ENERGY AND DEMAND SAVINGS FROM IMPLEMENTATION COSTS IN INDUSTRIAL FACILITIES[1]

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ABSTRACT

The twenty-five most frequently suggested energy saving assessment recommendations in the Industrial Assessment Center program national database were examined using linear regression techniques to correlate between energy savings and demand reduction, and implementation costs. Poor overall correlations indicate that direct prediction of savings from implementation costs is generally unfeasible, with a limited number of exceptions. Correlations for the twenty-five most frequently suggested Texas A&M University recommendations were better than those for the national dataset. The value of this procedure to speed assessments seems not worthwhile considering the poor correlations and the value of the calculations it would replace.

INTRODUCTION

The Industrial Assessment Center (IAC) program, funded by the Department of Energy (DOE), consists of faculty and student teams from 30 universities nationwide that perform industrial assessments of small and medium-size manufacturing firms. Program goals include providing university students with energy conservation learning experiences combined with service to private manufacturers. These assessments target energy and waste stream reduction opportunities, as well as productivity improvements. A typical assessment consists of utility use analysis, a site visit, and a written report that summarizes the plant's energy use, production processes, and waste handling. The report will also contain several assessment recommendations (ARs) that are thorough analyses of specific energy or cost saving measures and include expected savings, implementation costs and simple financial analysis (payback). Further information may be obtained from the Internet [1].

Saman, et al. showed a linear relationship exists between implementation costs and cost savings for certain types of projects in the Texas LoanSTAR program, which addresses primarily commercial and institutional buildings. They examined eight broad categories of energy cost reduction measures including such things as heating, ventilation and air conditioning (HVAC) components, energy management systems (EMS), and motors, pumps, lights and steam systems. Each main category had subcategories of control adjustment, equipment changes and upgrades and optimization. Using a least squares method of linear regression analysis, the general chiller and lighting categories showed a strong correlation, and were considered candidates for predicting costs savings from implementation costs. The HVAC and motor projects had poor correlations while the EMS, pumps and steam correlations were neither strong nor weak. Saman's analysis also indicated that weighted least squares differed by only 2.5% and a power law relationship departed from the actual data set; therefore, a simple least squares application was well suited [2].

Heffington, et al. noted that a direct calculation of cost savings from the implementation cost could eliminate as much as 30% of the preparation time (and associated cost) for the LoanSTAR reports. The savings result from not having to calculate energy or demand reductions in order to obtain cost savings in turn [3]. If cost savings could be estimated from implementation costs, then logically, energy and demand reductions could also be estimated in the same way. The chief goal of this project is to determine if a similar simple relationship might exist between implementation costs and energy or demand savings for industrial plants visited by the Texas A&M University (TAMU) IAC and others in the national program. If implementation costs and energy or demand savings are simply related, the direct calculation of energy or demand savings from

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carefully determined implementation costs could reduce assessment report generation times.

The IAC program, formerly known as the Energy Analysis and Diagnostic Center program, was established in 1976. In October 1995, its name changed to the Industrial Assessment Center program, and its focus expanded the energy conservation program to include waste reduction and eventually productivity enhancement. Beginning in 1980, the assessment results have been compiled into a database. The Office of Industrial Productivity and Energy Assessment (OIPEA) at Rutgers University currently maintains the database, which has been publicly accessible since 1993 [4]. The IAC at TAMU has operated since 1986, and has involved over 125 students, identifying savings totaling $20 million per year for manufacturers.

One of the strengths of the IAC program is its detailed calculation of the energy conservation and demand reduction achieved by the various energy related recommendations. The students use hand calculations and simple spreadsheet programs to generate the savings from basic data. This method is an excellent learning technique that contributes to detailed, easily followed reports. Estimated demand (load) and duty factors are probably the greatest contributors of inaccuracy to the energy and demand calculations [5]. Implementation cost estimates are generally made for conceptual rather than detailed designs. Although they lack the accuracy generally associated with detailed work, they do provide sufficient information so that manufacturers can make budgetary decisions regarding follow-on work.

