Measured Zero Net Energy Performance: Results, Lessons, and Surprises

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ABSTRACT

As more and more zero net energy (ZNE) buildings are built and monitored, we can learn from both careful case studies of individual projects as well as a broader perspective of trends over time. In a forum sponsored by Pacific Gas and Electric Company (PG&E), eight expert speakers discussed:

- Results and lessons from monitoring occupied ZNE buildings,
- Best practices for setting performance targets and getting actionable performance information, and
- Things that have surprised them about monitored ZNE buildings.

This paper distills the content of the forum by laying out the most common hurdles that are encountered in setting up monitoring projects, frequent performance issues that the monitoring uncovers, and lessons learned that can be applied to future projects.

Introduction

On November 4, 2015, Pacific Gas and Electric Company (PG&E) hosted a forum on Measured ZNE Performance. Expert speakers discussed results and lessons from monitoring ZNE buildings over time, best practices for setting performance targets and getting actionable performance information, and things that have surprised them about monitored ZNE buildings. Primary topics of discussion included how to get data to determine whether the buildings were performing as designed and expected, and how to use monitored data to improve performance or ensure good performance over time.

The speakers were organized into three sessions[2]:

- New projects and results from single buildings
  - Dr. Jon Roberts - Senior Scientist, The Cadmus Group
  - David Kaneda, PE, FAIA, LEED AP - Managing Principal, Integral Group
  - Dylan Connelly, PE, LFA, LEED AP BD+C – Associate Principal, Integral Group

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[1] This ZNE work at PG&E was under the oversight of Peter Turnbull.
[2] Links to all presentations can be found in the References section.

- Perspectives on target setting and ongoing performance tracking from National Labs and universities
  - Shanti Pless - Senior Energy Efficiency Research Engineer, National Renewable Energy Laboratory
  - John Elliott - Chief Sustainability Officer, Lawrence Berkeley National Laboratory
- Issues across a range of project types and metrics
  - Dr. Edward Dean, FAIA, LEED AP BD+C - Principal, Bernheim + Dean, Inc.
  - Abhijeet Pande - Associate Vice President, Building Science Research, TRC Companies, Inc.
  - Dr. Carrie Brown - Senior Technical Consultant, Resource Refocus LLC

In these sessions, the following buildings were discussed:

- DPR Construction San Francisco Office
- The Packard Foundation Building
- NREL Research Support Facility (RSF)
- Lawrence Berkeley National Laboratory
- UC Davis West Village Student Housing

While the speakers all gave individual presentations, this paper has organized the discussion into a number of overarching topic areas and lesson learned.

Common Hurdles Encountered in Setting Up Monitoring Projects

Planning the Monitoring

Questions. To design an effective monitoring plan, it is essential to identify questions of interest in order to determine the data required to answer them:

- Did the building produce as much energy as it consumed over the year? For site energy, utility bills are sufficient. For source energy, site-source multipliers are also required. In either case, separate consumption and production data is better (TRC 2016).
- What are the overall patterns of energy use? Monthly end use data suffices.
- What can the public learn from an energy display? Real time end use data can be very engaging.
- What equipment is not performing as expected? Short interval data for specific pieces of equipment is required.
- What is the plug load consumption of this set of occupants? Average data for plug loads is useful for an energy model for a building retrofit or a new building for the same occupants (Connelly 2015; Elliott 2015).
- What is the as-operated performance of the building? Hourly end use data can be used to calibrate an energy model for help in decision making (Elliott 2015; Connelly 2015).

Once the monitoring goal is identified, it is useful to first list the specific metrics to be tracked and then extrapolate backwards to determine the required measurements and their appropriate intervals (Elliott 2015).

Process. “You can’t manage what you don’t measure. But most don’t manage what they do measure” (Roberts 2015). Even without an official monitoring effort, nearly all buildings have at least some performance information available in the form of monthly utility bills or building management system (BMS) data. But this data won’t benefit anyone without a clear process to track and learn from it. Even for buildings that advertise themselves as ZNE, it is surprisingly difficult to get energy data to verify performance. Sometimes this is because the data isn’t available and sometimes it’s because the process is so time consuming that people just don’t bother (Dean 2015).

