LEAN ENERGY ANALYSIS: IDENTIFYING, DISCOVERING AND TRACKING ENERGY SAVINGS POTENTIAL

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ABSTRACT
Energy in manufacturing facilities is used for direct production of goods, space conditioning, and general facility support such as lighting. This paper presents a methodology, called lean energy analysis, LEA, for graphically and statistically analyzing plant energy use in terms of these major end uses. The LEA methodology uses as few as 60 easily obtainable data points. Multivariable change-point models of electricity and natural gas use as functions of outdoor air temperature and production data are developed. The statistical models are used to subdivide plant energy use into facility, space-conditioning and production-related components. These breakdowns suggest the savings potential from reducing non-production and space-conditioning energy use. In addition, graphical analysis of the statistical models and data promotes the discovery of energy saving opportunities. Finally, the models can be used to predict energy use for energy budgeting, measure savings, determine cost structures, and for diagnostic purposes. Case study examples demonstrate the lean energy analysis method and its application.

INTRODUCTION
Most energy reduction opportunities in industrial facilities are identified after observation and analysis of the facility. However, much can be done before a site visit to identify possible energy-reduction opportunities.

This paper discusses techniques for the analysis of energy billing, weather and production data that can be performed before a site visit. When used in this manner, these techniques help focus attention on the most promising areas for reducing energy use, and help to identify specific energy saving opportunities in advance of the visit. LEA is also useful for budgeting, costing and tracking savings over time.

We call the analysis techniques presented here lean energy analysis, LEA, because of their synergy with the principles of lean manufacturing. In terms of lean manufacturing, “any activity that does not add value to the product is waste”. The LEA techniques developed in this paper:

- Quantify production, space conditioning and non-production related energy use, and hence the potential for reducing “waste”.
- Uncover energy savings opportunities.
- Help develop accurate budgets and costing models.
- Track savings and the transition to “lean” energy operation.

In this paper, we break LEA into five levels:

1. Standard Billing Analysis
2. Quick Energy Use Breakdowns
3. Statistical Lean Energy Analysis (LEA)
4. Using LEA to Discover Savings Opportunities
5. Using LEA for Budgeting, Costing and Tracking Savings

Case study examples are used to demonstrate each level of the LEA method and its application.

LEVEL 1: STANDARD BILLING ANALYSIS
Level 1 analysis includes the following tasks:

- Graph trends
- Summarize rate schedule
- Verify billing amounts
- Disaggregate costs
- Identify savings opportunities

These tasks are generally performed as part of any standard analysis of energy billing data. The importance of graphing energy use data cannot be overstated. In general, our eyes are much better at identifying patterns and trends from graphical information than from tables of numbers.

For example, the anomaly in Figure 1was discovered only after graphing monthly electrical demand data. In this case, electrical demand spiked in the middle of the winter in a production facility located in Washington D.C. with a large air conditioning load. The cause of the demand spike was subsequently discovered to be a short scheduled shutdown of steam service, which caused electrical resistance heaters throughout the building to operate at full load.

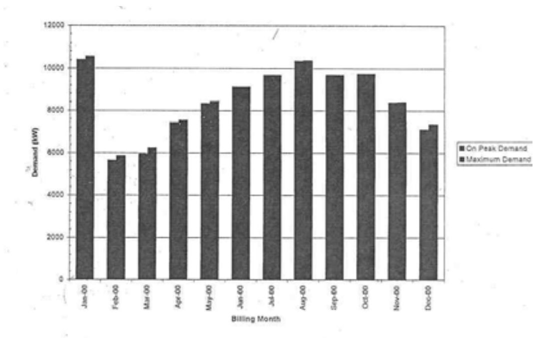

Figure 1. Monthly electrical demand.

In general, we recommend plotting at least one year of monthly electrical demand and energy use data on the same graph. In many cases, such as in Figure 2, electrical demand is less volatile than electrical energy use since the same major electrical equipment is typically operated simultaneously at least once during each month. A patterned increase in electrical demand during the summer is often associated with air conditioning. The variation in electrical energy use is often associated with changing levels of production.

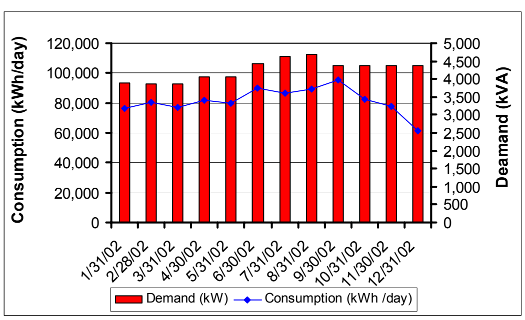

Figure 2. Monthly electrical demand and energy use.

The next step is to summarize rate schedules. Despite their apparent complexity, most electrical rate schedules can be simplified into charges for service, total energy use, peak electrical demand, and low power factor. After the rate schedules are understood, the total billing amount can be calculated and compared to the total amount charged by the utility. This process, which is illustrated in Figure 3, identifies billing errors and verifies that the proper rate schedule is being applied.

