FACILITY WIDE APPROACH TO CALCULATING ENERGY USE INTENSITY

CHERYL GLANTON, NEW YORK STATE ENERGY RESEARCH AND DEVELOPMENT AUTHORITY
JOHN DEFREES, MODERN ENERGY, LLC

ABSTRACT

Evaluating energy savings for a one for one equipment retrofit is straightforward and well documented, but what about evaluating a system, or a manufacturing line or a whole plant upgrade? The evaluation of energy savings in complex systems in any facility can be complicated by many factors. The scale of the projects that are undertaken and interaction among sequential or parallel processes can make direct estimation or measurement of savings difficult. For energy intensive processes, the embedded energy in each part should be considered. In other situations, interactive effects (debottlenecking, etc.) not directly associated with the subject measure can contribute to improvements in energy use intensity (EUI) most easily detected on a facility wide basis. This paper presents several case studies where it proved more effective to evaluate the energy savings on a per unit of production basis as a whole rather than focusing on a single system component particularly when large impacts on consumption (> 10 - 20%) were anticipated. The criteria under which this approach proved successful are explained and documented for a disparate set of industries. The methods used to derive the overall savings and improved EUI are presented. In addition to improved results the advantages credited to this approach included reduced data requirements, the ability to capture inactive effects among ancillary services and relative ease of analysis as compared to component level assessments.

INTRODUCTION

For simple equipment retrofits there are well established methods for calculating energy savings. Many circumstances lend themselves to direct monitoring and this can often be accomplished with simple devices. However, in many larger, more complex systems all of the desired instrumentation may not be available at the system level. In these cases, savings can be analyzed in two ways: As a build-up of all the component pieces, where each motor, drive, pump, etc. are monitored, savings calculated and the results summed to achieve an approximation of the system level savings. Or, the savings can be analyzed at the facility level, by calculating EUI for the facility as a whole, using utility meter data in conjunction with production data. The latter provides multiple benefits including capturing all the interactive effects the component by component approach misses, it is less costly and less time consuming. This was exemplified by recent cases that included:

- Throughput was increased at a food production facility on growth of product demand. This resulted in multiple rapid expansions being undertaken. Little difference was noted in the performance of the individual system components installed although collectively the EUI improved as a consequence of the increased capacity eventually realized.

- A manufacturing facility upgraded its production equipment during a move to a new facility. It was possible to directly observe reductions the overall energy consumption as individual lines were shut down in the old facility and subsequently restarted at the new plant. A productivity improvement was calculated on the increased output.

- An industrial facility upgraded a single manufacturing line dependent on a series of continuous heating cycles. Temperature control was achieved by configuring each stage with an individual gas burner, circulating fan(s), conveyors and other devices. All other production lines were unaffected. Analysis of the collective output, waste reduction and facility energy consumption were sufficient to isolate the associated energy savings.

In each of these circumstances it proved more suitable to evaluate energy savings on a per unit of production basis than focusing on a single system component. Further detail regarding each of these examples is presented here to illustrate the nature this approach. The data in each case have been disguised to provide anonymity to the respective sites.

FOOD PRODUCTION FACILITY

The subject facility was engaged in a plant wide expansion to increase the output of a food product using a multistep process consisting of primary and buffer storage, separation sequences and both heating and cooling utilities. The initial approach to calculate savings was a component by component level analysis. For example, entrained solids were separated by centrifuges in one typical step. The planned use of new centrifuges was expected to increase throughput by almost 65%; the equivalent of more than 300,000 gallons of product per week. Specifications submitted for the new hardware suggested the EUI would be reduced 22%. An initial effort was made to isolate and contrast the performance of the existing equipment as indicated in Table 1 based on a short term monitoring effort lasting several weeks. The expected annual savings given the difference in equipment characteristics and increased production were subsequently derived as;

$$\left(EUI_{pre} - EUI_{post}\right) \times Annual\ Production = Energy\ Savings$$

$$\left(4.3\ \frac{kWh}{1{,}000\ gals} - 3.4\ \frac{kWh}{1{,}000\ gals}\right) \times\ 873{,}200\frac{gals}{wk} \times 52\frac{wks}{yr} = 40{,}866\ kWh$$

Savings of similar magnitude were anticipated for the changes required in the following processing steps to support the increased throughput. Because this approach relied on the deployment of data loggers, this was costly and time consuming. In addition, because this approach is most practical for short durations, it introduces uncertainty as to whether all the process variation has been captured. In addition to these issues, even when combined the savings were found to be comparatively minimal despite the overall production increasing by millions of gallons per year.