DATABASE

Data from IAC visits are stored in two databases: one records the summaries of the visits and the other records the summaries of each AR generated from the visit. The former contains information on the principle products, number of resource streams tracked, sales, production hours, energy and waste costs, and particular assessment information for each plant visit. Specific identifiers such as plant name and street address are not publicly accessible in order to protect the confidentiality of the private manufacturers served by the program.

The latter database codes each AR by the type of recommendation and the strategy employed. Recommendations are separated into one of three general types: energy management, waste minimization/ pollution prevention, or direct productivity enhancements. Energy management is further subcategorized into nine general strategies. The general strategy categories are further subdivided into information on specific recommendations (e.g., “Insulate Bare Equipment” or “Use Most Efficient Type of Electric Motors”). The energy management strategy category “Ancillary Costs” includes non-energy related factors affecting utility costs (e.g., rate schedule changes and tax-free status applications). As there is no direct energy savings from this strategy category, it was excluded from the study.

The database also contains information on the resource streams conserved. Resource streams are classified into four general types: energy, waste, resource costs (administrative, materials, etc.) and production. Table 1 lists fifteen energy resource streams tracked in the database and their assigned identification codes. All of the streams listed in Table 1 are in units of million Btu except demand (kW-month/year) and fees ($). A maximum of four of these streams is tracked for each AR, which are ranked according to their impact on the facility (listed in the database as primary, secondary, tertiary, and quaternary). Only the energy resource streams in Table 1 were examined in this study. Prior to October 1995, all reported electrical energy savings combined consumption, demand and/or fees into the electricity stream (E1 in Table 1). As there is no way to distinguish what actual resource was conserved, i.e., consumption, demand, fees or some combination, all ARs coded E1 were excluded from this study. After September 1995, electrical consumption, demand and fees were tracked separately. The remaining data include only one energy stream (e.g., natural gas) in each code [6].

Table 1. Energy Streams

STREAM	CODE
Electrical Consumption	EC
Electrical Demand	ED
Other Electrical Fees	EF
Electricity	E1
Natural Gas	E2
L.P.G.	E3
#1 Fuel Oil	E4
#2 Fuel Oil	E5
#4 Fuel Oil	E6
#6 Fuel Oil	E7
Coal	E8
Wood	E9
Paper	E10
Other Gas	E11
Other Energy	E12

The current database contains records of nearly 9000 assessment visits and almost 64,000 ARs. It is publicly accessible via the Internet [4], and is easily sorted and manipulated using Microsoft Access® and Excel® to obtain the information needed for this study.

The twenty-five most frequently suggested energy-related ARs for the national program are ranked by frequency in Table 2, with the number of projects for each AR and the correlations resulting from this analysis. Table 3 lists the correlations for demand reduction for the national program. Some projects are found in both Tables 2 and 3 because they demonstrate both significant energy conservation and demand reduction. Tables 4 and 5 show similar information for ARs made by the TAMU IAC. Tables 2 through 5 were generated from the twenty-five most often recommended "Energy Management" ARs, and are not necessarily lists of the twenty-five most often recommended projects. The ARs that primarily resulted in waste reduction or productivity enhancements were not included.

ANALYSIS

Linear least squares regression is used to determine the correlation between implementation costs (I) and energy (or demand) savings (S) for each AR. A strong correlation will indicate the likelihood that savings can be calculated directly from the implementation costs. Conversely, a poor, or even mediocre correlation, will suggest that a simple linear relationship cannot be used to predict savings with confidence. Saman, et al. arbitrarily used 0.84 as the minimum acceptable "strong" correlation [2].

