Using Measured Whole-Building Performance for Green Building Program Evaluation

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ABSTRACT

Green building program energy efficiency strategies often use integrated design, precluding the measurement of results simply from deemed savings of specific measures. This paper describes the use of whole-building measured energy use, by month and fuel, to evaluate the achievements of high performance building programs at both the individual building and program level. A subgroup of 23 buildings, drawn from a previous exploratory of review of post-occupancy LEED building energy performance, is examined here to understand the drivers of the wide variability in individual performance levels revealed in the initial review. Energy signatures, showing monthly patterns of annual energy use by fuel in relation to outside air temperatures, are used to estimate end use breakdowns and identify likely areas for performance problems. The results give a quick picture of unusual patterns, potential areas for improvements, or drivers of particularly good performance. This paper presents several examples of the use of energy signatures in this fashion, identifying some of the key observed performance factors, and demonstrating that useful insight into measured building performance is possible with a relatively simple set of data. It concludes by discussing enhancements that could extend the use of these tools. The audience includes program managers seeking to better evaluate program results and understand possible sources of future improvements. The audience also includes building operators looking for more efficient ways to identify potential problem areas in their facilities.

Introduction

To make dramatic progress toward very low energy buildings, owners, designers, and energy program managers need prompt and meaningful whole building measured performance feedback, which has not been widely implemented. Energy efficiency strategies used in green building programs often encourage integrated design, deriving energy savings from a coordinated combination of siting, building envelope design, lighting, and HVAC. The integrated approach precludes quantifying results simply from deemed savings from verification of specific measures. This paper describes the use of whole-building measured energy use, by month and fuel, to evaluate the achievements and challenges of high performance building programs at both the individual building and program level.

Background

New Buildings Institute conducted an exploratory nationwide review of the measured energy performance of LEED-NC commercial buildings for the USGBC in 2007 (Turner & Frankel 2008). That study covered 121 buildings, 22% of the total LEED NC certifications at the time. Wide variability among individual building results masked any clear correlations between the initial level of anticipated savings and the whole-building performance results. Results showed that the 100 medium energy buildings in this group had lower average energy use intensity (EUIs) than comparable non-LEED commercial building stock, but there was wide variation among individual project results.[1] For example, the figure below shows EUIs for

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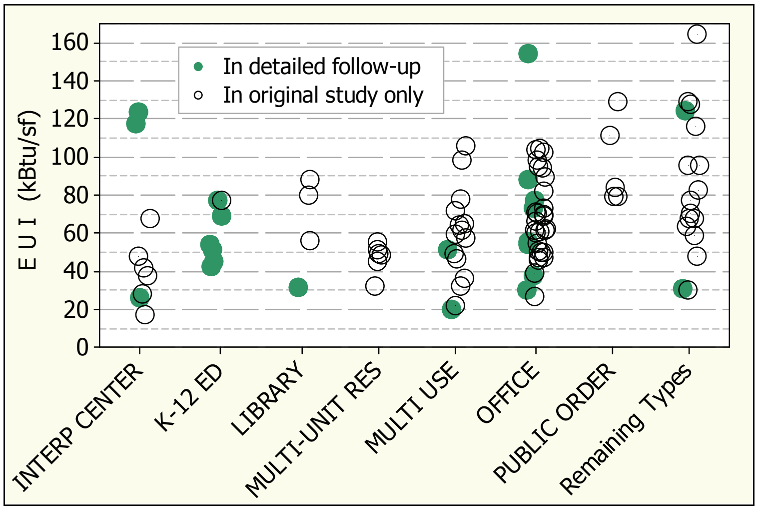
[1] At the time this paper was being drafted, two important independent analyses of the data from the 2007 study had been

several activity types in the study. For each type with ten or more buildings, the highest measured EUI was at least five times the lowest in the same group. Other metrics showed similar performance ranges: one-quarter had Energy Star ratings worse than the national median; and, when comparing measured EUIs to initial modeling predictions, some buildings used as little as one-third of the model while others twice as much.



The measured EUIs (kBtu/sf) of 100 LEED-NC buildings are shown as a dots on this chart, grouped by activity type.

Another 21 buildings, categorized as 'high energy activity types' solely on the basis of their reported activity, are not shown here. This latter group, housing activities requiring high plug and equipment loads, would require a much larger Y axis scale to display their EUIs, ranging up to nearly 700 kBtu/sf.

Figure 1: Measured EUI by Building Activity Type

The variability in commercial building EUIs is neither a recent development nor unique to green building. It is clearly displayed throughout the national commercial building stock, as seen in the Commercial Building Energy Consumption Survey (CBECS) (EIA 2009). That quadrennial survey by the Department of Energy's Energy Information Administration has always shown an extremely wide spread of performance levels, for every activity type and construction era. For example, CBECS EUIs just for office buildings differ by a factor of nearly 10, from 18 to 180 kBtu/sf, *after* excluding the highest and lowest 5%.

