Diagnostic Benchmarks: Revolutionary Benefits of Eliminating Sampling Error

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Pervasive Sampling Error, Consequences, and Remedies

We all strive to understand conservation behaviors and investments with hard-to-measure results. Measurement error should have no place in this effort, but pervasive and avoidable sampling errors persist. The shortest representative sample for a cyclic process is exactly one cycle. Sampling over a non-integer number of cycles produces error. Buildings experience daily and weekly cycles. Data summarized over ***typical*** weekly cycles constitutes the only error-free sampling scheme. Analyses of hourly, daily, or monthly sampled energy use data suffer surprisingly large errors. Effects of monthly (vs. weekly) sampling include need for larger samples, long delay of results, prolonged exposure to random factors that mask changes of interest, and poor characterizations of pre & post energy use.

Figure 1 shows "typical" weekly data has roughly 1/32 as much variability as hourly data, and 1/3 as much variability as "mixed" weekly data that includes atypical (holiday) weeks. Figures 2 & 3 show an emergent trend versus temperature from a month's data; the monthly aggregated data lie 10% below the emergent trend. These figures show that monthly data are plagued by excessive scatter.

Before-and-after energy use studies of buildings receiving treatments likely to affect HVAC energy use require weather normalization for valid comparisons. ***For consistently occupied, maintained, and operated buildings, cycle-average energy use rate varies solely with weather***.

Coincident outside temperature (T_{out}) correlates well with cycle-average energy use rate. Atypical cycles, such as weeks with holidays, breakdowns, or transitions to changed operating conditions, appear as outliers. "Diagnostic Benchmarks", curve fits of separated heating and "other" energy use rates versus T_{out} ,often show $R^2 > 0.95$, producing much smaller error bars in before-and-after comparisons. All-season data can often be obtained in 20 weeks. More points, with less scatter from sampling error, support robust statistics, prioritizing effort, faster, more accurate savings estimates, greatly improved O&M management, and diagnostic and sustainability benefits.

Diagnostic Benchmarking

In evaluation or regular operations, using "free" monthly utility bills, and a traditional statistical approach - sample randomly and equally weight all data – is unjustifiable, compared to sampling of "typical" weeks. The examples show benchmarks for gas and electricity. Data was collected using "eyeball" meter readings at a US military base, well worth the effort if you don't have AMR.

Figure 4 shows robust baseline trends ($R^2 > .96$); the more-numerous weekly data points allowed highly accurate second order fits, in 20 weeks. Figure 5 shows results for two trial O&M treatments, with interactive effects, for the same building. For O&M treatments, a step change in trend immediately shows if the change is effective. Figures 6 & 7 show baselines, followed by a malfunction (fig 6) and an improved operating mode discovered while trouble-shooting the malfunction (fig7). Gas use fell by 50% and electric use by 10%. Figure 8 shows a 3 week baseline followed by corrected VAV throttling ranges, damper repairs, and reduced outside air to solve a cooling problem that had threatened critical equipment. Figure 9 shows right-sizing of replacement boilers during a remodel.

When improvements are completed, continued benchmarking provides an alarm, signaling if breakdowns or unwanted operational changes occur. Follow-up then preserves efficiency gains.

Want more information or a more complete report? Send an email to llambert@bendcable.com

Diagnostic Benchmarking: Revolutionary Benefits of Eliminating Sampling Error

…Drives Technology Advancement

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"I belong to those theoreticians who know by direct observation what it means to make a measurement. Methinks it were better if there were more of them." – Erwin Schrödinger

"If you cannot measure it, then it is not science." – Lord Kelvin

$\partial\dot{E}/\partial T_{out}$

…Improves Measurement Accuracy

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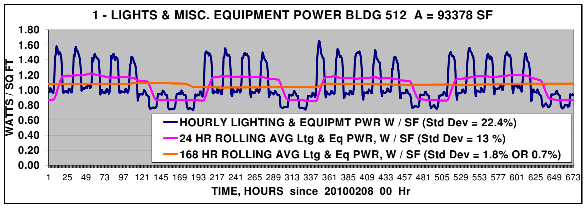
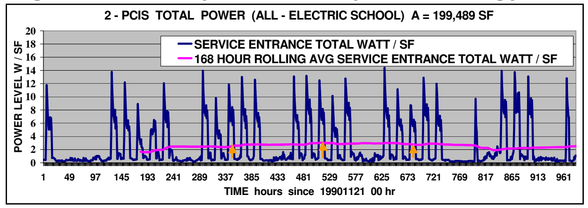
Figure 1: Proper Sampling = Exactly One Cycle



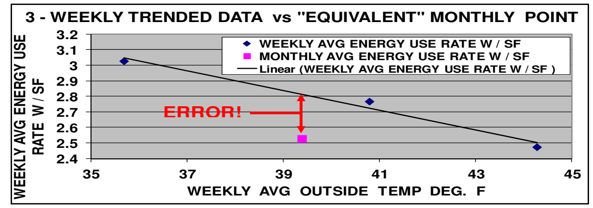
Using weekly (168 hour) rolling average reduces standard deviation of a "consistent" load from 22.4% to 1.8% (for all weeks) *or* to 0.7% for "consistent" weeks (with no holidays). Readings once per week (168 hours apart) provide the same benefit.