Date	Days	Consumption (kWh/period)	Avg Daily Consumption (kWh/day)	Actual Demand (kW)	Power Factor	Load Factor	Billed Amount ($/period)	Unit Cost ($/kWh)	Calculated Amount ($/period)
11/20/01	32	1,743,914	54,497	6,731	93%	0.34	$110,757	$0.064	$110,758
12/20/01	30	1,526,951	50,898	6,610	93%	0.32	$103,913	$0.068	$103,914
1/21/02	32	1,404,734	43,898	6,699	93%	0.27	$102,091	$0.073	$102,093
2/20/02	30	1,515,385	50,513	4,131	88%	0.51	$95,426	$0.063	$95,427
3/20/02	28	1,325,472	47,338	3,945	87%	0.50	$90,469	$0.068	$90,470
4/19/02	30	1,334,098	44,470	3,734	88%	0.50	$90,694	$0.068	$90,695
5/20/02	31	1,241,993	40,064	3,548	87%	0.47	$88,291	$0.071	$88,293
6/20/02	31	1,335,909	43,094	3,758	86%	0.48	$90,741	$0.068	$90,742
7/19/02	29	1,197,403	41,290	3,596	85%	0.48	$87,128	$0.073	$87,130
8/20/02	32	1,357,669	42,427	3,467	88%	0.51	$84,359	$0.062	$84,361
9/20/02	31	1,248,546	40,276	3,256	86%	0.52	$81,513	$0.065	$81,514
10/21/02	31	1,260,806	40,671	3,321	86%	0.51	$81,833	$0.065	$81,834
Tot/Avg	367	16,492,880	44,953	4,400	88%	0.43	$1,107,214	$0.067	$1,107,215

Figure 3. Comparison of calculated and actual billing amounts.

The next step is to disaggregate the total electricity bill into components. In most facilities, demand and energy charges account for the vast majority of the total charge are roughly equal. A high ratio of demand to energy costs generally indicates one-shift operation and/or disproportionably high demand costs. In either case, a high ratio of demand to energy costs signals the potential for reducing costs by reducing demand. A high ratio of energy to demand costs generally indicates three-shift operation, disproportionably high energy costs, and/or equipment being left on after production has stopped.

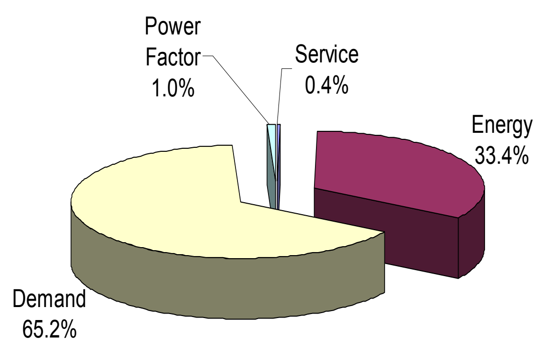

Figure 4. Disaggregate electricity costs.

In summary, savings opportunities from standard billing analysis include:

- Billing errors
- Primary/secondary service
- Power factor correction
- Meter consolidation
- Demand reduction potential

LEVEL 2: QUICK ENERGY USE BREAKDOWNS

In Level 2 analysis, electrical and thermal energy use can be quickly disaggregated into space conditioning and production components using graphical analysis. Electrical and thermal energy use by equipment can be estimated and calibrated to match the previous breakdowns. These quick breakdowns help target and screen energy saving opportunities.

Electrical demand can be segregated into production and air conditioning by drawing a line through winter demand. Electrical demand below the line is for production and electrical demand above the line is for air conditioning. For example, in Figure 2 winter demand is about 3,900 kW and peak summer demand is about 4,700 kW, indicating that air conditioning demand is about 800 kW.

The size of the air conditioning equipment can be estimated by applying the estimated efficiency of the air conditioning equipment to the estimated air conditioning demand. For example, SEER 10 air conditioning equipment requires about 1.2 kW/ton. In Figure 2, this would suggest that the building uses about 670 tons of air conditioning.

Similarly, electrical demand can be segregated into production and air conditioning by drawing a line through winter electricity use. Electrical use below the line is for production and electrical use above the line is for air conditioning. For example, in Figure 2 winter electricity use is about 78,000 kWh/day and average electricity use is about 83,000 kWh/day, indicating that about 94% of electricity use is for production and about 6% is for air conditioning.

Thermal energy use can also be segregated into production and space heating components by drawing a line through summer gas use. Gas use below the line is for production and gas use above the line is for space heating. For example, in Figure 5, summer gas use is about 310 Mcf/day and the annual average gas use is about 430 Mcf/day, indicating that about 72% of gas use is for production and about 28% is for space heating.

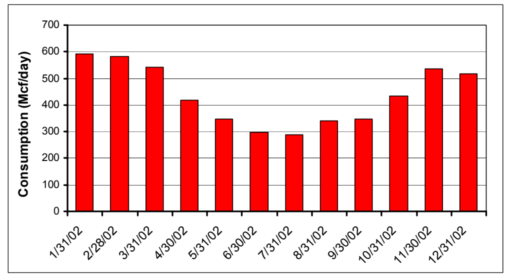

Figure 5. Monthly gas use showing typical U-shaped winter, summer, winter pattern.

Finally, energy use by equipment can be estimated based on rated power, fraction loaded, and hours of operation (Figure 6). Initial estimates of electricity and gas use by equipment should be calibrated to match the breakdowns of electricity and gas use into production and space conditioning components (Figure 7). This process insures that estimated energy use by equipment does not exceed the actual quantities purchased and conforms to the patterns of use in evident in the billing data.

