netZero Village:

A Commissioning and Third-Party Measurement and Verification Report

Final Report | Report Number 19-10 | February 2019

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NYSERDA provides resources, expertise, and objective information so New Yorkers can make confident, informed energy decisions.

Mission Statement:

Advance innovative energy solutions in ways that improve New York's economy and environment.

Vision Statement:

Serve as a catalyst – advancing energy innovation, technology, and investment; transforming New York's economy; and empowering people to choose clean and efficient energy as part of their everyday lives.

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netZero Village:

A Commissioning and Third-Party Measurement and Verification Report

Final Report

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Notice

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Executive Summary

The measurement and verification approach for this project was a success, meeting all stated goals and helping ensure the project realized its net zero energy performance target.

One of the stated goals of the measurement and verification (M&V) for this project, and a way in which it differs from some of the traditional M&V approaches, was early warning of issues that would impact the project's achievement of net zero. There were several examples of the M&V process providing the owner with early warning of pending issues:

- An initial round of analysis was conducted within the first months of occupancy, even though complete data was not yet available. As part of this analysis and an associated follow-up visit, all units were within normal ranges and on track to meet or exceed targets. It was concluded that the apartment location (interior, exterior, top, or bottom floor) had very little impact on energy use providing early confirmation of the effectiveness of the air sealing and insulation techniques used at the project.
- Some of the earliest data available was through the eGauge system monitoring individual end uses in the apartments. This system was intended to help identify which systems (based on signature use patterns) were responsible for energy spikes and use in over- and under-achieving apartments. An early discovery through this system was incandescent light bulbs in the microwaves were left on more than expected and were a significant contributor to energy use in some apartments. Based on this discovery the owner proceeded to replace all microwave bulbs with LED substitutes.
- The highest impact discovery from the M&V process was a failure of the PV system serving Building 4. This was discovered by both Taitem and the owner independently before it had a chance to impact more than one month of billing data. Perhaps the greater accomplishment is the owner caught the issue before he was notified (which will translate into continued savings and optimal operation even after the formal M&V period ends). This speaks to the real-life utility of this monitoring system.

Besides these early successes, and despite a few issues with the monitoring equipment discovered later in the project, the M&V process succeeded in achieving all its stated goals and continues to provide the owner with ongoing, meaningful data. A testament to the effectiveness of this system is the developer's installation of similar monitoring systems as part of the next phase of this project as well as in his newest facility at a nearby site.

Additionally, and importantly, the project met its net zero energy performance target with minimal difficulty. A metric used by many groups to compare energy use is the Site Energy Use Intensity (EUI)[1] factor. The Site EUI for a typical apartment is roughly 79. The average apartment use at netZero Village is only 15.9.[2] The lowest users have EUI's as low as seven, and the highest user is only 40.5 (roughly half that of a typical apartment). These low-usage levels are key to ensuring the on-site renewable systems can offset energy use.

The success of this project can be attributed to many factors, but a few of these factors stood out as being particularly well executed, critical to the project's success, or as playing a more significant role in this project than usual. In brief, those factors can be distilled to the following:

- An involved project team
- Significant and sustained onsite presence
- Commitment to net zero use from the start, but flexibility in methods of achievement
- Innovative project financing
- Clear and measurable project goals and targets

These elements will not independently ensure project success, but are good indicators of a successful project and the areas in which this project excelled.

1 Background and Methodology

1.1 Project Description

netZero Village is an eco-friendly, market rate apartment community located in Rotterdam, New York, designed and constructed in a manner intended to achieve net zero energy performance.

Measurement and verification services were performed on phase I of the project,[3] consisting of the first six buildings and containing a total of 72 apartments. Each three-story building has an identical layout, with two shared entrances, two sets of stairs, and 12 apartments (six on each side).

Figure 1. Schematic Site Plan for All Six netZero Village Buildings Completed in Phase I

Solar photovoltaic (PV) arrays on carports associated with each building provide electricity for the common areas and apartments associated with that building and are tied in through the common area electric meters. The electricity generated by the PV systems, minus what is used by the common areas, is credited to the developer by the utility company and used to offset the apartment usage for that building.[4]

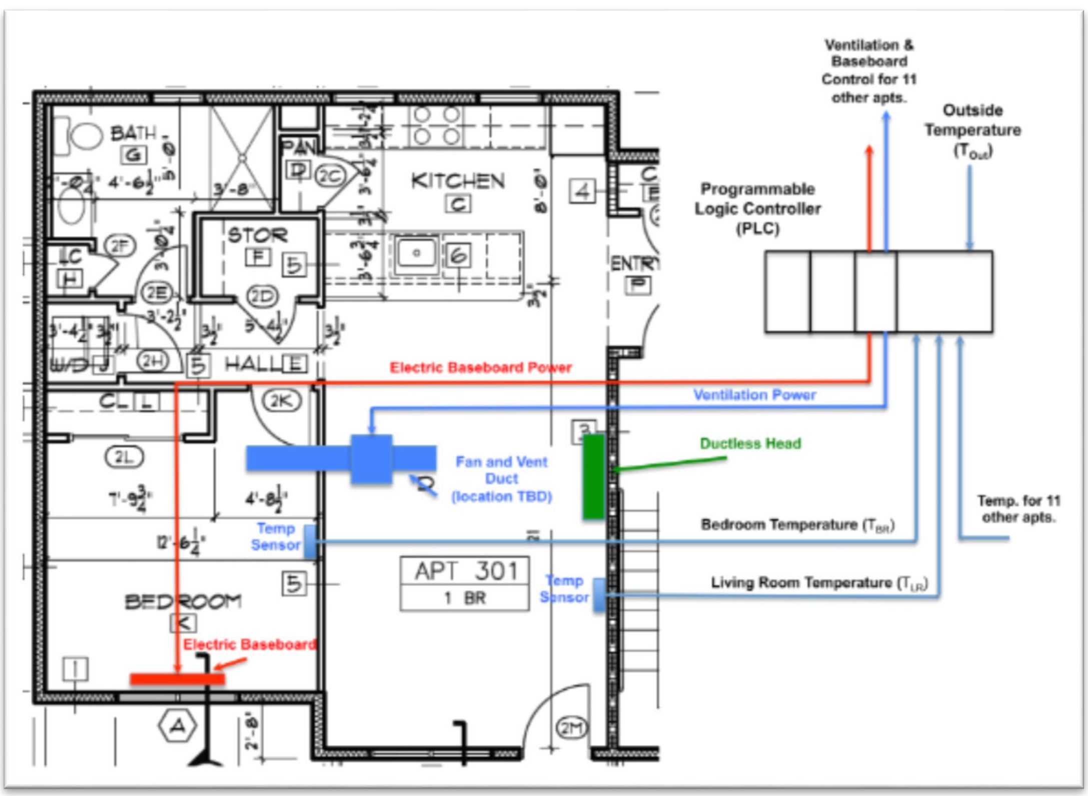
There are two solar thermal arrays on each building roof which satisfy most of the buildings' hot water needs. The solar thermal systems are supplemented by electric resistance heat as needed.

