LBNL-6288E

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Reprint version of journal article published in "Energy Policy", please cite as:

Peter Therkelsen, Aimee McKane, Implementation and rejection of industrial steam system energy efficiency measures, Energy Policy, Volume 57, June 2013, Pages 318-328

May 2013

Implementation and Rejection of Industrial Steam System Energy Efficiency Measures

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Abstract

Steam systems consume approximately one third of energy applied at U.S. industrial facilities. To reduce energy consumption, steam system energy assessments have been conducted on a wide range of industry types over the course of five years through the Energy Savings Assessment (ESA) program administered by the U.S. Department of Energy (U.S. DOE). ESA energy assessments result in energy efficiency measure recommendations that are given potential energy and energy cost savings and potential implementation cost values. Saving and cost metrics that measure the impact recommended measures will have at facilities, described as percentages of facility baseline energy and energy cost, are developed from ESA data and used in analyses. Developed savings and cost metrics are examined along with implementation and rejection rates of recommended steam system energy efficiency measures. Based on analyses, implementation of steam system energy efficiency measures is driven primarily by cost metrics: payback period and measure implementation cost as a percentage of facility baseline energy cost (implementation cost percentage). Stated reasons for rejecting recommended measures are primarily based upon economic concerns. Additionally, implementation rates of measures are not only functions of savings and cost metrics, but time as well.

[keywords: steam system efficiency, industrial energy efficiency, industrial energy efficiency barriers]

Introduction

Industrial sector energy consumption (defined as the quantity of energy applied to an entity) (ISO, 2011) accounted for 32% of the 105.5 EJ of energy applied within in the United States in 2008 and cost the industrial sector US$247.19 billion (DOE, 2011). To increase industrial energy productivity and facilitate competitiveness, the U.S. government promotes energy savings measures. While the government can encourage facilities to adopt energy efficiency measures, ultimately individual facilities decide whether or not to implement these measures.

Industrial energy systems can be disaggregated into five major system types: steam, process heat, fans, pumps, and compressors. Steam systems account for one third of all industrial energy consumption, and will be the focus of this study (DOE, 2002a, 2006). Industrial steam is used to heat raw materials and treat semi-finished products. It is also a power source for equipment, as well as for building heat and electricity generation (DOE, 2002a, 2012c).

Industrial sectors that use fossil fuels as an energy source typically devote significant proportions of these fuels to steam production. Such sectors include: pulp and paper (81%), food processing (57%), chemicals (42%), petroleum refining (23%), and primary metals (10%) (Einstein et al., 2001). Due to this reliance on steam, improving steam system energy efficiency can greatly reduce industrial energy consumption and cost. The U.S. DOE has estimated that energy and associated expenditure savings of 10-15% can found throughout industrial steam systems (DOE, 2012c).

The U.S. DOE offers a large number of publications, trainings, and tools aimed at reducing industrial energy consumption. Additionally, the U.S. DOE offers facility energy assessments through their Industrial Assessment Centers (IAC) and the Energy Savings Assessment (ESA) program. Small and medium facilities (fewer than 500 employees and gross annual sales below US$100 million) can participate in a one to three day IAC assessment while the largest, most energy-intensive industrial plants in the U.S. can receive a three-day assessment as part of the ESA program. IAC assessments are conducted for all facility system types while ESA assessments target one of the five major system types: compressors, fans, process heating, pumps, and steam. Both assessment programs establish a baseline of energy consumption and energy cost in addition to recommending energy saving measures. Follow up assessments record energy and cost savings reported due to implementation of recommended measures.

The U.S. DOE has been collecting ESA assessment data since October of 2007. The ESA database contains assessed facility baseline energy consumption and cost along with recommended steam system energy efficiency measures. Potential annual energy and energy cost savings values as well as an implementation cost value are provided for recommended energy efficiency measures. Three follow up assessments conducted six, 12, and 24 months following the initial assessment are made. During follow-up assessments, recommended energy efficiency measure implementation status is recorded as either implemented, in progress, or rejected. Additional measures are not recommended. For implemented measures, reported energy and energy cost savings as well as implementation cost are recorded. In the case of measure rejection, a reason for rejection is selected for a pre-determined pick list.

Facilities that participate in the ESA program are not required to publicly report and the database used for this paper has been expunged of all facility identification. However, a number of ESA assessment case studies are available that do identify facility information (DOE, 2012b).

This study examines five years of available ESA data to determine factors that affect the implementation or rejection of steam system energy efficiency measures recommended to U.S. industrial facilities, the accuracy of predicted energy and energy cost savings, as well as implementation cost and payback are compared to reported values. Additionally, barriers preventing implementation are examined in the form of measure rejection reasons. These reasons are assessed in a manner that parallels previous studies that have identified energy efficiency deployment barriers (Brown, 2001; DeCanio, 1993; Palm and Thollander, 2010; Rohdin and Thollander, 2006; Schleich and Gruber, 2008; Sorrell et al., 2000; Sovacool, 2009; Thollander et al., 2007; Trianni and Cagno, 2012; Umstattd, 2009; Weber, 1997). Finally, the rate of implementation is studied as a function of savings and cost metrics as well as time. By understanding factors that drive energy efficiency measure implementation, governments and policy makers can better target steam system efficiency measure recommendations to industry.

Methodology

This study of industrial steam system energy efficiency measure implementation and rejection was conducted by analyzing steam system energy assessments in the ESA database. The ESA database includes facility baseline energy consumption and energy cost, recommended energy efficiency measures, measure savings and cost values, and implementation status of recommended measures recorded six, 12 and 24 months following an initial assessment. If a measure has been rejected, a reason for rejection is selected from a pick list and recorded.

