Quantifying Energy Savings from Industrial Productivity Improvements

John Seryak, Go Sustainable Energy LLC
Mark D'Antonio and Gary Epstein, Energy & Resource Solutions, Inc.
Dave Bebrin, Northeast Utilities

ABSTRACT

Determining energy savings from reductions in the energy intensity of manufacturing processes is increasingly popular. However, promoting energy efficiency through productivity improvements is not a widely accepted practice. As such, accepted methods used to calculate energy savings from productivity improvements are not prevalent.

In this paper, a conceptual and mathematical framework for determining energy savings from productivity improvement projects is presented. Several existing energy efficiency programs that either promote productivity improvements or claim energy savings from productivity improvements are described, along with the rational of these programs. Several existing savings calculation methods are briefly described. Then, the relationship between production and manufacturing energy use is reviewed on a plant-wide and equipment level. Four categories are proposed to categorize manufacturing equipment based on their relationship between production and energy use. Next, the importance of establishing both a baseline and production-adjusted baseline of energy use for each equipment category is discussed. Finally, two proposed mathematical approaches for calculating energy savings will be presented with examples as applied to several "Lean Manufacturing" improvements.

Energy Efficiency Savings from Productivity Improvements

A number of energy-efficiency programs and academic papers have recently promoted claiming energy savings from productivity improvements. However, it is not yet widely accepted that improving productivity results in energy savings, nor is there an authoritative method on how to calculate or measure such. One valid concern preventing wide acceptance is that productivity improvements often use more energy due to increased production. Thus, while energy use is more efficiently used, it is not conserved.

In the following section, we will briefly describe several existing programs which address links between productivity and energy use. Additionally, we will discuss the difference between efficiency and conservation as it relates to the conceptual framework of claiming energy savings from productivity improvements. Finally, we will describe several existing approaches to quantifying energy savings prior to proposing alternate methods.

Existing Productivity-Related Energy Efficiency Programs

Several energy-efficiency programs exist which promote productivity improvements and claim energy savings from them. Two such programs are the Northeast Utilities' (NU) Process Reengineering for Increased Manufacturing Efficiency (PRIME) Program and the Department of Energy's Industrial Assessment Center (IAC) programs (Seryak, et al., 2006a). Other programs, such as the NSTAR Eco-Efficiency assessments and the New York State Energy Research and

Development Authority (NYSERDA) Flextech assessments allow for the evaluation of productivity measures (Epstein, et al., 2003). For the NSTAR and NYSERDA programs, any productivity gains may be claimed as non-electric benefits (NEBs). However, energy benefits are typically not claimed from improving productivity measures.

NU's PRIME program has existed for several years and annually sponsors approximately 25 Lean Manufacturing events in both its Connecticut Light & Power (CL&P) and Western Massachusetts Electric Co. (WMECO) utility territories. Lean Manufacturing is an umbrella term often used to describe many different types of productivity improvements. Energy savings are estimated using an algorithm with built-in assumptions and a few required inputs based on expected increased production and energy use characteristic assumptions.

The IACs' are tasked primarily with evaluating energy savings opportunities, but also waste reduction and productivity opportunities. While productivity measures are not required to have calculated energy savings, they may be claimed if the authors wish. Guidelines to calculating energy savings have been published by the IAC program managers previously (Mitrovic and Muller, 2002; Papadaratsakis, et al., 2003; Kissock, 2005; Oppenheim, 2007).

Energy Efficiency versus Energy Conservation

The main rational for promoting productivity improvements is that the energy intensity of the manufacturing process typically improves. This is because productivity improvements often increase production quantity, while the required energy increases minimally. As a result, there are often cases where energy savings are claimed from more efficient processes, even though there is a net increase in energy! Many stakeholders are uncomfortable with this rational, as even though there is an improvement in energy efficiency, there is a lack of energy conservation.

There are many widely-accepted programs and frameworks which promote energy-efficiency even at the expense of energy conservation. A good example is that of new building construction. New building construction nearly always is a new source of energy use. However, new construction projects are often given incentives to be more energy-efficient as all stakeholders realize that the building will use less energy than it would have absent the incentive. Such may also be the case with productivity improvements, or "New Production" (Seryak, et al., 2006b). If production is going to increase anyways, then reducing the energy intensity of the process further with productivity improvements results in avoided energy use, or energy savings.