There are many questions around the process of collecting and analyzing data (Connelly 2015; Dean 2015; Elliott 2015; Pless 2015; Roberts 2015):

- Who’s responsible for collection? For maintenance? For analysis?
- Where is the data stored? How can it be downloaded? Who has access?
- What are the metrics being tracked? How are they calculated from the raw data?
- Who’s going to look at it? Are there different levels of access for different people?
- What are the default views (tables and graphs) of the data?
- How often should it be looked at?

Early answers to these questions make it easier to set the monitoring up in a user-friendly manner.

One option to learn from monitoring data is to hire an outside firm on a monthly or annual contract. For example, DPR Construction included commissioning and monitoring of their retrofitted San Francisco office for 18 months in Integral Group’s design and engineering contract. They use their office for marketing their sustainability and high performance expertise, so understanding performance and uncovering issues was especially valuable to them (Connelly 2015; Kaneda 2015). Some of the issues identified are discussed below.

Another increasingly popular model is to employ a master service integrator who is involved from the beginning of the design process all the way through post occupancy (Dean 2016). They ensure that all the different controls systems correctly communicate both with each other and with the monitoring equipment.

Team selection. Including monitoring and as-operated performance goals in the Request for Proposal / Request for Qualification (RFP/RFQ) can be a great way to attract the right team. When releasing bid documents, Lawrence Berkeley National Laboratory links to a standard document so that all potential bidders know the expectations up front (Elliott 2015; LBNL 2013). This also allows monitoring and as-operated performance goals to be used as criteria for choosing contractors (Elliott 2015; Roberts 2015).

Monitoring Equipment and Commissioning

Choosing appropriate equipment. Current transformers (CTs) are some of the most commonly used monitoring equipment. However, if they are not sized or configured correctly, they will give erroneous readings. On several projects, anomalous results were traced back to incorrectly sized CTs or misconfigured submeters (CT size, CT Ratio and pulse output settings must match meter specifications/settings) which needed to be removed and replaced (Roberts et al 2014, Dean 2015).

Setting up equipment. Data is much more likely to be used if it is collected in a useful format. Depending on what's being monitored, it may be more appropriate to set up the logger to record a change of state, an instantaneous value, or a cumulative value over a wide variety of time scales (Roberts 2015). Once again, this goes back to the goals of the monitoring; there is no need to quickly fill a logger's memory with 15 second data when hourly data is sufficient to answer the intended questions. Careful planning and installation from the beginning will save time overall and increase the chances that the data will actually be used (Elliott 2015; Roberts 2015).

Commissioning equipment. The equipment needs to be commissioned across all failure points, mainly that it was installed and set up correctly (Elliott 2015). The meters also need to be calibrated, preferably with a handheld power meter both when they are installed and then periodically after that (Connelly 2015; Dean 2016). As an overall check of the system, it is useful to compare the aggregated monitoring data from the distributed CTs with whole building meters to verify that the numbers agree (Connelly 2015). This is a critical step that should be included in the building commissioning scope (Roberts 2015).

Documentation. Elliott suggests having dedicated drawings to show where monitoring equipment was installed, by which trade, and how the systems are integrated (2015). For example, one building had some anomalies in the monitoring data and in this case, the dedicated facility manager and the design engineer were unaware of how the meters were circuited. Ed Dean, a case study author, questioned the discrepancies in the data reported by the two parties, which triggered an examination of this question and led to the final correct set of performance data for the building.

Using Monitoring Data

Audience for Analysis

Different views of the monitoring data are useful for different users. An energy efficiency engineer might appreciate detailed end use trend data. But, an occupant who is less informed about potential issues and expected patterns might only be interested in the quick takeaway of whether of not the building is working well. One way to do this is to compare the current performance to expectations, derived either from an energy model or from a comparison to the previous day or season. Figure 1 shows such a dashboard developed for NREL's Research Support Facility (RSF) where green indicates better performance than predicted, red worse than predicted, and white in the range of the prediction (Pless 2015).

