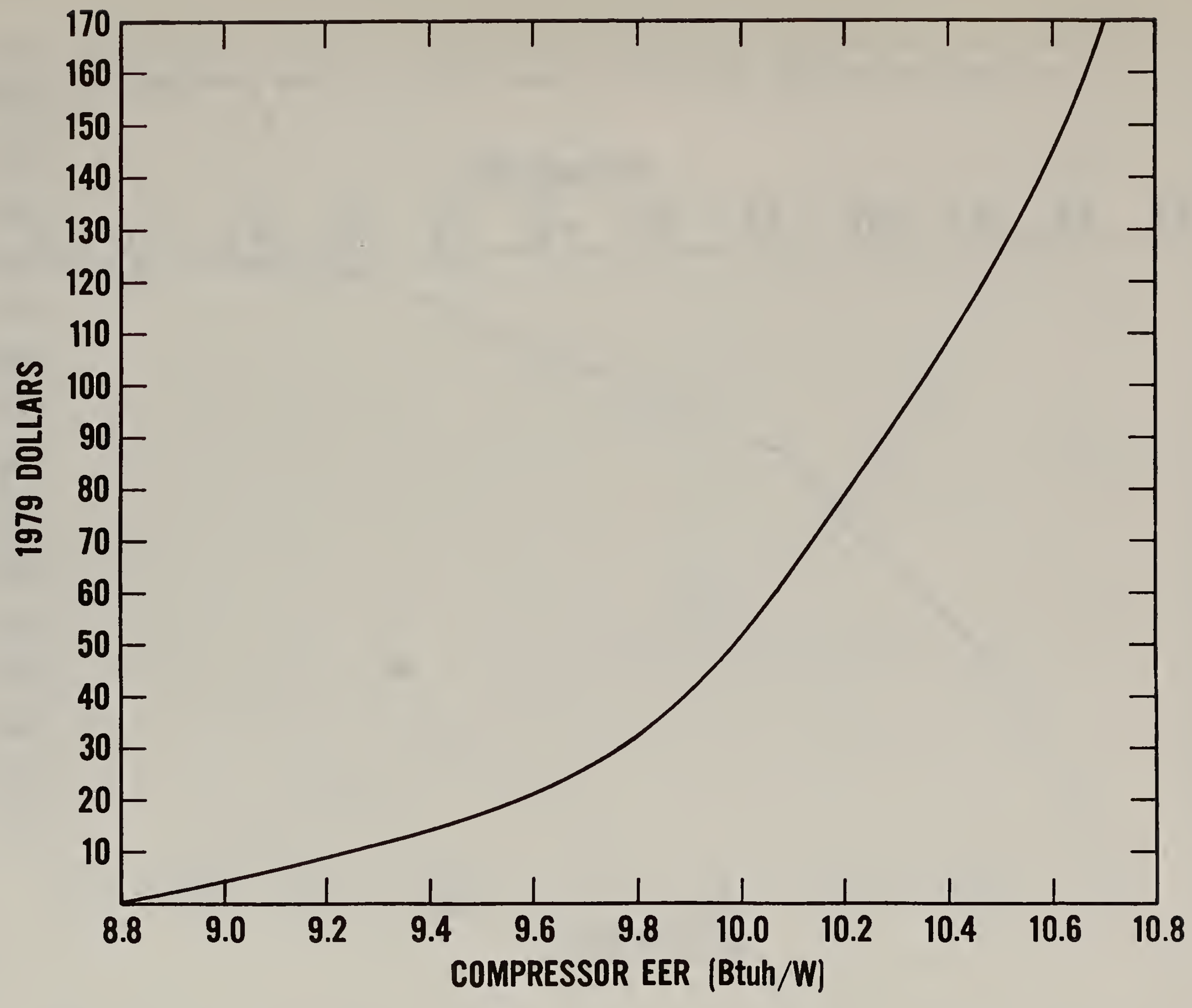


Figure 4.13 Increased Compressor Costs as a Function of Compressor EER.

