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LEAN Energy Analysis

Using Regression Analysis to Assess Building Energy Performance

Issue Brief

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Introduction

Benchmarking energy use across a portfolio of buildings identifies opportunities for energy efficiency that lead to cost savings and improved building performance. The process of assessing a building's performance has traditionally involved completing individual on-site energy audits, and the up-front effort and cost can be prohibitive to many owners. This paper reviews approaches to assessing building energy performance without in-person audits, and it specifically describes one leading approach called Lean Energy Analysis (LEAN), which uses a statistical procedure known as regression to generate a model of building energy performance. This model can be used to predict energy use, to estimate savings, and to assess building energy performance trends. By comparing the results of the analysis for a portfolio of buildings, LEAN can identify sites with the greatest energy saving opportunities and recommend the types of energy efficiency measures most likely to exist for a building. Moreover, LEAN derives all of this actionable information from readily available monthly utility bill data from two or three prior years to analyze performance.

Regression Analysis for Building Applications

Regression techniques identify relationships, in the form of mathematical models, between one or more independent variables and a dependent variable using sets of raw data. For an energy analysis of a building, the dependent variable is normally the electric or fossil fuel utility usage, and the independent variables can include weather statistics (e.g., average temperatures or degree days), occupancy levels, and utilization factors (e.g., rented square feet, school days, production quantities). Regression analysis has been used for decades to measure the energy savings associated with building retrofits,[1] to weather-normalize building energy use in the U.S. EPA ENERGY STAR™ buildings program,[2] and for measurement and verification of energy savings associated with energy efficiency projects following the IPMVP protocol[3] or ASHRAE Guideline 14.[4] These programmatic applications of regression analysis are described in more detail below. The elements these applications employ make up the basis for the LEAN approach.

Definitions

- **Energy Use Intensity (EUI)** is the annual facility energy use per unit of gross, conditioned, or occupied area.
- **Regression Coefficients** relate changes in model input variables (e.g., average outdoor air temperature) to changes in the predicted model output (e.g., source EUI).

Measuring Energy Savings

The PRISM® (PRInceton Scorekeeping Method) is one of the earliest applications of using regression analysis to measure energy savings in commercial buildings. Released in 1986, it has been used by utilities, private companies, government agencies, and universities to estimate energy savings from building efficiency programs. PRISM is a statistical procedure that uses a year of monthly building billing data to produce a weather-adjusted index of energy consumption. This method normalizes the calculated energy use intensity (EUI) with weather data so that changes in energy use can be attributed to building performance, rather than changes in weather.[5] The savings represent the difference between the energy predicted by the model (for post-retrofit conditions) and the actual measured energy usage.

[1] Fels, M. F. 1986. "PRISM: An Introduction." *Center for Energy and Environmental Studies*, Princeton University, Princeton, NJ

[2] Kissock, J.K. and C.W. Eger, 2007. "Understanding Industrial Energy Use through Sliding Regression Analysis." *ACEEE Summer Study on Energy Efficiency in Industry.*

[3] International Performance Measurement & Verification Protocol: Concepts and Options for Determining Energy and Water Savings, 2002. Vol. I. http://www.nrel.gov/docs/fy02osti/31505.pdf

[4] Haberl, J.S., C. Culp, and D.E. Claridge, 2005. "ASHRAE's Guideline 14-2002 for Measurement of Energy and Demand Savings: How to Determine What Was Really Saved by the Retrofit." *Proceedings of the Fifth International Conference for Enhanced Building Operations.* http://www-esl.tamu.edu/docs/terp/2005/esl-ic-05-10-50.pdf

[5] Margaret F. Fels, Kelly Kissock, Michelle A. Marean, and Cathy Reynolds, 1995, "Advancing the Art of PRISM Analysis." *Home Energy Magazine Online*, July/August.

U.S. EPA ENERGY STAR Portfolio Manager

> ***Source energy*** represents the total amount of raw fuel that is required to operate the building. It incorporates transmission, delivery, and production losses.