Figure 1. Building energy dashboard for NREL's Research Support Facility with gauges for quick assessment of performance. *Source:* Pless 2015.

Frequent Performance Issues that Monitoring Uncovers

Schedules. Equipment schedules are one common cause of performance issues and heat maps can be a very effective way of diagnosing them. Figures 2 and 3 show a heat map of the usage intensity with hour of the day on the x-axis, day on the y-axis, and electricity consumption of a condensing unit at the DPR San Francisco office with the color scale. The building operating hours (7 am – 6 pm) are immediately visible from the green blocks on the right and left and the weekends from the horizontal green stripes. But in August the condensing unit started running all night. The building has a "kill switch" that the last person out the door is supposed to hit to turn off almost all of the plug and HVAC loads. The graph below shows that it stopped working in August. Because Integral Group had a monitoring contract with DPR, they were able to notice that the kill switch wasn't working and inform them of the problem, which was fixed in September (Connelly 2015).

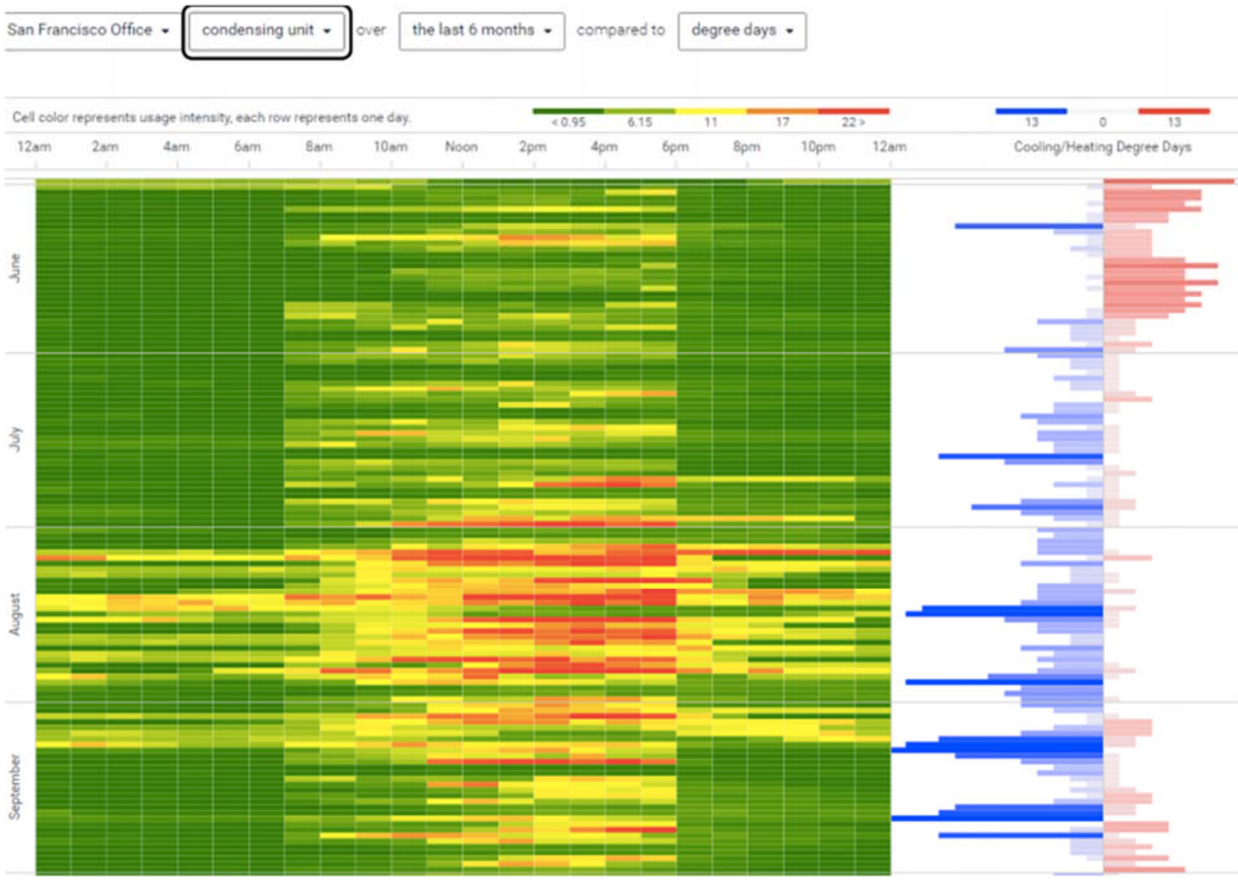

Figure 2. Energy consumption of a condensing unit at the DPR San Francisco office by day and hour with heating and cooling degree days. *Source:* Connelly 2015.

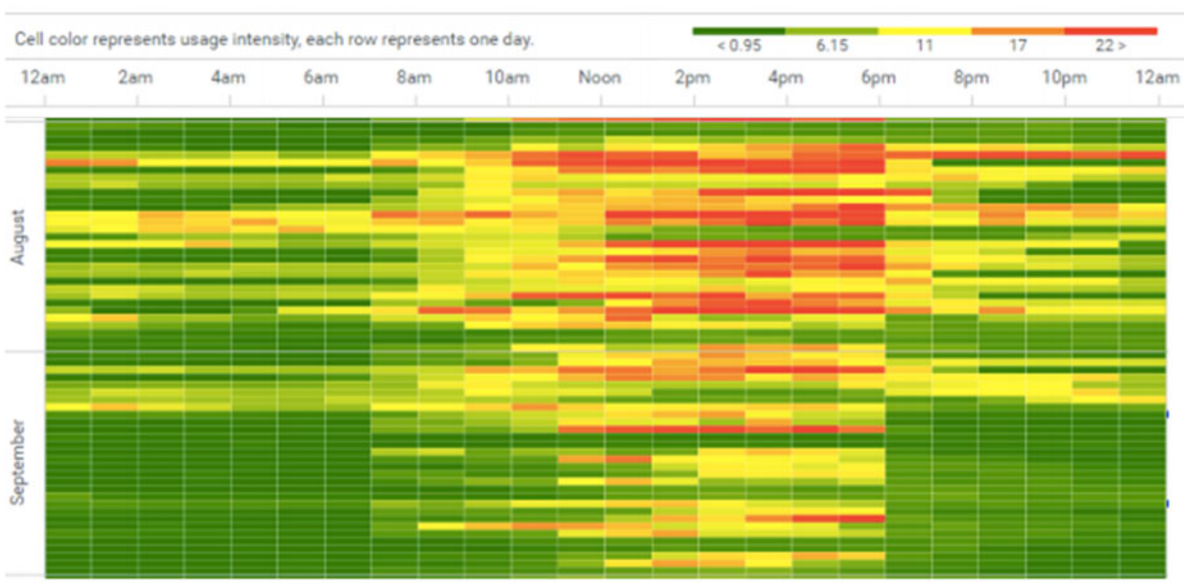

Figure 3. Magnified July and August energy consumption from Figure 2. *Source:* Connelly 2015.

Another scheduling issue that arose in multiple projects is the behavior of the systems when people (for example janitorial or security staff) come in at night. There is no reason for the full HVAC or lighting systems to come on for a few people who may not stay very long (Connelly 2015; Pless 2015).

PV inverters. While occupants and building operators don't need to interact with PV systems in general, it is still important to monitor these systems because inverters occasionally go down, which we observed in several projects (Davis Energy Group 2016; Pless 2015; Risko and Gustafson 2016). Depending on how the PV is sized, this can mean the difference between meeting and falling short of a ZNE goal.