Mechanical heating and cooling of each apartment is supplied by a single-head ductless mini-split heat pump located in each apartment's living room. This single heat pump was sufficient to condition the entire, multiple bedroom apartment in most cases.

A transfer fan between the living room and bedrooms and a single section of electric baseboard were installed in each primary bedroom to supplement the heat pump if needed. These systems are controlled with a program created and implemented by the developer and only operate when certain outdoor and space temperature conditions are met.

Figure 2: Apartment HVAC System Schematic

Schematic drawing of a typical apartment with key HVAC systems and their connection to the developer provided supplemental heat control system.



Ventilation is provided by individual heat recovery ventilators installed for each apartment, providing 23 CFM of continuous exhaust[5] from the bathrooms and introducing equivalent amounts of outdoor air to the apartment. These units have higher nameplate airflow rates but are controlled by an adjustable timer that runs them intermittently (20 minutes out of every hour, etc.). This approach allows the owner to control ventilation rates much more accurately than he would be able to do if trying to balance each unit to a precise low airflow.

Apartment and common areas have hard-wired, high-efficiency LED fixtures. Common area lighting has occupancy sensor control. Exterior fixtures have photo sensor control. Apartment appliances were selected based on efficiency, cost, and reliability.

eGauge brand smart meters were installed on each apartment electric meter to track and influence occupant behavior by providing real-time feedback on their usage. Usage data from each apartment is tagged with a unique, randomly assigned identifier and displayed on a screen located in the building entrance.

Figure 3: Behavior Modification System

Photo of usage display screens in apartment vestibules.

1.2 Measurement and Verification Approach

1.2.1 Goals

The initial goals of the Measurement and Verification (M&V) process included the following:

- Provide early warning, identify potential obstacles, and provide possible solutions to achieving net zero energy performance
- Assess the performance of the heating system and control strategy from both a comfort and efficiency perspective
- Identify potential design improvements for use in Phase I, Phase II, and beyond
- Demonstrate through defensible methods that the building has (or has not) achieved net zero energy performance
- Attempt to identify reasons for net zero energy performance success or shortfall

In addition, this project is serving as a demonstration for NYSERDA's Low-rise Residential New Construction program, which added several additional secondary "bonus" goals. How each goal and secondary goal was met is addressed in the conclusions section.

1.2.2 Approach

It was determined early in the process that most of the data needed to meet the measurement and verification goals could be gathered using the developer's eGauge system. After confirming the eGauge system was expandable and had reasonable specifications and rated accuracy for these purposes, it was decided that adding supplemental sensors to this system would have a significant cost benefit when compared with installing a second set of stand-alone sensors or logger systems.

A set of four discrete M&V tasks were identified to use this system to meet the primary goals and to provide support for the secondary goals:

- Measurement and Verification Plan Creation
- Commissioning of Essential Building Systems
- Execution of Measurement and Verification Activities
- Final Utility Analysis

1.2.3 Task 1: Develop a Measurement and Verification Plan

The measurement and verification plan was created when technical details were developed for installation, sensor requirements, and coordination between metering systems installed by the developer and those being installed as part of the measurement and verification scope.

It was determined that the developer would perform the installation and provide infrastructure for all units, including those being used exclusively for measurement and verification. The number of points (one for each apartment and several to monitor independent end-loads within certain apartments) were agreed upon and the eGauge unit specifications were confirmed to show adequate sensitivity, response time and connectivity to allow remote monitoring of all the required loads at the necessary level of accuracy and precision.

The plan was developed over a course of meetings with the developer, NYSERDA, and members of the project team. In addition, it outlined a proposed schedule for frequency of analysis and how real-time data from apartments could be leveraged through the use of "load signatures," patterns made each time a specific appliance or device was used.

1.2.4 Task 2: Commissioning

The second task, commissioning, is not typically included in measurement and verification projects. Its inclusion was due in part to the emphasis placed on early warning and active involvement to ensure savings were achieved on this project. As they are installed, commissioning systems can provide a level of assurance that systematic problems in installation and equipment operation are caught early and dealt with before significantly impacting project goals.

A secondary impetuous to include commissioning was the intent to use load signatures to isolate certain loads from the apartment-level use. For this approach to work, it was imperative that the signatures collected for each load correctly reflect operating systems and there be no question about operating conditions or activities when load profiles were collected. Commissioning provided assurance for this project.

The last reason for including commissioning was as a way of ensuring a seamless transition between the installation of the measurement systems (developer) and the use of these systems to collect data (Taitem). As part of the commissioning, the installed systems were spot checked, and issues addressed earlier and more thoroughly than if a more traditional measurement and verification approach had been taken.