Numerous factors contribute to this general variation, broadly including climate, design and condition of the building, type and condition of building systems, operating practices, schedule of building use, and equipment loads of the occupants. In addition, the responsibility for energy performance is fragmented among many groups, with different roles and accountability for designers, builders, owners, operators and occupants. That fragmentation has made it easy for each of these parties to assume that problems lie in areas outside their own control. For example, the energy optimization in LEED-NC focuses on design and prediction of a building's envelope, HVAC and lighting systems, in the context of the known climate, and with a fixed assumption regarding operating approach and future tenants' schedule and plug loads. Often the final occupant activities, schedule, and loads are not known at the design stage. Thus, common responses to questions about higher than anticipated energy consumption state that the building was used differently than intended, or that the building operator is not properly controlling the systems, or that the as-built facility did not accurately reflect the initial design. Differences from these sources are not typically verified or quantified, but performance feedback addressing these issues is essential to continuous improvement toward high performance buildings.

The annual EUI-based metrics summarized in the initial LEED study could provide no insight into the underlying causes of performance differences. This report presents results from a follow-up study that

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approved for future publication (Newsham, Mancini & Birt 2009; Scofield 2009). Each applies a more rigorous statistical approach than the initial study to quantifying the average difference between energy use in LEED and general commercial building stock.

investigated what drove those differences. The review process used could lead to more informative general feedback mechanisms.

Caveats

This study reviewed a limited set of buildings of varying types, designs, climates, and operational strategies. Although more detailed than the initial analysis, it was not an in-depth examination or audit of the features and component performance of the participating buildings. Rather, informed by the experience and perspectives of multiple building analysts, these examples present several considerations with potential broad applicability to typical new construction and building operation.

Study Approach

The follow-up review focused on the top and bottom tier performers of the original study to provide examples of factors driving the greatest degree variation and possible paths to improving measured results. Medium energy activity type buildings from these two ends of the performance spectrum were invited to participate. Twenty-three, representing a variety of activity types, climate zones, building sizes, and LEED achievement levels, were willing and able to commit the time to this voluntary study and included in the analysis (shown by solid circles in Figure 1). The EUIs in Figure 1 reflect the purchased site energy for the most recent year of experience available. Year-to-year changes were also reviewed for insights into performance stability or the impact of operating or behavioral changes.

To best understand each building's existing performance characteristics, this study focuses primarily on site energy, the total energy delivered as kWh, therms, etc. to the building. Directly reflecting the actual metered energy usage, site energy patterns are the most relevant to the question of why an existing individual building is performing at the observed level. Source energy, which includes losses from power generation, transmission, and distribution, is a valuable alternative view, especially useful in broader policy analyses. Source energy is readily calculated from verified site energy by fuel.

This study focused strategically on interviews and analysis of the monthly temperature-based energy signatures of the buildings to identify key issues related to the core question of why the energy usage of "high performance" buildings varies so much. The energy signatures, described in the next section, provided a more detailed look at the originally reported monthly energy consumption data. That tool was used to better understand how energy appeared to be consumed in each building and to inform the subsequent interview with owners and operators. Thus, these results represent the level of insight generally obtainable from informed attention to basic utility billing data and the observations of building operators and occupants.

Energy Signatures and Inverse Models

This section provides a general definition of the energy signature concept and terminology as used in this paper, explains the key differences between the approach to inverse modeling used here and similar procedures described in the literature, and explains this paper's use of a reference building.

Definitions

Building energy is sensitive to many factors, such as sun, wind, occupancy, and HVAC systems. However, for a given set of physical and occupant characteristics, the dominant relationship throughout the year is between the building's energy use and outside temperature. While a conventional EUI benchmark expressed as energy/sf/yr provides a single measured number, the energy signatures in this analysis provide an entire temperature-dependent curve, permitting the comparison of performance characteristics between buildings in different climates or for the same building at different times of the year. In an energy signature, the horizontal axis is temperature based, not calendar based. The vertical axis of the graph is expressed in average power density units of Watts/square foot. (Electricity and fuel usage for each period are converted to kilowatt-hour units, and then divided by the number of hours in the period and by the square feet in the building.) Whole building monthly utility bills (or modeling results) and records of local outside temperatures are sufficient to characterize that relationship, resulting in a pattern such as that shown in Figure 2. For simplicity, this example shows the signature for the total energy use of the building, combining all types of energy used (e.g., electricity, natural gas). Viewing individual curves for each fuel can often provide additional insight, as will be seen in some of the presented cases.