There are two main caveats to this conceptual framework. One is that productivity improvements often result in production increases where none were intended. Thus, productivity improvement programs may actively promote increases in energy use, instead of reducing imminent new loads. The second is that there is a difference between the energy savings from *production increases* and those due to *productivity improvements*. The distinction between the two is important. For example, production increases will almost always result in process energy intensity reductions as equipment is operated at greater capacity. Therefore, claiming energy savings from production increases that did not result from productivity improvements (but to some other factor such as market demand) is a dubious approach. It would allow a manufacturing plant to claim itself as increasingly energy efficient, when in fact it has only gotten larger. Alternately, productivity improvements may improve the energy efficiency of the process.

With this in mind, the method we propose in this paper will incorporate production-quantity adjusted baselines, so as to capture only the energy savings due to the productivity improvement.

Existing Savings Calculations Methods

The IACs must report expected energy, waste and productivity savings from their assessment recommendations. While there is no mandated calculation methodology for estimating energy savings from productivity improvements, guidelines have been published by several centers (Papadaratsakis, et al., 2003; Kissock, 2005; Oppenheim, 2007). Papadaratsakis et al. proposed calculating "effective" energy savings by comparing pre and post-improvement energy intensity and multiplying the difference by post-implementation production rates.

Kissock developed a similar but more detailed method. While, Papadaratsakis et al. only considered energy intensity, Kissock discussed energy intensity and net energy use. Kissock also used inverse modeling of regression models to disaggregate production quantity-dependent, temperature-dependent and operating hours-dependent (time-dependent) components of energy use.

Recognizing the influence of product demand on energy savings, Kissock showed that net energy savings and energy-intensity savings depend on whether production quantity increased with the productivity improvement. If production quantity did not increase, net energy use decreased – but only if the facility shut down when not manufacturing. Additionally, Kissock acknowledged that operating-hours dependent equipment energy use often stays the same from baseline to post-event scenarios. Most of these conclusions are consistent with the methods proposed later in this paper. The main issue Kissock did not address is that of adjusting the baseline energy use for post-event production quantity.

Finally, Oppenheim also approaches energy savings by considering the energy intensity (also energy density) of the manufacturing facility and process. Oppenheim also recognizes the inherent difference between what he terms "infrastructure" and "process" energy uses, in regards to productivity. This approach is consistent with Kissock's, with the exception that temperature-dependent energy use would be grouped with infrastructure in the Oppenheim approach.

The PRIME savings algorithm is similar to Kissock and Oppenheim's approach in that it breaks-out components of energy use, although into production-quantity dependent, production-hours dependent and independent energy use. The PRIME method is unique in that it includes an intermediate step to calculate a production-adjusted baseline of energy use, to account for the influence of increasing production. Another unique feature is that energy savings are not calculated plant-wide, but only for the area affected by the productivity improvement. The PRIME method is consistent with the "Energy Breakdown" method proposed later in this paper.

As calculating energy savings must be cost effective in itself, the PRIME method uses a number of like assumptions for each project. For example, 15% of total energy use is defined as production-quantity dependent, 20% as production-hours dependent, and 65% as independent energy use. Thus, PRIME avoids the time and labor intensive process of creating an inventory categorization of equipment and engineering calculations to determine energy use in the baseline, adjusted-baseline and post-event scenarios. Furthermore, since savings calculations for equipment dependent on production quantity and production hours are especially complicated, NU has employed a novel solution, recognizing that energy savings for this type of equipment can be approximated by a variable percent (ERS, 2006).

Accepted Savings Methodology (IPMVP)

The International Performance Measurement and Verification Protocol (IPMVP) is an authoritative source on measuring energy savings. While the IPMVP documents suggest calculating adjusted-baseline energy use to account for production, weather, occupancy and other changes when calculating or measuring energy savings, it does not explicitly address energy savings calculations for productivity improvements.

Conceptual Framework - Energy Use and Production

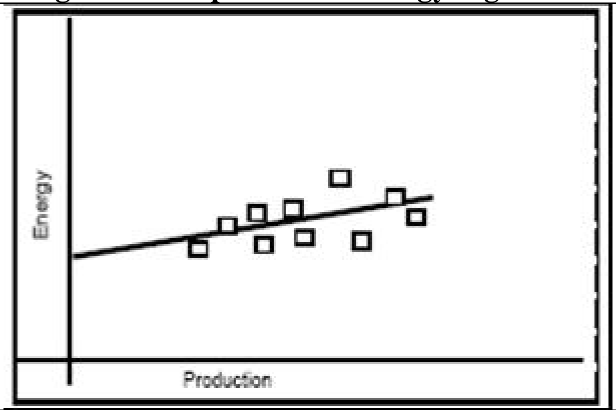
In a manufacturing facility, energy use is nearly always influenced by production quantity to some extent. Following we will discuss the relationship between industrial energy use and production, both at the plant and equipment levels.