Heat pump water heaters. Heat pump water heaters (HPWHs) are popular in ZNE buildings because they have very high efficiency ratings and are all electric. In order to serve the highest demands for hot water, these heat pumps come with backup electric resistance heat. However, the sequencing of these two heating methods doesn't always work as intended. Control malfunctions can cause the much less efficient backup resistance system to be on for hours or days. By separately metering the heat pump, electric resistance heating, and water flow, this behavior was discovered at the West Village development at UC Davis[3]. Researchers noticed that increased energy consumption for heating water was not always associated with increased demand for hot water, and closer examination of trend data revealed a controls issue with the backup electric resistance heaters. Once identified, run lights were installed to help staff quickly identify and correct this behavior (Risko and Gustafson 2016). Other projects have seen similar performance (Davis Energy Group 2016).

Best Practices for Using Data to Improve Performance

"Net zero energy is a process, not just a goal to be accomplished," and using data to improve performance is an important part of that process (Pless 2015).

Controls and timers. Performance issues associated with schedules can often be solved with controls or with timers. Timers are often the preferred solution because they are less expensive and less complex than automated controls, especially in post-occupancy applications (Connelly 2015).

Manual controls, especially when combined with timers, can also be very effective. The "kill switch" in DPR's San Francisco office described above means that every individual does not have to remember to turn off all of their equipment every night in order to almost eliminate unnecessary overnight consumption (Connelly 2015; Dean 2016). Another approach to this is for the default state of lights, HVAC, and power strips to be off so that occupants have to find a switch if they want any of these things. No one is going to forget to turn on the lights they need, but it's easy to forget to turn them off again when they don't need them. At the NREL Research Support Facility (RSF), once the lights are on, they are automatically dimmed based on daylight sensors and turned off by timers and time clocks, but they do not turn on automatically (Pless 2015).

[3] West Village is a residential multi-family and mixed-use development serving approximately 2,000 students, faculty and staff on the UC Davis campus. The end use energy consumption of 126 of the 663 residential units was monitored for 21 months.

Alerts. Because it is time consuming to constantly check the performance of a building or individual subsystems, simple alerts can catch relevant people's attention when necessary. As discussed above, when run lights were installed in the hot water plants at West Village to quickly indicate improper operation of the HPWHs, the energy consumption required to heat water dramatically reduced. Similarly, inverter uptime increased at West Village after developing a simple interface for the building operators to check the status of PV inverters (Risko and Gustafson 2016).

Taking this idea a step farther, some receive email alerts when energy consumption is higher than expected (Connelly 2015). In this case, the alerts need to be carefully calibrated to avoid desensitizing the recipient while still communicating important information.

Prioritization. There is not enough time to catch and fix every performance issue, so it is important to concentrate on the interventions that will have the greatest impact (Elliott 2015; Connelly 2015; Brown 2015). At West Village, HVAC consumption was prioritized because it accounted for just over a third of all the energy consumption and was also significantly higher than predicted. Using another level of prioritization, the project team tested interventions on a small group of units before introducing them to all monitored units. The interventions restricted the possible thermostat set points that occupants could choose and tied air handler operation to calls for heating and cooling, rather than allowing the fan to run continuously. This successfully reduced the highest HVAC consumers (Risko and Gustafson 2016; Brown 2015).

Occupant behavior. The Packard Foundation building is operated and occupied by people who are very excited about and engaged in the ZNE goal. In 2012, the year the building opened, they achieved site ZNE, and then they still reduced energy consumption by 20% in 2013 (Kaneda 2015).

The West Village monitoring project is particularly valuable source of information about the influence of behavior on energy use because we can compare the consumption in 126 units with the same specifications, built by the same people, occupied by the same type of occupant, and monitored over the same time period. As shown in Figure 4, the lowest ten consuming units use about a third of the energy of the highest ten units, and half of the population average. Their entire consumption is less than either the plugs and lights or HVAC consumption of the highest ten. This dramatic example of individual variation shows an enormous opportunity for energy savings through occupant engagement. It also illustrates that modeling data is not sufficient for understanding building performance (Risko and Gustafson 2016; Brown 2015).