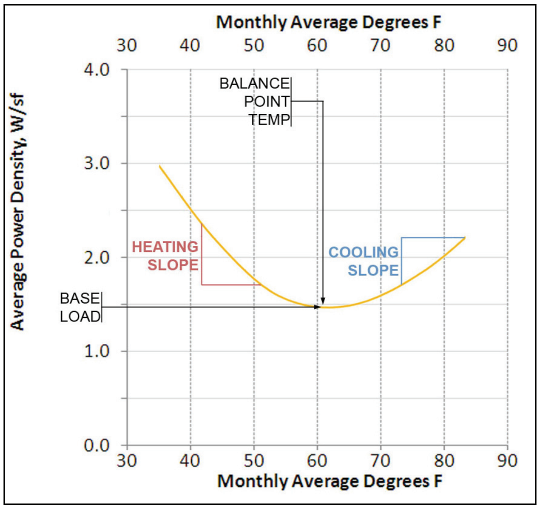


Figure 2: Sample Energy Signature, with Key Characteristic Points

The sample signature above makes readily apparent four key performance-related characteristics: baseload, balance point, heating slope, and cooling slope. The last three relate largely to the building operations, systems and physics, not the specific activities of the tenants/occupants. The baseload, on the other hand, *is* affected by internal loads and by the tenants' schedule, as well as being strongly affected by the faulty operation of systems and controls. The list below briefly describes each of these indicators, with more specific examples provided in the Results section.

The **baseload**, or minimum *power density* on the energy signature, shows the lowest level of average monthly energy use over the course of the year. In our observations, the baseload commonly accounts for two thirds to three quarters of total energy use. The baseload always includes the combined effect of lighting, plug loads, fans, DHW, and the tenants' occupancy schedule. High plug and equipment loads not only generate a high baseload condition but also release heat inside the building, affecting the building's heating and cooling needs. Significantly, high baseload may also suggest that the HVAC system is simultaneously providing heating and cooling to the building. For example, electric resistance reheat may be used in one portion of the building to counteract air conditioning distributing air perceived as too cold.

The **balance point** of the energy signature is the outside air *temperature* at which the minimum energy use occurs. In a typical, newer commercial building, this will occur between 50 and 60 degrees. An unusually high balance point, suggesting heating energy continuing to be used at moderate outside temperatures can also indicate simultaneous heating and cooling, or possibly a high humidity climate in a building without energy recovery units for make-up air.

The **heating and cooling slopes** refer to the steepness of the line at temperatures below and above the balance point, in other words the rate of increase in W/sf as the temperatures become more extreme. As it gets warmer outside, cooling energy naturally increases, and the rate at which it increases reflects the efficiency of the cooling equipment and effectiveness of the building shell.

Alternative Approaches to Inverse Modeling

An energy signature can be readily derived from energy billing and temperature data by a variety of curve fit techniques, and this has been a typical part of the process for normalizing the observed energy use of a building to a normal or reference year. However, in the simple weather-normalizing process, the curve fit parameters are merely algebraic numbers with little direct physical significance for building performance. Previous researchers have described several general approaches to using these regression-based energy signatures in evaluating retrofit results or targeting areas for savings (for example, Kissock, Haberl & Claridge 2003; Kissock & Mulqueen 2008). These approaches use variations of statistical models to fit the observed usage pattern, with increasing attempts to link the statistical parameters to physical characteristics that have clear significance to building performance. The general approach is loosely described as inverse modeling, that is modeling that starts with the observed energy use and proceeds backwards to the probable causes of the performance.

The process used in this study differs from those described above primarily in reliance on an underlying physical model of the building for the initial derivation of the energy signature (Robison & Reichmuth 1999; White & Reichmuth 1996; see also Robison 2009 for description of a tool using this approach). The method identifies a set of physical characteristics (system type and efficiency, ventilation rates, insulation levels, etc.) for which a building model would provide the best fit between the measured energy usage pattern and temperature. This underlying model provides several primary advantages.

(1) It assures an energy signature consistent with basic building physics. For example, the inability to identify a set of physical parameters consistent with the observed usage pattern will often correctly suggest inaccurate or incomplete information was provided.

(2) The set of physical parameters that best fit the observed pattern can point to more likely areas for investigation. For example, all sets of reasonable parameters that fit the data may have to include a high air exchange rate.

(3) Once established, the building's model provides a convenient tool for estimating end-use splits and the impact of potential changes in operation or system characteristics.