At the Plant Level

Plant-wide energy use is mainly a function of three variables: outdoor temperature, production quantity and production operating hours. The impact of temperature and production on plant energy use can be quantified relatively easily using statistical regression software. Multivariable change-point regression models, which we refer to as “energy signatures”, can be constructed using monthly energy, production and temperature data (Kissock, et al, 2003). Plant management often tracks monthly energy use and productions, and weather data is readily available on the Internet. Energy signatures allow quick disaggregating of plant energy use into temperature-dependent, production-quantity dependent and time-dependent energy use. Thus, with statistical regression models unitized energy metrics of Btu/unit, Btu/F and Btu/hour can be derived from historical data (Kissock, et al., 2004a).

Figure 1 shows a simplified example of a two-parameter (2P) energy signature of energy use versus production (Patil, et al., 2005). Energy use is plotted on the Y-axis, and production on the X-axis. The squares represent historical data points, while the solid line represents the regressed energy signature. The equation of the line associated with the energy signature in Figure 1 has two parameters. The y-intercept represents the production-hour dependent component and the slope of the line represents the production-quantity dependent energy component. The figure shows that at low levels of production quantity, the plant would use unproportionally high amounts of energy. Thus, significant quantities of energy are used that do not add value to the product, from production independent equipment such as lighting, to equipment with poor part-load efficiency, such as an air compressor operating in modulation, or a pump with outlet valve control.

Figure 1. Simplified 2P Energy Signature

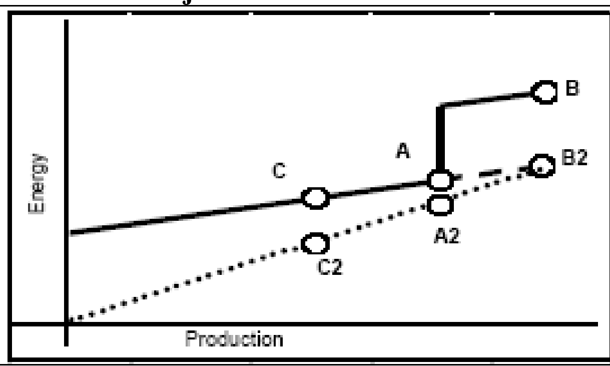


It is also important to understand how production quantity is affected by productivity improvement projects (hereafter, synonymous with the term "Lean Manufacturing"). Lean Manufacturing projects can target many improvements, but are often implemented to improve product quality and delivery while reducing wasted time and materials. That said many Lean Manufacturing projects target production quantity directly. We have found that many of these types of Lean Manufacturing projects may increase the production *capacity* of a plant, though increased production *quantity* may not actually be achieved at the same time. Also, Lean Manufacturing may or may not improve the energy intensity of the manufacturing process throughout the production quantity range. Thus, if production quantity increases, energy savings can likely be claimed. If production quantity does not increase, energy savings may or may not be claimed, as we will show.

For example, Figure 2 illustrates how Lean Manufacturing affects the relationship between production quantity and energy use. Figure 2 shows the same energy signature shown in Figure 1, but with the production-adjusted baseline and post-event energy signatures, as well as six points of reference. Point A represents the maximum production possible using the baseline equipment with the baseline operating procedures. The solid line to the left of Point A represents baseline energy use, while the solid line to the right of Point A represents the production-adjusted baseline energy use. The dashed line represents the post-event energy use at post-event production quantity, *if* production increases. If post-event production does not increase beyond Point A, the relationship between production and energy use is usually best described by the unadjusted baseline. However, in some cases productivity improvement affects post-event energy use at all points of production, as represented by the dotted line. This occurs when the Lean Manufacturing project results in equipment being either turned off when not manufacturing parts, or being better controlled at part loads. While it is unclear how often this occurs with Lean Manufacturing projects, the potential exists. Our savings methods proposed later assumes that productivity improvements do not impact all points of production equally, and that post-event energy use at production rates to the left of Point A is the same as the baseline energy use. We have based our method on this assumption as it is consistent with the results of most of the completed projects we have observed.