The ESA database includes 1165 energy assessments made at 928 unique facilities for all system types: compressors, fans, process heating, pumps, and steam. A number of facilities participated in multiple assessments; most of which focused on different system types, though a few facilities requested multiple assessments for the same system type. Of all assessments, 42% focused on steam systems, and are the subject of this paper. Steam systems account for 53% of total database facility baseline energy consumption and 51% of total facility energy cost. The second largest energy system, process heating, accounts for 29% of assessments, 25% of total facility energy consumption, and 27% of total facility energy cost.

For this analysis, incomplete and non-steam system assessments and facilities were removed from the database, resulting in 105 assessments conducted at 104 facilities. Incomplete data included assessments with no baseline data, or assessments that did not have complete six, 12, and 24-month reassessment entries. One general manufacturing facility received two distinct steam system assessments. These two assessments are included independently and are not aggregated. The assessments include 606 energy efficiency measures recommendations made up of 98 unique steam system energy efficiency measures.

Figure 1 shows facility baseline energy and energy cost data for all facilities in the ESA database. Each facility is represented by the outline of a black diamond. Black diamonds filled in with red indicate facilities that received a steam system assessment, including those assessments deemed to be incomplete. Lastly, green circles indicate facilities that took part in a steam system and are included in this analysis. Figure 1 shows that the facilities included in this paper matches well with the overall distribution of facilities in the ESA database. Figure 1 highlights the linear relationship between facility energy consumption and energy cost.

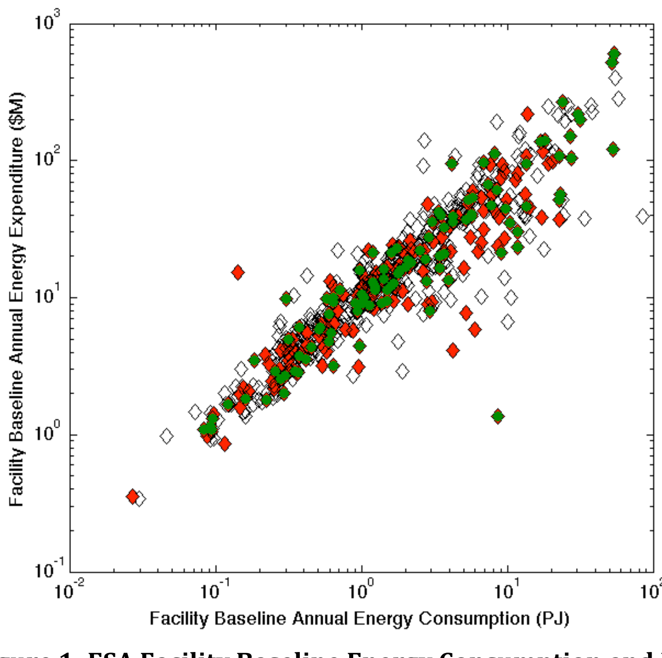

Figure 1: ESA Facility Baseline Energy Consumption and Energy Cost

This analysis of steam system assessments is conducted with aggregated data. However, as reference information, facility energy consumption, energy cost, and industry type are disaggregated. Assessments are disaggregated by annual facility energy consumption into four bins: less than 0.2 PJ; 0.2 to 0.4 PJ; 0.4 to 4.2 PJ; and greater than 4.2 PJ. The columns of Table 1 list the number of facilities that fall into each of these bins.

Additional disaggregation is made based upon self-identified industrial sectors. The five most commonly assessed sectors are: chemical; forest products; food processing; general manufacturing; and automotive. These sectors constitute 86% of assessments and are known to use large quantities of energy to produce steam (DOE, 2002b). Industrial sectors are not individually analyzed in this paper but are listed in Table 1 as reference.

Table 1: Number of Assessments included in Analysis. Aggregated and Disaggregated by Annual Facility Energy Consumption and Industrial Sector.

	All Assessments	Less Than 0.2 PJ	0.2 – 0.4 PJ	0.4 – 4.2 PJ	Greater Than 4.2 PJ
Aggregated	105	7	11	52	35
Chemical	32	0	3	10	19
Forest Products	21	0	0	12	9
Food Processing	21	7	5	8	1
General Manufacturing	10	0	2	6	2
Automotive	6	0	1	5	0

Table 2 lists aggregated and disaggregated assessed facility energy consumption and energy cost data. Data are summed and averaged in aggregate and per disaggregated bin. In total, assessed facilities annually consumed 721.9 PJ of energy at a cost of US$5.2 billion. The chemical sector is the largest consumer of energy in total and per assessment. The five disaggregated sectors do not share common energy consumption or energy cost values per assessed facility. Facilities that consume 4.2 PJ or more of energy account for the majority of total energy consumed and energy cost. The number of facilities that consume greater than 4.2 PJ of energy is larger than any other energy consumption bin and the energy consumed per facility in this bin is considerably higher than those in other bins.

Table 2: Total and Averaged Assessed Facility Energy Consumption and Energy Cost in Aggregate and Disaggregated.