A simple least squares regression analysis seeks a linear relationship in the form:

$$S= \alpha + \beta I \qquad \text{Equation (1)}$$

with β as the slope and α as the intercept. In reality, the line generated from the regression coefficients should pass through the origin. The least squares regression analysis may yield a non-zero intercept that is acceptable even if the data model is expected to pass through the origin, particularly if the dataset is scattered [7]. The sample correlation coefficient R^2 is a measure of the "goodness of fit" for an estimated linear relationship, representing the percentage of the total variation of the dependent variable that is accounted for by the relationship with the independent variable [8]. The greater the R^2, the more the variation in the actual data is covered by the estimation equation. Smaller values of R^2 may indicate a good fit for larger data sets.

Total energy conservation was examined, taking into consideration the combined savings from all types of energy consumption that are tracked in units of millions of Btus. The resulting correlations and number of points considered for each AR are shown in Tables 2 and 4 under the heading "Total Energy." The Table 2 results are not encouraging, with only one R^2 greater than 0.65 ("Improve Lubrication Practices" was 0.91, but has only four data points that are widely scattered). Therefore, the correlations of implementation costs with electrical consumption and natural gas are also investigated in Tables 2 and 4, because they are highly important both nationally and in Texas. In fact, the total number of projects that primarily conserve other energy streams (E3 through E12 in Table 1) is only 15% of the number of projects that conserve either electrical consumption or natural gas. For example, about 11,000 ARs list electrical consumption as the primary conserved resource stream, while only about 600 conserve #2 fuel oil.

Tables 3 and 5 show the demand reduction projects, where correlations of demand savings, whether tracked as primary, secondary, tertiary or quaternary resource streams conserved, are shown as "All Streams." Also shown are the correlations for projects listing demand as the primary resource stream conserved. In the case of demand reduction projects, demand savings are often found in company with energy reduction, which is indicated by the much larger number of points in the "All Streams" column compared to the "Primary Stream" column. Items with less than four data points for both correlations were omitted in both Tables 3 and 5. Projects for which there are three or fewer points are marked "na", as there are not enough data for a meaningful regression result.

Table 2. National IAC Energy Conservation - Implementation Cost Correlations

Rank		No. Nat'l	Assessment Recommendation (AR)	Total Energy		Electrical Consumption		Natural Gas	
Nat'l	TAMU	Projects	Description	R^2	No. Points	R^2	No. Points	R^2	No. Points
1	2	6628	Utilize Higher Efficiency Lamps and/or Ballasts	0.47	1640	0.49	1635	0.94	4
2	8	3773	Use Most Efficient Type of Electric Motors	0.65	1134	0.71	1127	0.99	6
3	1	3132	Eliminate Leaks in Inert Gas and Compressed Air Lines /Valves	0.32	1030	0.37	1017	0.00	12
4	26	3104	Install Air Compressor Intakes in Coolest Locations	0.13	1005	0.11	981	0.34	22
5	23	2636	Utilize Energy-Efficient Belts and Other Improved Mechanisms	0.15	504	0.61	498	0.07	4
6	5	1922	Insulate Bare Equipment	0.14	1285	0.44	191	0.14	926
7	4	1896	Use More Efficient Light Source	0.57	467	0.57	465	na	2
8	17	1665	Analyze Flue Gas for Proper Air/Fuel Ratio	0.06	1663	0.25	6	0.04	1436
9	20	1446	Install Timers and/or Thermostats	0.16	1047	0.19	198	0.11	805
10	15	1400	Reduce the Pressure of Compressed Air to Minimum Required	0.03	517	0.03	516	na	1
11	46	1183	Install Occupancy Sensors	0.52	604	0.52	597	0.40	7
12	30	1072	Replace Electrically-Operated Equipment with Fossil Fuel Equipment	0.35	328	0.34	313	0.40	281
13	22	937	Reduce Illumination to Minimum Necessary Levels	0.09	266	0.09	265	na	1
14	10	820	Install Set-back Timers	0.00	61	0.06	19	0.01	40
15	6	798	Optimize Plant Power Factor	0.00	10	0.00	9	na	0
16	12	738	Reschedule Plant Operations or Reduce Load to Avoid Peaks	0.03	25	0.12	21	na	3
17	25	691	Insulate Steam/Hot Water Lines	0.21	675	0.83	7	0.32	520
18	55	650	Use Multiple Speed Motors or AFD for Variable Pump, Blower, and Compressor Loads	0.46	287	0.64	271	0.76	14
19	7	640	Turn Off Equipment During Breaks, Reduce Operating Time	0.14	174	0.02	70	0.13	93
20	21	619	Recover Waste Heat From Equipment	0.50	554	0.23	11	0.50	496
21	19	612	Turn Off Equipment When Not in Use	0.13	318	0.05	231	0.13	80
22	53	602	Recover Heat from Air Compressor	0.10	552	0.18	45	0.10	469
23	13	527	Improve Lubrication Practices	0.91	4	na	3	na	0
24	16	487	Use Waste Heat from Hot Flue Gases to Preheat Combustion Air	0.29	483	na	2	0.31	449
25	11	464	Use Synthetic Lubricant	0.03	198	0.03	198	na	0