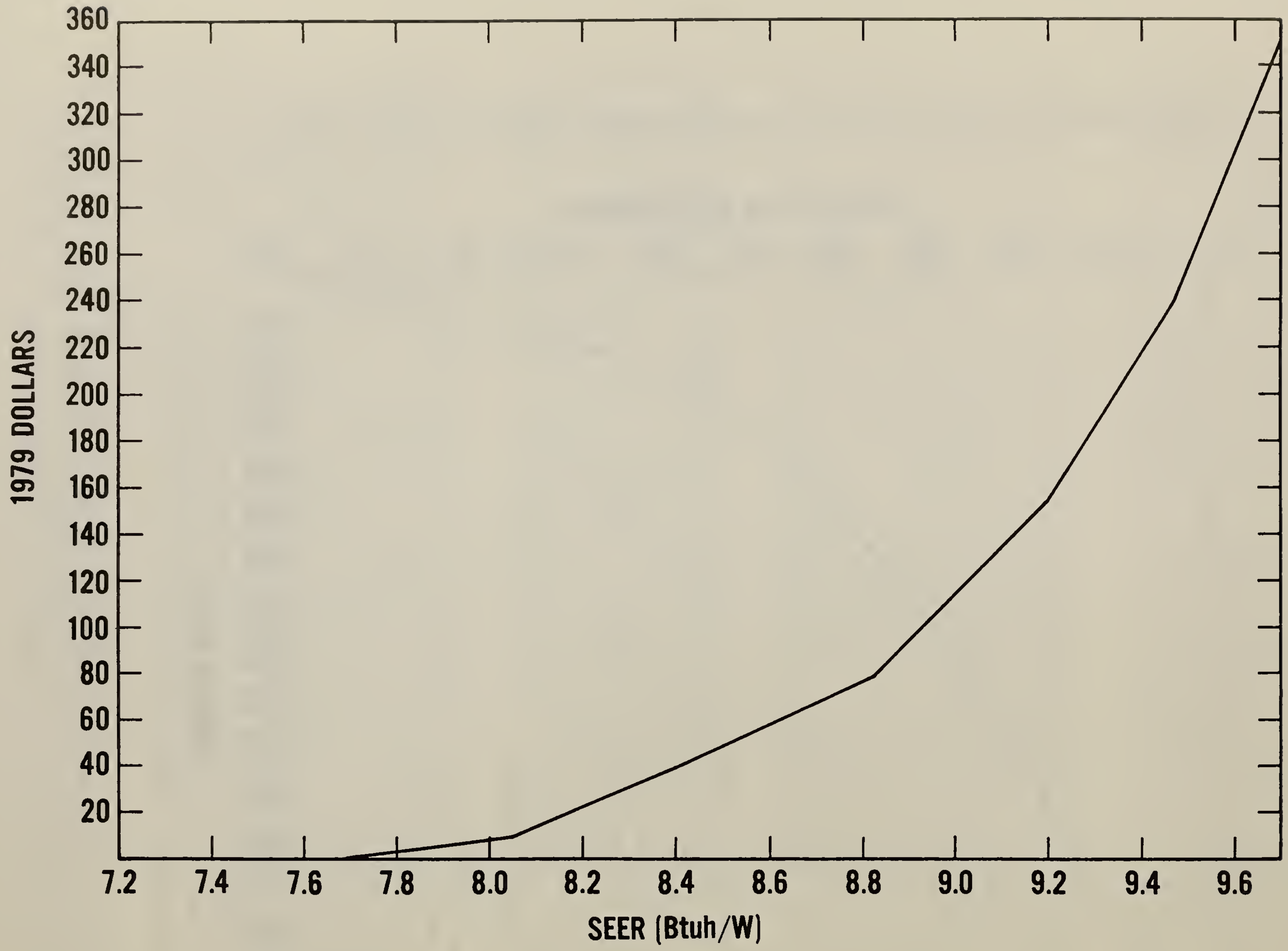


Figure 4.14 Increased Cost of 36,000 Btuh CAC by SEER, Engineering Analysis.