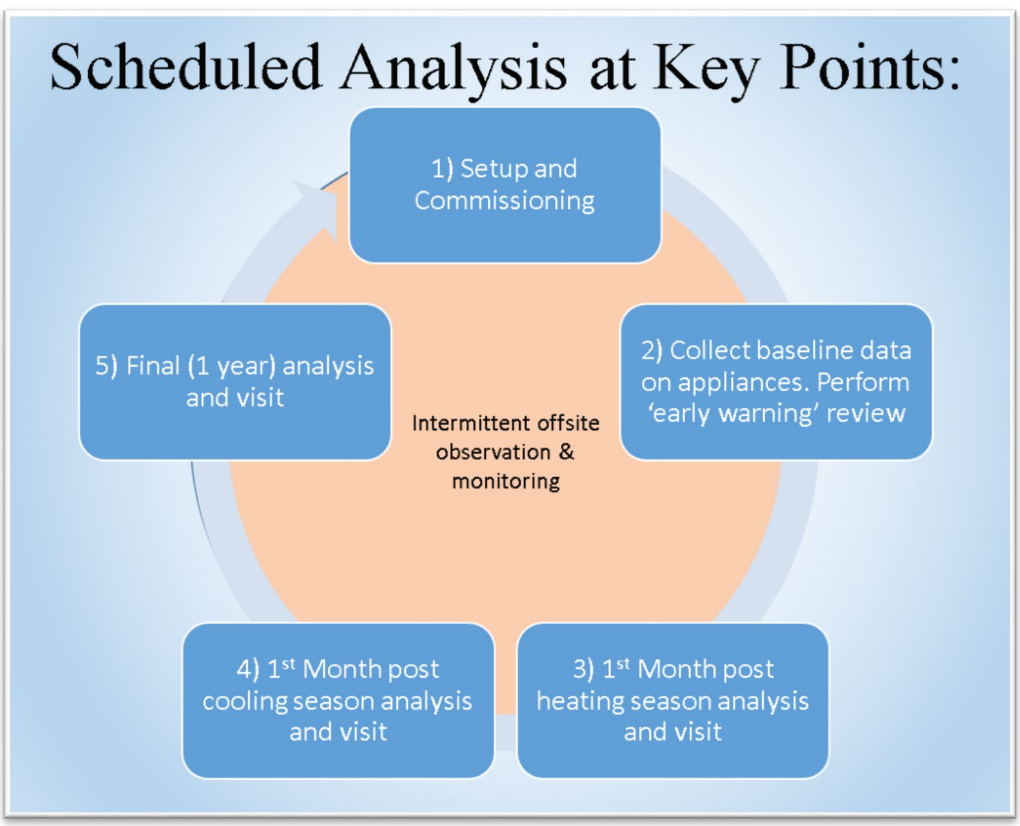
1.2.5 Task 3: Execution of Measurement and Verification Activities

Measurement and verification activities were planned to coincide with specific points in the building operation, with an emphasis on scheduling activities in such a way that issues could be caught before significantly impacting energy use. These verification activities were expected to rely heavily on the eGauge monitoring systems and supplement both ongoing spot checks of the data and a final, overall analysis of the project performance[6] at the end of the first year of use.

Three key points were targeted for the preliminary, early-warning rounds of analysis. The first round was planned to occur after the first month of occupancy, catching any significant issues, but not necessarily tied to any specific weather conditions. The next round of analysis was planned to occur after the first month of heating use (identifying issues with heating systems), followed by another analysis after the first month of cooling use.

Figure 4. Cyclic Analysis Diagram

Graphic of task flow and scheduled analysis targets for commissioning and measurement and verification processes. Circular diagram intended to show continuing pattern and ongoing intermittent involvement as well as key interaction points.



Because of delays in construction and in the installation of the monitoring setup,[7] the actual monitoring period extended two years instead of one year as expected. Some modifications to the analysis schedules and final tasks were necessary to allow the project to adapt to the longer monitoring period. Lessons learned about the building operation and usage patterns during early stages of the monitoring helped minimize the impact of these modifications. This allowed for more of a focus on aspects of the project most useful to NYSERDA and the developer while accepting the reality of an extended monitoring schedule.

1.2.6 Task 4: Final Utility Analysis

The final analysis and overall determination of project performance was based on utility usage data instead of eGauge measurements. As the final assessment of success, it was important that the measurements be entirely transparent and repeatable. The more granular eGauge data provided no advantage for this level of overall use assessment and basing calculations off utility meter readings meant data was collected with a universally accepted and highly standardized device.

1.2.6.1 Unique Analysis Features and Approach

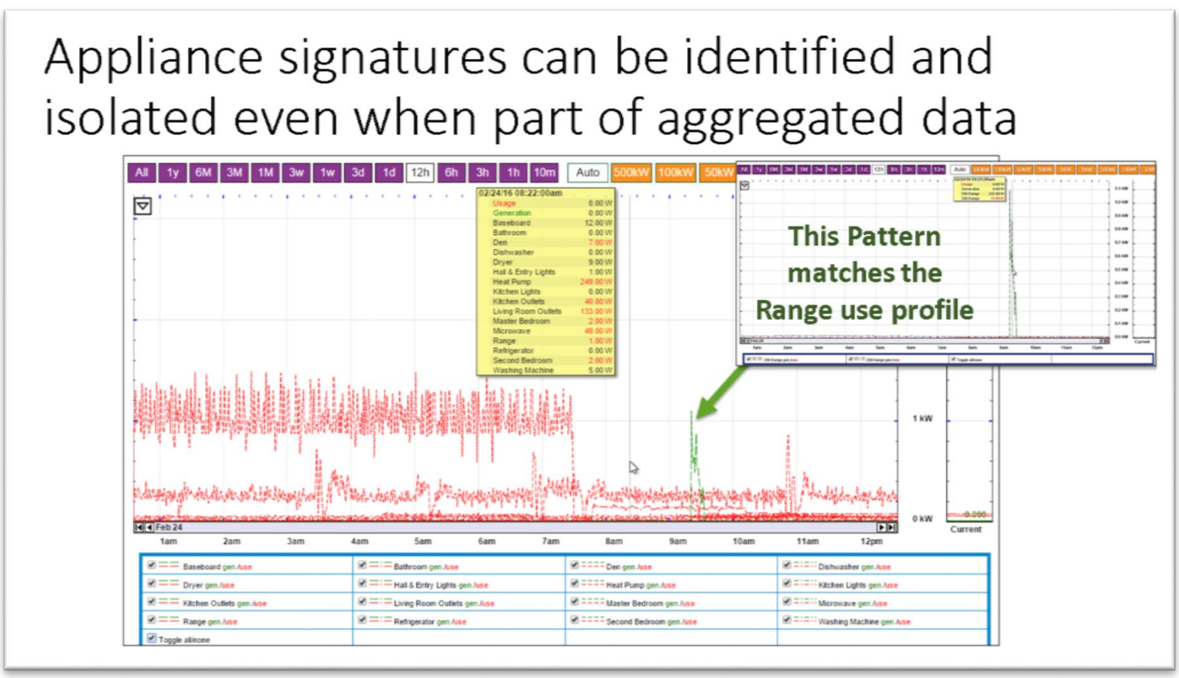
One of the project goals was to identify any successful design and control strategies and identify ways of improving those that were not. Monitoring units at the apartment level, while significantly enhanced by real-time, remotely accessible data, simply is not enough on its own to establish which systems are operating and how much they are using at any given time. Conversely, monitoring all loads in all apartments is not a cost-effective solution.

Adopting sampling strategies to cost effectively monitor specific end loads in a subset of the apartments is one way to begin to gather data on how the different appliances and systems contribute to the apartment usage. Typically, a small sample of devices would be monitored, and assuming similar use was observed, their average usage levels attributed to the rest of the units.