The ENERGY STAR Portfolio Manager tool provides a framework for evaluating building energy consumption and benchmarks building performance to assign a building rating. The ENERGY STAR model is a regression-based model that builds on the PRISM approach by using degree-day models. It includes additional independent variables such as number of occupants, operating hours and number of computers. Regression coefficients are established by fitting statistical models to data collected in the Energy Information Agency's (EIA) Commercial Building Energy Consumption Survey (CBECS). The tool allows buildings to be benchmarked with an ENERGY STAR score (1-100) that is an estimate of the fraction of comparable buildings nationwide that have higher normalized source EUIs. An ENERGY STAR score of 75 indicates that the building's source EUI is better than 75 percent of similar buildings nationwide.[6]

ENERGY STAR regression models are based on source EUI, which is equal to the total source energy divided by the gross floor area of the building. The regression equation explains the variation in source EUI associated with each of the independent variables.[7]

Measurement and Verification of Savings

As the energy efficiency industry matured, regression-based techniques for measuring energy savings were enhanced and additional approaches for measuring savings were developed. A formal practice known as measurement and verification (M&V) emerged.

In order to more accurately measure and verify energy savings after building retrofits, ASHRAE developed the Inverse Model Toolkit (IMT), which includes variable break-even temperature models, change-point models, and multivariable regression models.[8] Temperature change-point models were described and extended by Kissock et al. (1998[9] and 2003[10]).

LEAN builds upon these approaches and adds value by isolating regression coefficients and recognizing that they have physical meaning (Kissock, 2011)[11]. The interpretation of the regression coefficients helps to illuminate potential causes of differences in EUI among a portfolio of buildings. This analysis can also identify potential energy waste in buildings that goes undetected because of offsetting effects (e.g., excessive ventilation rates being offset by very efficient cooling equipment).

Calibrated Building Simulation Models

Over the last 50 years, several building energy simulation models have been developed (e.g., BLAST, EnergyPlus, DOE-2, eQUEST, TRNSYS, and Trane Trace). These models are very detailed and require the user to carefully define the physical characteristics of the building envelope and interior, the energy consumption and operating characteristics of the equipment in the building, occupancy profiles, and hourly weather and solar intensity data. Once this definition data is provided, conservation of mass and energy equations are solved to provide hourly estimates of thermal loads and energy consumption.

[6] Matson, N.E. and M.A. Piette, 2005. "Review of California and National Methods for Energy-Performance Benchmarking of Commercial Buildings." *LBNL*, http://cbs.lbl.gov/sites/all/files/LBNL-57364_0.pdf

[7] "ENERGY STAR Performance Ratings Technical Methodology." US Environmental Protection Agency, http://www.energystar.gov/ia/business/evaluate_performance/General_Overview_tech_methodology.pdf

[8] Kissock, J.K., J.S. Haberl, and D.E. Claridge, 2003. "Inverse Modeling Toolkit: Numerical Algorithms." *ASHRAE*

[9] Kissock, K. A. Reddy, and D. Claridge. 1998. "Ambient-Temperature Regression Analysis for Estimating Retrofit Savings in Commercial Buildings." *ASME Journal of Solar Energy Engineering*, Vol. 120(3): 168- 176.

[10] Kissock, J.K., J.S. Haberl, and D.E. Claridge, 2003. "Inverse Modeling Toolkit: Numerical Algorithms." *ASHRAE.*

[11] Sever, F., K. Kissock, D. Brown, and S. Mulqueen, 2011, "Estimating Industrial Energy Savings using Inverse Simulation," *ASHRAE.*

Estimating the potential energy savings from retrofitting buildings using simulation models is traditionally a time-intensive process, requiring the models to be carefully defined and calibrated. LEAN aims to avoid this complex and time-consuming process by developing a model of annual energy consumption from readily available utility and weather data. Since the LEAN model is developed with actual building energy use data, it is considered to be automatically calibrated.