	All Assessments		Annual Facility Energy Consumption		Annual Facility Energy Cost	
			Summation	Average	Summation	Average
			(PJ)	(PJ)	(US$M)	(US$M)
	105	Aggregated	721.9	6.87	$5,191.2	$49.9
Top Five Industrial Sectors	32	Chemical	399.4	12.48	$3,134.0	$97.9
	21	Forest Products	112.1	5.34	$724.8	$34.5
	21	Food Processing	21.1	1.00	$123.9	$5.9
	10	General Manufacturing	29.0	2.90	$183.4	$18.3
	6	Automotive	7.0	1.67	$63.8	$10.6
Facility Annual Energy Consumption	7	< 0.2 PJ	0.8	0.11	$11.6	$1.7
	11	0.2 – 0.4 PJ	3.5	0.32	$43.1	$3.9
	52	0.4 – 4.2 PJ	89.9	1.73	$844.3	$16.2
	35	> 4.2 PJ	627.6	17.93	$4,292.1	$122.6

Energy efficiency measure potential and reported savings and cost values are provided in the ESA database. These values are functions of facility steam system energy consumption and energy cost, making direct comparison of the savings and cost values from different assessments unreliable. Use of energy consumption and energy cost as proxies for facility steam system energy and energy cost allows for normalization of these savings and cost values, thus making direct comparison of measure savings and cost metrics from different assessments possible. Four metrics not native to the ESA database were calculated and used in this analysis: energy savings percentage, energy cost savings percentage, implementation cost percentage, and payback period. Potential and reported versions of each metric were calculated. The four metrics are detailed:

- Energy savings percentage = 100 * measure potential annual energy savings / baseline facility annual energy consumption
- Energy cost savings percentage = 100 * measure potential annual energy cost savings / baseline facility annual energy cost
- Implementation cost percentage = 100 * potential measure implementation cost / baseline facility annual energy cost
- Payback period (months)= (measure implementation cost / annual energy cost savings) x 12 months

Calculated savings and cost percentage values represent the impact a recommended measure will have at a facility. Greater energy savings percentage values indicate that implementation of an energy efficiency measures will result in a larger fraction of facility energy consumption being reduced as compared to a measure with lower energy savings percentage. Similarly, a large energy cost savings percentage value indicates a measure will reduce a large fraction of facility energy cost as compared to a measure with a lower energy cost savings percentage. For these two savings metrics, a higher value equates to greater positive impact with regards to facility energy consumption and energy cost.

A large implementation cost percentage value indicates that implementing a recommended energy efficiency measure will require an investment that represents a large fraction of the total annual facility energy expenditure. Payback period specifies the length of time before the cost of implementing an energy efficiency measure is recuperated through energy cost savings.

Results

The examination of ESA steam system assessments focuses on the implementation and rejection of recommended energy efficiency measures. Analyses of: measure recommendations, implementations and rejections, reported barriers to implementation, recommended measure savings and cost accuracy, and time dependency of measure implementation are included.

Recommended Energy Efficiency Measures

During initial ESA assessments, energy efficiency measures are identified and recommended to assessed facilities. Measures are selected from a pre-defined pick list common to the IAC and ESA programs. Recommended measures are ascribed potential energy and energy cost saving values and potential implementation costs. Measures are recommended to facilities based upon the observations and expertise of the assessor, not preset formulas related to facility energy consumption, energy cost, or industry type.

Of the 105 analyzed assessments, 84% received between two and eight recommendations. A small fraction of facilities were recommended more than 8 measures, to a maximum of 15 measures recommended to one facility. 24% of all assessments included 5 recommended measures. In some instances measures were recommended multiple times during a single assessment. This typically occurred when a facility employed multiple steam systems. The number of recommendations made during an assessment and the associated potential energy and energy cost savings do not relate to facility energy consumption, energy cost, or industry type.

All 606 recommended energy efficiency measures are illustrated in Figure 2. The figure shows potential energy cost savings percentage against potential energy savings percentage. Marker color denotes potential payback period and marker size represents potential implementation cost percentage. A black reference marker is provided with a potential implementation cost percentage of 1.0%. A small percentage of recommended measures reported negative potential energy savings values. These measures are not often implemented and more typically have positive energy cost savings percentages. Such measures include those that involve installing combined heat and power systems, larger boilers, or steam driven equipment as replacement for electric powered equipment. Recommended measures with positive energy savings have typical potential energy savings that range from 0 and 20% and potential energy cost savings that would save between 0 and 15% of facility energy cost each year. A linear relationship between energy and energy cost savings percentages exists. Cost metrics (payback period and potential implementation cost percentage) are not functions of savings metrics (energy and energy cost savings percentage).

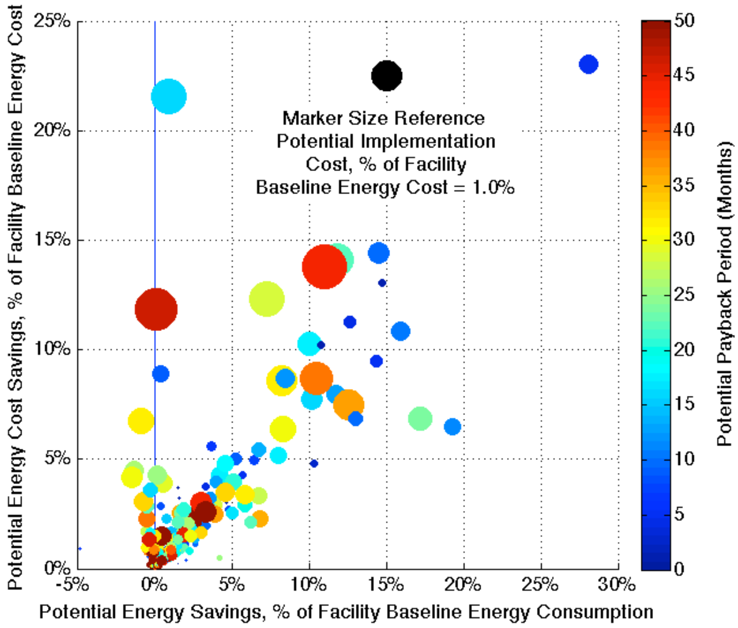

Figure 2: All Recommended Steam System Energy Efficiency Measures and Respective Savings and Cost Metrics.

In addition to analysis of recommended measures in aggregate, select energy efficiency measures are disaggregated and analyzed. To reduce statistical skew, only measures recommended 10 or more times are disaggregated. Of the 98 unique measures, 16 measures meet this requirement. These 16 measures account for 64% of all recommendations made, 75% of total recommended potential energy savings, 51% of total recommended potential cost savings, and 42% of total recommended potential implementation cost.

