COST OF INDUSTRIAL ENERGY-EFFICIENCY MEASURES: ITS EFFECT UPON THEIR IMPLEMENTATION

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Introduction

Energy efficiency captured the attention of all societal sectors in the 1970s when energy supplies diminished and energy prices increased. The industrial sector reacted with varying effectiveness, but small- and medium-sized plants generally lacked the resources to cope effectively. One of the U.S. government's responses was to offer them technical assistance, such as the Industrial Assessment Center Program.[1]

Though many factors have intervened since then, manufacturers still seek ways to reduce costs and enhance profitability, and improved energy efficiency is one of those ways. Naturally, questions arise about how to reach that goal, but it is essential first to identify measures to improve energy efficiency and then decide their implementation according to criteria of feasibility and profitability. Technical assistance identifies the measures and provides data for decisions whether or not to implement.

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Costs of those measures are an obviously essential component of profitability, but too little is known about the effects of implementation cost and its related parameters of savings rate and pay-back time. One possibility is that the size of implementation cost could be independently controlling, regardless of return on investment, especially among small- and medium-sized manufacturing plants. If the implementation cost is so high that it becomes a deterrent, questions arise about the implications of that deterrence for public policy. *In other words, is the cost of implementation so important that it becomes a public policy issue?*

To address that question we examined results of recommended and implemented measures to improve energy efficiency among 3,831 small- and medium-sized plants during each of the years from 1993 through 1997. The data, which are available via Internet access,[2] represent results of energy assessments conducted in plants by university engineering faculty and their students. They function with support from the U.S. Department of Energy through the Industrial Assessment Center (IAC) Program.

Methodology of Data Selection and Analysis

Assessments conducted in the 3,831 small- and medium-sized plants between 1993 and 1997 produced 23,531 recommended energy conservation opportunities (ECOs). In the database each plant's record includes the implementation cost, the associated energy and cost savings, the energy sources involved, and the fate of each ECO (whether implemented or not). Moreover, every recommendation is given a number, called the assessment recommendation code (ARC), corresponding to its category.[3]

Assessment data are stored in two databases, ASSESxxy.DBF and RECCxxy.DBF. The xxy refers to the version number (xx) and number of revisions made to the current version (y). The information in the databases is arranged in alphabetical order by IAC, and within a particular IAC, the records are arranged in chronological order. ASSESxxy.DBF contains plant information such as standard industrial classification (SIC) code, annual sales and production figures, number of employees, plant area, energy and materials usage and costs, and assessment information such as report number, date, and location. RECCxxy.DBF contains assessment recommendation information. That is, each one of the recommended ECOs is archived and relevant information such as ARC type (i.e., 2 = energy, 3 = waste, 4 = productivity), ARC number, implementation status, implementation cost, resource code, energy conserved (by sources), cost savings (by sources), and word description are documented.

Our objective was to learn the effects of implementation cost upon the decision to implement or not. To that end, we selected the five most recent years with relatively complete results in the database—fiscal year (FY) 1993 through FY

1997—and decided to examine them at different levels of detail.[4] To carry this task through, we located assessment date information in one database and linked it to the corresponding assessment recommendations in the other database. We isolated the data by fiscal year.

The ARC system organizes results into nine broad categories: (a) combustion systems; (b) thermal systems; (c) electrical power; (d) motor systems; (e) industrial design; (f) operations; (g) building and grounds; (h) ancillary costs; and (i) alternative energy usage.

The first level of detail that we used consisted of the following narrower categories (simplified here into two-digit numerical designations): 11 (furnaces, ovens, and directly fired operations); 12 (boilers); 13 (fuel switching); 21 (steam); 24 (heat recovery); 25 (heat containment); 26 (cooling); 32 (power factor and demand management); 34 (cogeneration); 41 (motors); 42 (air compressors); 43 (other equipment); 51 (industrial design systems); 61 (maintenance); 62 (equipment and control); 71 (lighting); 72 (space conditioning); 73 (ventilation); 74 (building envelope); and 81 (ancillary costs – administration).

Using three or more ARC digits permits even greater detail, and that information will be stated when appropriate.

As a single ECO criterion of implementation costs to be examined, we chose $10,000 because our experience had revealed that level as a realistic dividing line between more- and less-expensive classifications among managers of small- and medium-sized plants. We then tabulated the numbers of ECOs recommended in a category and the numbers implemented that cost at least $10,000 and those that cost less, together with their fractional frequency of implementation. For example, if a category of ECOs costing at least $10,000 had been recommended 50 times in a given year and implemented 30 times, the fractional frequency of implementation would have been 0.60.

In addition, for each year we tabulated for a category the aggregate cost savings, aggregate implementation cost, and simple payback, separated by the $10,000 criterion into more and less expensive.

Also tabulated was a term designated by the Greek letter gamma (γ), which is the ratio of the fractional frequency of implementation of more-expensive to that of less-expensive measures. If γ was equal to 1, then the two types of measures were implemented with equal frequency. Accordingly, if γ was less than 1, the more expensive were implemented less frequently. Values of γ were calculated for each of the stated two-digit ARC categories in a given year.

Once the values of γ had been tabulated, we attempted to relate them to patterns of other results for a specific ARC, such as aggregate values of implementation cost, cost savings, and simple pay-back times. The next section of this paper presents the results of those attempts.

To enhance the representative nature of the data examined, we decided to analyze only those two-digit ARCs that had been implemented at least 25 times in a given year. To ensure the significance of the measures costing $10,000 or more, we focused on those ARCs occurring at least 10 times in a given year.

Results

Plant Characteristics: Assessments of the 3,831 small- and medium-sized plants generated 23,531 recommendations to improve energy efficiency, of which 11,927 were reported as implemented. The universities' engineering faculties and students who conducted these assessments were contractually required to contact each plant served within a year to obtain specific data on the fate of every recommendation offered and then to report data to the IAC program database.

The implementation frequencies for each of the years examined show the consistencies in table 1.

The plants served represent a broad spectrum of industries, significant sales volumes, and considerable numbers of employees. Table 2 presents those characteristics for each of the years FY 1993-1997.

The number of plants in each industry varied from year to year, but they also exhibited similarities, as indicated in figures 1-5.

Figures 1-5 show some clearly defined trends in the distribution of plants audited each year by the IACs. For example, large number of plants within SIC codes 20, 30, 34, and 35 were audited each year while only a few plants within SIC codes 29, 31, and 39 were audited. This trend is largely the result of the criteria that plants must meet in order to be classified as small- and medium-sized, but it does not suggest that IACs target specific plants or that the plants with the highest assessment rates were the ones that consumed the most energy or spent the most in energy-related costs.

Some of the concentrations in industries were attributable to the size range of the plants included in this study. For example, the absence of large plants excludes most steel mills, petroleum refineries, automotive plants, and many chemical producers.

Cost-Saving Opportunities: As manufacturers, they consume energy at high costs and they welcome opportunities to reduce those costs. In every instance, of course, those opportunities entail implementation costs, which were the primary focus of this study. To indicate the size of energy consumption cost and possible savings, we have summarized those characteristics in table 3.