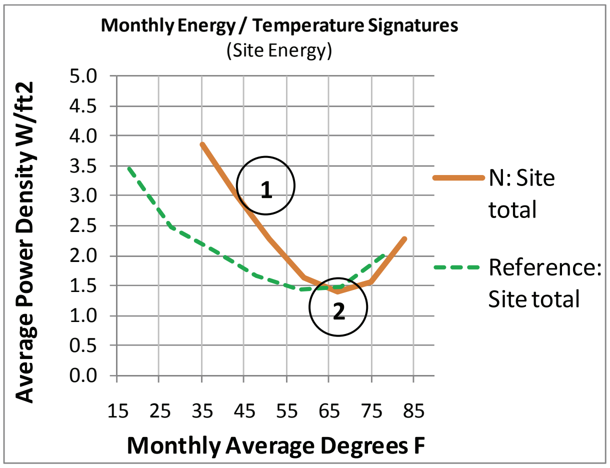
One particularly important aspect of the underlying physical model used here is the integrated inclusion of both electricity and gas (or other fuel) billing data in a single model.[2] This takes into account results such as the impact of higher or lower plug loads on heating and cooling needs. As noted in the brief overview of energy signatures, many factors can theoretically affect the slope, baseload, or balance point. Once the set of physical parameters is determined, signatures can be drawn for individual fuels as well as total energy. It is only this integrated, temperature-based view of all energy use that that enables confident hypotheses of the most likely causes for the specific signature being examined.

The Reference Building

In practice, an energy signature of a building is highly "benchmarkable;" it can be compared to the signature of a known building to benchmark several aspects of energy usage. To help evaluate individual building energy signatures, we specified a general reference model. This model is not intended to suggest the best possible performance, but is simply a comparison line based on an *actual* building with good overall

[2] Because the model is temperature-based rather than date-based, the common situation of different meter-read dates for gas and electric bills does not present a problem. Each billed amount is simply aligned with the actual mean temperature for its billing period.

measured energy efficiency that came from sound basic design, good operations management, and readily available, proven technology. When the reference signature is plotted with that of another building, key differences are readily obvious. In the figure below, the orange line represents the performance of a building in the study, based on its actual utility data. The dashed green line adds the signature for the reference building. The reference line makes two characteristics particularly notable in this example, suggesting likely candidates for further investigation: The *heating slope* (①) is much steeper than that of the reference building, and the *balance point* of 67 degrees (②) is somewhat high.



Circled numbers refer to items in the preceding discussion

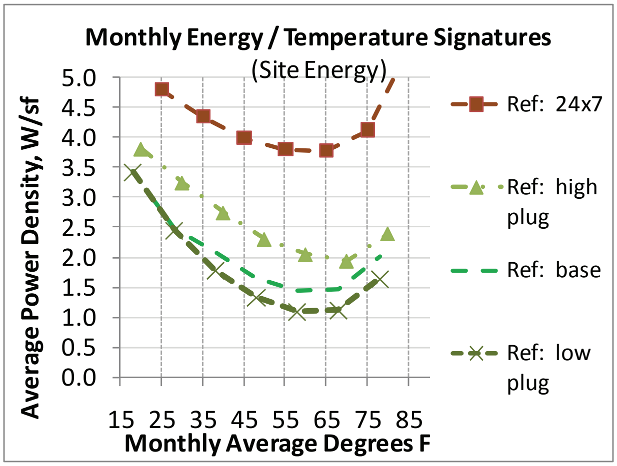
Figure 3: Sample Energy Signature, Total Site Energy

A reference line comparison is used throughout this report to examine and demonstrate characteristics of buildings in the study. For consistency and continuity, the same reference line is included in each case. The degree to which "the" reference might appropriately be adjusted for comparison to a given measured building (rather than always using the same line) depends on the purposes of the comparison. Aspects to consider for potential reference adjustment might include climate, activity type, schedule, and HVAC systems.

Climate. The energy signature shows a pattern of performance over a range of temperatures, not the total annual usage or the fraction of the year that the building spends in each temperature range. As such, the signature itself does not need any material adjustment for different climate zones. Knowledge of the local climate obviously does enter into optimizing the design and the operation of any facility. Identical buildings in two different climates will have different total EUIs, because the local climate determines which section of the temperature spectrum has the most impact on total building energy use.

Activity type and schedule. The key occupant-related characteristics that affect energy use are plug/equipment loads and schedule. The common practice of benchmarking a building's energy use against others of the same activity type essentially uses the type as a proxy for average schedule and equipment loads. However, actual operating hours and loads vary widely within any one type. It is much more useful, for example, to benchmark a mixed-use community center building operating 80 hours/week and including a high PC density with an office building of similar schedule and equipment density, than with an average community center. The physical model underlying the energy signatures in this report makes it relatively easy to customize a reference signature for schedule if desired. More research is needed to adjust precisely for differences in loads, with the proper degree of adjustment depending in part on whether the benchmarking is targeting building operation only or the combination of building operation and tenant activities.

Figure 4 shows the general magnitude of changes from a sample of plug level and schedule differences in the reference model.