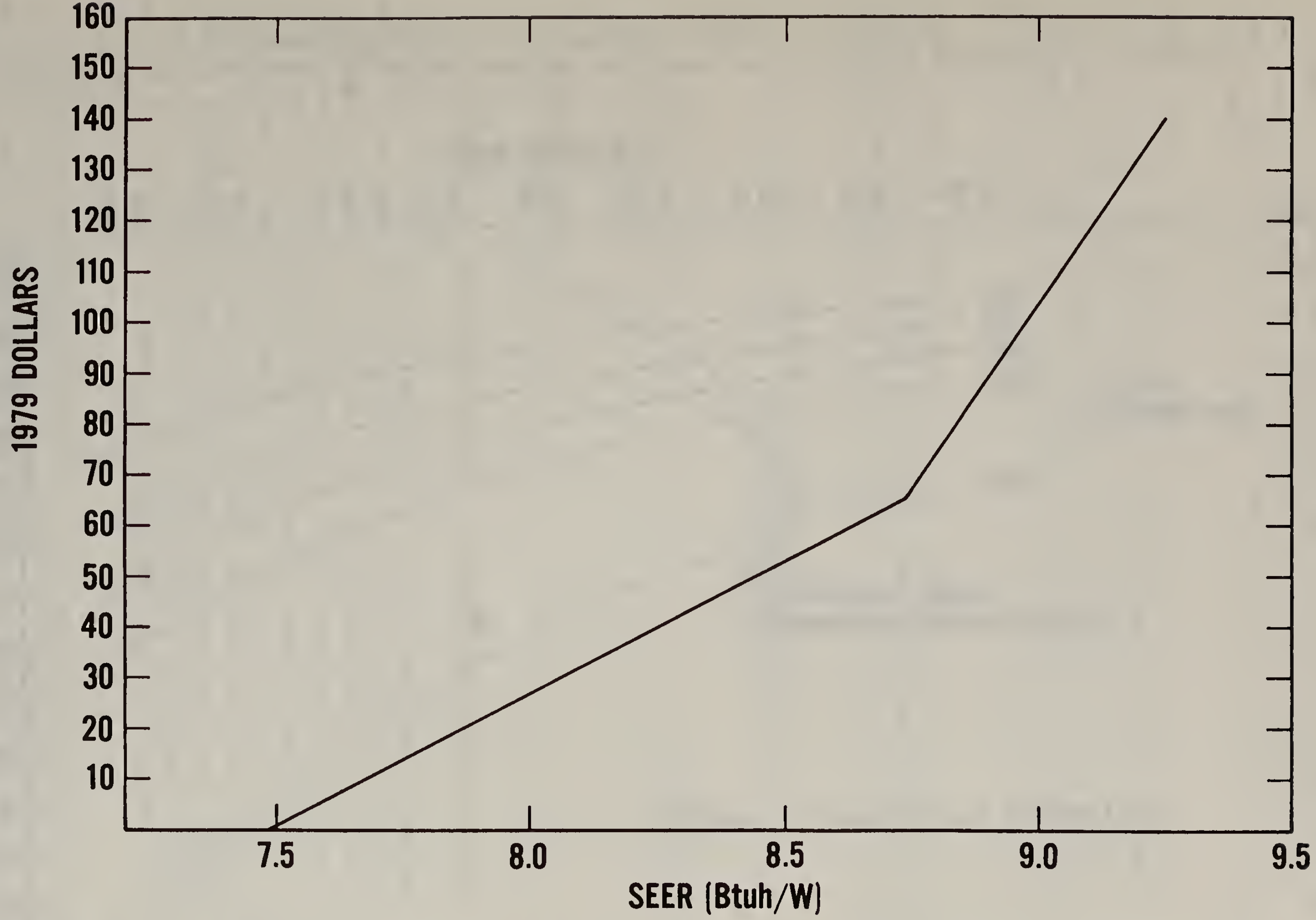


Figure 4.15 Incremental Cost per 0.5 Btu/W Improvement in SEER, Engineering Analysis, 36,000 Btuh CAC.