Absent Lean Manufacturing, increasing production requires additional equipment or shifts. In such cases, the production-dependent energy and the operating hour-dependent energy both increase, and we would expect production and energy use to be located at Point B. However, if Lean Manufacturing techniques were used, then production quantity could be increased while only production-dependent energy use increased, and operating hours remained the same. Thus, we would expect production and energy use to be located at Point B2. The difference in y-coordinate values of B and B2 is the energy savings from increased productivity. However, we see that if market factors decreased product demand, production and energy use in both the production-adjusted baseline and post-event scenarios would be located at the same point, (Point C). Therefore, energy savings can usually be claimed only if production is greater than the baseline maximum production rate. As we mentioned, if the productivity improvement also results in equipment being turned off or better controlled at part loads, then whether there is increased (Point B2), equivalent (Point A2) or decreased (Point C2) production quantity, energy savings could be claimed. However, it is not the authors experience that this is common.

Figure 2. Production-Adjusted Baseline and Post-Event Energy Signatures



At the Equipment Level

The relationship between equipment energy use and production differs based on the type of equipment. There are four main categories of equipment:

- Equipment with energy use independent of production (includes office equipment and temperature-dependent equipment).
- Equipment with energy use dependent on production quantity.
- Equipment with energy use dependent on operating hours.
- Equipment with energy use dependent on both production quantity and operating hours.

Mathematical Methodology for Calculating Energy Savings

Our proposed approaches begin with the same general Equation 1:

Energy Savings = Post-event Energy Use – Baseline Energy Use (Equation 1)

This general equation can be used with statistical regression models, which we will refer to as the "Energy Signature" method. The same equation is the basis for considering the energy use of the specific industrial equipment involved, which we will refer to as the "Energy Breakdown" method. Examples of both methods are presented below.

The Energy Breakdown method involves calculating the energy savings for each piece of electricity-using equipment. The main steps used in the Energy Breakdown method are:

1. Develop an inventory of energy using equipment.
2. Determine how each piece of equipment uses energy (independent, production-quantity dependent, etc).
3. Calculate baseline energy use for each piece of equipment, based on pre-Lean event production quantity and manufacturing process.
4. Calculate production-adjusted baseline energy use for each piece of equipment, based on post-Lean event production quantity and pre-Lean event manufacturing process.
5. Calculate post-event energy use for each piece of equipment, based on post-Lean event production quantity and post-Lean event manufacturing processes.
6. Compare post-event to production-adjusted baseline energy use to calculate energy.

The details of energy savings calculations using the energy breakdown method differ depending on which Lean Manufacturing improvement type has been implemented. As such, like improvement types will be explored for the Energy Breakdown method.

Inventory Reduction and Space Reduction

One common Lean Manufacturing project focuses on inventory reduction. Inventory reduction typically does not affect manufacturing energy use. However, in some cases an inventory reduction could result in a reduction in space use. Reducing space use can result in energy savings, provided the lighting and air conditioning equipment in the eliminated space can be turned off or reduced. To calculate energy savings, lighting, air-conditioning and other equipment should be inventoried, with power requirements and existing runtimes detailed.

For example, consider a small warehouse illuminated by ten 400-W Metal Halide fixtures drawing 460-Watts each that operates 20 hours per day, and ventilated by two 5-HP fans that operate 24 hours per day. The first step for calculating energy savings would be to inventory equipment, as presented in Table 1.

Table 1. Equipment Inventory

Equipment	Qty	Rating	Calculated Power (kW)	Runtime (hrs/day)
400-W Metal Halide	10	460 Watts	0.46	20
Ventilation Fans	2	5 HP	3.1*	24

From this information, the baseline, production-adjusted baseline and post-event energy use can be calculated as 241 kWh/day, 241 kWh/day and 0 kWh/day, respectively. Substituting these values into Equation 1, the savings would be 241 kWh/day. As stated previously, it is rare that inventory reductions result in a space reduction.

Part Travel, Direct Efficiency Improvement

Lean Manufacturing projects may also result in reduced part travel time, or direct efficiency improvements, although these are rare and involve specific knowledge of the manufacturing process. For example, a cellular manufacturing measure could reduce the number of conveyor belts needed for part transport from ten to five. Or a "5S" cleaning and organization project could decrease conveyor belt friction by cleaning idlers or casters. Baseline, production-adjusted baseline and post-event energy use for these scenarios would be calculated in a similar fashion to that described for space reduction, requiring specific knowledge of the process, equipment and engineering calculations.