Listed in Table 3, the 16 measures are assigned measure numbers in order of descending implementation rate 24-months after initial assessment. Additionally, Table 3 lists the number of times a measure was recommended along with averaged energy efficiency metrics: potential energy savings, potential energy savings percentage, potential energy cost savings, potential energy cost savings percentage, potential implementation cost, potential implementation cost percentage, and potential payback. Table 3 provides an accessible connection between absolute savings and costs and associated percentage values. Average, maximum, and minimum measure metric values are included providing comparative ranges.

Energy efficiency measures listed in Table 3 are found in other U.S. DOE steam system efficiency reports and studies, including ESA assessment case studies and steam system tip sheets. Ten measures found in Table 3 are mentioned in these other documents (DOE, 2012c). Additionally, nine measures listed in Table 3 are mentioned as top steam system energy efficiency measures in a U.S. DOE steam system best practices handout (DOE, 2006). Industrial steam system energy efficiency measures listed in Table 3 are found in lists and reports generated by third parties including: IAC top 50 most recommended measures for all system types including steam (DOE, 2012a), IAC top 10 steam system potential energy cost savings list by ORNL (Wright et al., 2010), and a steam system energy efficiency study by LBNL (Einstein et al., 2001). Varying fonts identify measures listed in Table 3 that are found in third party lists and reports: <u>underlined</u> (<u>IAC top 50</u>), **bold** (**ORNL report**), and *italicized* (*LBNL report*).

Table 3: Disaggregated Energy Efficiency Measures and Associated Metrics. Varying Fonts Indicated Measures Also Found in Third Party Lists and Reports: Underlined = IAC Top 50 Listing, Bold = ORNL IAC Report, and *Italicized = LBNL Steam Systems Report*.

				Average Potential:						
Measure Number	Energy Efficiency Measure Description	Implementation Rate After 24 Months	Number of Times Recommended	Annual Energy Savings (TJ)	Annual Energy Savings Percentage	Annual Energy Cost Savings (US$)	Annual Energy Cost Savings Percentage	Implementation Cost (US$)	Implementation Cost Percentage	Payback (Months)
1	*Repair And Eliminate Steam Leaks*	64%	24	39.27	0.41%	249,613	0.30%	81,896	0.17%	9.3
2	*Repair Faulty Insulation On Steam Lines*	60%	10	12.11	0.16%	80,390	0.13%	68,600	0.09%	9.4
3	***Repair Or Replace Steam Traps***	60%	46	24.35	0.91%	153,593	0.88%	76,774	0.48%	8.5
4	Repair Leaks In Lines And Valves	57%	17	10.78	0.28%	54,527	0.23%	28,149	0.16%	6.7
5	*Analyze Flue Gas For Proper Air/Fuel Ratio*	51%	51	15.77	0.91%	110,876	0.68%	87,040	1.35%	16.5
6	*Insulate Steam / Hot Water Lines*	38%	15	13.17	0.64%	93,283	0.47%	31,867	0.35%	8.1
7	*Insulate Bare Equipment*	38%	31	31.53	0.44%	167,204	0.55%	229,335	0.86%	12.9
8	Use Minimum Steam Operating Pressure	36%	26	358.69	3.50%	1,126,909	3.43%	1,060,923	4.38%	16.0
9	*Use Flue Gas Heat To Preheat Boiler Feedwater*	29%	22	29.55	2.17%	228,063	1.96%	276,107	3.41%	26.1
10	*Use Heat From Boiler Blowdown To Preheat Boiler Feed Water*	28%	34	16.14	0.69%	97,639	0.63%	107,368	0.88%	13.1
11	Reduce Excessive Boiler Blowdown	25%	26	9.55	0.95%	65,251	0.79%	267,606	2.72%	26.5
12	***Increase Amount Of Condensate Returned***	21%	54	43.67	1.09%	245,910	0.90%	362,819	1.10%	19.9
13	Preheat Boiler Makeup Water With Waste Process Heat	18%	11	12.95	0.97%	91,044	0.79%	101,245	1.60%	19.0
14	**Replace Electric Motors With Back Pressure Steam Turbines**	16%	23	35.34	0.33%	669,418	2.82%	1,934,834	0.45%	42.5
15	**Use Steam Pressure Reduction To Generate Power**	14%	23	61.24	0.64%	451,233	1.83%	535,652	4.30%	25.9
16	Flash Condensate To Produce Lower Pressure Steam	13%	16	20.23	2.58%	103,509	2.23%	89,219	1.79%	14.5
	Average	35%	27	45.90	1.04%	249,279	1.16%	333,715	2.13%	17.2
	Maximum	64%	54	358.69	3.50%	1,126,909	3.43%	1,934,834	4.38%	42.5
	Minimum	13%	10	9.55	0.16%	54,527	0.13%	28,149	0.09%	6.7

Implementation and Rejection After 24 Months

The average implementation rate for all recommended industrial steam system energy efficiency measures after 24 months is 34%. The 16 individually analyzed energy efficiency measures have a comparable average implementation rate of 35% as seen in Table 3.

Figure 3 illustrates implementation and rejection rates for the 16 disaggregated measures listed in Table 3. For these 16 measures, implementation rates ranges from 13% to 64%. Five measures, all involving maintenance and operational improvements, have implementation rates greater than 50%. Of these five measures, four involve repairing previously installed steam equipment; steam lines, valves, traps, and insulation. These repair activities require little or no capitol cost, are typically funded through existing maintenance budgets, and can be performed during scheduled maintenance. In studies of industrial motor system energy efficiency measures, a connection has been made between an energy management system standard such as *ISO 50001 -Energy management system standard,* with its emphasis on operational control, and enhanced implementation of cost effective system energy efficiency measures and improved system maintenance (McKane and Hasanbeigi, 2011; McKane et al., 2005). A principal goal of ISO 50001 is to foster continual and sustained energy performance improvement through a disciplined approach to operations and maintenance practices. The fifth measure, "analyze flue gas for proper fuel/air mixture," is performed during normal production operation and corrective actions likely to result from this analysis, such as adjusting burner settings, can also be made during production periods.