Equipment	Rated Power	Frac Loaded	Oper Hours (hr/yr)	Elec Use (kWh/yr)
AC #1	50 hp	90%	5,000	187,500
Lights	10 kW	100%	6,000	60,000
…	…	…	…	…
Other				10,000
	Utility Bill Total =			257,500

Equipment	Rated Input (Btu/hr)	Frac Loaded	Oper Hours (hr/yr)	Gas Use (MBtu/yr)
Boiler 1	1,000,000	70%	5,000	3,500
Make Up #1	500,000	100%	2,000	1,000
…	…	…	…	…
Other				500
	Utility Bill Total =			5,000

Figure 6. Example of estimating electricity and gas use by equipment.

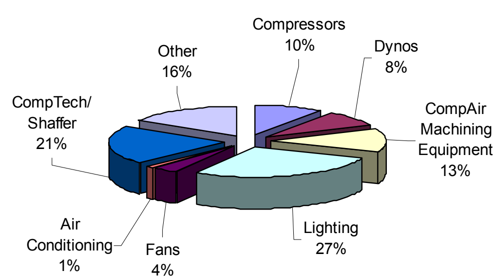

Figure 7. Example of electricity use breakdown by equipment.

In summary, Level 2 quick energy use breakdowns can target savings opportunities by identifying:

- Air conditioning load / potential
- Space heating load / potential

- Process electricity and gas loads / potentials
- Equipment loads / potentials

It can also be used to screen savings opportunities by estimate annual savings as a fraction of annual energy use, and then determining acceptable implementation costs by applying the savings payback threshold to the savings. For example, the implementation cost for a 2-year simple payback would be twice the expected annual savings. If this seems reasonable, then the idea should be pursued.

LEVEL 3: STATISTICAL LEAN ENERGY ANALYSIS

In Level 3 analysis, statistical modeling is used to disaggregate electricity and thermal energy use into the following components:

- Facility
- Space conditioning
- Production

The statistical models were developed specifically to model energy use as a function of outdoor air temperature and other influential variables (Kissock et al., 1998a; Kissock et al., 2003). Other papers (Haberl et al., 2003; Kissock and Seryak, 2004) address the interpretation of statistical parameters in more detail.

Source Data

The source data for the models are monthly electricity use, natural gas use, production and outdoor air temperature. Altogether, only 60 data points are required to analyze one year of electricity and gas use. Electricity and natural gas use are from utility billing data. Average temperatures for the energy billing periods are available from many sources including the UD/EPA Average Daily Temperature Archive, which posts average daily temperatures from 1995 to present for over 300 cities around the world (http://www.engr.udayton.edu/weather/). Production data are logged by most companies. Monthly electricity use, natural gas use and production are normalized by the number of days in the data period to remove the influence of variable-length data periods from the analysis.

Software

The software used to develop the models is Energy Explorer (Kissock, 2000). Energy Explorer integrates the previously laborious tasks of data processing, graphing and statistical modeling in a user-friendly, graphical interface. The multivariable change-point models described above are included in Energy Explorer. These models enable users to quickly and accurately determine baseline energy use, predict future energy use, understand factors that influence energy use, calculate retrofit savings, and identify operational and maintenance problems.

Statistical Analysis of Natural Gas Use

Figure 8 shows monthly natural gas use and average outdoor air temperature during 2002. The graph shows that natural gas use increases during cold months and decreases during warm months, however, some natural gas is used even during summer. Thus, outdoor air temperature appears to have some influence on natural gas use, but does not appear to be the sole influential variable.

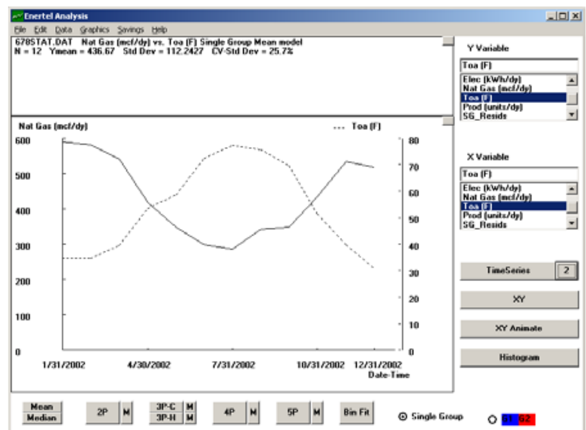

Figure 8. Monthly natural gas use and outdoor air temperature.

Figure 9 shows monthly natural gas use and number of units produced during 2002. The graph shows some correlation between production and natural gas use. For example, gas use declines during low-production months such as July and December.

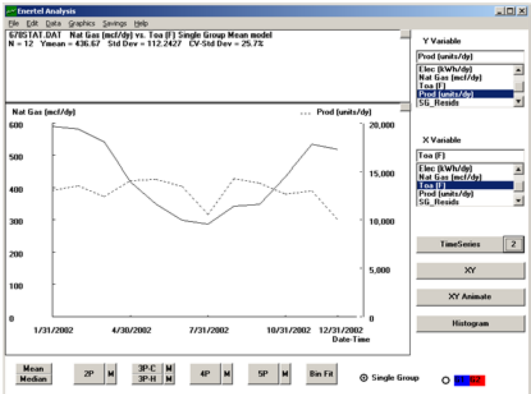

Figure 9. Monthly natural gas use and quantity of units produced.