Implementation Costs: Aggregate implementation costs for each previously defined narrower (two-digit) category of assessment recommendations were collected in tables 4-8, together with aggregate savings, the number of recommendations (ECOs), and their simple paybacks, all separated into measures

Table 1

IMPLEMENTATION FREQUENCIES OF SMALL- AND MEDIUM-SIZED PLANTS' ENERGY-EFFICIENCY MEASURES, FISCAL YEARS (FY) 1993-1997

Year	Number of Recommendations	Number of Recommendations Implemented	Percent of Implementation
FY 1993	3,988	1,995	50.0
FY 1994	5,279	2,582	48.9
FY 1995	5,496	2,828	51.5
FY 1996	4,905	2,645	53.9
FY 1997	3,863	1,877	48.6
Totals	23,531	11,927	50.7

with implementation costs of at least \$10,000 and those costing less. The costs, savings, and paybacks represent aggregate implementation data. The numbers of ECOs and their frequencies of implementation were derived from all the ECOs recommended.

Also included is the term γ, which was defined as:

$$\gamma = \frac{>10\text{k frequency}}{<10\text{k frequency}} \tag{1}$$

and which defined frequency as:

$$\text{frequency} = \frac{\text{number implemented}}{\text{number recommended}}. \tag{2}$$

For a given category of recommendations, designated as a two-digit ARC, the number of measures varied widely from fewer than 10 to several hundred. Therefore, it seemed reasonable to adopt as a sign of equality between types of measures the value 1.0 ± 0.1, so that a γ of 0.9 could be considered as being as much a sign of equality as a γ of 1.1. That consideration is consistent with the ultimate public policy question addressed by this study: Do small- and medium-sized plants need a stimulus to invest in recommended energy efficiencies?

It was apparent that γ values of 0.9 and higher occurred often enough to justify further study of implementation costs, because ECOs costing \$10,000 or more were in many cases implemented as often or more often than those costing less.

Table 2

PLANT CHARACTERISTICS, FISCAL YEARS (FY) 1993-1997

Industry	Food	Tobacco	Textiles	Apparel	Wood	Furniture	Paper
SIC[a]	20	21	22	23	24	25	26
FY 1993							
Sales (million $)	3,031	0	445	237	612	622	765
Employees	12,008	0	5,178	3,238	3,161	4,411	4,277
Energy costs (million $)	32.5	0.0	24.3	1.8	8.1	6.5	14.0
FY 1994							
Sales (million $)	4,201	0	442	443	622	446	1,534
Employees	14,699	0	4,019	3,873	5,197	4,820	8,481
Energy costs (million $)	43.0	0.0	14.3	3.6	15.7	4.4	33.3
FY 1995							
Sales (million $)	4,457	170	800	515	1,046	496	1,049
Employees	15,927	480	5,137	7,289	4,809	5,937	5,675
Energy costs (million $)	51.4	0.6	17.8	4.3	14.9	6.0	15.5
FY 1996							
Sales (million $)	5,501	100	1,065	739	900	456	992
Employees	18,294	375	7,135	6,245	4,541	2,663	5,094
Energy costs (million $)	59.7	1.2	33.9	5.6	13.6	2.4	19.1
FY 1997							
Sales (million $)	3,187	60	1,260	420	561	686	1,303
Employees	13,522	500	4,870	3,204	4,397	5,359	6,460
Energy costs (million $)	35.0	1.2	22.9	3.3	7.4	7.3	22.5

[a]SIC = standard industrial classification.

(continued)

Discussion of Results

Relative Frequencies of Implementation: The chief purpose of this study was to examine the effect of implementation costs upon rates of implementation by small- and medium-sized plants where Industrial Assessment Centers had recommended specific measures to reduce energy consumption and cost. Our efforts were directed to FY 1993-1997, the most recent years for which data are available for recommended and implemented results in the IAC program database.

Table 2 (continued)

PLANT CHARACTERISTICS, FISCAL YEARS (FY) 1993-1997

Industry	Printing	Chemicals	Petroleum	Rubber, Plastics	Leather	Stone, Clay, Glass
SIC[a]	27	28	29	30	31	32
FY 1993						
Sales (million $)	417	1,023	83	1,188	189	569
Employees	3,469	3,823	450	9,610	1.268	3,984
Energy costs (million $)	5.5	19.1	2.0	22.7	4.0	57.4
FY 1994						
Sales (million $)	626	1,396	307	1,778	85	696
Employees	6,301	4,010	661	14,541	1,335	4,392
Energy costs (million $)	8.9	14.5	10.2	43.0	1.1	30.5
FY 1995						
Sales (million $)	915	1,462	92	2,029	67	520
Employees	8,670	4,581	329	13,279	803	3,573
Energy costs (million $)	16.4	22.0	1.8	35.9	0.4	23.0
FY 1996						
Sales (million $)	1,217	1,704	40	1,691	143	1,033
Employees	8,886	3,672	124	10,834	1,795	4,376
Energy costs (million $)	12.3	17.5	0.7	33.8	2.9	26.2
FY 1997						
Sales (million $)	813	678	74	2,343	171	250
Employees	6,112	2,157	203	13,563	2,421	1,403
Energy costs (million $)	7.9	8.3	1.5	43.9	2.4	7.3

[a]SIC = standard industrial classification.

(continued)

As a criterion of high implementation cost, $10,000 was chosen because experience had indicated that to be a realistic level among plants considered small- and medium-sized. In the preceding section of this paper γ was defined as the ratio of fractional implementation frequencies for measures costing at least $10,000 and for those costing less. In each instance, frequency of implementation was the fraction of implemented measures relative to recommended.

In tables 4-8, we found 40 occurrences of γ values smaller than 0.9 and 41 larger. On that basis, we concluded that the implementation frequency of a category

Table 2 (continued)

PLANT CHARACTERISTICS, FISCAL YEARS (FY) 1993-1997

Industry	Primary Metals	Metal Products	Machinery, Non-electrical	Electrical Products	Transportation	Instrumentation	Miscellaneous
SIC[a]	33	34	35	36	37	38	39
FY 1993							
Sales (million $)	590	1,666	1,885	1,075	669	589	326
Employees	3,906	10,377	11,222	8,809	5,901	4,791	1,156
Energy costs (million $)	17.5	23.2	21.4	14.4	10.9	4.8	2.0
FY 1994							
Sales (million $)	1,174	1,909	2,823	1,656	982	591	182
Employees	6,700	13,463	17,933	13,692	6,075	5,525	1,285
Energy costs (million $)	28.4	26.2	24.6	19.6	10.9	7.6	1.7
FY 1995							
Sales (million $)	1,173	2,831	1,885	2,758	2,034	723	405
Employees	7,673	21,266	13,446	15,480	9,912	4,703	3,129
Energy costs (million $)	35.2	46.5	19.9	25.8	13.8	5.6	3.9
FY 1996							
Sales (million $)	1,090	2,822	1,988	1,901	2,074	830	195
Employees	6,485	17,622	13,373	13,653	13,068	3,767	1,632
Energy costs (million $)	29.4	35.3	20.3	25.1	19.1	5.8	1.8
FY 1997							
Sales (million $)	1,398	1,843	2,692	1,066	1,584	744	538
Employees	5,894	12,797	14,318	8,207	9,489	3,220	2,733
Energy costs (million $)	29.1	23.4	22.2	13.7	14.7	2.8	4.0

[a] SIC = standard industrial classification.

of energy-conserving measures was often as high for those costing $10,000 or more as it was for those costing less. Moreover, for all but one category of recommendation (ARC 81, administrative ancillary costs), the value of γ was larger than 0.9 for at least one of the five years.