Downtime, Changeover Time, Setup Time and Cycle Time Reduction

Calculating energy savings for reduced downtime, changeover time, setup time or cycle time begins with inventorying electricity-consuming equipment. However, with these cases, equipment should be categorized into one of the four equipment types discussed above. In addition, knowledge of cycle loaded and unloaded times and power draw are required. Based on this information, the baseline, production-adjusted baseline and post-event energy use for each piece of equipment can be calculated. Example applications of this energy savings methodology follow.

Example Application of Savings Methodology

Example 1 – cycle time reduction for anodizing process. Consider the following simplified hypothetical metal anodizing process and Lean Manufacturing event. The process operates 10 hours per day, and produces 10 units during this period. Four pieces of electrical equipment support the process, and each is of a different type. An exhaust fan is production independent and operates constantly drawing 1 kW and thus 24 kWh per day. Lights operate constantly during production hours, drawing 10 kW. An anodizing tank rectifier operates only when a unit is being anodized, drawing 50 kW and shutting off between cycles. A chiller cooling the anodizing tank operates constantly during production, drawing 25 kW when a unit is being anodized, but idles when a unit is not being anodized, drawing only 10 kW. Each unit is anodized for ½ hour, resulting in ½ hour idle time between units.

A Lean Manufacturing event increases production to meet increased demand to 13 units per day, while production hours remain the same. Would this Lean Manufacturing event have not occurred, the plant would have had to operate additional production shifts. The baseline, production-adjusted baseline and post-event energy use for each piece of equipment can be calculated, as shown in Table 2.

Table 2. Baseline, Production-Adjusted Baseline and Post-Event Energy Use

Equipment Type (Description)	Baseline (kWh/day)	Production-Adjusted Baseline (kWh/day)	Post-Event (kWh/day)
Independent (Exhaust Fan)	= 24 kWh/day	= 24 kWh/day	= 24 kWh/day
Production Hours Dependent (Lights)	= 10 kW x 10 hrs/day = 100 kWh/day	= 10 kW x 13 hrs/day = 130 kWh/day	= 10 kW x 10 hrs/day = 100 kWh/day
Production Qty Dependent (Rectifier)	= 50 kW/unit x 0.5 hr/unit x 10 units/day = 250 kWh/day	= 50 kW/unit x 0.5 hr/unit x 13 units/day = 325 kWh/day	= 50 kW/unit x 0.5 hr/unit x 13 units/day = 325 kWh/day
Prod. Hours & Qty Dependent (Chiller)	= 17.5 kWh/unit x 10 units/day = 175 kWh/day	= 17.5 kWh/unit x 13 units/day = 228 kWh/day	= 15.2 kWh/unit x 13 units/day = 198 kWh/day
Total	**549 kWh/day**	**707 kWh/day**	**647 kWh/day**
Intensity	**54.9 kWh/unit**	**54.4 kWh/unit**	**49.8 kWh/unit**

The energy savings would be the difference between the post-event and production-adjusted baseline energy use, 60 kWh/day. Note that only the equipment types with production hour dependent components result in energy savings. In this case, as the hypothetical plant has excess production hours, there would be no electrical demand savings. The peak demand set in the baseline, production-adjusted baseline and post-event scenarios would be identical.

Example 2 – changeover time reduction for anodizing process. Now, consider the same hypothetical manufacturing process. Once per week the anodizing tanks must be changed over, that is, drained, cleaned and refilled with a fresh mixed solution. This process takes four hours, reducing daily production to just six units or a weekly average of 9.2 units. During changeover, the rectifier turns completely off while the chiller idles. A Lean Manufacturing event focused on quick changeover reduces the changeover process to just two hours, thus increasing production to eight units on changeover days, and increasing the weekly average to 9.6 units. The baseline, production-adjusted baseline and post-event energy use for each piece of equipment can be calculated, as shown in Table 3.