Figure 10 shows a three-parameter heating (3PH) change-point model of monthly natural gas use as a function of outdoor air temperature. In Figure 10, the flat section of the model on the right indicates temperature-independent natural gas use, Ycp, when no space heating is needed. At outdoor air temperatures below the change-point temperature, Xcp, of about 66 F, natural gas use begins to increase with decreasing outdoor air temperature and increasing space-heating load. The slope of the line, X1, indicates the how much additional natural gas is consumed as the outdoor air temperature decreases. The model's R2 of 0.92 indicates that temperature is indeed an influential variable. The model's CV-RMSE of 7.5% indicates that the model provides a good fit to the data.

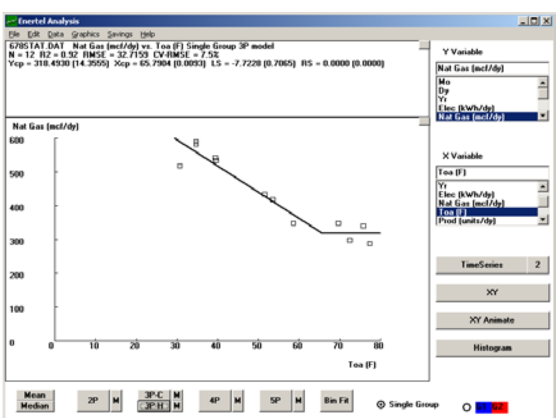

Figure 10. Three-parameter heating (3PH) change-point model of monthly natural gas use as a function of outdoor air temperature.

Despite the relatively good fit of the outdoor air temperature model shown in Figure 10, inspection of Figure 11 indicates that production also influences natural gas use. Figure 11 shows a two-parameter model of natural gas use as a function of number of units produced. The model shows a trend of decreasing natural gas use with production, and a very low R2 = 0.02. This indicates that production alone is a poor indicator of natural gas use.

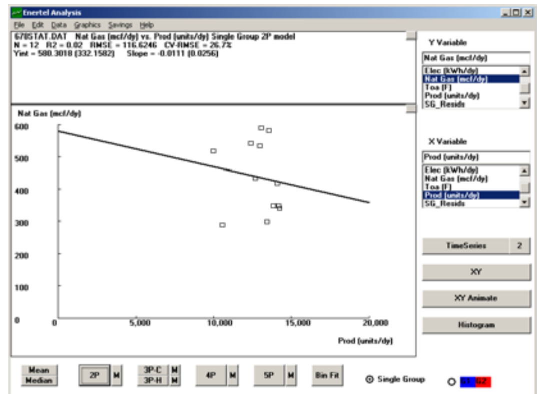

Figure 11. Two-parameter model of monthly natural gas use as a function of quantity of units produced.

Figure 12 shows the regression results of a three-parameter heating model of natural gas use as a function of outdoor air temperature, that also includes production as an additional independent variable. This model is called a 3PH-MVR model since it includes the capabilities of both a three-parameter heating model of energy use versus temperature, plus a multivariable-regression model (MVR). The model's R2 of 0.97 and CV-RMSE of 5.1% are improvements over either of the previous models that attempted to predict natural gas use using air temperature of production independently. Thus, this model provides a very good fit to the data. In addition, note that when combined with temperature data, the model coefficient for production (X2 = 0.0199) is now positive, indicating that gas use does indeed increase with increased production.

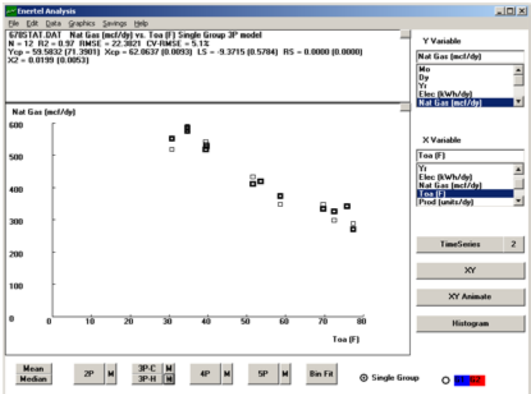

Figure 12. Results of three-parameter heating model of natural gas use as function of both outdoor air temperature and production (3PH-MVR). Measured natural gas use (light squares) and predicted natural gas use (bold squares) are plotted against outdoor air temperature.

Using the regression coefficients from Figure 12, the equation for predicting natural gas use, NG, as a function of outdoor air temperature Toa and quantity of units produced, P, with a 3PH-MVR model is:

$$NG = Ycp + LS \times (Xcp - Toa)^{+} + (X2 \times P) \text{ NG (mcf/dy)} \quad (1)$$

$$NG = 59.58 \text{ (mcf/dy)} + 9.372 \text{ (mcf/dy-F)} \times [62.06 \text{ (F)} - Toa \text{ (F)}]^{+} + 0.0199 \text{ (mcf/dy-unit)} \times P \text{ (units)}$$

where the superscript + on the parenthetic term indicates that the value of the term is zero when the enclosed quantity, (Xcp - Toa), is negative. In Equation 1, the total natural gas use, NG, is the sum of the three terms that represent facility natural gas use, temperature-dependent natural gas use (space heating), and production-dependent natural gas use. Thus, natural gas use can be broken down into the following components:

$$\text{Fac NG} = 59.58 \text{ (mcf/dy)} \quad (2)$$

$$\text{SH NG} = 9.372 \text{ (mcf/dy-F)} \times [62.06 \text{ (F)} - Toa \text{ (F)}]^{+} \quad (3)$$

$$\text{Prod NG} = 0.0199 \text{ (mcf/dy-unit)} \times P \text{ (units)} \quad (4)$$

Equations 1,2,3 and 4 can be used to calculate total natural gas use, and natural gas use by each component.