Rejection rates range from 8% to 73% and tend to increase as implementation rate decreases. Two measures; 6, "insulate steam/hot water lines," and 13, "preheat boiler makeup water with waste process heat," do not fit this trend, having significantly lower rejection rates and larger "in progress" rates than their corresponding implementation rates. Three measures which involve installing major pieces of equipment in the steam system: 14, "replace electric motors with back pressure steam turbines," 15, "use steam pressure reduction to generate power," and 16, "flash condensate to produce lower pressure steam," have rejection rate values greater than 50% and implementation rates below 15%. In contrast, most measures with higher implementation rates involve modifying operation conditions or making adjustments to the steam flow path.

Measures recorded as being "in progress" account for 14% to 64% of the total implementation status and average to be 30% of the total for each disaggregated measures. The database does not record when a decision to implement a measures is made, leaving no way to discern if measures labeled as "in progress" have been approved for implementation or not. Measures labeled "in progress" do not always end up implemented.

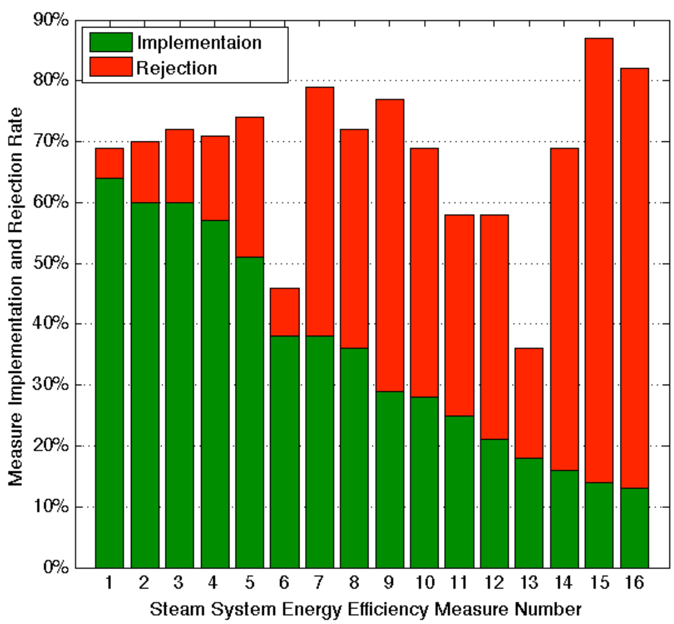

Figure 3: Measure Implementation and Rejection Rates 24 Months After an Initial Assessment.

The implementation of energy efficiency measures can be financed through a variety of methods, including through existing or temporarily expanded maintenance budgets, capitol improvement funding, or external financing such as an ESCO. The

ESA database does not indicate what form of financing was used to implement energy efficiency measures.

Relationships between measure implementation rate and potential savings and cost metrics for the 16 disaggregated energy efficiency measures are shown in Figure 4. Measures with high implementation rates have low energy savings percentage (x-axis) and thus little impact on facility energy consumption. Additionally, energy efficiency measures with high implementation rates are characterized by short payback periods (marker color). The five measures with implementation rates greater than 50% have payback periods less than 18 months. As payback period increases (blue to red), implementation rate decreases exponentially. Similarly, measures with low implementation cost percentage (marker size) are implemented at higher rates.

These factors indicate that facilities primarily implement energy efficiency measures that do not represent a large fraction of total plant energy consumption and have payback periods less than 24 months, regardless of the fact that these measures provide low energy and energy cost savings impact. *These findings support the conclusion that near-term financial concerns and payback are the driving force behind a facility's decision to implement energy efficiency measures, not the reduction of energy consumption. Facilities studied adhered to this pattern even when increased annual energy savings would result in financial gains though annual energy cost reductions.*

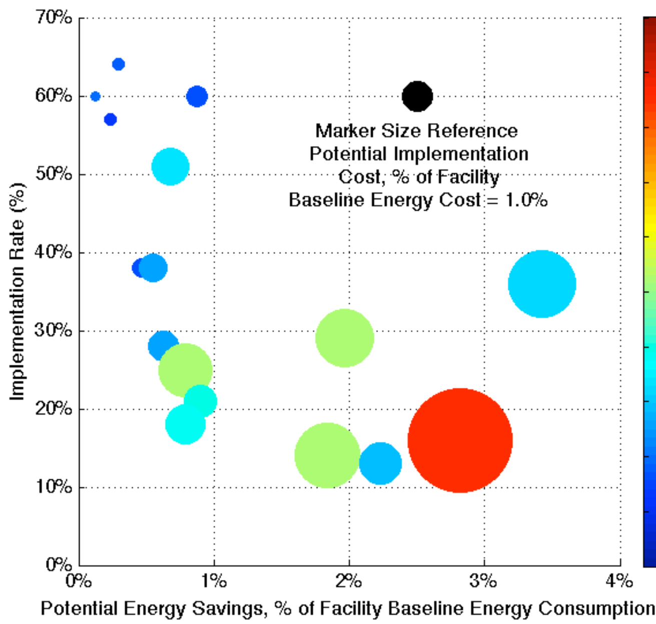

Figure 4: Relationships Between Implementation Rate, Potential Energy Savings Percentage, Potential Payback (Marker Color), and Potential Implementation Cost Percentage (Marker Size).