As an alternative to the component level analysis, data for the entire facility were subsequently examined. This was done because a number of ancillary services were required to support production. The bulk of these services (refrigeration, material handling, etc.) were derived primarily by electrical means. The first step was to collect detailed electric consumption data from the host utility in time series (15 minute) format. The data were subsequently totaled on a weekly basis to be consistent with the production data available from the site and summarized monthly in Table 2. As a second step in the analysis the regression line shown in Figure 1 was used to predict the amount of energy that would be consumed weekly based at the higher output level. In following general recommended practice[1], a linear regression was used since there was no theoretical or practical reason to expect the data to be otherwise related and a

Table 1 Monitored Centrifuge Performance During Nominal Weekly Periods

Configuration	Total Output (10^3 gals)	Total Runtime (hrs.)	Electric Usage (kWh)	EUI (kWh/10^3 gals)
Original System	535.4	147.1	2,309	4.3
New System	873.2	139.7	2,963	3.4
Differential	337.8	-7.4	654	-0.9

[1] blog.minitab.com/blog/adventures-in-statistics

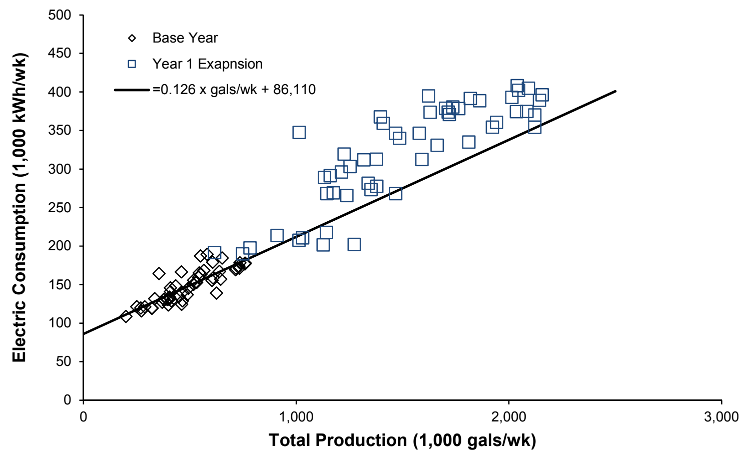

Figure 1 - Energy Consumption Dependence on Weekly Output

Table 2 Plant Production and Electric Energy Consumption[1]

Month	10^3 gals	Base Year kWh	kWh/gal	10^3 gals	Year 1 Expansion kWh	kWh/gal
Jan	1,563	601,860	0.385	4,186	994,562	0.238
Feb	1,488	508,077	0.342	4,460	838,231	0.188
Mar	1,254	489,626	0.390	4,831	1,101,922	0.228
Apr	1,595	543,891	0.341	4,923	1,132,270	0.230
May	2,199	656,727	0.299	6,920	1,517,635	0.219
Jun	2,020	591,003	0.293	5,682	1,371,435	0.241
Jul	1,889	601,008	0.318	8,172	1,821,266	0.223
Aug	2,841	861,719	0.303	7,467	1,552,342	0.208
Sep	2,601	715,615	0.275	8,139	1,513,114	0.186
Oct	3,477	842,469	0.242	9,242	1,799,978	0.195
Nov	2,323	633,475	0.273	6,440	1,344,453	0.209
Dec	2,413	662,799	0.275	7,855	1,578,892	0.201
Overall	25,662	7,708,270	0.300	78,318	16,566,099	0.212
				47,316	9,610,045	0.203

1. Shaded area denotes performance during M&V period.

straight line proved a good fit to the data in this scenario. Output was expected to increase from about 500,000 to 2,000,000 gallons per week on completion of the first expansion. The corresponding weekly electric usage was subsequently derived as;

$$Total\ Gallons\ per\ Week\ \times\ 0.126\frac{kWh}{gal} + 86{,}110\frac{kWh}{wk} = Weekly\ Energy\ Use\ \frac{kWh}{wk}$$

$$2{,}000{,}000\ \frac{gals}{wk} \times 0.126\ \frac{kWh}{gals} + 86{,}110\ \frac{kWh}{wk} = 338{,}110\ \frac{kWh}{wk}$$

This energy usage was then used to predict the future EUI would be:

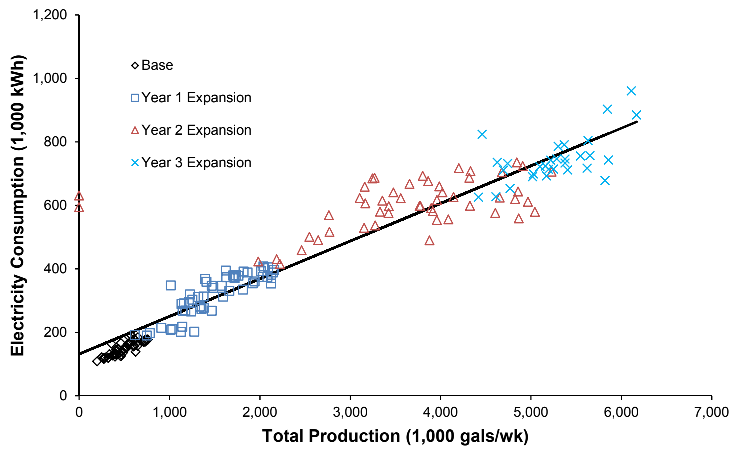

Figure 2 - Energy Consumption Dependence on Weekly Output Through Additional Expansions

$$Weekly\ Energy\ Use\ \frac{kwh}{wk} \div Total\ Gallons\ per\ Week = Specific\ Consumption\ \frac{kWh}{gal}$$

$$338{,}110\ \frac{kWh}{wk} \div 2{,}000{,}000\ \frac{gals}{wk} = 0.169\ \frac{kWh}{gal}$$

The anticipated energy savings and incentive were subsequently projected as;

$$\left(EUI_{pre-actual} - EUI_{post-predicted}\right) \times Annual\ Production = Estimated\ Energy\ Savings$$

$$\left(0.300\ \frac{kWh}{gal} - 0.169\ \frac{kWh}{gal}\right) \times\ 2{,}000{,}000\ \frac{gals}{wk} \times 52\frac{wks}{yr} = 13{,}624{,}000\ \frac{kWh}{yr}$$

The final step was to calculate the actual saving for the project. This was accomplished by conducting measurement and verification over a subsequent six month period assuming production had reached its nominal level. As indicated in Table 2, the EUI was reduced to 0.203 kWh per gallon. This was approximately 80% of the incremental reduction that was initially expected. Following the same process as outline above, the actual savings were calculated as;

$$\left(EUI_{pre-actual} - EUI_{post-actual}\right) \times Annual\ Production = Actual\ Energy\ Savings$$

$$\left(0.300\ \frac{kWh}{gal} - 0.203\ \frac{kWh}{gal}\right) \times\ 47{,}316{,}000\ \frac{gals}{6\ mo.s} \times 2 = 9{,}179{,}304\ \frac{kWh}{yr}$$

The facility completed two more expansions in the following years. The increased production load had an almost constant effect on the electric consumption as shown in Figure 2. The regression parameters were recalculated on completion of each phase. The revised algorithm was then used to predict energy consumption prior to the next stage of the expansion being undertaken although the actual savings were calculated on the observed performance as reported in Table 3.

Table 3 Plant Production and Electric Energy Consumption[1] Under Continuing Expansion

	Year 2 Expansion			Year 3 Expansion		
Month	10^3 gals	kWh	kWh/gal	10^3 gals	kWh	kWh/gal
Jan	10,673	1,761,904	0.165	19,815	2,733,017	0.138
Feb	10,730	2,077,743	0.194	21,404	2,935,861	0.137
Mar	12,781	2,653,534	0.208	27,016	3,521,874	0.130
Apr	18,908	3,121,096	0.165	19,508	2,766,783	0.142
May	14,632	2,453,711	0.168	20,678	2,982,260	0.144
Jun	17,355	2,806,149	0.162	26,829	3,812,752	0.142
Jul	18,511	3,292,835	0.178	22,583	3,573,046	0.158
Aug	15,658	2,343,062	0.150			
Sep	15,803	2,215,282	0.140			
Oct	23,609	2,883,502	0.122			
Nov	18,240	2,711,509	0.149			
Dec	12,810	3,049,718	0.238			
Overall	189,710	31,370,044	0.165	157,832	22,325,594	0.141
	104,630	16,465,908	0.158	70,090	10,368,058	0.148