Figure 13 shows the breakdown of natural gas use using these equations. It also shows the good agreement between actual plant-wide natural gas use and the natural gas use predicted by Equation 1.

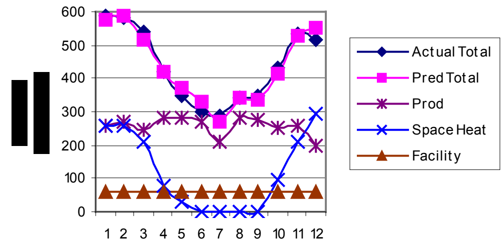

Figure 13. Time trends of actual and predicted natural gas use by component versus month of the year.

<u>Statistical Analysis of Electricity Use</u>

Figure 14 shows monthly electricity use and average outdoor air temperature during 2002. The graph shows that electricity is slightly higher during summer and early fall, when the outdoor air temperatures are higher and air conditioning loads are greatest. In the fall, electricity use declines steeply; however, it is unlikely that the dramatic reduction in electricity use is caused solely by the cooler air temperatures since electricity use during the first part of the year remained relatively high despite similarly cold temperatures. Thus, outdoor air temperature appears to have some influence on electricity use, but does not appear to be the sole influential variable.

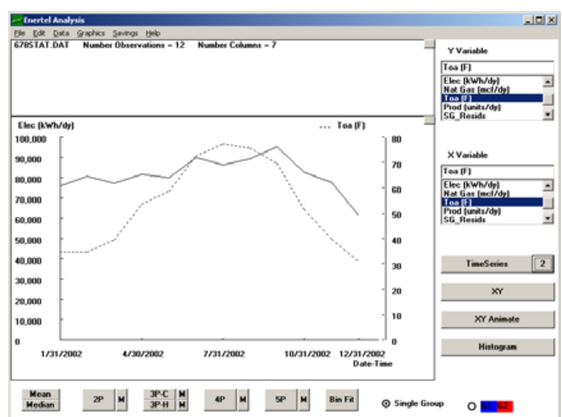

Figure 14. Monthly electricity use and average daily temperatures during 2002.

Figure 15 shows monthly electricity use and the quantity of units produced each month during 2002. The two trends appear to be relatively well correlated, frequently rising and falling in unison. However, summer electricity use is distinctly higher than electricity use during the rest of the year. Thus, both production and outdoor air temperature appear to significantly influence electricity use.

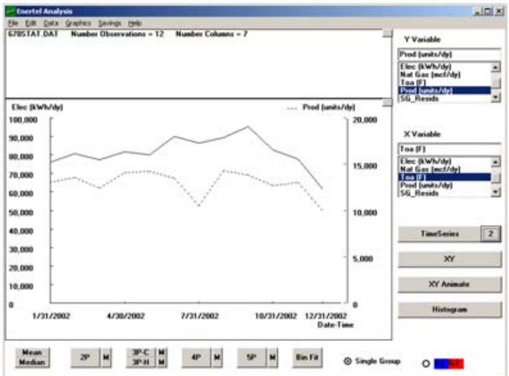

Figure 15. Monthly electricity use and number of units produced during 2002.

Figure 16 shows a three-parameter cooling (3PC) change-point model of monthly electricity use as a function of outdoor air temperature. Three-parameter change-point models are so named because they have three coefficients; Ycp is temperature-independent energy use, Xcp is the outdoor air temperature above which space cooling energy use increases, and X1 is the additional electricity use for space cooling per degree of outdoor air temperature. In Figure 16, the flat section of the model on the left indicates temperature-independent electricity use, Ycp, when no air conditioning is needed. At outdoor air temperatures above the change-point temperature, Xcp, of about 32 F, electricity use begins to increase with increasing outdoor air temperature and air conditioning load. The slope of the line, X1, indicates the how much additional electricity is consumed as the outdoor air temperature increases.

The model's R2 of 0.67 indicates that temperature is indeed an influential variable. CV-RMSE is a non-dimensional measure of the scatter of data around the model. The model's CV-RMSE of 6.4% indicates that the model provides a good fit to the data.

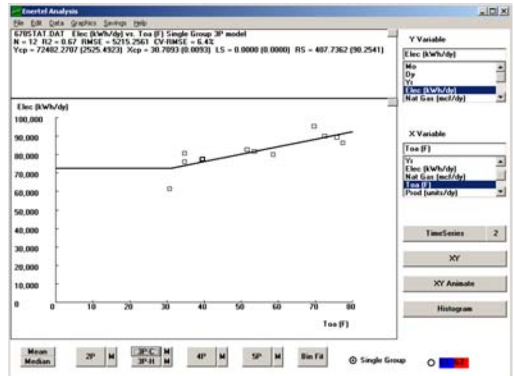

Figure 16. Three-parameter cooling (3PC) change-point model of monthly electricity use as a function of outdoor air temperature.