LEAN: Methodology and Approach

LEAN develops inverse models of building energy performance from utility data and uses them to analyze historical trends and benchmark the performance of similar buildings. LEAN provides a preliminary estimate of the size and make-up of potential energy efficiency projects. The following sections describe the LEAN process and its elements in detail.

Data Requirements

The LEAN methodology uses monthly utility bills for the energy consumption data because of their wide availability and accuracy. The gross or conditioned floor space is needed to normalize the energy consumption. The method uses both actual and typical weather data, which is available from many sources, including the U.S National Weather Service. Finally, the primary use of the building (e.g., office, K-12, higher education, hospital) is needed so that benchmarking can be performed across similar building types. Additional data may be required for the regression analysis of certain building types. For example, academic calendars for educational facilities, building occupancy for large commercial buildings, or the production rate of a product for manufacturing facilities may be required to develop an accurate regression model.

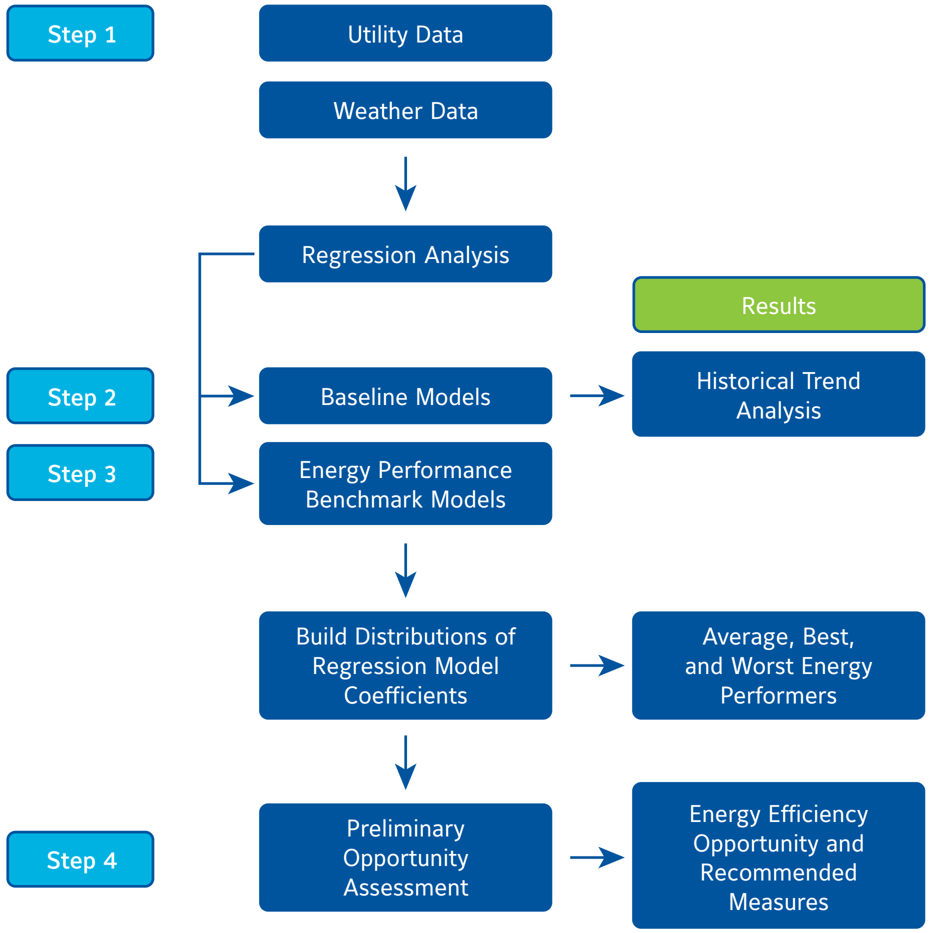
Process Step-by-Step

The first step is to create regression models of energy use versus weather for each building in the portfolio and for each type of energy used by the building. The model parameters represent weather-independent energy use (or base load), weather-dependent energy use (or building heating or cooling sensitivity), and the building balance-point temperature. The second step involves building a baseline model from older utility data to analyze historical performance trends. The third step involves building a model from recent utility data to benchmark the building performance. The final step is to estimate the size of the energy efficiency opportunity for each building and to provide general recommendations of measures for improving a building's performance.