1. Shaded area denotes performance during M&V period.

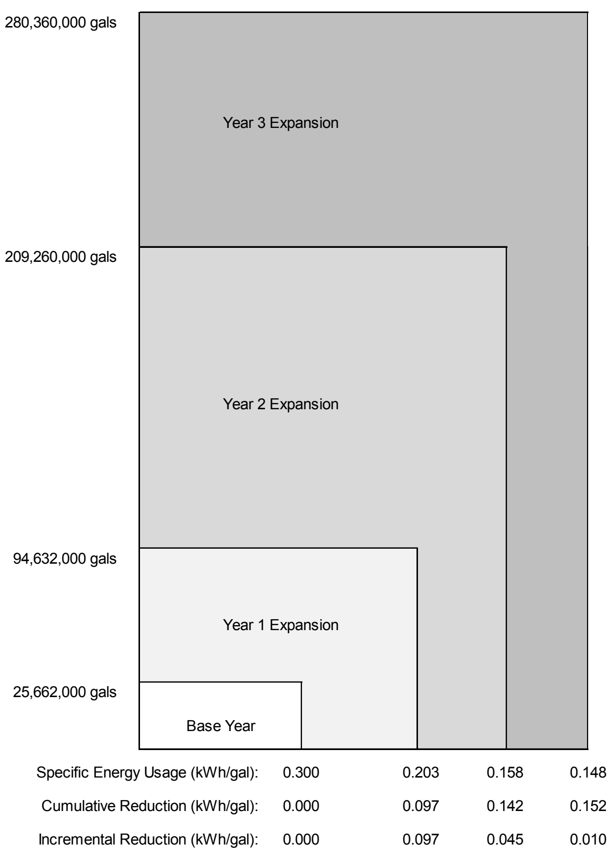

Figure 3 - Productivity Improvement by Phase Based on Data Collected During the Respective M&V Periods

On a plant wide basis the EUI was eventually reduced by 0.152 kWh per gallon; principally from the base energy consumption being allocated over a greater number of production units. Figure 3 shows the improvement in the EUI with each phase of expansion. In general, data for a three to six month period before and after each new stage of expansion were used to calculate the annual savings. This was done on two tiers; savings were calculated against the base case for the increased output and incrementally at the current rate of production for the productivity improvement as demonstrated below using the most recent data set.

The regression line shown in Figure 2 was used to project the amount of energy that would be consumed weekly based on a production estimate provided by the site. Output was expected to increase to 6.8 million gallons per week on completion of the Year 3 expansion. The corresponding electric usage was subsequently derived as;

$$6{,}800{,}000\ gals \times 0.117 \frac{kWh}{gals} + 131{,}470\ kWh = 927{,}070\ kWh$$

This indicated the EUI would be:

$$927{,}070\ kWh\ \div 6{,}800{,}000\ gals = 0.136\ \frac{kWh}{gal}$$

The increase in production expected during the final stage of expansion was estimated using the last six months of 2011 as a point of reference to exclude any influence from the prior cycle.

Prior Rate of Production: $$104{,}630{,}000\ \frac{gals}{6\ months} \times 2 = 209{,}260{,}000\ \frac{gals}{yr}$$

Anticipated Output: $$6{,}800{,}000 \frac{gals}{wk} \times 52\ \frac{wks}{yr} = 356{,}600{,}000\ \frac{gals}{yr}$$

Added Production: $$356{,}600{,}000\ \frac{gals}{yr} - 209{,}260{,}000\ \frac{gals}{yr} = 144{,}340{,}000\ \frac{gals}{yr}$$

Using the first year performance as the comparative baseline for the added production only, the applicable energy savings were projected as;

Incremental Improvement: $$\left(0.158\ \frac{kWh}{gal} - 0.137\ \frac{kWh}{gal}\right) \times 209{,}260{,}000\ \frac{gals}{yr} = 4{,}394{,}460\ kWh$$

Credit to Expansion: $$\left(0.300\ \frac{kWh}{gal} - 0.137\ \frac{kWh}{gal}\right) \times 144{,}340{,}000\ \frac{gal}{yr} = 23{,}527{,}420\ kWh$$

Projected Savings: $$4{,}394{,}460\ kWh + 23{,}527{,}420\ kWh = 27{,}921{,}880\ kWh$$

M&V was conducted over a three month period following the last expansion cycle with the knowledge that production had not reached its full capacity. This was done to avoid other upcoming changes at the facility from skewing the results. As indicated in Table 3, the EUI was reduced to 0.148 kWh per gallon. This was approximately half the incremental reduction that was expected. Following the same process as outline above, the adjusted savings were calculated as;

Prior Rate of Production: $$104{,}630{,}000\ \frac{gals}{6\ months} \times 2 = 209{,}260{,}000\ \frac{gals}{yr}$$

Observed Rate of Production: $$70{,}090{,}000\ \frac{gals}{qtr} \times 4 = 280{,}360{,}000\ \frac{gals}{yr}$$

Actual Increase: $$280{,}360{,}000\ \frac{gals}{yr} - 209{,}260{,}000\ \frac{gals}{yr} = 71{,}100{,}000\ \frac{gals}{yr}$$