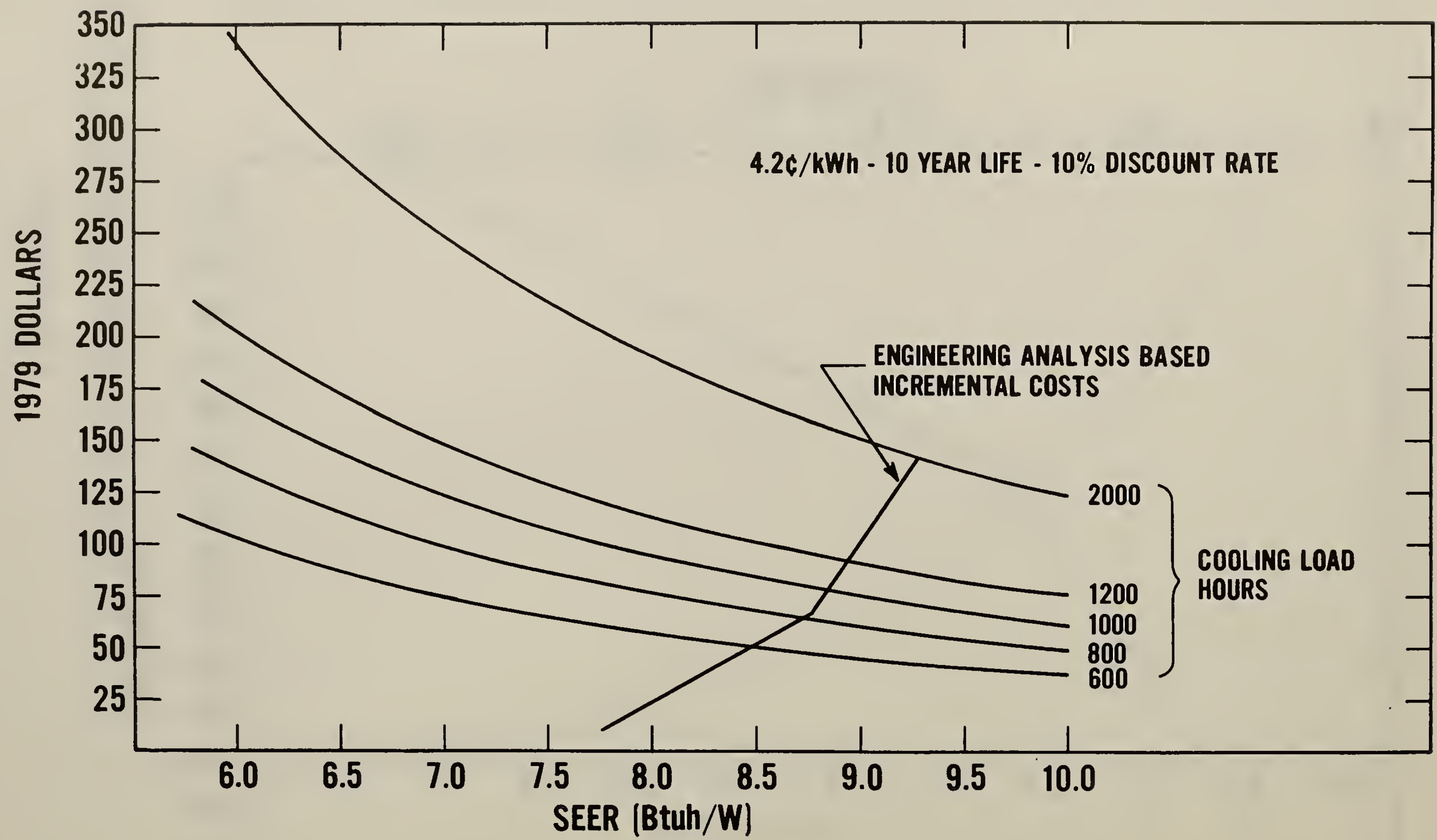


Figure 4.16 Incremental Dollar Savings and Cost per 0.5 Btu/W Improvement in SEER, Engineering Analysis, 36,000 Btuh CAC.