Quick-start to Energy Management with a LEAN Energy Analysis:

- Highly scalable approach to target and assess energy efficiency opportunities in one or many buildings.
- Low-cost, no-touch building pre-audit using readily available data, including each building's location, size, and 2+ years of utility data.
- Advanced benchmarking approach that identifies both the size of the opportunity and the specific performance improvement measures.
- Resulting models can be further used to validate energy savings from projects that are implemented.
- Like lean manufacturing, data-driven analytics provide decision support to building owners and operators for managing their energy costs.

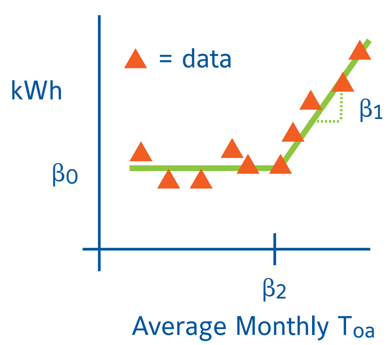
Figure 1: LEAN Process Diagram



Building the Models

Kissock et al. (2003)[12] identified that the energy consumption of many buildings can be adequately described by parameterized models that relate energy consumption to outside air temperature. The figure and equation below illustrate the form of a typical model for electrical energy consumption as a function of average monthly outside air temperature:

[12] Kissock, J.K., J.S. Haberl, and D.E. Claridge, 2003. "Inverse Modeling Toolkit: Numerical Algorithms." *ASHRAE.*



$$\text{Energy} = \text{Baseload } (\beta_0) + \text{Cooling Sensitivity } (\beta_1)\ 2 \times \{\text{Outside Air Temperature } (T_{oa,1}) - \text{Cooling Break-even Temperature } (\beta_2)\}$$

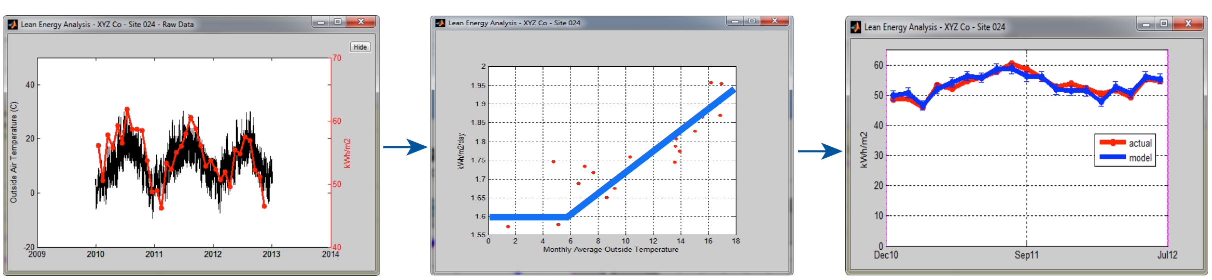
This monthly energy model shows that the electrical energy consumption has a base load that is independent of the outside air temperature as indicated by the first term. When the outside air temperature exceeds the break-even temperature, the electrical energy consumption varies linearly with outside air temperature as described by the slope coefficient (Cooling Sensitivity). Therefore, the building's monthly electrical energy use displays both weather-independent and weather-dependent behavior. While this example is for a building with energy usage having only cooling weather sensitivity, it is common for buildings to have energy usage that shows only heating weather sensitivity or both heating and cooling weather sensitivities. It is often desirable to include additional independent variables to improve the model fit. For example, for a building that exhibits strong occupied/unoccupied operation, an occupancy variable should be added.