Table 3. Baseline, Production-Adjusted Baseline and Post-Event Energy Use

Equipment Type (Description)	Baseline (kWh/day)	Production-Adjusted Baseline (kWh/day)	Post-Event (kWh/day)
Independent (Exhaust Fan)	= 24 kWh/day	= 24 kWh/day	= 24 kWh/day
Production Hours Dependent (Lights)	= 10 kW x 10 hrs/day = 100 kWh/day	= 10 kW x 10.4 hrs/day = 104 kWh/day	= 10 kW x 10 hrs/day = 100 kWh/day
Production Qty Dependent (Rectifier)	= 50 kW/unit x 0.5 hr/unit x 9.2 units/day = 230 kWh/day	= 50 kW/unit x 0.5 hr/unit x 9.6 units/day = 240 kWh/day	= 50 kW/unit x 0.5 hr/unit x 9.6 units/day = 240 kWh/day
Prod. Hours & Qty Dependent (Chiller)	= 17.5 kWh/unit x 9.2 units/day = 161 kWh/day	= 17.5 kWh/unit x 9.6 units/day = 168 kWh/day	= 15.2 kWh/unit x 9.6 units/day = 164 kWh/day
Total	**515 kWh/day**	**536 kWh/day**	**528 kWh/day**

The energy savings would be the difference between the post-event and production-adjusted baseline energy use, or 8 kWh/day. Note that as before, only the equipment types with production-hour dependent components result in energy savings.

Aside, increased production quantity may also increase the operating efficiency of pumps, fans or motors, as they could be more fully-loaded. It could also decrease the efficiency if equipment is over-loaded. Thus, unless equipment loading in relation to design load is known, we recommend neglecting this effect for savings calculations.

Rework/Scrap

Calculating energy savings due to rework or scrap reductions is very similar to the method presented above for reduced downtime and changeover. The slight difference here is that production quantity reflects the sum of quality and defective units. For example, consider the same hypothetical process described above produces eight good units per day with a defective rate of 20%. Including defective units, the total production is really 10 units per day. Scrap reduction would keep the total production at 10 units per day, but may increase the number of quality units to nine per day. Therefore, the baseline and post-event units per day are equal at 10 units per day. However, the production-adjusted baseline units/day equals nine good units plus the 20% defective rate, for a total of 11.25 units per day. The baseline, production-adjusted baseline and post-event energy use for each piece of equipment can be calculated, as shown in Table 4.

Table 4. Baseline, Production-Adjusted Baseline and Post-Event Energy Use

Equipment Type (Description)	Baseline (kWh/day)	Production-Adjusted Baseline (kWh/day)	Post-Event (kWh/day)
Independent (Exhaust Fan)	= 24 kWh/day	= 24 kWh/day	= 24 kWh/day
Production Hours Dependent (Lights)	= 10 kW x 10 hrs/day = 100 kWh/day	= 10 kW x 11.25 hrs/day = 113 kWh/day	= 10 kW x 10 hrs/day = 100 kWh/day
Production Qty Dependent (Rectifier)	= 50 kW/unit x 0.5 hr/unit x 10 units/day = 250 kWh/day	= 50 kW/unit x 0.5 hr/unit x 11.25 units/day = 281 kWh/day	= 50 kW/unit x 0.5 hr/unit x 10 units/day = 250 kWh/day
Prod. Hours & Qty Dependent (Chiller)	= 17.5 kWh/unit x 10 units/day = 175 kWh/day	= 17.5 kWh/unit x 11.25 units/day = 197 kWh/day	= 16.4 kWh/unit x 10 units/day = 164 kWh/day
Total	**549 kWh/day**	**615 kWh/day**	**538 kWh/day**

The energy savings would be the difference between the post-event and production-adjusted baseline energy use, or 77 kWh/day. Note that with rework/scrap reductions, the production quantity dependent equipment realizes energy savings in addition to the production hour dependent equipment.

Setup Time (Non-Production Hours)

Finally, setup time may occur during production hours, or prior to production, such as early Monday morning or late Sunday evening. If setup time occurs during production hours, the energy savings resulting from reduced setup time should be calculated using the method described for quick changeover. Otherwise, the savings would result from only the reduction of use of hourly production equipment. For example, if in our previously described plant setup each day takes two hours, this would extend the operation of the lights. Reducing setup time to one hour would not increase production, but would reduce the time the lights were on. The baseline, production-adjusted baseline and post-event energy use for this case are presented in Table 5.