Despite the relatively good fit of the outdoor air temperature model shown in Figure 16, inspection of Figure 17 indicates that production also influences electricity use. Figure 17 shows a two-parameter model of electricity use as a function of number of units produced. The model shows a trend of increasing electricity use with increased production. However, the model R2 is 0.32, which indicates that production alone is a poor indicator of electricity use.

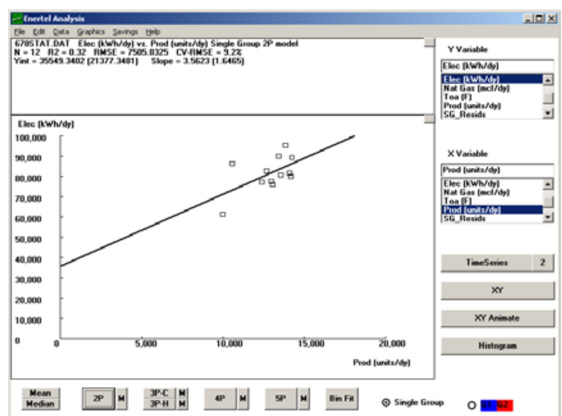

Figure 17. Two-parameter model of monthly electricity use as a function of quantity of units produced.

Clearly, the best model for predicting electricity use would include both outdoor air temperature and production. Figure 18 shows the regression results of a three-parameter cooling model of electricity use as a function of outdoor air temperature, that also includes production as an additional independent variable. This model is called a 3PC-MVR model since it includes the capabilities of both a three-parameter cooling model of energy use versus temperature, plus a multivariable-regression model (MVR). In

Figure 18, the measured electricity use (light squares) and predicted electricity use (bold squares) are plotted against outdoor air temperature. It is seen that the measured and predicted electricity use are almost on top of each other for each monthly temperature, which graphically indicates that the model is a good predictor of electricity use. The model's R2 of 0.82 and CV-RMSE of 5.1% are improvements over the previous models that attempted to predict natural gas use using air temperature of production independently. In addition, the coefficient that describes natural gas use per unit of production, X2, is now positive as expected. Thus, this model provides a very good fit to the data.

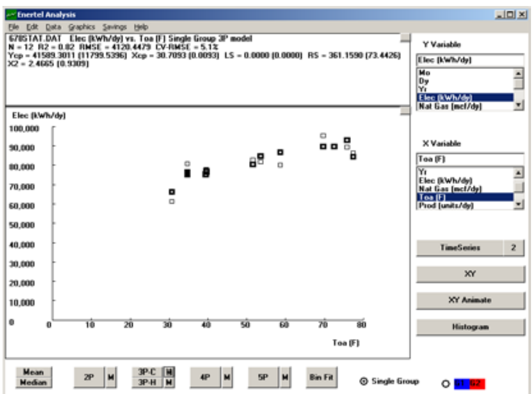

Figure 18. Results of three-parameter cooling model of electricity use as function of both outdoor air temperature and production. Measured electricity use (light squares) and predicted electricity use (bold squares) are plotted against outdoor air temperature.

Using the regression coefficients from Figure 18, the equation for predicting electricity use, E, as a function of outdoor air temperature Toa and quantity of units produced, P, with a 3PC-MVR model is:

$$E = Ycp + RS \times (Toa - Xcp)^{+} + (X2 \times P) \quad (5)$$

$$E\ (kWh/dy) = 41{,}589\ (kWh/dy) + 361.159\ (kWh/dy\text{-}F) \times [Toa\ (F) - 30.7093\ (F)]^{+} + 2.4665\ (kWh/dy\text{-}unit) \times P\ (units)$$

where the superscript + on the parenthetic term indicates that the value of the term is zero when the enclosed quantity, (Toa – Xcp), is negative. In Equation 5, the total electricity use, E, is the sum of the three terms that represent non-production electricity use, temperature-dependent electricity use (air conditioning), and production-dependent electricity use. Thus, electricity use can be broken down into the following components.

$$Fac = 41{,}589\ (kWh/dy) \quad (6)$$
$$AC = 361.16\ (kWh/dy\text{-}F) \times [Toa\ (F) - 30.71\ (F)]^{+} \quad (7)$$
$$Prod = 2.4665\ (kWh/dy\text{-}unit) \times P\ (units) \quad (8)$$

Equations 5-8 can be used to estimate total electricity use, and electricity use by each component (Figure19). Inspection of Figure 19 shows reasonably good agreement between actual plant-wide electricity use and the electricity use predicted by Equation 5.

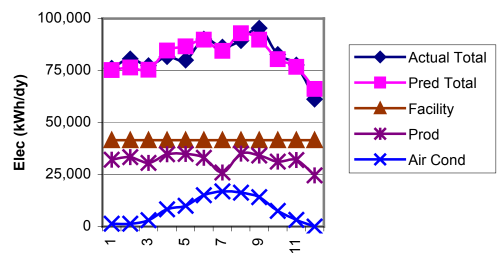

Figure 19. Time trends of actual and predicted electricity use by component versus month of the year.