Barriers Leading to Measure Rejection After 24 Months

As shown, implementation of steam system energy efficiency measures is dependent upon cost metrics such as implementation cost. However, rejection of recommended measures occurs regardless of implementation cost level indicating other barriers to implementation exist. Other studies have examined a wide range of industrial sectors and facility sizes, confirming that cost-effective energy conservation measures are not always implemented. This energy efficiency gap is attributed to energy efficiency barriers (Brown, 2001; DeCanio, 1993; Palm and Thollander, 2010; Rohdin and Thollander, 2006; Schleich and Gruber, 2008; Sorrell et al., 2000; Sovacool, 2009; Thollander et al., 2007; Trianni and Cagno, 2012; Umstattd, 2009; Weber, 1997).

Of the 187 rejected steam system measures, 86% were assigned a reason for rejection, selected from a pre-determined pick list of 29 unique rejection reasons. For this study, rejection reasons are grouped into six rejection barrier categories: economic; facility/production; behavioral; organizational; attempted; and other.

Economic, behavioral, and organizational categories were established by other researchers and are detailed by Sorrell et al. (Sorrell et al., 2000). Facility/production, attempted, and other categories are included based upon rejection reasons found in the pre-determined pick list. The classification of implementation barriers is not unambiguous, as discussed by Weber (Weber, 1997). Table 4 lists rejection barrier categories and rejection reasons along with the percentages for both the categories and reasons within each category.

Most reported rejections, 41%, are related to the economic barrier category. Two rejection reasons, “too expensive initially,” and, “unsuitable return on investment,” account for 85% of all economic category rejections. *This finding agrees with previous analyses showing the importance cost metrics have with respect to measure implementation rate and that economics is the greatest barrier to measure implementation.* The low number of “cash flow prevention,” responses indicates that, for the group of facilities studied, obtaining capitol is not a large problem if a facility decides to implement a measure.

As the ESA database does not indicate how implemented measures were funded it is not possible to determine if external organizations, such as energy service companies (ESCOs), would be able reduce the perceived financial risk of implementing certain energy efficiency measures. Studies suggest that ESCOs have experienced limited success in transferring their commercial sector business model to the industrial sector (Elliott, 2002). The lack of success of ESCOs in the industrial sector has been attributed to a number of reasons including; low energy prices, limited access to decision makers, difficulty in evaluating project success, and lack of expertise in the industrial sector (Farnsworth, 2007). Due to their background, ESCOs tend to concentrate on system types that are found in commercial buildings such as lighting and ventilation. This focus results in ESCOs missing most of the potential energy savings at industrial sites, including steam systems (IEA, 2007).

Facility/production rejection barriers represent 25% of all rejection reasons. Reasons included in this category are those that would negatively affect production or that the facility has been altered so that the recommended measure is no longer applicable. The largest barrier within the facility/production category is attributed to "process and/or equipment changes," indicating that the recommended measure is no longer applicable to the facility. In order to be effective, energy efficiency measures must apply to ever changing industrial processes and equipment.

The behavioral barrier rejection category is defined by Sorrell et al. (Sorrell et al., 2000) as including barriers such as: "inadequate information to stimulate action", "resistance to change due to current inertia," and "a lack of trust in provided information." These barriers roughly match the rejection reasons listed in the behavioral category- "not worthwhile," "impractical," and "disagree." Behavioral barriers account for one fifth of all rejection reasons.

Barriers listed in the organizational rejection category accounts for a low percentage of total rejections. This could be due to the inherent design of the ESA program in which facilities proactively sought governmental assistance to increases energy efficiency, indicating they are predisposed to consider energy efficiency measures.

The major rejection reason in the organizational category, "bureaucratic restrictions," indicates that measures that normally would be implemented are not due to internal decision-making structures. These may include a lack of communication between those who authorize and finance projects and those who analyze energy assessment results. An energy management system, such as ISO 50001, with its emphasis on top management support, may help address this barrier by providing a broader business context for energy efficiency project implementation decisions (ISO, 2011).

Only one measure was rejected after implementation was initiated, indicating that measures are either rejected before being tried, or once implemented are not removed or discontinued within the 24-month reporting period.

Table 4: Energy Efficiency Measure Rejection Barrier Categories and Rejection Reasons

Rejection Barrier Category / Rejection Reason	Barrier Category %	Fraction of Category %
Economic	**41%**	
Unsuitable return on investment		43%
Too expensive initially		42%
Cash flow prevents implementation		14%
Facility/Production	**25%**	
Process and/or equipment changes		41%
Unacceptable operating changes		29%
Facility change		10%
Plant Closure		9%
Suspected risk or problem with equipment or product		7%
Material restrictions		3%
Production schedule changes		1%
Behavioral	**19%**	
Disagree		34%
Impractical		33%
Not worthwhile		33%
Other	**8%**	
Other		76%
Unknown		24%
Organizational	**7%**	
Bureaucratic restrictions		58%
Lack of staff for analysis and/or implementation		32%
Risk or inconvenience to personnel		11%
Attempted	**0%**	

Accuracy of Measure Recommendation Values

Facilities use potential energy and energy cost savings as well as potential implementation cost values when deciding whether to implement or reject recommended efficiency measures. Potential values are estimates based upon expert opinion so potential values differ somewhat from reported savings and cost values. Depending upon the direction and magnitude of the error between potential and reported values, decisions to implement or reject measures may be affected. Errors between potential and reported values are examined for measures with both potential and reported savings and cost values implemented 10 or more times.