While using regression to correlate energy consumption to weather or other variables is not a new practice, recent work identified that the regression coefficients for models have physical meaning. The horizontal line segment represents the base load (e.g., a combination of lights, plug loads and process loads). The slope coefficient is a function of the building envelope, ventilation/infiltration air, and the efficiency of the heating or cooling system. The break-even temperature is a function of the temperature setpoint in the building and the internal heat loads. As a result, these model coefficients can be used for energy performance benchmarking and for evaluating energy savings opportunities. For example, if the model shows that the cooling sensitivity coefficient is high, that may mean the building's cooling system requires maintenance or replacing.

By having a model of energy consumption that is a function of weather conditions, occupancy and other variables, users can factor out the influence those variables have on energy consumption. This makes it possible to determine whether changes in the building's energy consumption are truly a result of changes in operation, the integrity of the building envelope, the efficiency of mechanical equipment, or the amount of ventilation, rather than normal or extreme variations in weather or occupancy.

The figure below shows the process of building a model. The first graph shows five years of utility bill data in red and hourly outside air temperature data from a local weather station in black. The second graph shows the energy use versus average outside air temperatures and the resulting model fit using regression. The last graph shows the energy usage data for the 10 months used to tune the model in red and the predicted energy usage from the model in blue. In this case, the model calibration is very good and can be used to reliably predict and project energy usage.

Figure 2: Process to Build a Regression Model



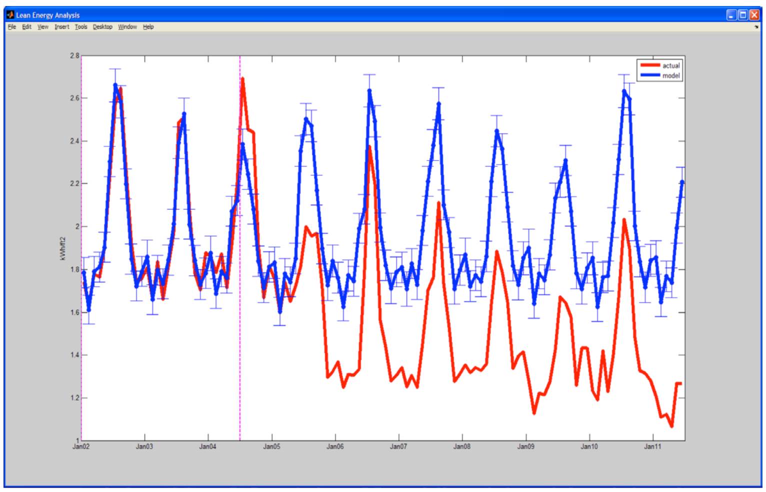
Historical Trend Analysis

A series of energy performance regression models based on a sliding window of historical data can detect statistically significant changes in building performance over time. Such changes can be attributed to changes in building use or size, performance improvements due to previously implemented retrofits, or performance penalties from improper operations or natural degradation of equipment.

The figure below shows historical energy use at a Midwestern community college that underwent an energy efficiency retrofit at the end of 2004. The first two years of energy usage data were used to create the baseline model, and the fourth year shows a 21 percent energy reduction after the retrofit. Persistence of savings can be a common problem with building retrofit projects, leading to lost savings and the need to re-commission buildings every five to seven years.[13]

[13] http://www.institutebe.com/Existing-Building-Retrofits/Retro-commissioning-Significant-Savings.aspx

Figure 3: Historical Energy Use Graph



In the community college example, additional savings of one to two percent were generated for each of the six years following the retrofit. These savings were achieved through a continuous improvement process where an energy engineer monitored the building's performance and assisted with regular operational improvements.