Incremental Improvement: $$\left(0.158\ \frac{kWh}{gal} - 0.148\ \frac{kWh}{gal}\right) \times 209{,}260{,}000\ \frac{gals}{yr} = 2{,}092{,}600\ kWh$$

Credit to Expansion: $$\left(0.300\ \frac{kWh}{gal} - 0.148\ \frac{kWh}{gal}\right) \times 71{,}100{,}000\ \frac{gal}{yr} = 10{,}807{,}200\ kWh$$

Total Savings: $$2{,}092{,}600\ kWh + 10{,}807{,}200\ kWh = 12{,}899{,}800\ kWh$$

Plastics Extruding Plant

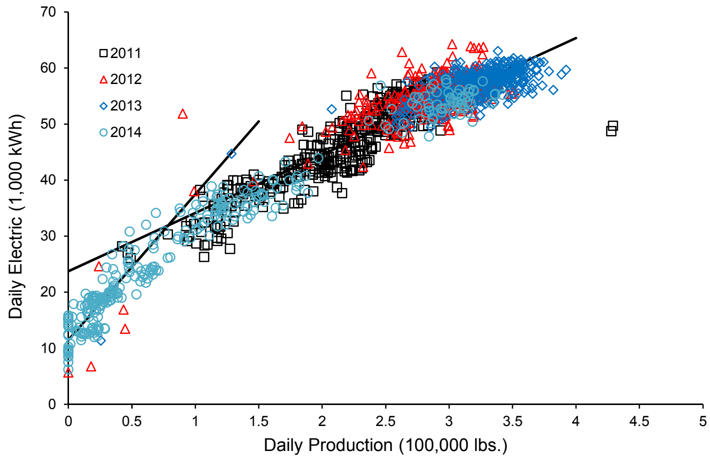

Figure 4 - Electric Consumption Profile at Original Production Facility

In the next example, in order to increase production a company producing extruded plastic forms decided to move to a new facility. Although much of the same equipment was employed the new facility provided additional physical space. This allowed enhancement of ambient cooling process and thus an increase in line speed; more throughput was expected for virtually the same energy input. A facility wide approach to savings, similar to the previous example was used for this site as well due to the increased size of the facility and changes in the ancillary equipment.

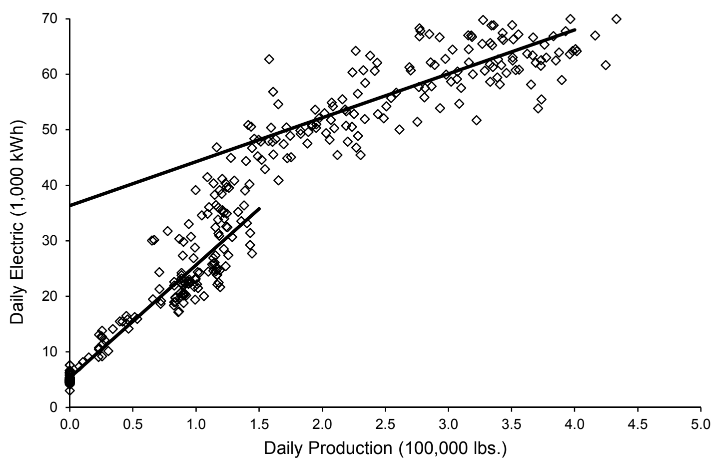

Figure 5 - Electric Consumption Profile at New Production Facility Based on Initial Observations

In abandoning the existing facility it was possible to establish what the base or housekeeping load was under "no load" conditions as illustrated in Figure 4. At production above 100,000 pounds per day the consumption of electricity was linearly dependent on the output. Below this threshold[2] the consumption declined to a lesser level than the balance of the data otherwise would have indicated. The observed data suggest the old facility incurred a base load on the order of 10,000 kWh per day. Figure 5 shows an early data set from the new plant that exhibits a similar phenomenon. At production levels up to 150,000 pounds per day[3] the consumption followed a trend line indicating the base load was less (~7,500 kWh/day) than might be concluded from the balance of the other data (~35,000 kWh/day). Although no firm conclusion can be drawn from the second data set given the small size of the data set it seems probable in both cases that at minimum outputs the housekeeping loads become the dominate factor determining the level of consumption.

Figure 6 express the EUI for each plant as a function of the daily output. The data for the old facility are representative of the last full year of production and less than 220 days of normal production at the new

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[2] The line segments in Figure 4 characterize different data sets. During the latter half of 2014 a number of the production machines were shut down and moved to the new facility.