With real-time data, sampling specific end uses or devices can also be leveraged to provide more information about the unsampled units. Many of the sampled systems have distinctive use patterns that can be used to identify when that device is active, even when partially masked by simultaneous energy usage from other devices. This can allow certain end uses to be identified from within apartment level data and can provide information on how much energy is being used by a device and how frequently it is being used in each apartment.[8] It is important to note that after performing initial analysis rounds for winter usage discrepancies were discovered between the utility meters and utility grade metering equipment installed for the M&V. Further end-use analysis was curtailed due to inaccurate data reported by the eGauge units in favor of more detailed utility billing analysis.

Figure 5. Identifying Appliance Use Signatures

Display of multiple end uses from an apartment with a single use pattern isolated and highlighted in green.



The final unique approach taken with the measurement systems was acknowledging the opportunity present in planning monitoring systems for new construction. Although it is rarely cost-effective to install sensors on all end-loads and systems in a building, it is always desirable to have access to this data. One benefit of the eGauge units is that sensor leads can be extended up to 100 feet or more using CAT5 ethernet cable. This cable is relatively inexpensive, and each run can carry data from as many as four individual sensors.

By running CAT5 cable from a central utility room to each apartment electrical panel while the building was in construction, capability was built in to move sensors from one apartment to another, and between different end loads, as needed. This allowed us to use a single set of equipment[9] to collect more specific information on any units with higher than anticipated use, and to shift the investigation focus to specific sets of appliances.

Figure 6. eGauge Monitoring System Setup—Central eGauge Systems

Photo of several eGauge units installed in the common utility room. CAT5 cable run from the apartments is connected to each monitoring unit as required.

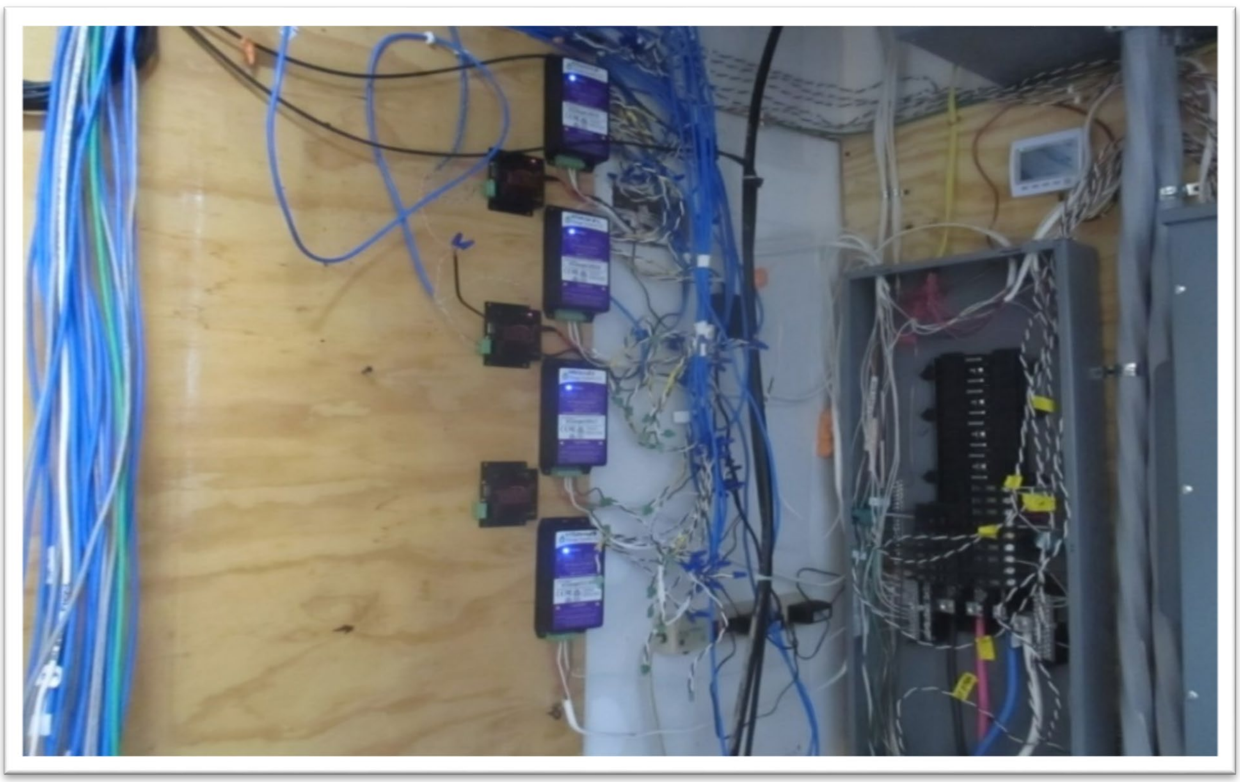
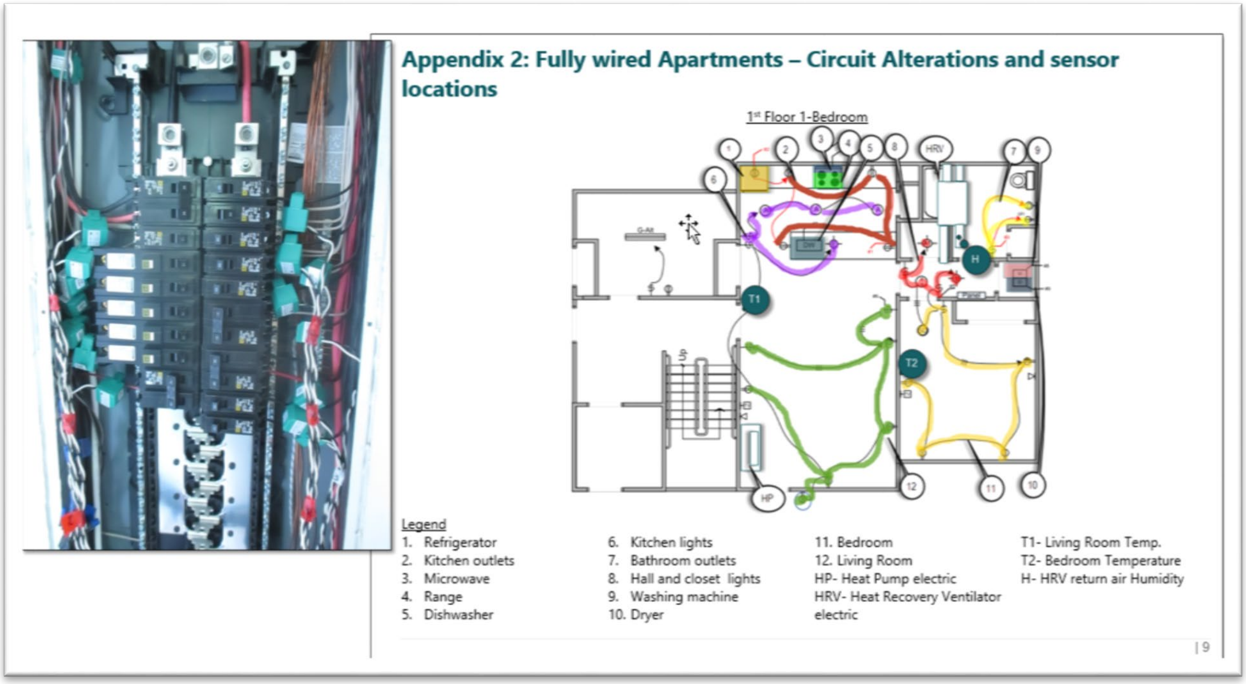