Error metrics are developed for potential energy savings percentage, potential energy cost savings percentage, potential implementation cost percentage, and potential payback:

- Error metric = (reported value – potential value) / potential value

The algebraic sign preceding savings error metrics has a different meaning than those preceding cost error metrics. In the case of savings metrics, positive error causes the recommended measure to appear to have lower savings potential than it would result in if actually implemented, potentially deterring implementation. In the case of savings error metrics, a positive value means that the opposite is true - measures may potentially appear more attractive to facilities than they should. This convention also holds for cost error metrics and is summarized in Table 5.

Table 5: Savings and Cost Metric Error Value Meaning

	Positive Error Value	Negative Error Value
Energy savings metrics: • Energy savings ratio • Energy cost savings ratio	Measure looks less attractive than it is reported to be.	Measure looks more attractive than it is reported to be.
Cost metrics: • Implementation cost ratio • Payback period	Measure looks more attractive than it is reported to be.	Measure looks less attractive than it is reported to be.

Metric error values for the 16 disaggregated steam system energy efficiency measures are calculated and plotted on two graphs, both against implementation rates greater than 30% in Figure 5. Savings metric error values are plotted on the left graph and cost metric error values on the right. The impact of metric error on implementation rate cannot fully be discerned from the available data. However, generalization can be concluded.

As seen in the left graph of Figure 5, implementation rate decreases as savings metric error increases. This trend may be the result of large negative savings error values causing measures to appear more attractive to facilities, thus increasing their implementation rate. Measures with implementation rate below 40% have positive savings rate error values that potentially could cause these measures to appear less attractive.

A clear trend of implementation rate and cost savings error values is not established as seen on the right hand graph of Figure 5. While implementation cost error seems to indicate that measures that falsely appear more attractive are implemented at higher rates, payback period error confounds this conclusion by not establishing a clear relationship with implementation rate. A strong correlation between cost metric error values and implementation rate may be partially obscured by how repair activities, the most commonly implemented measures, are accounted for. An assessor will typically estimate the full cost of implementing a measure. However, since repairs are often undertaken by existing staff when production demands are low, the cost of implementing energy measures involving repairs may be embedded in routine labor costs, rather than as a separate cost. As a result, the final cost of implementing the measure may not be fully captured in the subsequent reporting.

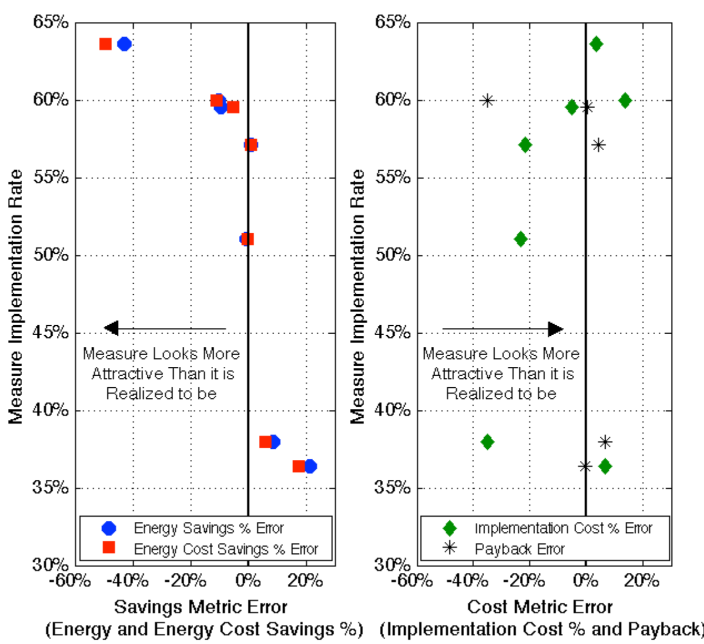

Figure 5: Implementation of Energy Efficiency Measures and Savings and Cost Metric Error

Time Dependence of Implementation and Rejection Rates

Changes in implementation and rejection rate between follow up assessment periods of recommended energy efficiency measures are examined. Table 6 lists average, maximum, and minimum changes in energy efficiency measure implementation, rejection, and "in progress" status for the 16 earlier identified measures. For each implementation status category, three change periods are identified: 6 – 24 months, 6 – 12 month, and 12 – 24 months. Average values indicate the trend in status change while maximum and minimum values provide contextual ranges. From this table, time dependence upon measure implementation and rejection can be seen.

Table 6 shows that between the six and 24-month reporting period, measures implementation increased by 17%. The vast majority of these measures were implemented between the six and 12 month reporting periods. *This indicates that if one of these 16 measures is to be implemented, it will be implemented within a year of being recommended.* Measures are also implemented after the 12-month assessment period but at lower rates. As indicated by negative minimum values, implementation of some measures decreases between assessment periods. These measures typically are reassessed to be "in progress" and are not implemented at a later time. No reason for the change in status is provided in the database. While the largest increase in implementation rate is seen between the six and 12-month reassessment periods, the largest increase in rejections occurs between the 12 and 24-month periods. As with implementation rate, negative minimum rejection rate change values indicate that a number of rejected measures were reassessed, either as implemented or as "in progress." While implementation and rejection rates increased dramatically between different assessment periods, the number of "in progress" measures decreased evenly between the three assessments periods. The increases in implementation and rejection rates nearly match the decreases of "in progress" measure rates.

Table 6: Changes in Implementation, Rejection, and "In Progress" of Measures Between Assessment Periods

Change Between Assessments	Average	Maximum	Minimum
	Measure Implementation Rate Change		
6 – 24 Month	17%	30%	5%
6 – 12 Month	13%	27%	-10%
12 – 24 Month	3%	40%	-15%
	Measure Rejection Rate Change		
6 – 24 Month	9%	44%	-9%
6 – 12 Month	-1%	12%	-27%
12 – 24 Month	11%	44%	-6%
	Measure "In Progress" Rate Change		
6 – 24 Month	-26%	3%	-50%
6 – 12 Month	-12%	7%	-33%
12 – 24 Month	-14%	21%	-44%

Time dependence of implementation rate and its relationship to savings and cost metrics is analyzed for all 606 recommended energy efficiency measures in Figure 6. Measures are segregated into potential energy savings percentage bins (y-axis). Average implementation rate (color) and potential implementation cost percentage (size) are calculated for each bin. Small red squares indicate bins that do not contain measures and thus no implementation or cost data.