Table 3. National IAC Demand Reduction - Implementation Cost Correlations

Rank		Assessment Recommendation (AR)	All Streams		Primary Stream	
Nat'l	TAMU	Description	R^2	No. Points	R^2	No. Points
1	2	Utilize Higher Efficiency Lamps and/or Ballasts	0.66	1667	0.78	247
2	8	Use Most Efficient Type of Electric Motors	0.68	1049	0.74	99
3	1	Eliminate Leaks in Inert Gas and Compressed Air Lines /Valves	0.46	552	0.78	79
4	26	Install Air Compressor Intakes in Coolest Locations	0.12	676	0.02	66
5	23	Utilize Energy-Efficient Belts and Other Improved Mechanisms	0.48	394	0.91	47
6	5	Insulate Bare Equipment	0.30	70	0.01	9
7	4	Use More Efficient Light Source	0.37	434	0.69	37
10	15	Reduce the Pressure of Compressed Air to Minimum Required	0.11	392	0.34	31
11	46	Install Occupancy Sensors	0.43	273	0.56	23
12	30	Replace Electrically-Operated Equipment with Fossil Fuel Equipment	0.20	306	0.48	52
13	22	Reduce Illumination to Minimum Necessary Levels	0.10	252	0.10	41
15	6	Optimize Plant Power Factor	0.36	96	0.36	96
16	12	Reschedule Plant Operations or Reduce Load to Avoid Peaks	0.07	130	0.08	114
18	55	Use Multiple Speed Motors or AFD for Variable Pump, Blower, and Compressor Loads	0.43	123	0.79	4
19	7	Turn Off Equipment During Breaks, Reduce Operating Time	0.04	12	na	1
20	21	Recover Waste Heat From Equipment	0.07	6	na	1
21	19	Turn Off Equipment When Not in Use	0.30	79	0.04	9
22	53	Recover Heat from Air Compressor	0.17	11	na	2
25	11	Use Synthetic Lubricant	0.00	159	0.00	24

Table 4. Texas A&M University IAC Energy Conservation - Implementation Cost Correlations