Investigated ARCs: To avoid effects of too little data for categories of ECOs, we focused on those two-digit ARCs that occurred at least 25 times in a given year and that had 10 or more ECOs costing $10,000 or more. That decision produced

Figure 1

PLANT DISTRIBUTION BY STANDARD INDUSTRIAL CLASSIFICATION (SIC) CODE FOR FISCAL YEAR 1993
(number of plants = 586)

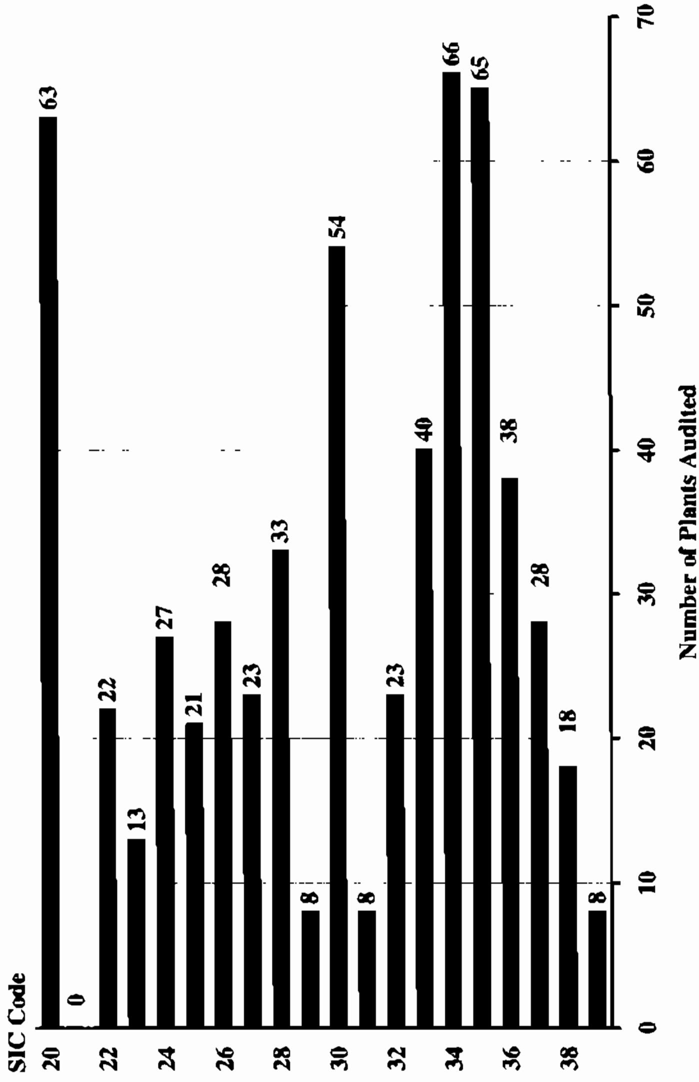

Figure 2

PLANT DISTRIBUTION BY STANDARD INDUSTRIAL CLASSIFICATION (SIC) CODE FOR FISCAL YEAR 1994
(number of plants = 777)

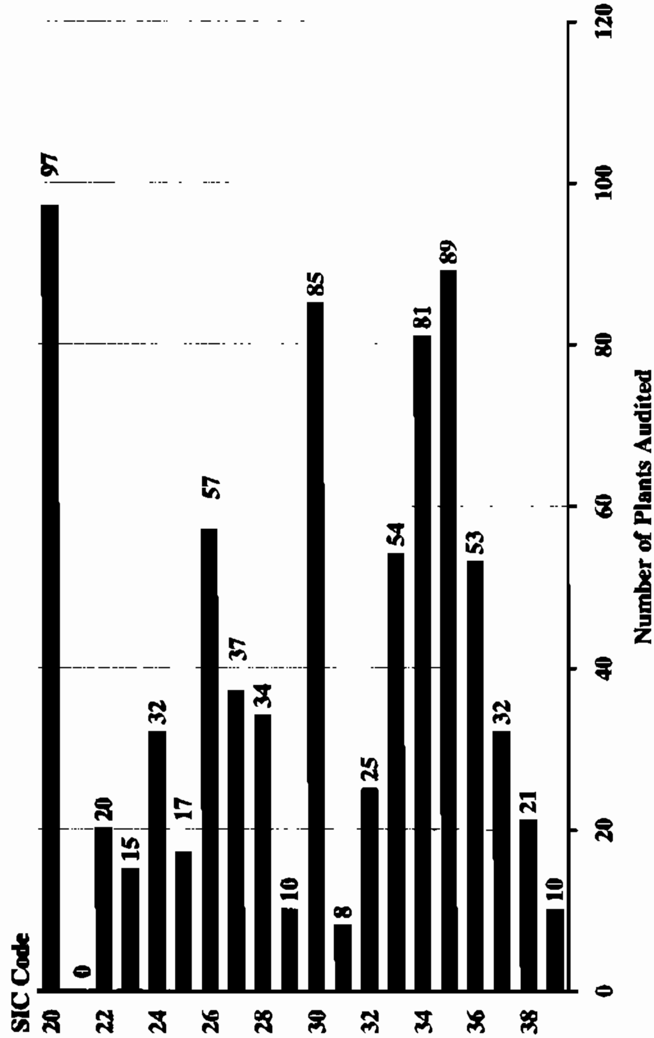

Figure 3

PLANT DISTRIBUTION BY STANDARD INDUSTRIAL CLASSIFICATION (SIC) CODE FOR FISCAL YEAR 1995
(number of plants = 877)