Energy Performance Benchmarking

The traditional approach for energy benchmarking normally uses simple factors such as the energy use intensity to compare buildings. The LEAN methodology provides greater insight through the use of the models and model coefficients. The model coefficients derived from these regression models have physical meaning (i.e., they are algebraic combinations of building parameters).[14] The numerical values of these coefficients can be compared to a distribution of coefficients from a large sample of buildings of similar type, use, age, and other characteristics. As a result of the regression analysis, the model coefficients are random variables. Therefore, inferential statistics can be used to draw conclusions about a population of buildings from a sample of buildings. Any outliers identified from this comparison will either indicate

[14] Sever, F., K. Kissock, D. Brown, and S. Mulqueen, 2011, "Estimating Industrial Energy Savings using Inverse Simulation," *ASHRAE*.

superior performers or buildings that have opportunities for energy efficiency retrofits. In addition, knowing which coefficient is the outlier allows for making preliminary hypotheses as to the specific cause of the poor energy performance (e.g., base load consumption, building envelope, mechanical system efficiency, ventilation or infiltration).

LEAN uses a functional benchmarking approach to compare sites and assess opportunities for implementing energy efficiency measures. A number of metrics are used in the analysis, including each site's EUI. Further metrics include the regression coefficients of the inverse models built using recent energy usage and weather data. The distributions of each metric across the sample of sites are analyzed to determine benchmark statistics used to target and estimate the savings opportunity.

Table 1 shows benchmarking results from an analysis of 25 buildings. Each performance metric is rated (i.e., good, typical or poor) based on how it compares to the sample of similar buildings used in the benchmark analysis.

Table 1: Energy Performance Benchmarking

Site	Energy Use Intensity (kWh/m2)	Base Load	Cooling Sensitivity	Cooling Break-even	Heating Sensitivity	Heating Break-even
XYZ Co - Site 001	149	Good	Good	Typical	Typical	Typical
XYZ Co - Site 002	177	Good	Typical	Typical	Typical	Good
XYZ Co - Site 003	185	Good	–	–	Typical	Typical
XYZ Co - Site 004	190	Good	Typical	Typical	–	–
XYZ Co - Site 005	198	Typical	Good	Typical	Typical	Good
XYZ Co - Site 006	202	Typical	Typical	Good	–	–
XYZ Co - Site 007	219	Typical	Typical	Typical	Typical	Typical
XYZ Co - Site 008	220	Good	–	–	Typical	Typical
XYZ Co - Site 009	243	Typical	Typical	Poor	–	–
XYZ Co - Site 010	255	Typical	–	–	Typical	Typical
XYZ Co - Site 011	271	Typical	Typical	Typical	Typical	Typical
XYZ Co - Site 012	276	Typical	Typical	Good	–	–
XYZ Co - Site 013	303	Typical	Typical	Typical	Typical	Typical
XYZ Co - Site 014	362	Typical	Poor	Good	Poor	Typical
XYZ Co - Site 015	375	Typical	Typical	Typical	Typical	Typical
XYZ Co - Site 016	395	Typical	Typical	Typical	Typical	Poor
XYZ Co - Site 017	403	Typical	Typical	Typical	Typical	Typical
XYZ Co - Site 018	426	Typical	Typical	Typical	Typical	Typical
XYZ Co - Site 019	429	Typical	Typical	Poor	–	–
XYZ Co - Site 020	433	Typical	Good	Poor	–	–
XYZ Co - Site 021	463	Typical	Poor	Typical	Typical	Typical
XYZ Co - Site 022	511	Poor	Typical	Typical	Typical	Typical
XYZ Co - Site 023	528	Typical	Poor	Poor	–	–
XYZ Co - Site 024	605	Poor	Poor	Typical	–	–
XYZ Co - Site 025	675	Poor	Poor	Typical	Poor	Typical

Preliminary Opportunity Assessment

Further analysis of the model coefficients is completed next to identify the potential size of the retrofit opportunity and the specific energy efficiency measures for each building – good, typical, and poor. Patterns in the coefficients relative to the benchmarked sample of buildings and an understanding of the physical meaning behind the coefficients are used to determine the measures. While the ability to identify potential energy efficiency measures without auditing the building is impressive, there are limits to the resolution and accuracy of the approach. Therefore, LEAN is used to qualify energy efficiency opportunities and target further energy audits and analysis.