Rank		No. TAMU Projects	Assessment Recommendation (AR)	Total Energy		Electrical Consumption		Natural Gas	
TAMU	Nat'l		Description	R^2	No. Points	R^2	No. Points	R^2	No. Points
1	3	242	Eliminate Leaks in Inert Gas and Compressed Air Lines /Valves	0.71	75	0.79	72	0.22	3
2	1	209	Utilize Higher Efficiency Lamps and/or Ballasts	0.53	15	0.53	14	na	1
3	33	135	Make a Practice of Turning Off Lights When Not Needed	0.00	68	0.00	67	na	0
4	7	117	Use More Efficient Light Source	0.43	9	0.43	9	na	0
5	6	104	Insulate Bare Equipment	0.43	80	0.15	12	0.42	66
7	19	89	Turn Off Equipment During Breaks, Reduce Operating Time	0.00	16	1.00	12	0.11	4
8	2	81	Use Most Efficient Type of Electric Motors	0.83	22	0.82	21	na	1
9	45	68	Utilize Daylight Whenever Possible in Lieu of Artificial Light	0.78	22	0.78	22	na	0
11	25	63	Use Synthetic Lubricant	1.00	25	1.00	25	na	0
12	16	58	Reschedule Plant Operations or Reduce Load to Avoid Peaks	1.00	2	1.00	2	na	0
14	70	50	Reduce Exterior Illumination to Minimum Safe Level	0.17	6	0.17	6	na	0
15	10	48	Reduce the Pressure of Compressed Air to Minimum Required	0.00	8	0.00	8	na	0
16	24	43	Use Waste Heat from Hot Flue Gases to Preheat Combustion Air	0.56	43	na	0	0.56	43
17	8	37	Analyze Flue Gas for Proper Air/Fuel Ratio	0.17	36	na	0	0.21	35
18	84	37	Install Skylights	0.84	19	0.84	19	na	0
19	21	3	Turn Off Equipment When Not in Use	0.00	15	0.01	8	0.19	7
20	9	34	Install Timers and/or Thermostats	0.43	16	na	1	0.72	15
21	20	29	Recover Waste Heat From Equipment	0.09	28	na	0	0.09	26
22	13	28	Reduce Illumination to Minimum Necessary Levels	0.58	5	0.58	5	na	0
24	42	24	Repair Leaks in Lines and Valves	0.99	24	na	0	0.98	23
25	17	22	Insulate Steam/Hot Water Lines	0.40	22	na	0	0.43	20

Table 5. Texas A&M University IAC Demand Reduction - Implementation Cost Correlations

Rank		Assessment Recommendation (AR)	All Streams		Primary Stream	
TAMU	Nat'l	Description	R^2	No. Points	R^2	No. Points
2	1	Utilize Higher Efficiency Lamps and/or Ballasts	0.19	30	0.16	19
3	33	Make a Practice of Turning Off Lights When Not Needed	0.38	36	0.60	19
4	7	Use More Efficient Light Source	0.39	16	0.69	7
5	6	Insulate Bare Equipment	0.95	5	na	1
6	15	Optimize Plant Power Factor	0.55	37	0.55	37
8	2	Use Most Efficient Type of Electric Motors	0.79	26	0.95	5
11	25	Use Synthetic Lubricant	1.00	9	1.00	9
12	16	Reschedule Plant Operations or Reduce Load to Avoid Peaks	0.00	13	0.00	13
14	70	Reduce Exterior Illumination to Minimum Safe Level	0.15	10	0.60	5
15	10	Reduce the Pressure of Compressed Air to Minimum Required	0.25	13	0.10	5
22	13	Reduce Illumination to Minimum Necessary Levels	0.31	9	0.63	5

DISCUSSION

As seen in Table 2, three recommendations in the national dataset had R^2 values that would indicate candidacy for simple linear estimation. However, the sample sets were very small (six or less) for all three cases (and two of the three are natural gas savings associated with lighting and electric motor projects) so they were dropped them from consideration. The national database regression sample correlations for the three different breakdowns varied from 0 to 0.99. Ignoring the results with only a few data points (an arbitrary distinction of less than 10), the largest R^2 value is 0.71. As noted earlier, when the number of data points is large, smaller R^2 values may be acceptable criteria for a simple linear assumption. However, the low values are a strong indication that such a linear relationship is inadequate for the ARs examined. In Table 3, "Utilize Energy-Efficient Belts and Other Improved Mechanisms," has an R^2 value of 0.91 (with 47 data points) when considering demand savings as a primary resource stream only, yet the R^2 drops to 0.48 when all demand streams are analyzed. The electrical consumption R^2 for that AR is only 0.61 with 498 data points. A good demand reduction correlation accompanied by a poor energy conservation correlation (or the reverse) for the same recommendation indicates a problem, because demand reduction and energy conservation savings depend on many of the same inputs. Thus this project is not a good candidate.