Figure 7. eGauge Monitoring System Setup—Apartment Electrical Panels

Photo of the interior of a fully monitored apartment. CT sensors are located on all end loads in the apartment. Circuit layout is displayed in the diagram to the right.



1.2.7 Challenges

1.2.7.1 Scheduling and Coordination

As noted earlier, delays in the deployment of the developer-provided and installed eGauge units had a significant impact on the measurement and verification schedule. eGauge units were to be installed by the developer as part of an innovative behavior modification approach. Apartment usage is publicly displayed in the common entry (with each apartment assigned a unique identifier).

Installation of this system by the developer was delayed multiple times due to other pressing concerns. Typically concerns involved correcting a recently discovered issue that was increasing energy use. Although this negatively impacted the ability to provide early warning for some of the units, prioritizing correction of known issues is a reasonable approach.

Because of the emphasis on early warning, and the lack of eGauge data early in the project, the first month use/heating season analysis was performed based on utility bills instead of eGauge data. This provided some assurance that major energy consumption issues were not being missed.

Similar issues and delays were experienced in obtaining data on apartment temperatures collected by the developer-provided control system. This system's installation lagged behind the occupancy of the apartments by a year, and eventually stand-alone data loggers were deployed to measure apartment temperatures.

As with any project involving multiple parties, a certain amount of coordination and difficulty was expected going into the project. In this case, the opportunity to significantly expand the measurement capabilities of the system without placing undue financial stress on the project budget was worth the delays and limitations.[10]

1.2.7.2 Monitoring Equipment Failures

Midway through the project it was discovered the eGauge monitoring system was reporting apartment level usage that differed, sometimes significantly, from the posted use recorded by the utility meters.[11] A significant amount of time was devoted to substantiating these divergences, determining which of the two revenue-grade devices was incorrect, confirming that erroneous readings were in no way due to faulty installation or setup, and finally in running the analysis to conclude that the results from the eGauges varied significantly, and unpredictably enough that further use for apartment analysis was inadvisable.

A discussion of these findings is included in the lessons learned section of this report. As the eGauge results were determined to be unreliable, further analysis was largely dropped from the scope of Task 3. Instead, that task was expanded to include the investigation into why readings varied and which of the two metering devices was reading correctly.

2 Results and Analysis

2.1 Commissioning

Commissioning of the HVAC systems, appliances, and eGauge monitoring system was conducted on August 24 and 25, 2015. The testing proceeded relatively smoothly with most findings addressed and confirmed corrected during the visit. Because of issues the owner encountered while setting up the eGauges, only one of the four eGauges had been set up and not all the end loads were being monitored at the start of the testing. As a result, a significant portion of the visit was devoted to troubleshooting issues with the eGauge setup and finalizing the wiring and programming, instead of testing.

The overarching goal of performing the commissioning was to ensure that the end loads being monitored were characteristic of properly operating systems and that their usage was being read correctly. By confirming correct monitoring setup and comparing usage levels at different stages of operation, much of the testing scope while helping wire and program the sensors was covered.

Sufficient testing was completed on all the installed systems to have a high level of confidence in the validity of using them to establish baseline conditions. Some systems, such as the solar PV and electric backup heat/transfer fan controls, were not yet ready for testing. Although unfortunate from a commissioning perspective, this allowed building comfort levels to be evaluated without those systems, one of the goals of the M&V process.

2.1.1 Selected Commissioning Findings

In general, the project installation was performed thoroughly and well. This is both a testament to the contractors involved, the invested construction management team, and active owner presence on the site.[12] Despite no significant operational issues, there were minor issues:

- The exterior lights on Building 3 were observed to turn on and off multiple times around 4:00 p.m. on the afternoon of August 25. We informed the owner and recommended the controller for these lights be recalibrated.
- The disconnect switches powering the supplemental domestic hot water heaters serving the west side of Building 2 were turned off. The solar appeared able to supply the peak demand simulated, but during the first round of testing, stored water was being pulled from both hot water tanks directly at only 80°F. One of the tanks was powered on and the other isolated and the tests repeated with satisfactory result.

- During the testing, four sets of data was exported from each eGauge at different points. While comparing results it was noted that some of the raw data did not make sense with respect to the end use being monitored. The data exported from each of the four files overlapped at certain points and that was used to identify the issue. One of the four exports for eGauge NYSERDA01 contained corrupted data that made several hours unusable. This was investigated, and the corrupted data purged.
- It was noted that some of the installed appliance makes and models changed from the initial design make and model. In general, the differences were small, but might increase Building 2 energy usage by roughly 70 kWh per year over the entire building.

2.1.2 Sensor Configuration and Issues

- The eGauge units were not fully set up prior to arrival at the site for testing. The owner encountered some issues with the connection, and after discussions with the manufacturer, concluded that the nearby radio tower was creating interference that the sensor wires were picking up. On inspection and extended troubleshooting, there was some interference from the radio tower, but the primary issues were poor wire labeling and bad connections. Radio interference was minimized by distributing sensors on longer wire runs equally between the eGauge units and then relocating CTs from particularly troublesome runs to nearer apartments.
- The eGauge units and sensors reviewed during this visit were explicitly for end-use logging.[13] Apartment-level units were not yet installed. Several of the end uses could not be monitored because installation was not complete (transfer fans, electric baseboard), installation wiring was different than design (apartment HRVs), and provided cabling was deemed too long and susceptible to interference (several of the apartment end loads). A record was made of all changes, and alternate end uses were selected for monitoring.