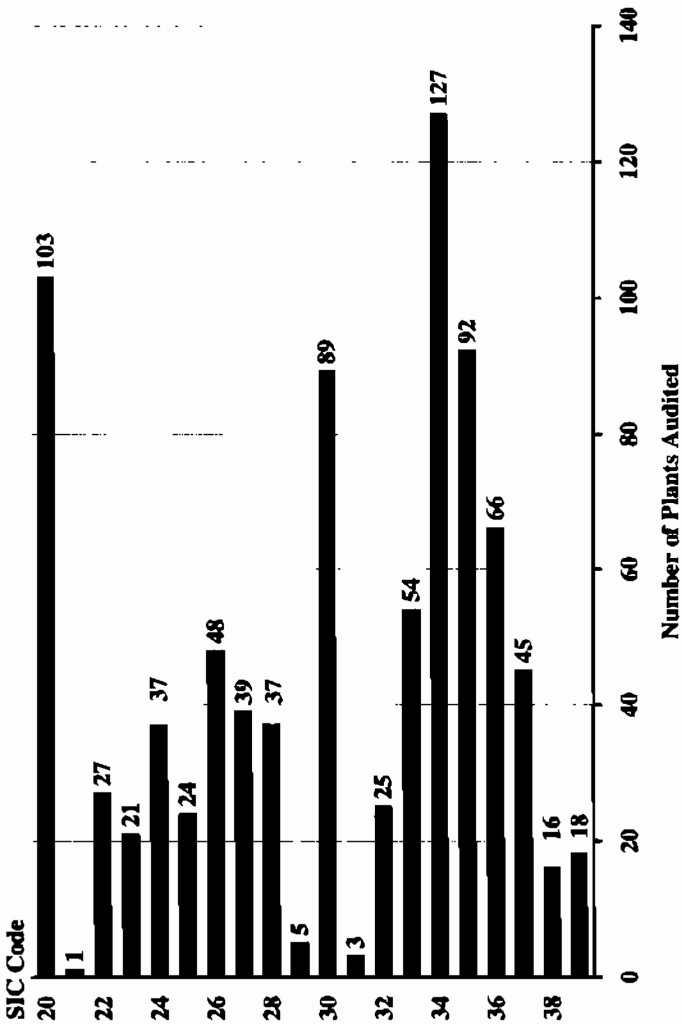

Figure 4

PLANT DISTRIBUTION BY STANDARD INDUSTRIAL CLASSIFICATION (SIC) CODE FOR FISCAL YEAR 1996
(number of plants = 864)

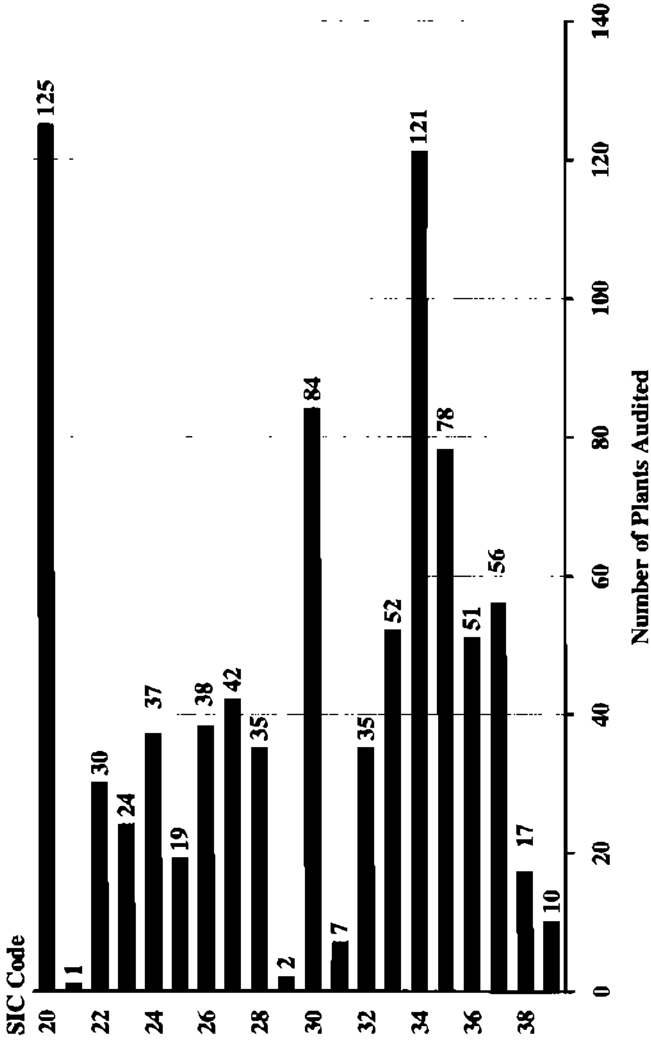

Figure 5

PLANT DISTRIBUTION BY STANDARD INDUSTRIAL CLASSIFICATION (SIC) CODE FOR FISCAL YEAR 1997
(number of plants = 727)

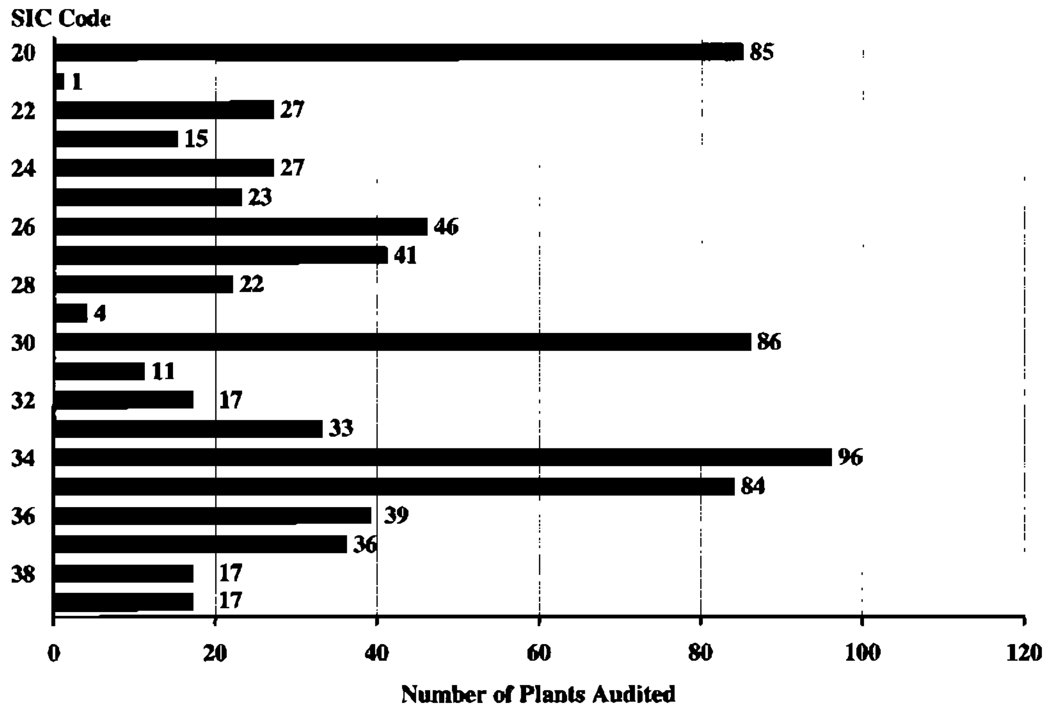

Table 3

ENERGY COSTS AND POSSIBLE COST SAVINGS, FISCAL YEARS (FY) 1993-1997
(in million dollars per year)

Year	Energy Costs	Energy Cost Savings: Recommended	Energy Cost Savings: Implemented	Percent Implemented
FY 1993	291.9	31.01	10.88	35.1
FY 1994	341.5	39.94	13.55	33.9
FY 1995	360.7	39.19	15.10	38.5
FY 1996	365.7	25.13	12.10	48.1
FY 1997	281.0	22.39	10.09	45.1

the following six ARCs for closer scrutiny: 13 (fuel switching); 24 (heat recovery); 32 (power factor and demand management); 41 (motors); 71 (lighting); and 72 (space conditioning).