The TAMU dataset in Table 4 yielded sample correlations ranging from 0 to 1.00. However, the five correlations with R^2 equal to 1.00 are not useful as they result from implementation costs always being listed as zero for these projects, thus, energy (or demand) savings in such cases cannot be predicted. Three ARs (not shown in Table 4), although ranking in the top twenty-five most frequent recommendations, had only E1 savings and were eliminated by that criterion. Of the ARs with R^2 values greater than 0.80, none of the sample sets had more than 24 data points, weakening their potential candidacy.

For TAMU, "Use Most Efficient Type of Electric Motors," had a fairly good correlation for electrical consumption of $R^2 = 0.82$ (Table 4). Table 5 shows that the electrical demand correlations for this project are not bad. The correlations in Tables 2 and 3 for this AR are 0.71 for electrical consumption and 0.74 for primary demand, which are the best correlations in the national set. The results may in part be due to the use of Motor Master energy efficient motor selection software at TAMU and at other IACs [9]. Motor Master is part of the DOE Motor Challenge [1], and has cost data for electric motors that provides implementation data of a high level of quality. In addition, the Motor Master software provides simple payback calculations that may also contribute to the lack of scatter for this AR.

The best fit was the "Repair Leaks in Valves and Lines" in Table 4, with an R^2 of 0.99 for all energy streams, which predominantly consisted of natural gas savings (R^2 of 0.98 with 23 data points). This presents the strongest case for predicting energy savings from implementation costs, although the national dataset had 206 projects conserving natural gas with an R^2 of 0.60 (not shown in Table 2). The TAMU AR "Install Skylights" (Table 4) had a correlation of 0.84 with 19 electrical consumption data points, but the national dataset yielded only 0.29 with 49 data points. This indicated the likelihood that it is not a good candidate for prediction at the national level. "Insulate Bare Equipment" (Table 4), had a high correlation of 0.95 for demand savings, but with only five data points, the results were suspect. The national dataset had 70 data points and yielded an R^2 value of 0.30, which indicated a poor correlation with a larger dataset.

Based on this analysis, three energy conservation assessment recommendations may be candidates for predicting energy savings from implementation costs. Table 6 shows slopes and intercepts of Equation (1).

Table 6. Recommended Prediction Coefficients

Assessment Recommendation (resource conserved)	Equation (1) coefficients	
	α, million Btu	β, million Btu/$
Use Most Efficient Type of Electric Motors (electrical consumption)	-131.7	25.25
Repair Leaks in Lines and Valves (natural gas consumption)	-457.8	0.9176
Install Skylights (electrical consumption)	1344	14.29

CONCLUSION

The poor correlations between implementation costs and energy or demand savings for the majority of the surveyed ARs in the national database indicate that a direct prediction of savings is unfeasible, and so is not recommended. Data from a single IAC (TAMU) yielded higher R^2 values, but these were derived from fewer data points. Although the TAMU IAC correlations were better than the national correlations, use of this technique to directly predict savings calls for a high level of confidence in the of implementation cost data. Moreover, the experience gained by the students in performing the energy and demand calculations, and the value to the manufacturers of seeing the simple calculations in the reports offsets benefits gained by reduction in report generation time.

The low correlation results do raise questions about the consistency and accuracy of the calculation of the implementation costs and savings. As noted earlier, energy conservation and demand reduction are carefully prepared, but implementation cost estimates for conceptual designs may add to data scatter and contribute to poorer correlations. However, these costs estimates are adequate for the intended purpose of plant budgetary decisions.

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