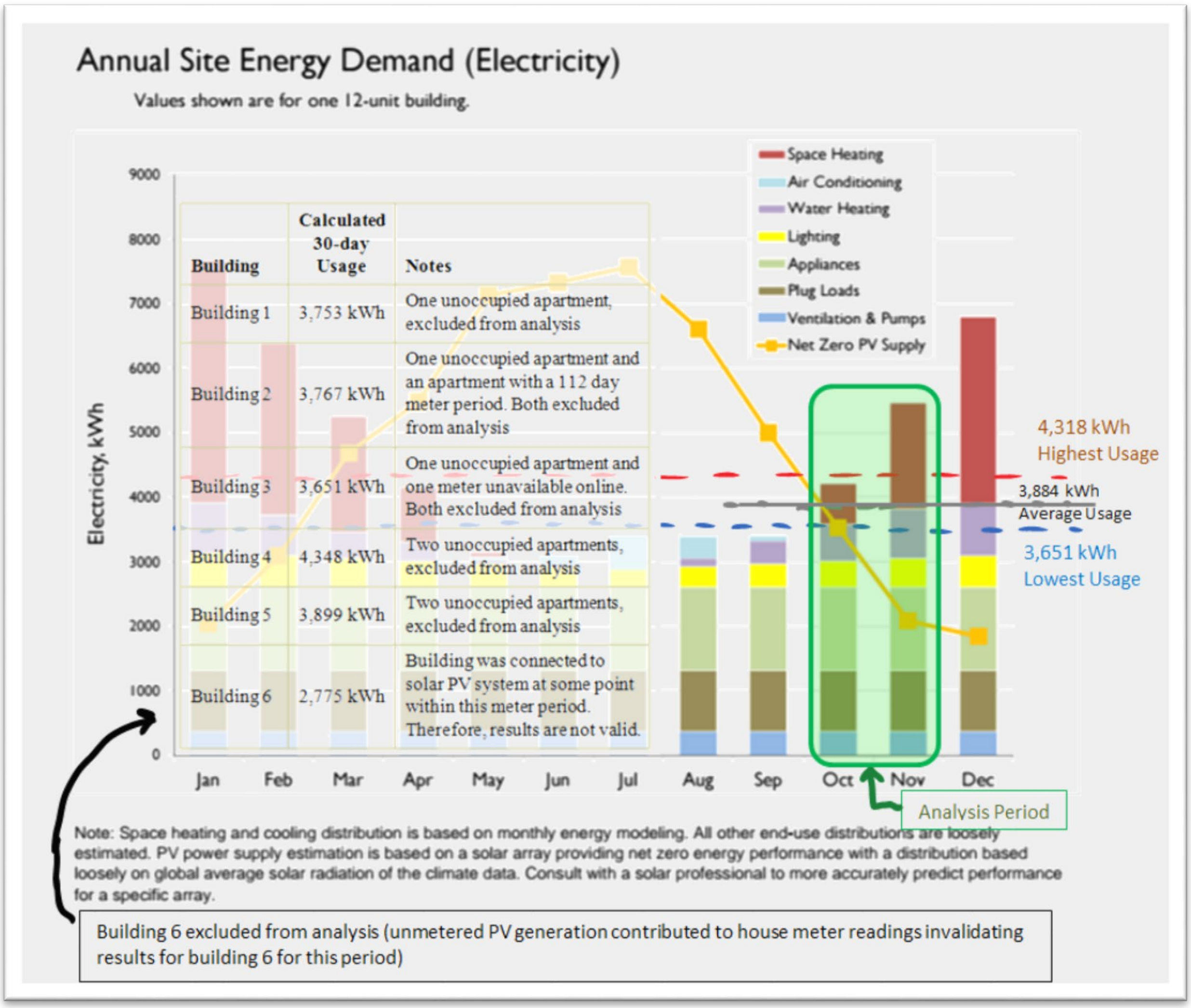
2.2 Initial Measurement and Verification Results

2.2.1 Overall Usage Findings

An initial round of analysis was performed on the first set of available data from each of the buildings to confirm usage was within expected ranges. Using target ranges from the building energy model created by GreenHammer as part of the design process, it was confirmed that all units were performing at or better than predicted levels.

Figure 8. Early Warning Energy Use Summary—Target versus Actual

Graphic displaying GreenHammer energy use and generation model results, annotated with table of 1st month usage data from each building and overlay of actual usage (min, max, mean) versus. predicted during the applicable date range.



The first round of analysis was completed immediately after the buildings were occupied and before most of the solar PV systems were operational. PV generation was omitted from this round of analysis.

2.2.2 Typical Apartment Findings

The first M&V inspection visit was performed on December 14, 2015. The visit intent was to identify characteristics of over- and under-performing apartments with an eye to early identification and potential intervention of any characteristics that pose a threat to achieving the net zero target. Prior to the visit, utility data was collected for all occupied apartments and analyzed.[14] Six of the lowest energy use apartments and 19 of the highest energy use apartments were selected as the initial pool of apartments to visit. These apartment numbers were provided to the owner a week in advance to arrange access with the understanding that not all occupants would be amenable and only a subset of each group was required for the visit.

Access was granted to nine of the high-energy use and four of the low-energy use apartments. In all but one[15] apartment, a full inventory was conducted for plug-in appliances as well as bulb type, counts, and wattage of tenant-supplied lighting fixtures.[16] Finally, additional end-use monitors were installed to monitor living room, bedroom, and heating system energy use in both a low- and high-energy use apartment.

General conclusions from the visit include the following:

- In general, the number of electronic devices in units was high. Nearly all apartments visited (high and low-use) had at least one and as many as five computers with associated peripherals (routers, printers, speaker systems, etc.). All but one apartment had multiple large screen displays (TV's, monitors, gaming systems) with the majority of apartments having one or more display in each bedroom and living room.
- Very few supplemental heating and cooling devices[17] were found, something that might not be expected in apartments where the utilities are paid by the landlord.
- Although internet and cable service is provided by the building, many tenants appeared to have their own cable boxes, modems, routers, and wireless systems. One of the routers found had a surface temperature of over 100°F with no devices actively using it, an indication of wasted electricity use. Investigation revealed that occupants were choosing to purchase and provide their own internet to gain higher speeds than the 5 Gbps provided by the building network.
- There was no single indicator to explain all the variations in loads across the apartments (although in some cases a primary source was evident). In a few specific cases a single appliance could be held directly accountable for higher energy use. Other high-use apartments had multiple smaller uses that could be responsible, but individually were not indicative of high-use. Roughly 50% of the high-use apartments were indistinguishable from the low-use apartments based on visual inspection only.