The above analysis could also be carried out for CAC's with different rated capacities, (e.g., 24,000, 48,000, and 60,000 Btuh), provided data were available to determine the effect of better compressors and larger condenser costs on the cost of differently sized units. These data are not currently available and are not likely to be in the near future. However, similar conclusions can be expected for all split-system CAC's, provided that compatable high efficiency compressors are available at the time of manufacture.

Based upon a review of currently available compressors, and those which are about to come on the market, it appears that by 1985 compressors with EER's in the neighborhood of 9.8 to 10.0 will be common in all capacities up to approximately 48,000 Btuh. Above 48,000 Btuh, compressors will likely be available by 1985 that are equal in performance to today's high efficiency, moderate capacity compressors; that is, that have EERs in the neighborhood of 9.2 to 9.5.

Based upon the above engineering and economic analyses and upon the assumption of compressor availability just described, the following tentative 1985 minimum standards for split-system CAC's appear to be economically justified on a life-cycle cost basis:

Tentative 1985 Minimum Standards for Split-System CAC's

Capacity (Btuh)	Minimum SEER
below 52,000	8.5
above 52,000	8.0

4.3 INTERMEDIATE AND 1985 MINIMUM STANDARDS FOR PACKAGE SYSTEMS

Ideally, the same type of analysis of retail cost data that was employed to arrive at economically justified intermediate minimum standards for split systems should also be carried out on package central air conditioners. However, package units constitute less than one-fifth of central air conditioner sales and the manufacturers of such units usually make only one (or at most two) product line(s). Since a minimum of three product lines having different levels of performance (e.g., good, better, and best) are needed to establish a meaningful relationship between incremental cost and SEER for a given manufacturer, it does not at this time appear possible to use the retail cost method to arrive at economically justified minimum standards for package systems.

To overcome these difficulties and to provide the Department of Energy with guidance on package CAC's, the analysis in this section is based on the detailed engineering analysis carried out by Purdue University [7]. The Purdue work, described in section 4.2, was performed under contract to NBS and was supported by funding supplied to NBS by the Department of Energy.

In addition to using a sophisticated computer model to evaluate the effect of design changes on split-system CAC's, Purdue University also performed the same type of analysis on package CACs and drew conclusions on the effect on performance of various design differences between split and package systems.

The Purdue University study showed that: a) cabinet losses in package systems probably account for a loss of 3.5-4.0 percent in efficiency, b) the power consumed by the indoor blower motor on package units contributes a loss of 2.5-3.5 percent (relative to that calculated using the DoE test procedure for split systems without indoor blowers) due to higher pressure losses, and c) the lower suction line pressure drop for package units tended to improve their efficiencies by one or two percent over split systems. Based upon these results, Purdue University concluded that a package unit would have a SEER from four to six percent lower than the SEER of a split system, assuming the "same" (i.e., having the same efficiency, size and type) compressor, condensor, evaporator and expansion device could be employed in both units. This upper value of six percent translates into an SEER for a package unit which is approximately 0.45 points lower than a comparably equipped split-system CAC having an SEER of 8.5.