"High plug" = 2x the reference level;
"Low plug" = 0.5x the reference level

Figure 4: Schedule and Plug Impacts on Energy Signatures

K-12 schools do have one schedule characteristic that differs from most other commercial buildings, being frequently closed in the summer. To facilitate benchmarking across activity types, NBI models non-year-round schools in two ways. One model fits the actual measured experience of the building throughout the year, incorporating the reduced summer schedule. That version is most useful for specific feedback to the building owner/operator and provides a site-specific reference line against which each future billing result can be compared. The second model, for the 9-10 month school, uses the same building characteristics identified in the first model, but projects modeled summer performance that would occur under a year-round schedule. That is the version presented in the graphs in this report, providing better benchmarking comparability among building types and among different schools that may have different schedules. These estimates of how the building would perform if occupied year round are easily developed from the tuned inverse model (as long as at least one occupied month occurs with average temperatures in the cooling range), although they will not be as accurate as if billings from 12 months of consistent occupancy levels were available.

HVAC Systems. For this report's purpose of identifying reasons for wide performance differences, it was appropriate to use a single consistent reference model for all buildings. However, as seen in some of the cases presented here, certain system types do exhibit distinct signature patterns. System-specific reference signatures can be quite appropriate for monitoring and refining an individual building or a group of buildings. It may be useful, for example, in a reviewing results of a utility-sponsored efficiency program focused on a particular HVAC technology.

Results

This presentation highlights the way that energy signatures were used in the review, revealing some of the observed performance drivers and demonstrating the review technique. More detailed descriptions of the overall study process and the characteristics associated with the full sample of 23 buildings will be presented in other reports.

System Types

Of the 23 buildings in this study, six used some type of ground source heat pump (GSHP), and all of those were at the better end of the performance spectrum. The narrower temperature range of the ground-tempered water, which a GSHP uses as a source/sink, increases overall efficiency and stability, keeping the system in its most efficient operating range more often. The left graph of Figure 5 shows two of the study buildings with GSHPs, with slightly different baseloads, both exhibiting the very flat heating and cooling slopes typical of GSHP site energy use. Note that this technology also provides an example of a case where a source energy comparison will give a slightly different view, as seen in the graph on the right. The site to source conversions here use the national average factors employed by EPA (purchased source electricity = 3.34 x site measured use; source natural gas = 1.047 x site measured use (EPA 2007)). The reference building uses natural gas for heating, while the GSHP buildings are all-electric. The *heating slope* advantage of GSHP that is apparent on a site energy basis is not evident from the source energy perspective, when the national average multiplier of 3.34 is used for electricity. For cooling, on the other hand, all three buildings in this example use electricity. In this case, the large multiplier for source electricity gives the cooling savings of the GSHP even more value from the source perspective. This is clearly a situation where the conclusions are in part affected by the purpose of the analysis. For example, for an individual building with a highly renewable electricity source (e.g. a largely hydro-based utility or using onsite renewable generation), the heating slope on a source energy basis would appear much more favorable

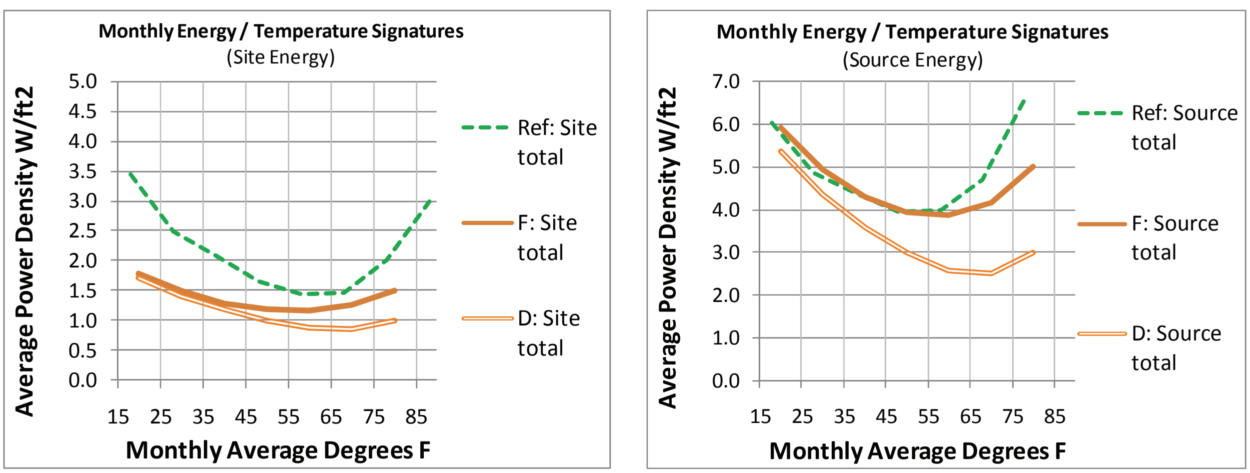


Figure 5: Site and Source Energy Signatures for GSHP vs Reference

Activity level differences

Low usage level. The lowest EUI building in this study, at 20 kBtu/sf, used multiple energy efficiency strategies, including GSHP, natural ventilation, focus on building envelope, and active ongoing monitoring. It is also true, however, that approximately one-third of the building was used primarily as warehouse space, fully conditioned but with a very low level of plug and equipment loads, which would naturally contribute to the lower energy use. Figure 6 shows the building's energy signature, benchmarked against both the standard reference and the "low plug" reference line from

Figure 4, to show the approximate effect of baseload reduction such as might come from the warehouse space usage in part of the building. This view clearly shows that the low measured EUI is not solely the result of the mixed space uses; the building's energy usage continues to be lower than the reference line throughout the temperature range.