Figure 2: Weekly vs. Monthly *Total Energy use*

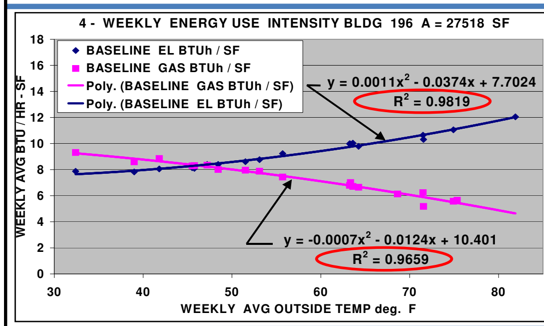


Now examine *total* energy use, varying week to week both with weather and holidays. The same data is shown as hourly data and as weekly rolling averages so holiday effects can be anticipated.

Figure 3: Same data summarized as three "consistent" weeks and one calendar month



Three points show the start of a temperature trend, from roughly one month's data. Note that "monthly" point for December lies about 10% below the trend. This large data summarization error for December illustrates the kind of error that occurs with monthly sampling, and results in unacceptable scatter in analyses of monthly data.



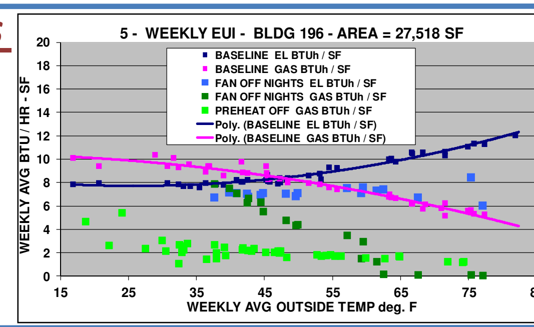
…Produces Spectacular Results

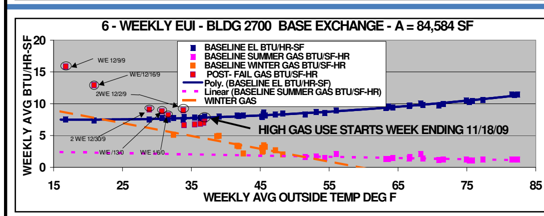
Figure 4: Baselines - Weekly Energy Use

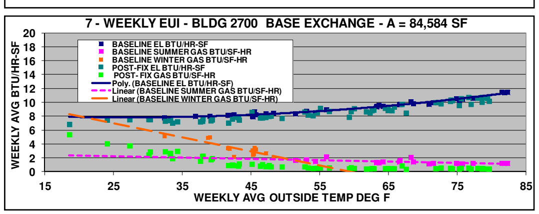
This Diagnostic Benchmarking clearly shows a problem with excess summer heating. The robust (R^2 >0.96) all-season trends for total electrical use and for heating fuel were produced in 20 weeks.

Figure 5: Seasonal trends - two trial O&M improvements, and interactive effects

Testing alternate ways to reduce reheat - reduced main HVAC fan duty cycle - 63% vs 100% (in dark green), and reduced preheat at main air handler (light green) with 100% fan duty. The lighter blue points are electricity use, showing savings from reduced fan duty cycle, which reduced fan and chiller energy use.





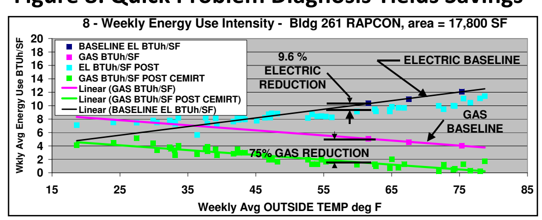


Figures 6 and 7: Pre-and-Post, Malfunction and Fix

Post-baseline, a problem occurs, is detected, and corrected. Problem diagnosis results in additional heating and fan energy savings.

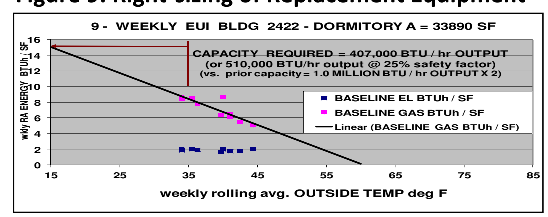
And…Enables Great* Evaluations

Figure 8: Quick Problem Diagnosis Yields Savings



Problem in critical facility prompts "quick and dirty" baseline plus CO2 and temperature survey; Problem found and fixed, with big savings.

Figure 9: Right-sizing of Replacement Equipment



Replacing boilers during cosmetic remodel became much less costly, compared to usual (same as old equipment) sizing practices.

* Faster, Cheaper, with More Capability and Greater Precision

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