- The weather during the base period used to identify high and low energy use was relatively mild, so heating and cooling use played a small role in apartment energy use. After correcting for apartment size there were no statistically significant trends in corner versus interior and upper versus lower floor energy use.
- Upon inspection, it appears that number of occupants, frequency of cooking/laundry, and occupancy schedules and use patterns play as significant a role in energy use as the devices found in each apartment. As examples, one apartment was occupied by a couple who worked opposite shifts (day and night), resulting in longer periods of occupancy in comparison to their neighbors and higher energy use. Another apartment with lower energy use and a similar number of electronic devices was occupied by an executive who frequently traveled, leaving the apartment vacant for extended periods of time.

2.3 Ongoing Monitoring

Monitoring efforts were hampered by delays in the installation of the remaining apartment level eGauge equipment, negatively impacted the ability of the system to provide early warning for some of the dwelling units. Monitoring did continue on a regular basis as construction progressed on the second phase of the project.

Once eGauge level data became available we discovered that results from the eGauge units varied from the utility meter readings over the same period. Several rounds of analysis were performed to determine whether this was a unique issue, and then to attempt multiple corrective actions. Diagnosis of the issue was an extended process due to the need verify each attempted correction with the utility bills from the next monthly billing period.[18]

2.3.1 eGauge Analysis

Issues with the eGauge units' accuracy in comparison with the utility meter readings was first flagged in early May 2016. This followed a brief analysis of the first billing period where both eGauge and utility data were available (March—April).

Because only some of the units were reading incorrectly, it was initially assumed that the sensors had been improperly installed, and the owner was asked to recheck the installation of the units in question. Some units were found to be incorrectly wired, but several were reported to be correctly installed, and no immediate cause for the variation could be found.

Installing a second eGauge unit to determine whether the unit had failed was suggested and agreed to by the owner. As with the initial eGauge installation this process was significantly delayed and despite multiple follow up attempts was not implemented. In the meantime, eGauge units were installed in the other buildings and exhibited similar issues, decreasing the likelihood that a single faulty meter was at fault.

On discovery of the larger pattern of issues, approval to shift time from eGauge analysis into further diagnostics and investigation of this issue was received from NYSERDA. The eGauge manufacturer was contacted, but initially claimed all issues were due to installation and inaccuracies with the utility meters.

After several rounds of offsite analysis and investigation and continued discussions with the manufacturer and owner, it was decided that a site visit would be conducted to have another party physically verify that units with unusual readings had been installed correctly.[19] This visit was coordinated with the manufacturer, who attended by phone to assist.[20]

Despite some communication and coordination difficulties during the investigation visit we were able to conclude the following: (a) the divergence of the eGauge results from the utility meters was <u>not</u> within expected deviations given the margin of error for both systems; (b) installation error was not to blame for issues with the readings; and (c) radio interference or other site specific issues were not causing the issue.

Next steps were discussed with the owner and eGauge manufacturer, with the following results:

- Hiring a local electrical engineer with suitable revenue-grade testing equipment was explored, but eventually discarded; the cost of such an investigation would eclipse the potential benefit, and no action was taken.
- The manufacturer proceeded to attempt offsite registry reconfiguration, in the continued belief that a local installation or configuration change would resolve the issue. When comparing results with the next month's utility meter readings, these modifications proved to be unsuccessful.
- Taitem was able to confirm that the utility meter readings were correct and could be used for the M&V analysis. Taitem also concluded the likely source of reading errors for the eGauges was due to the sampling method being used.[21] If the error was due to the sampling method, the only resolution would be to completely replace the eGauge system with a meter capable of RMS measurements.
- After conducting discussions with the owner and NYSERDA, it was determined there weren't enough resources available to continue investigating the eGauge units. As a tool for occupant education, the level of error was acceptable to the owner, and installation of an entirely new metering system was not a reasonable alternative to using the existing utility meters.

2.3.2 Early Warning

One of the stated goals of the project was early warning of issues that would impact the projects achievement of net zero. Although the previously mentioned issues with the eGauge monitoring system reduced the ability to do this as effectively as intended, there were several examples of the M&V process providing the owner with early warning of pending issues:

- Although eGauge data was not available within the first months of occupancy, an initial round of analysis was still conducted, based on utility data only. As part of this analysis and visit, it was confirmed that all units were within normal ranges, and even on track to exceed targets. We were also able to conclude that the apartment location (interior, exterior, top or bottom floor) had very little impact on energy use—providing early confirmation of the effectiveness of the airsealing and insulation techniques used at the project.
- Some of the earliest data available to us was through the eGauge system monitoring individual end uses in the apartments. This system was intended to help identify which systems (based on signature use patterns) were responsible for energy spikes and use in over- and under-achieving apartments. An early discovery through this system was that incandescent light bulbs in the microwaves were left on and were a significant contributor to energy use in some apartments. Based on this discovery[22] the owner proceeded to replace all microwave bulbs with LED substitutes.
- Perhaps the highest impact discovery from the M&V process was a failure of the PV system serving Building 4. This was discovered by both Taitem and the owner independently before it had a chance to impact more than one month of billing data. Perhaps the greater accomplishment is the owner caught the issue before he was notified (which will translate into continued savings and optimal operation even after the formal M&V period ends). This speaks to the real-life utility of this sort of monitoring system.

2.3.3 Temperature Relations

One of the initial design questions for the project was whether the apartment heat pumps would be able to provide sufficient heating and cooling to the bedrooms from a single central location.

This question was inadvertently answered through demonstration before there was a chance to investigate. Installation of the heat transfer and backup heating system for the apartment bedrooms lagged significantly behind the occupancy of the apartments.[23] As a result, occupants went through a full heating season without any backup heat in place. During this period, some occupants did request the transfer fans be turned on for a variety of reasons but similar requests for the supplemental baseboard to be enabled were not reported, confirming the single-head heat pump approach was working.

An unfortunate side effect of the lack of the backup/transfer control system was the absence of temperature data for the apartments.[24] Apartment temperature data from the system was unavailable during the initial stages of the M&V and no winter use data was collected.[25] Hobo data loggers were used to collect temperature data for select apartments during periods of summer use.