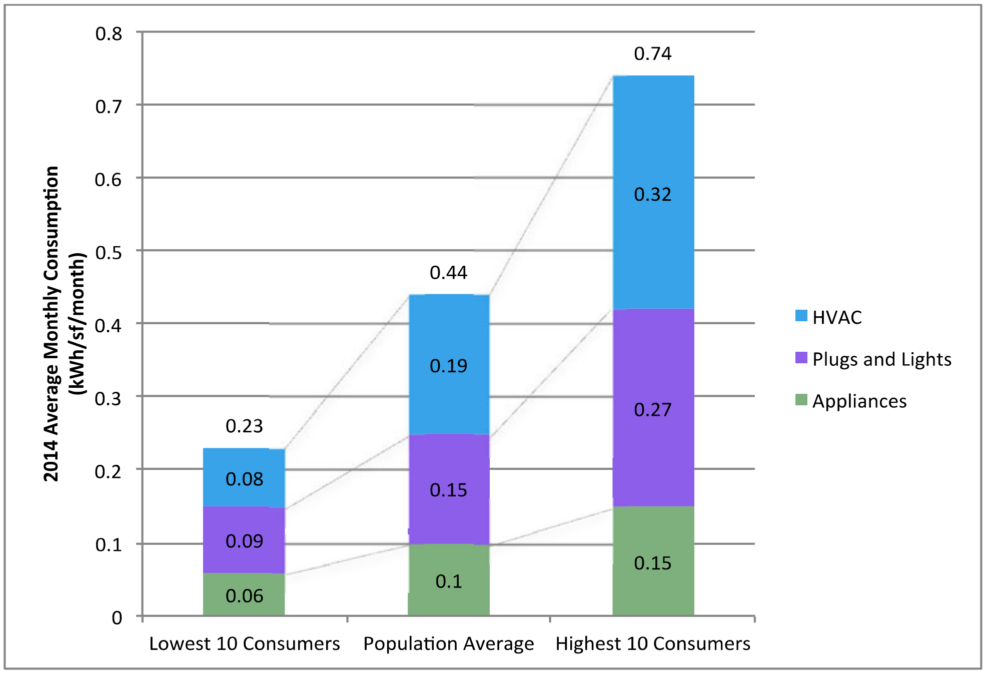

Figure 4. Ten units with the lowest, average, and highest energy consumption at West Village. *Source:* Brown 2015.

Conclusions

This paper highlights the results and lessons from monitoring occupied ZNE buildings, best practices for setting performance targets and getting actionable performance information, and surprising results uncovered in monitored ZNE buildings.

Exemplary monitoring begins with careful planning. This includes identifying questions early (and the data required to answer them) and selecting a team with a forward-looking plan. It also involves carefully planning out the appropriate selection and installation of equipment, commissioning this equipment, and clearly documenting it. Meticulous planning, installation, commissioning, and documentation may take longer in the early stages, but it will likely save time in the long run and provide more useful data.

As data comes in, it is also critical to consider the audience in order to best translate this information into actionable savings. For example, a non-technical user may just want a quick understanding of whether the building is performing well overall, while facilities staff may require detailed data and alerts to improve and maintain performance.

Several case studies were covered in this forum and frequent performance issues and best practices to correct them were described. Faulty equipment schedules, down PV invertors, and malfunctioning HPWH backup were common failure points. Successful solutions included commissioning controls and timers, setting alerts, and prioritizing the areas with the highest potential impact.

In these case studies, it was also clear that occupant behavior can vary widely, creating an enormous opportunity for energy savings through occupant engagement -- if usage can be tracked and explained in an actionable way.

On average, well designed, well implemented projects can achieve ZNE. However, at an individual level, performance may vary significantly. This trend has been seen both domestically and internationally in recent years (Palmer 2014; ZERO-PLUS). Case studies have revealed "significant problems with integrating new technologies, and especially configuring and optimizing BMSs. Some teams also had maintenance, controls and metering problems" (Palmer 2014).

As more ZNE projects are built and monitored, we can learn from careful case studies and develop a broader perspective of trends over time. Looking forward, as we see more regional ZNE goals, such as California's 2020 and 2030 ZNE goals, further work will be necessary to evaluate ZNE success beyond the individual building level. But, a strong understanding of individual building performance will provide a good foundation for these efforts.

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