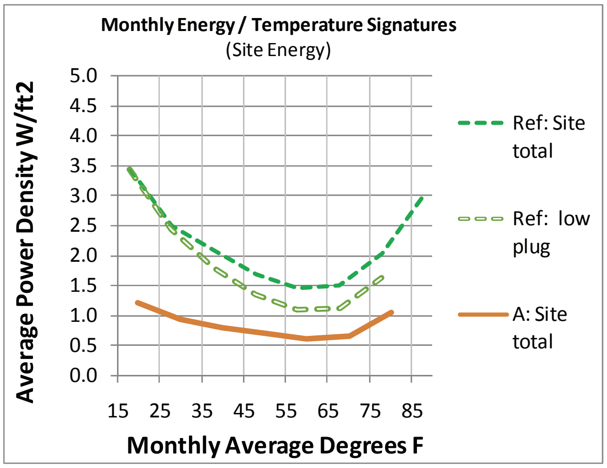


Figure 6: Mixed Office/Warehouse Space

24 x 7 schedule. One of the highest EUIs in the study, at 154 kBtu/sf, was for an office building operating around the clock, seven days a week. The question here is whether the building is inefficient, or merely reflecting the heavy schedule. Again, the energy signature shows that the schedule is only part of the story. The "high hours" reference line from

Figure 4, shown also in the figure below, portrays the reference building results with a change only in the schedule to 24 x 7. The actual office building displays an even higher baseload, with energy use above the reference line at all applicable temperatures. (This building is in the hot Climate Zone 2, and its signature line is not extended below the coldest temperatures it would be likely to experience.)

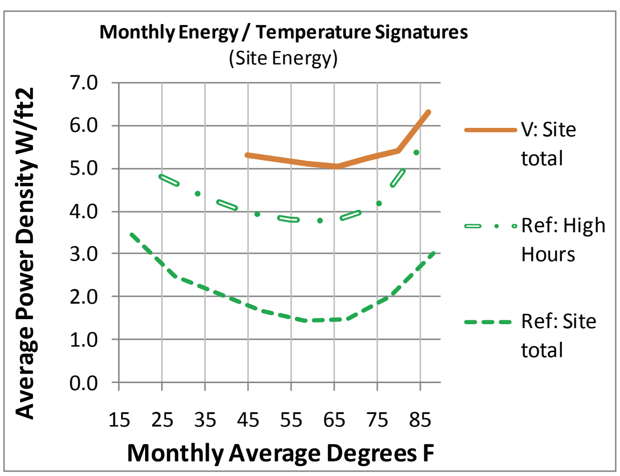


Figure 7: 24 x 7 Office

As noted earlier, the energy signature review was done at the outset of each investigation, to better inform interviews with building operators in this study. This building was one in which a new energy manager, hired when the building was approximately four years old, found that none of the energy management control routines were in place. He subsequently instituted changes that should be apparent in 2009 performance.

Control problems. Potential failure modes for control systems span the entire building delivery range from initial design through operations. Although this review did not compile detailed information on control systems and components, basic billing data can provide several indicators of potential control problems. Control problems can affect any of the major elements of an energy signature, but a bit of additional analysis can often identify situations where controls are a particularly likely culprit in poor building performance.

Irregular usage patterns. One suggestion of possible control problems comes early in the process of developing an energy signature. In some cases, no set of physical assumptions can fit the reported monthly usage amounts to a single smooth line. An irregular pattern may be the result of estimated rather than actual energy bills, mis-reported meter read dates, or of significant irregularity in building equipment loads or schedules. However, if none of these reasons applies, an irregular building response to consistent climate conditions suggests that a control problem is worth investigating. The most recent two years of gas bills for the building shown in Figure 8 exhibit this situation. The individual monthly usage points clearly do not all lie on a single curve. Two possible fits to portions of the data are shown here. Note that this is not a simple degradation or improvement of experience over time. Each year has some points falling on each of the two lines. In other words, the operation of the building under similar temperature conditions is unpredictable, suggesting control irregularity.