Only those ARCs that met those criteria in three or more years were analyzed. This was done to reveal trends that related values of γ (and therefore implementation frequency) to other parameters of the assessment, such as cost savings and pay-back times.

Parameters Affecting Implementation Frequency: Implementation of cost-saving recommendations in a manufacturing plant can depend upon many factors, some external and some internal. Potential cost savings and pay-back times are the obvious internal factors, but it is less clear how they affect more- and less-expensive opportunities as reflected in values of γ.

Only weak correlation between γ and cost savings and between γ and pay-back times were found when these were considered individually. Therefore, we combined those parameters in the following manner:

Let A designate ECOs costing less than $10,000 (<$10k) and B designate ECOs costing more than $10,000 (>$10k). Then, for a given year, let

$$R_1 = \frac{[\text{agsav}/\text{ECO}]_B}{[\text{agsav}/\text{ECO}]_A} \tag{3}$$

$$R_2 = \frac{[\text{agspb}]_A}{[\text{agspb}]_B} \tag{4}$$

Table 4

AGGREGATE VALUE (AG) OF IMPLEMENTATION COSTS (IC), COST SAVINGS (SAV), SIMPLE PAYBACK (SPB), GAMMA, AND NUMBER OF ENERGY CONSERVATION OPPORTUNITIES (ECOs) FOR FISCAL YEAR (FY) 1993

ARC[a]	AG-IC of ECO <$10 k[b] ($)	AG-IC of ECO >$10 k[b] ($)	AG-SAV of ECO <$10 k[b] ($/year)	AG-SAV of ECO >$10 k[b] ($/year)	AG-SPB of ECO <$10 k[b] (year)	AG-SPB of ECO >$10 k[b] (year)	Gamma	ECO <$10k[b]	ECO >$10k[b]
12	94,234	310,552	444,638	172,631	0.21	1.80	0.61	87	5
13	38,889	577,518	78,299	1,530,032	0.50	0.38	0.58	16	8
21	89,090	114,003	518,599	138,628	0.17	0.82	0.52	66	3
24	78,556	240,510	158,761	132,490	0.49	1.82	0.75	34	11
25	128,173	74,227	202,847	122,456	0.63	0.61	1.62	77	5
26	19,250	141,330	34,515	68,105	0.56	2.08	0.70	9	6
32	116,283	401,884	281,908	347,812	0.41	1.16	1.04	55	19
41	712,627	2,338,729	739,426	1,002,126	0.96	2.33	1.20	299	68
42	208,587	106,600	968,968	89,256	0.22	1.19	0.92	334	7
43	25,652	133,822	29,063	36,358	0.88	3.68	0.90	31	3
62	81,620	–	296,645	–	0.28	–	0.00	78	0
71	903,745	1,506,794	1,209,049	669,218	0.75	2.25	0.94	521	55
72	151,691	192,867	252,025	65,010	0.06	2.97	0.58	89	7
74	68,793	171,637	237,797	42,771	0.29	4.01	0.88	51	5
81	45,464	132,025	446,812	208,054	0.10	0.63	0.45	42	4

[a]ARC = assessment recommendation code; 12 (boilers); 13 (fuel switching); 21 (steam); 24 (heat recovery); 25 (heat containment); 26 (cooling); 32 (power factor and demand management); 41 (motors); 42 (air compressors); 43 (other equipment); 62 (equipment and control); 71 (lighting); 72 (space conditioning); 74 (building envelope); 81 (ancillary costs-administration).

[b]<$10 k = less than $10,000; >$10 k = greater than $10,000.

Table 5

AGGREGATE VALUE (AG) OF IMPLEMENTATION COSTS (IC), COST SAVINGS (SAV), SIMPLE PAYBACK (SPB), GAMMA, AND NUMBER OF ENERGY CONSERVATION OPPORTUNITIES (ECOs) FOR FISCAL YEAR (FY) 1994

ARC[a]	AG-IC of ECO <$10 k[b] ($)	AG-IC of ECO >$10 k[b] ($)	AG-SAV of ECO <$10 k[b] ($/year)	AG-SAV of ECO >$10 k[b] ($/year)	AG-SPB of ECO <$10 k[b] (year)	AG-SPB of ECO >$10 k[b] (year)	Gamma	ECO <$10k[b]	ECO >$10k[b]
11	13,870	12,000	43,257	27,860	0.32	0.43	2.00	9	1
12	109,710	120,600	469,209	78,240	0.23	1.54	0.95	78	4
13	37,339	531,592	84,165	501,920	0.44	1.06	1.17	17	13
21	293,254	333,034	589,011	170,087	0.37	1.52	0.28	185	15
25	96,389	335,480	317,704	230,159	0.99	1.46	0.79	86	5
26	24,652	51,660	51,731	36,065	0.48	1.43	0.30	11	2
32	105,286	902,356	487,827	580,357	0.22	1.55	1.25	77	28
34	5,500	77,000	31,719	56,050	0.17	1.37	0.04	1	1
41	1,048,579	3,007,386	1,006,651	1,545,639	1.04	1.95	0.96	372	106
42	263,689	155,200	1,314,111	70,335	0.20	2.21	0.99	444	7
43	30,479	317,600	93,337	145,151	0.33	2.19	0.86	43	4
51	7,611	993,394	2,404	534,260	3.17	1.86	6.00	1	6
61	1,358	–	11,930	–	0.11	–	0.00	11	0
62	71,603	183,900	476,180	123,746	0.15	1.49	1.35	97	6
71	1,255,797	2,286,635	1,536,238	1,198,324	0.82	1.91	1.00	648	98
72	138,415	281,820	384,606	138,122	0.36	2.04	0.76	82	11
73	4,710	25,000	6,566	21,861	0.72	1.14	2.20	3	1
74	59,306	353,691	74,613	102,917	0.79	3.44	1.43	50	9
81	27,754	777,522	394,483	546,712	0.07	1.42	0.83	40	10

[a]ARC = assessment recommendation code; 11 (furnaces, ovens, directly fired operations); 12 (boilers); 13 (fuel switching); 21 (steam); 25 (heat containment); 26 (cooling); 32 (power factor and demand management); 34 (cogeneration); 41 (motors); 42 (air compressors); 43 (other equipment); 51 (industrial design systems); 61 (maintenance); 62 (equipment and control); 71 (lighting); 72 (space conditioning); 73 (ventilation); 74 (building envelope); 81 (ancillary costs-administration).

[b]<$10 k = less than $10,000; >$10 k = greater than $10,000.