[3] Similarly to Figure 4, the line segments in Figure 5 represent different data sets and conditions at the facility as additional machines were brought online.

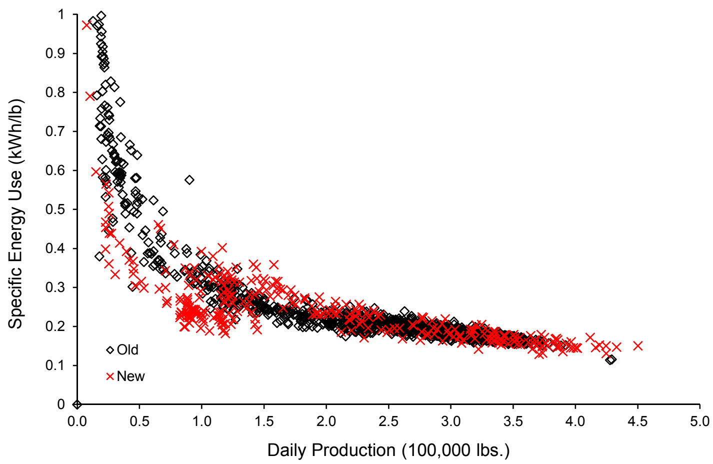

Figure 6 - EUI Profiled to Show Similarity in Operating Characteristics Between Sites

plant. The data scatter at low production rates in the latter case can be attributed to start-up activities and commissioning of the equipment following its transfer. At higher rates of production both data sets present comparable characteristics.

Metered electric consumption data were obtained from the local utility at hourly intervals for both facilities and subsequently totaled by day and month to be compatible with production records maintained by the site. The monthly data are summarized in Table 4. As indicated, the original facility operated at fairly consistent output yielding a EUI that never varied by more than 8%. The initial data from the new plant did not show an improvement, the shakedown and start up period took longer than anticipated as seen in the data. However, recent data from the site show a steady improvement[4] and recently surpassed the older facility. Assuming no further reduction in the EUI would be realized and using its average over the last two months, annual savings were projected under the supposition a target production rate of 12,000,000 pounds per month would eventually be achieved;

$$\left(0.172\ \frac{kWh}{lb} - 0.162\ \frac{kWh}{lb}\right) \times\ 12{,}000{,}000\ \frac{lbs.}{mo.} \times 12\ mo.s\ =\ 1{,}440{,}000\ \frac{kWh}{yr}$$

Table 4 Plant Production and Electric Energy Consumption Between Existing and New Facility

Month	Output (lbs)	Existing Facility Usage (kWh)	EUI (kWh/lb)	Output (lbs)	New Facility Usage (kWh)	EUI (kWh/lb)
Jan	9,703,711	1,706,495	0.176	0	148,662	NA
Feb	9,330,918	1,605,548	0.172	0	142,104	NA
Mar	10,881,784	1,843,797	0.169	660,171	325,555	0.414
Apr	9,508,749	1,705,385	0.179	2,646,339	651,492	0.246
May	9,542,374	1,719,620	0.180	3,010,545	712,108	0.237
Jun	9,660,203	1,714,091	0.177	3,591,575	888,071	0.247
Jul	9,791,277	1,778,581	0.182	3,968,539	1,231,374	0.310
Aug	10,364,159	1,818,176	0.175	5,609,392	1,515,372	0.270
Sep	9,865,955	1,687,575	0.171	7,182,057	1,496,955	0.208
Oct	10,263,759	1,793,420	0.175	9,439,166	1,785,154	0.189
Nov	9,320,174	1,695,351	0.182	10,580,588	1,696,577	0.160
Dec	9,733,406	1,719,400	0.177	10,894,936	1,797,725	0.165
Total	117,966,469	20,787,440	0.176	57,583,308	12,391,151	0.215 (0.162)[1]

1. Average over last two months of production.

[4] Adjustments were made to the consumption data to allow for extended run hours being incurred on some equipment to make up for the recent move.