Table 5. Baseline, Production-Adjusted Baseline and Post-Event Energy Use

Equipment Type (Description)	Baseline (kWh/day)	Production-Adjusted Baseline (kWh/day)	Post-Event (kWh/day)
Independent (Exhaust Fan)	= 24 kWh/day	= 24 kWh/day	= 24 kWh/day
Production Hours Dependent (Lights)	= 10 kW x 12 hrs/day = 120 kWh/day	= 10 kW x 12 hrs/day = 120 kWh/day	= 10 kW x 11 hrs/day = 110 kWh/day
Production Qty Dependent (Rectifier)	= 50 kW/unit x 0.5 hr/unit x 10 units/day = 250 kWh/day	= 50 kW/unit x 0.5 hr/unit x 10 units/day = 250 kWh/day	= 50 kW/unit x 0.5 hr/unit x 10 units/day = 250 kWh/day
Prod. Hours & Qty Dependent (Chiller)	= 17.5 kWh/unit x 10 units/day = 175 kWh/day	= 17.5 kWh/unit x 10 units/day = 175 kWh/day	= 17.5 kWh/unit x 10 units/day = 175 kWh/day
Total	**569 kWh/day**	**569 kWh/day**	**559 kWh/day**

The energy savings would be the difference between the proposed and baseline energy use, or 10 kWh/day.

Unadjusted Baseline and Production-Adjusted Baseline Energy Use

Here we would like to note the importance of measuring energy savings from the production-adjusted baseline. For example, the energy intensity of the baseline, production-adjusted baseline and post-event scenarios from Table 4 are 45.9 kWh/unit, 54.4 kWh/unit and 49.8 kWh/unit. As we discussed earlier, there is a reduction in energy intensity from the baseline to production-adjusted baseline scenarios. Thus, energy "savings" between these two scenarios are due to increased production, not from efficiency improvement in the manufacturing process. Therefore, these savings should not be included as a result of productivity improvements, and energy savings should always be calculated as the difference between the production-adjusted baseline and the post-event energy use.

Statistical Regression Method

Using statistical regression models and corresponding equations, we can calculate the baseline, production-adjusted baseline and post-event energy use for an entire plant given its baseline and post-event production quantity. For example, a hypothetical plant produces 5,000,000 units per month currently, and a Lean event increases production to 6,000,000 units per month. Production independent energy use at the facility is 1,000,000 kWh per month, while the production-quantity dependent component of facility energy use is 0.2 kWh per unit. Calculating baseline and post-event energy can be done using the resulting regression equation:

Baseline: 1,000,000 kWh/mo + 0.2 kWh/unit x 5,000,000 units/mo = 2,000,000 kWh/mo
Post-Event: 1,000,000 kWh/mo + 0.2 kWh/unit x 6,000,000 units/mo = 2,200,000 kWh/mo

Production-adjusted baseline energy use would be calculated using the regression equation coefficients. Here, the production coefficient, 0.2 kWh/unit, represents only the value added portion of the production energy. That is, it does not include the idle energy of production equipment. The production coefficient would remain the same when calculating the production-adjusted baseline energy use. However, the production independent coefficient would increase almost proportionally with increased production, as it includes equipment dependent on production hours. Remember that in the production-adjusted scenario, production hours increase proportionally with production quantity. The production independent coefficient also includes independent equipment such as office equipment, which would not increase energy use proportionally. Nonetheless, production-adjusted baseline energy use can be approximated using this equation. The baseline energy use in this case would be:

Production-Adjusted Baseline: 1,000,000 kWh/mo x (6,000,000 / 5,000,000) + 0.2 kWh/unit x 6,000,000 units/mo = 2,400,000 kWh/mo

Energy savings are the difference between the production-adjusted baseline and post-event values, or 200,000 kWh/month. This method is much simpler than the Energy Breakdown method. Provided that a Lean Manufacturing event affects 100%, or near 100%, of plant production, and that a statistically significant model can be developed, this method is potentially more accurate and easily applicable on a broad basis.

Conclusions

Productivity improvements can result in improved manufacturing process energy efficiency at production rates greater than the pre-event maximum. Productivity improvements may result in energy conservation when there are space reductions or direct efficiency improvements, although this is not always the case. Thus, while energy savings may be justified, care should be taken to only include savings from direct reductions and productivity improvement, and not those related to decreased energy intensity from increased production quantity. Calculated energy savings should consider disaggregating manufacturing process energy use into production, independent, production-quantity dependent, production-hour dependent, and production-quantity and hour dependent components.

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