More generally, in the ideal plant, all electricity use would be proportional to production or devoted to space conditioning; facility electricity use, which is unrelated to production or space conditioning, would tend toward zero. In terms of the well-known principles of lean production, any activity that does not directly add value to the product is waste. Seen in this light, the goal is to reduce facility electricity use as low as possible. The fact that statistical analysis indicates that facility electricity use accounts for over half of all electricity use, and that production electricity use is 11% greater than statistical production electricity use, indicates a large potential for reducing electricity use.

Several recommendations could address the high facility electricity use such as shutdown procedures and improving the performance of the compressed air system. With diligence, even traditionally non-production related tasks such as lighting and air compression can become more related to production. For example, turning off lights in areas where production has stopped would decrease the fraction of facility electricity use and increase the fraction of production-dependent electricity use. Similarly, fixing air leaks and using air compressors with good part-load energy performance, would both save energy use and increase the fraction of production-dependent electricity use.

LEVEL IV: USING LEAN ENERGY ANALYSIS TO DISCOVER SAVINGS OPPORTUNITIES

LEA indicators of savings opportunities include:

- Departure from expected shape
- Non-production dependent energy use
- High data scatter

Identification of these savings opportunities is demonstrated in the following examples.

<u>Departure From Expected Shape</u>

The five-parameter model of electricity as a function of outdoor air temperature shown in Figure 20 identified a previously unknown and unnecessary air conditioning load. The air conditioner was subsequently turned off.

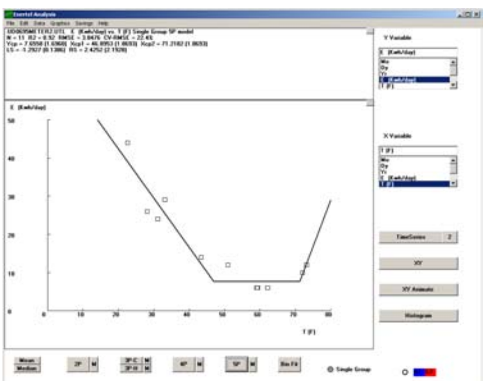

Figure 20. Five-parameter model of electricity as a function of outdoor air temperature.

The two-parameter model of electricity as a function of outdoor air temperature shown in Figure 21 identified malfunctioning economizers. The expected shape of electricity as a function of outdoor air temperature with functioning economizers would be a 3PC model, since the economizers should replace air conditioning electricity use during cold weather. After discussing the issue with plant maintenance personnel, it was discovered that the economizer dampers remained closed during winter. A highly cost-effective recommendation was made to fix the economizers.

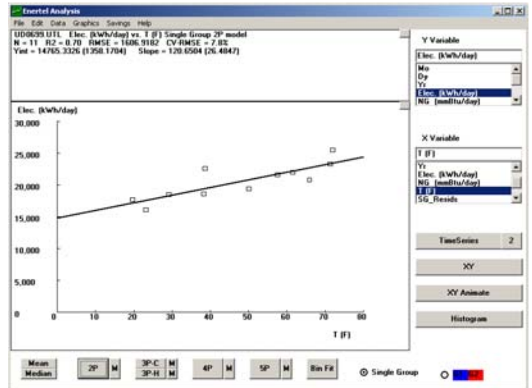

Figure 21. Two-parameter model of electricity as a function of outdoor air temperature. A three-parameter model was expected if the economizers were properly functioning.

<u>Non-Production Dependent Energy Use</u>

Figure 21 shows monthly electricity use graphed verses production. While production varies greatly, electricity use does not. Nearly the same amount of electricity used to make 250 parts is also used to make 25 parts. Statistically, this is shown by the very low R2 value of 0.01, indicating that production has almost no affect on electricity use. This suggests that the major electricity uses in the plant do not vary with production. In fact, an estimated 65% of plant electricity use did not vary with production: plant lighting (37%), air compressors (17%), and three 60-hp dust collection systems (11%).

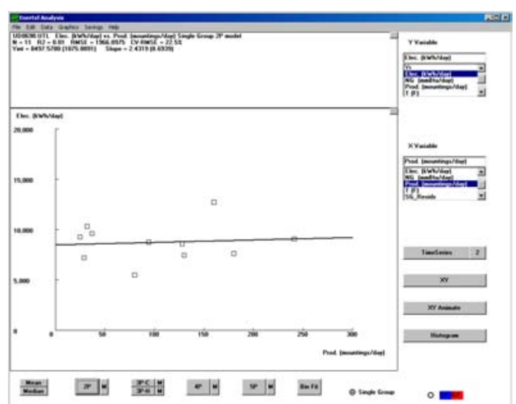

Figure 22. Two-parameter model of electricity as a function of outdoor air temperature. A three-parameter model was expected if the economizers were properly functioning.

Electricity use for all three of these systems could be varied with production. Lighting could be controlled by motion sensors, to turn off lights in areas when not in use. The air compressor mode of operation could be easily switched from "hand" to "load/unload" mode, allowing the compressors to unload when compressed air is not needed. Dampers could shut off dust-collection drops when not in use, varying the amount of air collected by the system. A variable-speed drive could be installed on the dust-collector motor to allow the power draw of the dust-collector motor to vary with varying dust collection. Thus, identifying non-production dependent energy use helped identify several energy savings opportunities.

<u>High Data Scatter</u>

Low data scatter indicates tight process control. For example, Figure 23 shows a model of natural gas use as a function of outdoor air temperature in a well controlled heat-treating plant. The CV-RMSE for this model is a relatively low 5.2%.