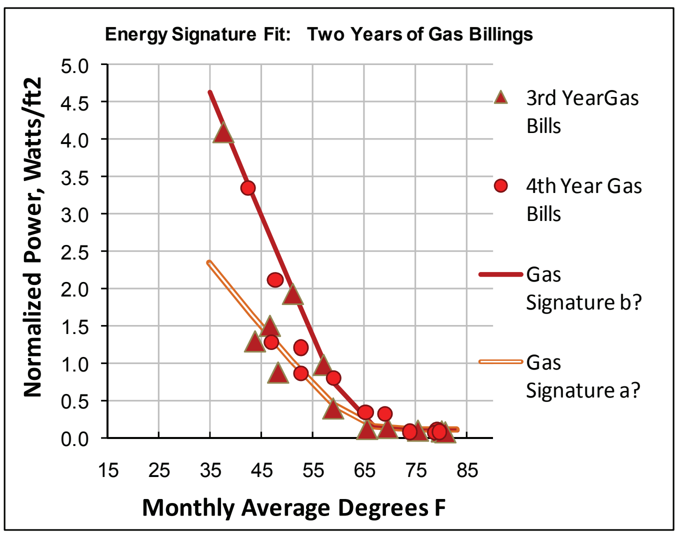


Figure 8: Example of poor signature fit

Subsequent conversations with the building manager did reveal complex and difficult to manage HVAC and control systems. Typically, such detailed investigation of historic energy use trends is impractical, requiring a busy building operator to remember unusual schedule or equipment changes that might have affected gas use more than a year ago. But timely use of an energy signature benchmarking tool each month could promptly identify current situations that warrant investigation.

Data from most of the participants in this study did not exhibit such irregular experience, but other indicators developed from basic billing data can also point to potential control problems.

Mild Weather Gas Use. A high baseload that is not explained by occupant activities is another indicator of possible control problems. The baseload is identified at the low point of the energy signature, typically occurring at mild temperatures when little heating or cooling should be required. The physical model underlying energy signature determination automatically takes into account the normal level of consecutive heating and cooling that would come from cold mornings and warm afternoons or a combination of cold and warm days in the same month. The model will then point to excessive simultaneous heating and cooling as a possibility when these standard levels do not match the observed patterns.

Because so many end uses are included in total baseload, more detailed measurements would often be required to isolate the specific size of the contribution from simultaneous heating and cooling. However, one good indicator *can* be easily isolated and quantified for a building heating with gas: the space-heating load occurring at an average outside temperature of 55 degrees. This mild temperature heating is likely to be a control problem, rather than the result of other heating inefficiencies, because most characteristics that affect total heating energy (such as building shell, ventilation, and HVAC equipment efficiency) affect primarily the heating *slope*, not the level of heating near the balance point temperature. In our set of 23 buildings, none of those with EUIs below 50 kBtu/sf used gas at 55^{o} in excess of 0.3 W/sf. On the other hand, several instances of 55^{o} gas use at or above 1 W/sf were seen in buildings with EUIs of 70 kBtu/sf or higher.

Figure 9 displays an example of simultaneous heating and cooling, showing both a high baseload and a high gas load at 55^{o}. The gas power density is at a full 1 W/sf, well above the building's minimum summer use for just domestic hot water. In the shaded temperature range, from 50 to 70 degrees, electricity use increases, presumably for cooling, while gas use significantly exceeds the minimum level.