Table 6

AGGREGATE VALUE (AG) OF IMPLEMENTATION COSTS (IC), COST SAVINGS (SAV), SIMPLE PAYBACK (SPB), GAMMA, AND NUMBER OF ENERGY CONSERVATION OPPORTUNITIES (ECOs) FOR FISCAL YEAR (FY) 1995

ARC[a]	AG-IC of ECO <$10 k[b] ($)	AG-IC of ECO >$10 k[b] ($)	AG-SAV of ECO <$10 k[b] ($/year)	AG-SAV of ECO >$10 k[b] ($/year)	AG-SPB of ECO <$10 k[b] (year)	AG-SPB of ECO >$10 k[b] (year)	Gamma	ECO <$10k[b]	ECO >$10k[b]
11	15,705	266,900	186,903	171,007	0.08	1.56	1.29	17	4
12	112,328	37,960	586,924	18,613	0.19	2.04	0.24	106	2
13	53,364	4,819,020	78,511	1,028,261	0.68	4.69	1.08	19	12
21	96,235	32,192	230,759	74,838	0.42	0.43	1.05	74	2
24	99,804	395,950	178,012	268,884	0.56	1.47	0.57	49	7
25	72,305	44,688	152,535	68,462	0.47	0.65	0.74	74	3
26	46,352	165,000	48,508	123,918	0.96	1.33	0.37	15	4
32	117,237	629,291	464,437	380,877	0.25	1.65	0.59	68	13
41	1,022,463	3,541,660	989,964	1,414,866	1.03	2.50	0.96	433	103
42	397,117	185,839	1,751,665	179,809	0.23	1.03	1.11	606	11
43	59,853	530,092	174,893	328,445	0.34	1.61	1.58	62	12
61	1,170	15,458	11,957	21,075	0.10	0.73	0.72	9	1
62	39,342	15,400	329,500	4,342	0.12	0.01	0.31	81	1
71	1,277,220	3,469,589	1,611,029	1,670,111	0.79	2.08	1.10	656	133
72	186,455	256,475	423,100	260,316	0.44	0.99	0.53	109	12
73	6,707	138,640	20,096	32,442	0.33	4.27	1.00	8	2
74	69,913	296,790	83,261	67,501	0.84	4.40	0.78	43	6
81	22,274	1,514,000	581,711	789,015	0.04	1.92	0.57	63	8

[a]ARC = assessment recommendation code; 11 (furnaces, ovens, directly fired operations); 12 (boilers); 13 (fuel switching); 21 (steam); 24 (heat recovery); 25 (heat containment); 26 (cooling); 32 (power factor and demand management); 41 (motors); 42 (air compressors); 43 (other equipment); 61 (maintenance); 62 (equipment and control); 71 (lighting); 72 (space conditioning); 73 (ventilation); 74 (building envelope); 81 (ancillary costs-administration).

[b]<$10 k = less than $10,000; >$10 k = greater than $10,000.

Table 7

AGGREGATE VALUE (AG) OF IMPLEMENTATION COSTS (IC), COST SAVINGS (SAV), SIMPLE PAYBACK (SPB), GAMMA, AND NUMBER OF ENERGY CONSERVATION OPPORTUNITIES (ECOs) FOR FISCAL YEAR (FY) 1996

ARC[a]	AG-IC of ECO <\$10 k[b] (\$)	AG-IC of ECO >\$10 k[b] (\$)	AG-SAV of ECO <\$10 k[b] (\$/year)	AG-SAV of ECO >\$10 k[b] (\$/year)	AG-SPB of ECO <\$10 k[b] (year)	AG-SPB of ECO >\$10 k[b] (year)	Gamma	ECO <\$10k[b]	ECO >\$10k[b]
11	15,340	72,460	54,501	91,196	0.28	0.79	1.87	12	4
12	78,773	114,280	339,434	42,148	0.23	2.71	0.57	67	2
13	75,981	306,477	142,908	350,947	0.53	0.87	0.43	28	7
21	70,383	79,345	221,441	65,510	0.32	1.21	0.81	64	4
24	98,491	403,734	123,903	381,438	0.79	1.06	0.89	48	11
25	122,518	57,750	213,967	43,735	0.57	1.32	0.48	92	2
26	31,636	852,160	130,142	354,437	0.24	2.40	1.66	16	12
32	187,187	740,860	747,003	529,152	0.25	1.40	1.10	72	20
41	1,000,742	2,579,903	649,802	827,942	1.54	3.12	0.87	421	82
42	412,923	223,620	1,323,509	109,485	0.31	2.04	0.71	606	11
43	49,621	2,638,000	83,791	929,604	0.59	2.84	0.75	60	5
62	53,942	194,060	261,241	277,205	0.21	0.70	1.70	79	5
71	1,127,855	2,914,470	870,764	909,524	1.30	3.20	1.01	552	117
72	252,711	474,190	337,272	339,825	0.75	1.40	0.94	106	18
73	8,627	50,000	18,828	15,364	0.46	3.25	1.10	10	2
74	46,565	24,862	62,232	6,994	0.75	3.55	0.33	38	1
81	37,287	91,400	446,649	35,537	0.08	2.57	0.69	68	3

[a] ARC = assessment recommendation code; 11 (furnaces, ovens, directly fired operations); 12 (boilers); 13 (fuel switching); 21 (steam); 24 (heat recovery); 25 (heat containment); 26 (cooling); 32 (power factor and demand management); 41 (motors); 42 (air compressors); 43 (other equipment); 62 (equipment and control); 71 (lighting); 72 (space conditioning); 73 (ventilation); 74 (building envelope); 81 (ancillary costs-administration).
[b] <\$10 k = less than \$10,000; >\$10 k = greater than \$10,000.

Table 8
AGGREGATE VALUE (AG) OF IMPLEMENTATION COSTS (IC), COST SAVINGS (SAV), SIMPLE PAYBACK (SPB), GAMMA, AND NUMBER OF ENERGY CONSERVATION OPPORTUNITIES (ECOs) FOR FISCAL YEAR (FY) 1997

ARC[a]	AG-IC of ECO <\$10 k[b] (\$)	AG-IC of ECO >\$10 k[b] (\$)	AG-SAV of ECO <\$10 k[b] (\$/year)	AG-SAV of ECO >\$10 k[b] (\$/year)	AG-SPB of ECO <\$10 k[b] (year)	AG-SPB of ECO >\$10 k[b] (year)	Gamma	ECO <\$10k[b]	ECO >\$10k[b]
11	8,411	22,440	24,033	10,400	0.35	2.16	1.45	10	1
12	72,090	206,800	310,205	323,425	0.23	0.64	0.82	56	8
13	47,955	1,444,536	172,646	899,858	0.28	1.61	1.10	17	11
21	49,100	18,000	160,976	28,570	0.31	0.63	0.35	45	1
24	65,761	1,001,959	121,567	588,618	0.54	1.70	1.05	29	14
25	103,550	227,687	236,350	81,754	0.44	2.79	0.95	73	8
26	21,914	656,647	81,858	79,807	0.27	8.23	1.11	9	5
32	123,258	356,827	344,135	404,427	0.36	0.88	1.05	48	12
41	601,834	2,144,394	360,445	792,196	1.67	2.71	0.99	269	60
42	293,828	127,286	896,182	60,729	0.33	2.10	0.93	431	6
43	43,926	691,400	48,913	1,152,734	0.90	0.60	0.52	35	3
62	45,522	0	177,205	–	0.26	–	0.00	55	0
71	824,368	3,064,146	679,574	724,061	1.21	4.23	1.15	417	90
72	103,954	174,728	216,838	167,449	0.48	1.04	0.90	49	8
73	19,790	115,500	27,323	26,972	0.72	4.28	1.14	9	3
74	41,167	47,708	72,737	41,393	0.57	1.15	0.68	29	2
81	35,467	504,240	565,445	299,235	0.06	1.69	0.75	58	6

[a]ARC = assessment recommendation code; 11 (furnaces, ovens, directly fired operations); 12 (boilers); 13 (fuel switching); 21 (steam); 24 (heat recovery); 25 (heat containment); 26 (cooling); 32 (power factor and demand management); 41 (motors); 42 (air compressors); 43 (other equipment); 62 (equipment and control); 71 (lighting); 72 (space conditioning); 73 (ventilation); 74 (building envelope); 81 (ancillary costs-administration).