Based upon the above results, the following tentative intermediate and 1985 minimum standards for package central air conditioners are provided for DoE's consideration:

Tentative Intermediate Minimum Standards for Package CAC's

Capacity (Btuh)	Minimum SEER
below 28,000	7.2
28,000 to 51,999	7.5
52,000 to 65,000	7.2

Tentative 1985 Minimum Standards for Package CAC's

Capacity (Btuh)	Minimum SEER
below 52,000	8.0
52,000 and above	7.5

The problem with this engineering factor approach to setting minimum standards is that it may lead to standards which may not be economically justified on a life-cycle basis. For instance, even though the minimum standards for split systems discussed above were developed using an economic optimization procedure and the difference in performance cited above between package and split system was based upon the use of the "same" compressor, coils, and expansion devices, there still could be differences which could lead to package units having larger (or smaller) incremental costs than comparably equipped split systems. Some of these differences are: package units tend to have larger cabinets requiring more sheet metal, shipping and installation changes might increase more rapidly with performance (size) than for split systems, and the lower number of units produced could lead to higher first costs. Whether these and other factors significantly affect the values recommended above for intermediate and 1985 standards can only be determined if additional cost data becomes available. Because of this, NBS labeled the above minimum standards for package CAC's as "TENTATIVE," and recommends: a) that DoE use these values only when they publish proposed minimum standards and b) DoE should, at that time, specifically request manufacturers to provide information on the cost of package systems at their (respective) proposed minimum standard levels and at levels above and below the proposed standard. This information can then be analyzed to determine whether the proposed intermediate and 1985 minimum standards for package CAC's should be revised.

5. SUMMARY AND CONCLUSIONS

A methodology, based on life-cycle cost analysis, has been developed to determine the maximum seasonal energy efficiency ratio (SEER) that can be economically justified for central air conditioners. This methodology is sensitive to cooling load hours, energy costs, and incremental costs of improvements in SEER, as well as other financial analysis criteria. The present dollar value of the energy savings realized from increasing SEER were calculated at a kWh cost of 4.2¢, based on the approximate 1979 average residential electricity cost, a life of 10 years, and a discount rate of 10 percent. Costs of improvements in SEER were estimated for a range of central air conditioner capacities, from 24,000 Btuh to 60,000 Btuh, based on current (1979) retail cost data from a number of sources. In addition, incremental costs of improvements in SEER were estimated in an engineering analysis of specific component improvements.

Based on an analysis of domestic central air conditioner sales, it was found that 90 percent of all such sales occur in regions with 600 or more cooling load hours. Since one criterion for the development of minimum SEER standards for new air conditioners is that such standards be cost effective, NBS recommends that no more than 600 CLH be used as a basis for establishing minimum acceptable levels of system efficiency. Other incentives, such as the generally high cost of electricity, labeling, and building energy performance standards should encourage the use of higher efficiency central air conditioning equipment where such an investment is warranted.

Using the retail cost data as a guide for near-term costs of higher efficiency central air conditioners, it was found that split-system central air conditioners in the 28,000-52,000 Btuh capacity range and having an SEER of approximately 8.0 could be economically justified in installations with at least 600 CLH annually.

For split-system central air conditioning units above and below this range, a slightly lower level, approximately 7.7, is probably the maximum level that can be economically justified at present due to lower volumes and less well matched components.

Using engineering analysis and cost data for actual component modification it appears that an SEER of 8.5 may be economically justified for split systems with a capacity less than 52,000 Btuh, and 8.0 above that point, provided that higher efficiency compressors are available to the system manufacturers. NBS suggests that this higher SEER level may be more appropriate as the basis for a 1985 standard than for interim standards.

Although adequate incremental cost data for SEER improvements for package systems is not available, some quantitative engineering data on inherent performance differences between split systems and package systems is available. This data suggests that standards for package units should be approximately 0.5 SEER less than those for split systems.

The general methodology presented in this report can be quite useful for providing quantitative data for minimum standards development. Refinements in the analysis of the incremental cost data can be made over time as such data becomes available. While other factors must be considered in the development of the final standards, such as the impact of such standards on the manufacturers and the levels of competition among the manufacturers, the data provided from this preliminary analysis can provide benchmark data that can serve as a central point of reference for such further analysis.

REFERENCES

1. "Advance Notice of Proposed Rulemaking and Notice of Public Meetings Regarding Energy Efficiency Standards for Nine Types of Consumer Products," Department of Energy, Office of Energy Conservation and Solar Applications, Federal Register, Volume 44, No. 1, Tuesday, January 2, 1979.