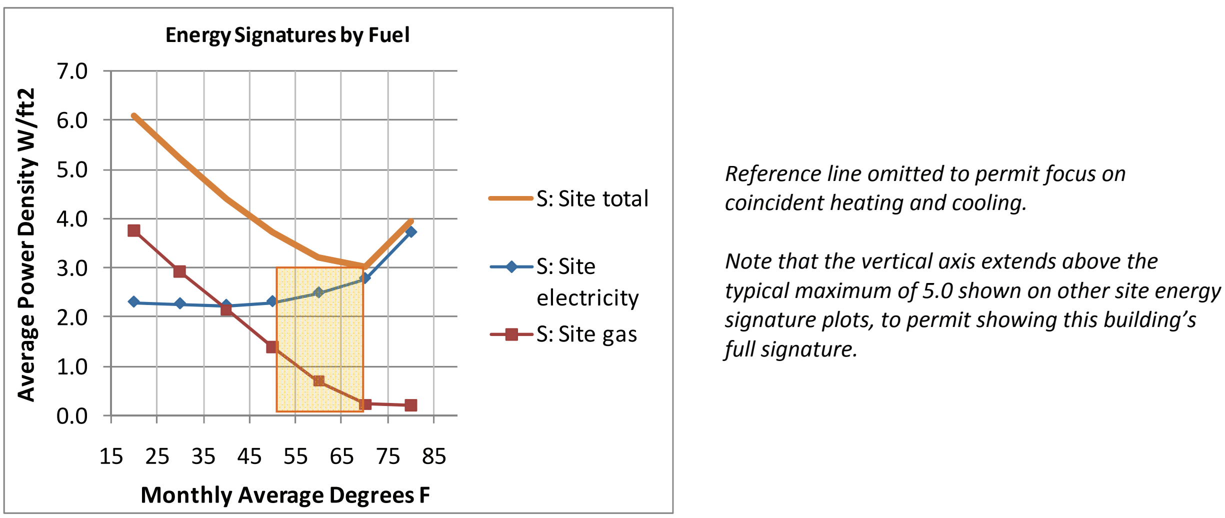


Figure 9: Simultaneous Heating and Cooling

Comparison with modeling. Considerable effort goes into developing design-stage energy models for LEED and other green buildings, to select energy efficiency measures and to estimate the energy savings that could result from the chosen design. However, very little useful information is typically carried forward from those models, whether for future use to inform the building owner's review of measured performance or to inform the design team on what worked and what changes might help their future practice. For example, the modeling always includes (or could easily generate) summaries of anticipated energy use by month and fuel, the key inputs to developing a modeled energy signature. Having an anticipated signature available would provide a reference for benchmarking each month's energy use as it occurs. That would automatically eliminate any questions about whether the difference in usage amount was the result of temperature variations in relation to a typical year. A single month's results will show whether usage is more or less than originally modeled, and further insight into possible reasons will develop as more months are added. If uncertainty regarding occupancy level and activities is a concern at time of initial modeling, a performance range could be provided for the initial signatures, similar to the plug load variations shown in

Figure 4.

The projected monthly detail from the original model was available for only two of the 23 buildings reviewed in this study. One of those examples is presented here. In this case, the comparison of actual usage to the model shows a similar baseload, but significant differences in heating and cooling energy.

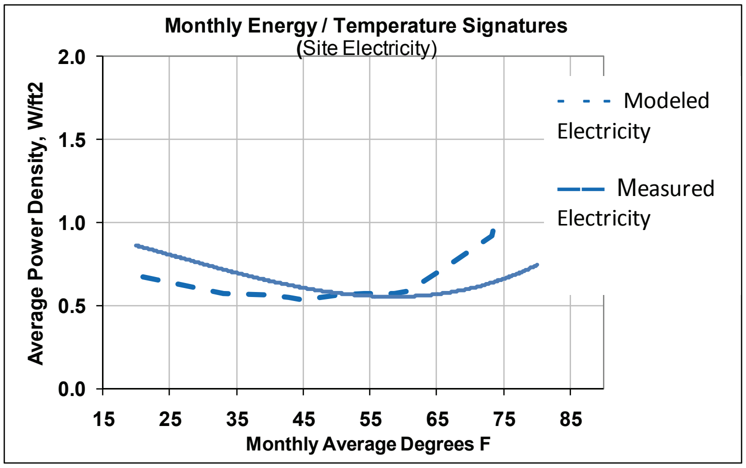


Figure 10: Modeled and measured energy signatures

A thorough measurement and verification (M&V) study of this building, done for the owner three years after occupancy, showed excess heating due to unexpectedly high use from an electric resistance vestibule heater. It also noted the better than expected cooling arising from reduced summer operating hours and better than expected individual zone control in the mini-split ductless cooling. In this case, the design model provided a reasonable total prediction, but the real world had two further lessons: 1) winter electric energy could be reduced by 20% or more by reining in the vestibule heater, and 2) particularly good cooling experience can be achieved from a ductless mini-split air conditioner with good zone control. These results could have been known and acted on after the first year of operation using a basic billing and temperature-based performance review, instead of three years later after a very expensive measurement and verification exercise.

Discussion

This paper reviewed a set of 23 LEED buildings, to explore reasons for the observed wide range of energy performance levels. While the limited sample could not identify a complete set of key performance drivers, it did identify a number of features related to the higher and lower ends of the performance spectrum. It also showed that simple and intuitive evaluation strategies can readily identify building characteristics that are strong indicators of overall energy performance. The summarized examples focus on ways in which energy signatures can be used for insight into measured building performance, even in the absence of submetering or post-occupancy calibration of complex building energy models. They can provide a useful integrated view of whole building performance that often reveals problems rarely revealed in, for example, commissioning as it is currently practiced in LEED new construction projects. An energy billing-based whole building performance review should be used to isolate significant performance problem areas in the first year of full occupancy operation. Some detailed M&V may then be necessary to follow up an indication of poor performance, but the detailed M&V is no substitute for a careful analysis of whole building monthly billing and temperature information as it becomes available.

These signatures can be useful at the individual building level, for feedback to both the owner/operator and designers. They can also be useful at the program level, to give a much better understanding of program accomplishments and challenges. Several enhancements could further improve their usefulness, including: capturing comparable information from initial modeling to provide an initial benchmark, refined formatting to more clearly display key results to those without an energy analysis background, and automating the fitting of the underlying physical model, to make the tool more widely accessible.

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