[b]<\$10 k = less than \$10,000; >\$10 k = greater than \$10,000.

and

$$\frac{R_1}{R_2} = \frac{[\$saved/ECO]_B}{[\$saved/ECO]_A} \tag{5}$$

during payback. Equation (5) can also be written in terms of aggregate implementation costs as

$$\frac{R_1}{R_2} = \frac{[agic/ECO]_B}{[agic/ECO]_A} \tag{6}$$

where

agsav = aggregate cost savings (dollars per year);
agspb = simple payback (year) based on aggregate implementation cost and cost saving;
agic = aggregate implementation cost (dollars); and
ECO = number of energy conservation opportunities.

The ratio of R_1/R_2 represents the savings achieved during payback of more-expensive measures (>$10k) relative to less-expensive measures (<$10k). Therefore, it was named the relative savings factor (RSF). In general, we found that as the value of RSF increased for a given ARC, so did the value of γ when the data were tabulated for each year FY 1993-1997 (table 9). However, there were some exceptions, such as ARC 13 (fuel switching), which revealed an entirely different behavior.

From table 9, it was possible to observe the following. For ARC 24 (heat recovery) gamma increased consistently with R_1/R_2 for all three years and for 32 (power factor and demand management) gamma increased consistently with R_1/R_2 for four years but not for 1995. Gamma was consistent for four years but not for 1994 for ARC 41 (motors). In ARC 71 (lighting) gamma increased consistently for four years but not for 1993. Finally, gamma increased with R_1/R_2 for 1994 and 1995 but not for 1996 for ARC 72 (space conditioning).

To assess the significance of these data we reviewed what they told us about manufacturers' implementation patterns. For five very different categories of measures (ARCs 24, 32, 41, 71, and 72) there seemed to be a consistency in their implementation frequency of more-expensive actions with the RSF of those actions.

Table 9

RELATIVE SAVINGS FACTOR AND GAMMA VALUES, FISCAL YEARS (FY) 1993-1997

Fiscal		Assessment Recommendation Code[a]					
Year		13	24	32	41	71	72
FY 1993	R_1		21,865	21,151	34,393	27,396	
	R_2		2,310	2,096	2,383	1,735	
	R_1/R_2		9.5	10.1	14.4	15.8	
	Gamma		0.75	1.04	1.20	0.94	
FY 1994	R_1	40,892		32,227	28,372	23,333	25,620
	R_2	2,196		1,367	2,819	1,938	1,688
	R_1/R_2	18.6		23.6	10.1	12.0	15.2
	Gamma	1.20		1.25	0.96	1.00	0.76
FY 1995	R_1	401,585		48,407	34,385	26,037	21,373
	R_2	2,809		1,724	2,361	1,947	1,711
	R_1/R_2	143.0		28.1	14.6	13.4	12.5
	Gamma	1.08		0.59	0.96	1.10	0.53
FY 1996	R_1		36,703	37,043	31,462	24,910	26,344
	R_2		2,052	2,600	2,377	2,043	2,384
	R_1/R_2		17.9	14.2	13.2	12.2	11.1
	Gamma		0.89	1.10	0.87	1.01	0.94
FY 1997	R_1	131,321	71,568	29,736	35,740	34,046	
	R_2	2,821	2,268	2,568	2,237	1,977	
	R_1/R_2	46.6	31.6	11.6	16.0	17.2	
	Gamma	1.10	1.05	1.05	0.99	1.15	

[a]13 (fuel switching); 24 (heat recovery); 32 (power factor and demand management); 41 (motors); 71 (lighting); 72 (space conditioning).

This consistency existed for 17 pairs of data points but not for four others. Therefore, it seemed reasonable to conclude not only that manufacturers relatively often implement energy-conserving recommendations costing $10,000 or more but their decisions appear heavily influenced by the dollar value of the savings per ECO of more and less expensive for a category in a given year.

None of this discussion affects the behavior found for fuel switching (ARC 13), but that issue will be considered later by examining energy-conserving recommendations at a further level of detail. The three-digit ARC category will also be applied to the four inconsistencies among two-digit ARCs other than ARC 13.

More Detailed Analyses: In *ARC 13 (fuel switching)*, manufacturers switch energy sources when there is an incentive, such as converting electrically heated equipment to gas-fired because of the lower unit price of natural gas. That was the principal contributor to the ARC 13 category, which differed in its pattern of results from those of the other five ARC categories (24, 32, 41, 71, and 72).

To observe the components of ARC 13 we drew upon the additional detail possible with three-digit ARCs. Our findings are offered in table 10.

It is evident that ARC 131 (electric to fossil fuel) is dominant in ARC 13 and that there was a wide savings gap in ARC 13 among the year—from $466,191 in FY 1994 to $4,819,020 in FY 1995. Moreover, we found that one occurrence accounted for $4.5 million (in implementation cost) of the $4.8 million in FY 1995 and one other for $1 million of the $1.4 million in FY 1997. These singular dependencies are reasons to expect differences in the conformity of R_1/R_2 and γ of ARC 13 relative to patterns of other ARCs less dependent on a single event. Implementing one large ECO had a minimal effect upon γ (based on frequency of implementation) while its effect on R_1/R_2 was monumental.

Again, it is essential to recall that the empirical agreement we found in some conservation categories between implementation ratios of more- and less-expensive measures and their RSF was an interesting and logically consistent phenomenon. We do not propose it to be an immutable law, and ARC 13 data demonstrate how other factors can intervene, such as dominance of a category by a single event in a particular year. When that happens, an empirical relation between frequency and implemented savings is likely to be distorted.

ARC 32 (power factor and demand management): Only 1995 showed an inconsistency in the relation of R_1/R_2 to γ, and only in that year was a single ECO dominant (table 9). Of the $254,000 savings attributed to ARC 329, installing a generator to limit peak demand at one plant, accounted for $170,000 and produced 27 percent of the cost savings among more-expensive measures in ARC 32 for FY 1995. As expected, the net result was a relatively low γ for the size of the savings achieved.