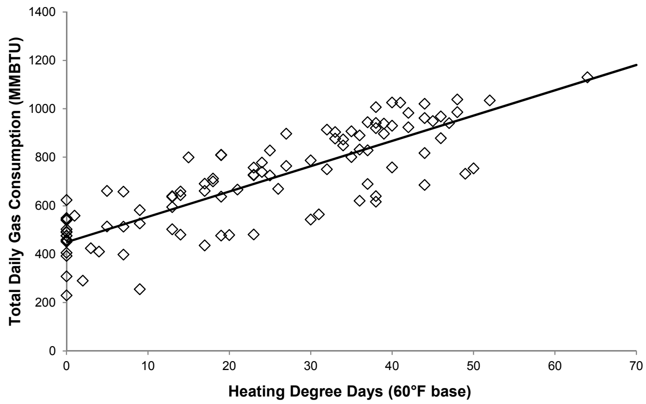

Figure 7 Daily Gas Consumption on Production Days Pre-Retrofit

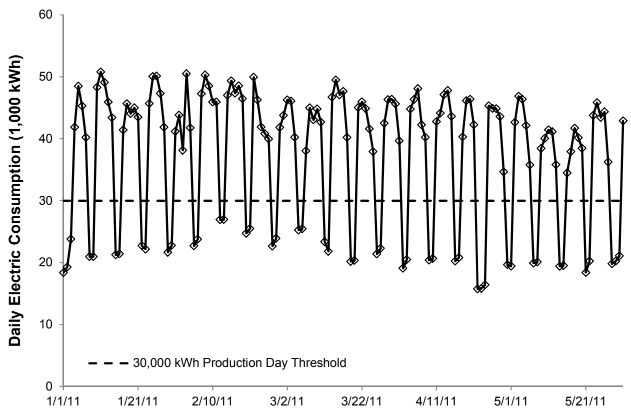

Figure 8 Daily Electric Consumption Used to Identify Production Days

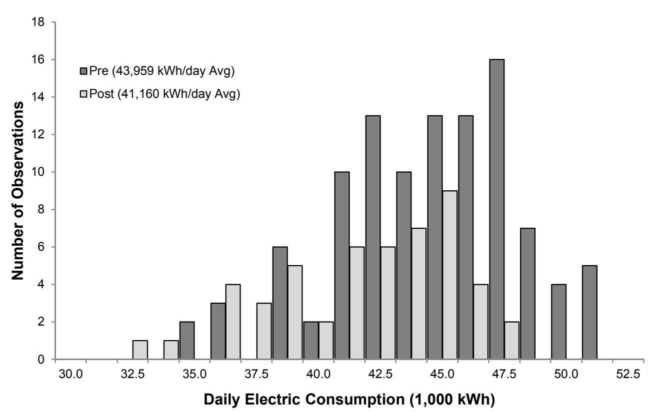

Figure 9 Production Day Electric Consumption Profiles

Further monitoring is planned to determine if the initial gains are sustained or improved in the future.

Treated Paper Facility

A site that prepares treated paper products undertook the expansion of a large curing line. The system was designed as a direct fired, open curing oven through which paper products were continuously transported to harden an applied surface treatment. Some product quality problems relating to insufficient or irregular curing were experienced with the equipment in its initial configuration. An intermediate section of the oven was identified as a bottleneck. The line speed had to be reduced to increase residence time in this section to minimize problems caused by inadequate curing. The remainder of the machine was capable of higher line speeds with no modifications. This section was subsequently lengthened to allow the material time to fully cure. Other improvements were made simultaneously. The new oven section was redesigned to circulate heated air more uniformly allowing the average temperature to be reduced and thus less natural gas being consumed. It was anticipated product losses would be reduced by 10% and the line speed would increase by 36% though no increase in total production was anticipated. The site planned to produce the same quantity of material by reducing its operating schedule from five to three or four days per week. The reduction in operating hours impacted other equipment at the plant primarily a regenerative thermal oxidizer (RTO) used to destroy volatile organic compounds (VOCs) released from hardener.

The site was unable to provide more than a minimum of data on the process line itself, and the data that was available lacked sufficient resolution to isolate the energy savings. However, since the paper line was one of the primary energy loads in the facility any significant changes in its operating characteristics were observable at the utility meters. Figure 7 describes the metered gas

Table 5 Site Performance Data

Condition	Production Days	Avg. kWh/day	Avg. MMBTU/day	Total Yards
Pre-Retrofit	104	43,959	450	8,873,000
Post-Retrofit	53	41,160	423	5,128,000

consumption for the entire facility as a function of heating degree days (base 60°F)[5] prior to the line being retrofit. The data was limited to production days defined by the amount of electricity consumed as indicated in Figure 8. A linear curve fit was applied to data sets for periods before and after the retrofit. The y-intercept derived in each case was taken as a direct measure of the average daily fuel consumption as reported in Table 5. No attempt was made to normalize for the ambient temperature. While a significant difference was noted between the y-intercepts the confidence intervals for the slope of each line overlapped implying the building heating load remained constant and could thus be ignored. The electric usage was treated similarly. Figure 9 compares the consumption distribution during each period. The difference in the respective averages was treated as the daily savings. This was consistent with prior observations that suggested the electrical consumption was independent of throughput and better characterized simply by whether or not there was any production activity. The respective electric and gas EUIs were subsequently derived using data from Table 5 as;