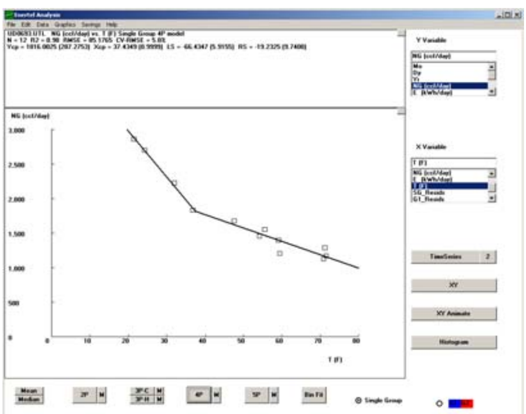

Figure 23. Four-parameter model of natural gas use as a function of outdoor air temperature in a well controlled heat treating plant.

In comparison, Figure 24 shows a three-parameter model of natural gas use as a function of outdoor air temperature at a plant that used natural gas only for space heating. While a 3PH model was the best regression fit, it is visually apparent that there is a high amount of scatter in the model; heating energy use varies by a factor of three at the same outdoor air temperature! This scatter is reflected in a CV-RMSE of 67.6%, which indicates that other factors influence gas use in addition to outdoor temperature. Discussions with plant personnel revealed that the shipping doors were frequently left open. Subsequent investigation showed a strong correlation between gas use and shipping-door open time. As a result, management agreed to install a plastic tarp to form a temporary wind barrier when shipping doors were open.

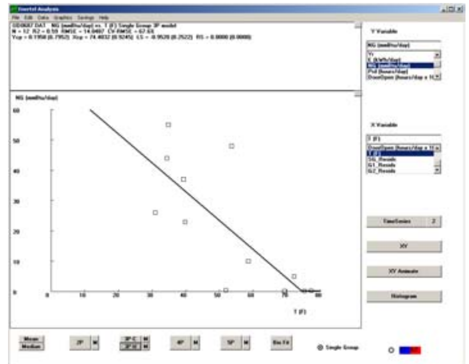

Figure 24. Three-parameter model of natural gas use as a function of outdoor air temperature.

LEVEL V: USING LEA FOR BUDGETING, COSTING AND TRACKING SAVINGS

In section LEVEL 3: STATISTICAL LEAN ENERGY ANALYSIS, Equations 1 and 5 were developed to estimate plant energy use based on production and outdoor air temperature. These equations can be used to predict future natural gas and electricity use for budgeting or other purposes. For example, if production is expected to change in the future, then future gas and electricity use as a function of the new levels of production could be predicted. In addition, it is relatively easy to bracket projected weather – related energy use by driving the models with temperature data from years with above-average and below-average temperatures.

Moreover equations 4 and 8 quantify plant energy use per unit of production. Thus, these equations could be used to quantify the actual cost of energy per unit. This information is useful in determining manufacturing costs, and subsequently the selling price, of energy-intensive products.

Equations 1 and 5 can also be used as a baseline for measuring savings from energy conservation retrofits. To "measure" retrofit savings, compare actual electricity use from after the retrofit to the electricity use predicted by Equations 1 and 5 when driven with the temperatures and production data from after the retrofit.

For example, Figure 25 shows three-parameter models of natural gas use as a function of outdoor air temperature before (upper blue line) and after (lower red line) a temperature setback retrofit. The savings are the differences between the upper blue line, which represents how much energy the facility would have used given the outdoor air temperatures that actually occurred, and the lower red data points which are the actual energy use after the retrofit.

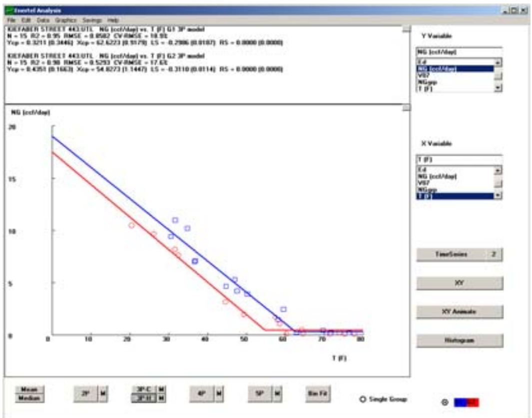

Figure 25. Three-parameter models of natural gas use as a function of outdoor air temperature before (upper blue line) and after (lower red line) a temperature setback retrofit.

SUMMARY

This paper presented a Lean Energy Analysis methodology of how to statistically analyze plant energy data and interpret the results. The LEA methodology was divided into five levels:

1. Standard Billing Analysis
2. Quick Energy Use Breakdowns
3. Statistical Lean Energy Analysis
4. Using LEA to Discover Savings Opportunities
5. Use LEA Models For Budgeting, Costing And Measuring Savings

LEA uses only 60 data points that are relatively easy for most plants to obtain. Multivariable three-parameter change-point models of electricity and natural gas use as functions of outdoor air temperature and production data are developed. The statistical models are able to breakdown plant energy use into facility, space-conditioning and production-dependent components, and suggest the savings potential from reducing non-production and space-conditioning energy use. Moreover, they can be used to discover savings opportunities, accurately predict energy use for budgeting, measuring savings or diagnostic purposes. More information about Lean Energy Analysis is available at www.engr.udayton.edu/udiac.

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