ARC 41 (motors): The data in table 9 for FY 1994 suggest that R_1/R_2 of 10.1 is too low for its γ value of 0.96, because R_1/R_2 was 14.6 for a γ value of 0.96 in FY 1995. The origin of this difference was traced to ARC 413 (hardware for motor systems), shown in table 11.

At this level of detail, the following is apparent: in FY 1994, only 228 ECOs < $10k were responsible for aggregate implementation cost (agic) of $875,880 and

Table 10

ASSESSMENT RECOMMENDATION CODE (ARC) 13 (FUEL SWITCHING) AND 131 (FUEL SWITCHING-ELECTRIC TO FOSSIL FUEL) ENERGY CONSERVATION OPPORTUNITIES (ECOs), FISCAL YEARS (FY) 1994-1997

	FY 1994			FY 1995			FY 1997		
ARC	Less than $10,000		Greater than $10,000	Less than $10,000		Greater than $10,000	Less than $10,000		Greater than $10,000
13 (Fuel switching)									
Aggregate implementation costs ($)	37,339		531,592	53,364		4,819,020	47,935		1,444,536
No. of ECOs	17		13	19		12	17		11
R_1/R_2 [a]		18.6			143.0			46.5	
γ [b]		1.20			1.08			1.12	
131 (Electric to fossil fuel)									
Aggregate implementation costs ($)	25,044		466,191	47,751		4,819,020	35,906		1,424,536
No. of ECOs	14		10	16		12	12		10
R_1/R_2 [a]		26.1			134.6			47.6	
γ [b]		1.28			1.29			1.36	

[a] R_1/R_2 = ratio indicating the savings achieved during payback of more-expensive measures (over $10,000) relative to less-expensive measures (under $10,000).

[b] Gamma (γ) = the ratio of the fractional frequency of implementation of more-expensive to less-expensive measures.

Table 11

ASSESSMENT RECOMMENDATION CODE (ARC) 413 (HARDWARE FOR MOTOR SYSTEMS) ENERGY CONSERVATION OPPORTUNITIES (ECOs), FISCAL YEARS (FY) 1994 AND 1995

	FY 1994			FY 1995		
ARC	Less than $10,000		Greater than $10,000	Less than $10,000		Greater than $10,000
413 (hardware for motor systems)						
agic ($)	875,880		2,392,278	847,526		2,761,399
No. of ECOs	228		97	275		87
R_1			24,663			31,740
R_2	3,842			3,082		
R_1/R_2[a]		6.4			10.3	
γ[b]		1.02			1.02	

[a]R_1/R_2 = ratio indicating the savings achieved during payback of more-expensive measures (over $10,000) relative to less-expensive measures (under $10,000).

[b]Gamma (γ)=the ratio of the fractional frequency of implementation of more-expensive to less-expensive measures.

R_2 of 3,842; in FY 1995, 275 ECOs < $10k were responsible for agic of $847,526 and R_2 of 3,082; in FY 1994, 97 ECOs > $10k were responsible for agic of $2,392,278 and R_1 of 24,663; in FY 1995, 87 ECOs > $10k were responsible for agic of $2,761,399 and R_1 of 31,740; even though γ was the same for both years, R_1/R_2 for FY 1994 was only 6.4 while it was 10.3 for FY 1995.

Since the results for FY 1995 are consistent with those for FY 1993, FY 1996, and FY 1997, the R_1/R_2 for FY 1994 is evidently too low for the γ value, and ARC 413 (hardware for motor systems) was the apparent source.

It is still true that for ARC 41 (motors) values of γ increased with values of R_1/R_2, and the source of the anomalous result for FY 1994 was a three-digit ARC (413). It is an open question about why ARC 413 performed in this manner.

ARC 71 (lighting): Four of the five years' values for R_1/R_2 and γ show consistency in table 9, but FY 1993 does not. Its R_1/R_2 appears to be too high for the value of γ attained. For example, in FY 1993, R_1/R_2 was 15.8 and γ was 0.94; in FY 1994 the two values were 12.0 and 1.00, respectively.

Much of the difference was due to the FY 1993 contribution of ARC 714 (lighting hardware), which had a value of R_1/R_2 of 13.5 and a γ value of 0.87. This ARC was responsible for 52 of the 55 ECOs comprising ARC 71 in FY 1993. As stated previously, we were able to identify the source of the difference but we did not know why from this kind of result.

ARC 72 (space conditioning): Results for ARC 72 show expected directional agreement for FY 1994 and FY 1995, but not for FY 1996. It is obvious from table 9 that in FY 1996 the R_1/R_2 value of 11.0 is much too low for a γ value of 0.94. Numbers developed from a more detailed study at the three-digit ARC level suggested that ARCs 723, 724, and 726 (heating/cooling hardware, air circulation hardware, and controls, respectively) were largely responsible (table 12).

The larger numbers for FY 1996 led to a higher overall value of R_2 and a lower overall value of R_1/R_2. The data in table 9 show that effect.

Table 12

ASSESSMENT RECOMMENDATION CODE (ARC) 72 (SPACE CONDITIONING) ENERGY CONSERVATION OPPORTUNITIES (ECOs), FISCAL YEARS (FY) 1994-1996

Less than $10,000	ARC[a]	FY 1994	FY 1995	FY 1996
Aggregate implementation costs ($)	723	25,210	20,632	62,772
	724	50,816	64,449	86,711
	726	39,581	65,304	71,608
No. of ECOs	723	4	6	16
	724	14	17	23
	726	32	50	40
Total		50	73	79

[a] ARC 723 = heating/cooling hardware, 724 = air circulation hardware, and 726 = controls.

Conclusions

There is much evidence to support the observation that groups of energy conservation measures costing at least $10,000 each are often implemented as frequently as groups of measures costing less. This conclusion is based upon results from 23,531 recommendations in 3,831 small- and medium-sized plants, which implemented 11,927 of them.

Among five categories (two-digit ARCs) of implemented ECOs occurring at least 25 times with no fewer than 10 ECOs costing at least $10,000 each, the implementation frequency of more- to less-expensive measures typically increased as the relative savings factor increased from year to year. This RSF was defined as the ratio of total cost savings per ECO, realized during payback, of more- to less-expensive measures. In one other category (two-digit ARC), this agreement was not found.

Examination of results in further detail was sometimes able to identify the sources of anomalies but not to explain them.

These results are significant for the formulation of public policies toward small- and medium-sized manufacturing plants and their energy efficiency. They reveal a willingness of the management to invest in implementation based on the cost savings per opportunity to be realized during payback.

NOTES

[1]U.S. Department of Energy, *The Industrial Assessment Center Program* (Washington, D.C.: Office of Industrial Technologies, 1999).

[2]U.S. Department of Energy, "The DOE Industrial Assessment Center Program Database," Office of Industrial Productivity and Energy Assessment, Department of Mechanical and Aerospace Engineering, Rutgers University, 1998.

[3]Michael R. Muller and Donald J. Kasten, "The ARC Manual," Office of Industrial Productivity and Energy Assessment, Department of Mechanical and Aerospace Engineering, Rutgers University, 1998.

[4]FY 1993 corresponds to the federal fiscal year from October 1, 1992 through September 30, 1993.