The left most column of boxes in Figure 6 represents implementation of measures six months following an initial assessment. During the six-month assessment, measures with potential energy savings percentage less than 3% and potential implementation cost percentage less than 8% are implemented at rates below 25%.

With additional time, measures with greater energy savings impact are implemented. By the 12-month assessment, energy savings percentage bins that had measures implemented by the six-month assessment have higher rates of implementation and larger average potential implementation cost percentages. This indicates that with additional time a greater number of "low hanging fruit" measures are implemented. Additionally, measures with potential energy savings percentages greater than those implemented after six months are implemented. Average potential implementation cost for these measures is greater than the lower energy savings percentage measures.

The large increase in number of energy savings percentage bins with some level of implementation seen between the six and 12-month assessments is not repeated between the 12 and 24-month assessment periods. This might be due to facilities not wishing to implement measures that would have any larger energy savings impact or that implementation of such measures takes longer than 24 months. Energy savings percentage bins mostly show greater implementation rates than during the six or 12-month assessments and the average potential implementation cost percentage for most bins increases as well. *With increased time, facilities implement steam system energy efficiency measures that have greater energy savings impact as well as measures that have greater implementation cost percentage*. This established trend might be further reinforced with follow up assessments conducted over a longer period of time (36 months and greater) in addition to the six, 12, and 24 month assessments currently conducted.

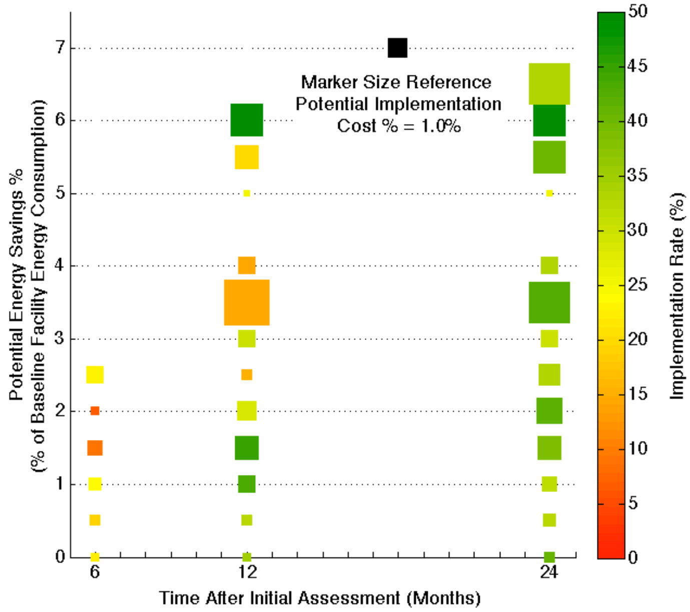

Figure 6: Time Dependence of Energy Efficiency Measure Implementation. Small Red Squares Indicate Potential Energy Percentage Bins That Have No Measures and Thus no Implementation Rate or Potential Implementation Cost Percentage.

Conclusions

Industrial energy assessment data gathered by the U.S. Department of Energy's Energy Saving Assessment program were analyzed to determine what factors govern the implementation and rejection of recommended steam system energy efficiency measures. ESA data contains baseline facility annual energy consumption and energy cost along with recommended energy efficiency measures and associated potential energy and energy cost savings values as well as potential implementation costs. Energy savings and cost percentage metrics that describe the impact energy efficiency measures will have at a facility are introduced and used in this paper.

The number of recommended measures, total energy savings, and cost, is not determined by industry type or facility baseline energy consumption. Measure potential energy cost savings percentage is closely related to potential energy savings percentage, though cost metrics (payback and implementation cost percentage) do not correlate to energy savings metrics.

Implementation rates of recommended energy efficiency measures relate to cost metrics, not energy or energy cost savings metrics. As either payback period or potential implementation cost percentage increase, implementation rate drops sharply. No relationship between implementation rate and savings metrics is found.

Stated rejection reasons confirm that facilities are most focused on cost barriers when determining whether or not to implement steam system energy efficiency measures. Other barriers to implementation include facility/production, behavioral, and organizational reasons. These barriers are similar to those studied by other researchers. While an energy management system, such as ISO 50001, should provide a broader context for implementation decisions, its impact on these barriers needs to be documented.

Predicted energy efficiency measure potential saving and cost values were found to be reasonably accurate when compared to reported savings and cost values. The magnitude and direction of savings or cost metric error may affect the implementation rate. Negative energy and energy cost saving metric error causes measures to appear to save more that they actually would when implemented. Correlations were found between the implementation rate and savings metric error values but not with cost metric error values, confounding the possible influence of metric error value on implementation rate.

Overall implementation rate of efficiency measures and implementation rate as a function of measure implementation cost percentage is found to be time dependent. Six months following an initial assessment measures with low potential energy savings percentage were implemented at modest rates. With increased time (12 months) these "low hanging fruits" were implemented at greater rates and similar energy saving measures with greater implementation costs were implemented.

Additionally, measures that have greater energy savings impact are implemented. By 24 months following an initial assessment, measures across a range of energy savings percentage values are implemented at even greater rates. This established trend might be further reinforced with follow up assessments conducted over a longer period of time (36 months and greater) in addition to the six, 12, and 24 month assessments currently conducted.

Acknowledgements

This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Energy Efficiency Department, Advanced Manufacturing Office, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

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