Natural Gas (pre-retrofit): $$\left(450\ \frac{MMBTU}{day} \times 104\ days\right) \div 8.873\ MM\ yds. = 5{,}274.4\,\frac{MMBTU}{MM\ yds.}$$

Electricity (pre-retrofit): $$\left(43{,}959\,\frac{kWh}{day} \times 104\ days\right) \div 8.873\ MM\ yds. = 515{,}241\ \frac{kWh}{MM\ yds.}$$

Natural Gas (post-retrofit): $$\left(423\ \frac{MMBTU}{day} \times 53\ days\right) \div 5.128\ MM\ yds. = 4{,}371.9\,\frac{MMBTU}{MM\ yds.}$$

Electricity (post-retrofit): $$\left(41{,}160\,\frac{kWh}{day} \times 53\ days\right) \div 5.128\ MM\ yds. = 425{,}405\,\frac{kWh}{MM\ yds.}$$

The plant nominally produced about 20 million yards of finished product annually. However, observations made during the monitoring period indicate the annual output will be on the order of 17 million square yards in the future. On this basis the energy savings were projected as;

Natural Gas: $$\left(5{,}274.4\,\frac{MMBTU}{MM\ yds.^2} - 4{,}371.9\,\frac{MMBTU}{MM\ yds.^2}\right) \times 17\ MM\ yds.^2\ = 15{,}343\ MMBTU$$

Electricity: $$\left(515{,}241\,\frac{kWh}{MM\ yds.^2} - 425{,}405\,\frac{kWh}{MM\ yds.^2}\right) \times 17\ MM\ yds.^2\ =\ \ 1{,}527{,}210\ kWh$$

EVALUATION RESULTS

Independent Impact Evaluation is part of the rigor applied to confirming reported program savings, and the food and paper examples have gone through this process. Elements of the evaluation include site visits, interviews with site personnel, extensive baseline analysis and review of the calculations.

In the case of the food production facility, the facility wide per unit of production approach was utilized by the evaluators as well. The baseline was analyzed and characterized as a new construction or market

[5] Above 60°F the daily consumption data show no dependence on ambient temperature.

opportunity baseline because the existing facility was at maximum capacity. Typically new construction baseline could be represented by either:

- The installation of typical standard practice new equipment at the existing facility, or
- Moving the production to a new facility that would be capable of achieving the intended higher production.

After extensive discussion with facility staff and research for publically available comparable data, it was determined that the existing equipment was a reasonable alternative for calculating baseline energy usage. Another area of note was that the savings were reliant on production levels and any significant variation over time would change the EUI and therefore savings of the project. Measurement and verification data was reviewed and the completed review of the project yielded a realization rate of 100%.

The paper project was also reviewed in a recent Impact Evaluation. In this case as well, the evaluator utilized a per unit of production calculation. In this case, the baseline was determined to be a retrofit baseline. In addition to calculating the EUI, the evaluation team also looked for correlation to weather and production volume. In the evaluation analysis it was determined that production days was a better metric rather production volume. With this difference in calculations, the realization rate for this project was 94%.

Overall, through these projects and others in the evaluation work, the per unit of production approach has been exhaustively discussed, debated and analyzed. Through this joint work the team believes this is a valid approach to energy savings as outlined in the summary below.

Comments and Summary

In each example consideration of energy consumption on a per unit of production basis better captured the apparent energy savings from interactive effects of subsidiary services and embedded energy in the product. Although the character of these services remained unchanged the energy productivity measured per unit of output was significant reduced.

In proper circumstances, evaluating performance on a per unit of production basis will not only capture these effects, but also greatly simplify the analysis. Less effort needs to be expended detecting and investigating subtle effects at a system or component level in favor of the larger collective impact particularly where the following conditions might apply;

- The appropriate utility data are available and recorded at reasonable intervals (i.e., 15 minute, hourly or daily).
- All statistically significant influencing factors (weather, production rates, operating temperatures, etc.) are known, recorded at periodic intervals and can be shown to have a consistent, repeatable effect on the level of energy consumption.
- The effect of the proposed ECM(s) is expected to be comparatively large, 10% or more.
- Interactive effects on any ancillaries or dependent utilities are inseparable from the principal systems.
- The nature of the subject processes is consistent.
- Stable or generally increasing production in the post case to sustain the energy savings.