2. "Proposed Rulemaking and Public Hearing Regarding Test Procedures for Central Air Conditioners, Including Heat Pumps," Federal Register, Vol. 44, No. 77, Part II, April 19, 1979.

3. G. E. Kelly, and W. H. Parken, Jr., Method of Testing, Rating and Estimating the Seasonal Performance of Central Air Conditioners and Heat Pumps Operating in the Cooling Mode, NBSIR 77-1271, National Bureau of Standards, April 1978.

4. R. R. McConnell, et al, "Reducing Energy Consumption During the Cooling Season," ASHRAE Journal, June 1976, pp. 61-65.

5. S. Borg and R. Moden, "Historic and Forecasted Energy Prices by U.S. DoE Region and Fuel Type for Three Macroeconomic Scenarios and One Imported Oil Price Escalation Scenario," DoE/EIA-0102127, U.S. Department of Energy, December 1978.

6. "Unitary Heating and Cooling Section's Report of Trading-Area Sales of Air Conditioners, Year-Round Air Conditioners-Single Package, Heat Pumps, and Split Systems," Form UT-5-Q, Air Conditioning and Refrigeration Institute, January-December, 1977.

7. William E. Murphy and Victor W. Goldschmidt, Analysis of the Performance Improvements of Central Air Conditioners for Residences, HL 78-25, Purdue University (Ray W. Herrick Laboratories), 1978. (Contract report to NBS).

8. Letter from Carrier Corporation to ERCDC, State of California, Docket No. 75-CON-3, August 10, 1976.

9. Energy Efficiency Program for Room Air Conditioners, Central Air Conditioners, Dehumidifiers, and Heat Pumps, Science Applications, Incorporated, March 1978.

10. Steven B. Thomas, David R. Tree, and Victor W. Goldschmidt, A Study of the Prediction and Measurement of Air Conditioning System Seasonal Performance Characteristics, HL 79-2, Purdue University (Ray W. Herrick Laboratories), 1979.

NBS-114A (REV. 9-78)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO. NBSIR 80-1993	2. Gov't. Accession No.	3. Recipient's Accession No.

4. TITLE AND SUBTITLE
Economic Analysis of Improved Efficiency for Central Air Conditioners in Support of Minimum Standards Development

5. Publication Date
June 1980

6. Performing Organization Code

7. AUTHOR(S)
Stephen Petersen, George E. Kelly, David A. Didion

8. Performing Organ. Report No.

9. PERFORMING ORGANIZATION NAME AND ADDRESS

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, DC 20234

10. Project/Task/Work Unit No.
742 2507

11. Contract/Grant No.

12. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS *(Street, City, State, ZIP)*

Dept. of Energy
20 Massachusetts Ave., NW
Washington, D.C. 20585

13. Type of Report & Period Covered
Final

14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The development of minimum performance standards for central air is required by the National Energy Act of 1978 and is the responsibility of the Department of Energy (DOE). This report attempts to assist DOE in this endeavor by providing an analysis of the life-cycle savings and costs associated with improvements in the energy efficiency of central air conditioners. It develops a rational methodology that can be used in setting minimum standards which are economically and technically justified and makes recommendations which the authors feel meet these criteria for both split and package central air conditioners.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Central air conditioners; economic analysis; incremental savings; life-cycle costs; minimum efficiency standards; minimum energy-efficiency levels

18. AVAILABILITY [X] Unlimited

☐ For Official Distribution. Do Not Release to NTIS

☐ Order From Sup. of Doc., U.S. Government Printing Office, Washington, DC 20402, SD Stock No. SN003-003-

[X] Order From National Technical Information Service (NTIS), Springfield, VA, 22161

19. SECURITY CLASS (THIS REPORT)	21. NO. OF PRINTED PAGES
UNCLASSIFIED	54
20. SECURITY CLASS (THIS PAGE)	**22. Price**
UNCLASSIFIED	$7.00

USCOMM-DC