Table 2 shows the results of further analysis of the 25 buildings from the above benchmarking example. The 10 sites with the greatest energy efficiency opportunity are shown with an estimate of the potential savings. These savings are determined by creating two regression models for each building, running the two models with inputs (e.g., weather) from a typical or specific year, and taking the difference in the predicted annual energy usage from the two models. The first model represents the building as it currently operates. The second model represents the building with improved operations and/or equipment, and it is created by using statistics from a large sample of similar buildings to adjust the model to be representative of a building with more typical energy efficiencies.

Table 2: Energy Efficiency Opportunity

Site	Ft^2	Current $/ft^2	Energy Efficiency Opportunity	
XYZ Co - Site 025	272,949	$1.13	$57K - $99K	19% - 32%
XYZ Co - Site 023	246,586	$1.15	$59K - $77K	21% - 27%
XYZ Co - Site 024	326,031	$1.12	$14K - $54K	13% - 19%
XYZ Co - Site 022	141,141	$1.17	$26K - $40K	16% - 24%
XYZ Co - Site 019	138,720	$0.90	$15K - $26K	12% - 21%
XYZ Co - Site 021	51,285	$1.33	$7K – $12K	10% - 18%
XYZ Co - Site 020	78,873	$0.87	$4K – $10K	6% - 14%
XYZ Co - Site 014	54,558	$1.16	$6K - $9K	9% - 15%
XYZ Co - Site 016	58,100	$0.88	$3K - $6K	5% - 12%

Table 3 is an example of the results that can be generated with a more sophisticated analysis of the data and regression models. In this case, specific measures that are likely to generate the estimated potential savings are identified for each building. Details of the analysis approach required for this example are beyond the scope of this paper; however they are based on the physical meaning of the regression model coefficients previously described.

Table 3: Potential Energy Efficiency Measures

Potential Measures	Site 025	Site 024	Site 023	Site 022	Site 021	Site 020	Site 019	Site 016	Site 014
Increase cooling setpoints									
Decrease heating setpoints	X		X				X	X	
Reduce equipment schedules	X	X		X					
Decrease ventilation			X						
Eliminate any electric heating	X			X	X			X	X
Decrease infiltration			X						
Reduce lighting load	X	X		X					
Reduce plug loads	X	X		X					
Add/fix economizers			X				X		
Increase cooling system efficiency		X			X				X
Increase heating system efficiency	X					X			X
Add wall/ceiling insulation	X		X						
Upgrade windows									
Check fossil fuel baseload	X			X			X		

Conclusion

LEAN uses regression analysis techniques to generate models of building energy performance that can be used for performance trend analysis, functional benchmarking, and preliminary assessment of energy efficiency opportunities. Within a portfolio of buildings, LEAN will identify which sites have the greatest energy saving opportunities and will recommend energy efficiency measures for each building. LEAN derives all of this actionable information from readily available monthly utility bill data. And beyond a simple EUI benchmarking comparison or an ENERGY STAR Portfolio Manager score commonly used today, LEAN provides a way to identify more potential energy waste and provides better insight to where specifically the savings opportunities might be for a building with poor energy performance. It is now being used in the private sector, most often with the assistance of a trained professional, to cost-effectively and quickly benchmark buildings in a portfolio, assess the opportunity for energy efficiency across the buildings, and identify potential energy efficiency projects at each site. Armed with all of this information, supplied from easily accessible utility data, building portfolio owners and managers can develop the most effective strategy to invest in energy efficiency in their buildings and get the most energy and greenhouse gas emissions reductions in return for their investments.

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The Institute for Building Efficiency is an initiative of Johnson Controls providing information and analysis of technologies, policies, and practices for efficient, high performance buildings and smart energy systems around the world. The Institute leverages the company's 125 years of global experience providing energy efficient solutions for buildings to support and complement the efforts of nonprofit organizations and industry associations. The Institute focuses on practical solutions that are innovative, cost-effective and scalable.

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