An interesting observation from the summer use analysis is that the space temperature setpoints have a limited correlation to the energy use of individual apartments. This indicates that plug loads and other occupant behavior patterns have more impact on the energy use than space temperature, which in turn supports the earlier observations that the envelope is extremely well sealed and insulated.

It is interesting to note the increasingly large impact consumer appliances are starting to have, particularly in buildings with highly efficient building envelopes and heating/cooling systems.

2.4 Overall Performance

Overall performance, as outlined in the original project scope, is confirmed through a full year of utility use. Use of the utility data as the confirming metric was a conscious decision made for the following reasons:

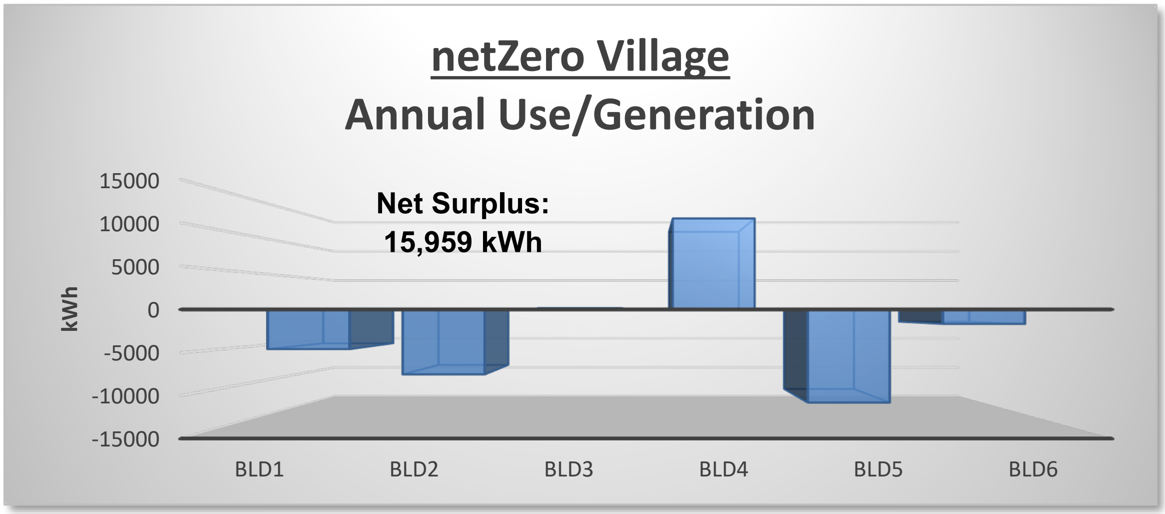
- Utility data is highly regulated, widely accepted as accurate[26] and readily available to all consumers in NYS interested in duplicating this.
- Utility data is collected, processed, and handled by a third party uninvolved with the M&V process, adding another layer of impartiality to the process.
- For the owner, and other parties interested in duplicating this type of building, the overarching metric that will determine if the project is a success is confirming that this is a financially viable way to build. Utility data is the direct measure of how energy use translates into direct costs to the owner.

The issues discovered with the eGauge monitoring system further support the use of utility data as the best final metric.

As noted in the summaries and elsewhere in this report, the results from the utility data are promising. All but one of the buildings were at or below net zero use levels.[27] Building 4 is the only unit that failed to achieve net zero levels of use due to a malfunction in the solar PV system serving that building. It should be noted that even with this malfunction, the amount of overshoot is the same general order of magnitude as the excess energy generated by some of the other buildings.

Figure 9. Annual Energy Use at netZero Village

Annual use per building bar chart showing all but one building at or below approximate usage targets.

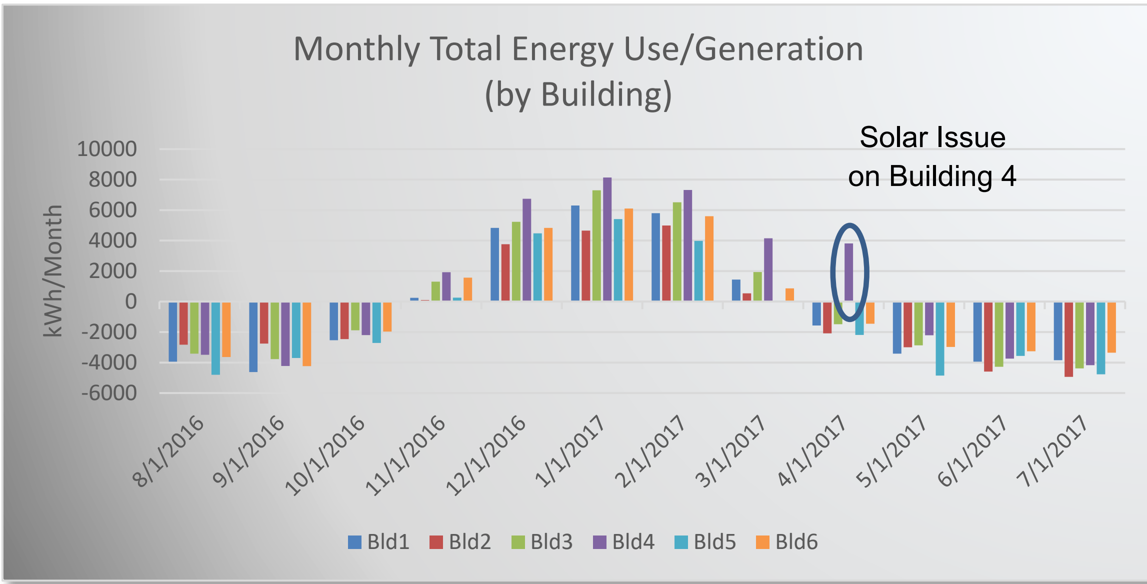


In total, the six buildings performed better than expected, generating a net surplus of 15,959 kWh[28] as measured by the utility during the monitored period. This is encouraging and shows potential for future years of net zero use, even after the solar generation starts to diminish and equipment efficiencies drop slightly.

Looking at the buildings' monthly use, it is clear that although there is some variation in use, in general the buildings are regular in their usage patterns and magnitude. Again, this is a promising sign as regular, repeatable usage patterns indicate a properly operating building and will help isolate abnormal usage patterns.

Figure 10. Monthly Building Energy Use at netZero Village

Monthly use per building bar chart showing one year of data. Outlier usage for Building 4 from solar issues highlighted in April portion of chart.



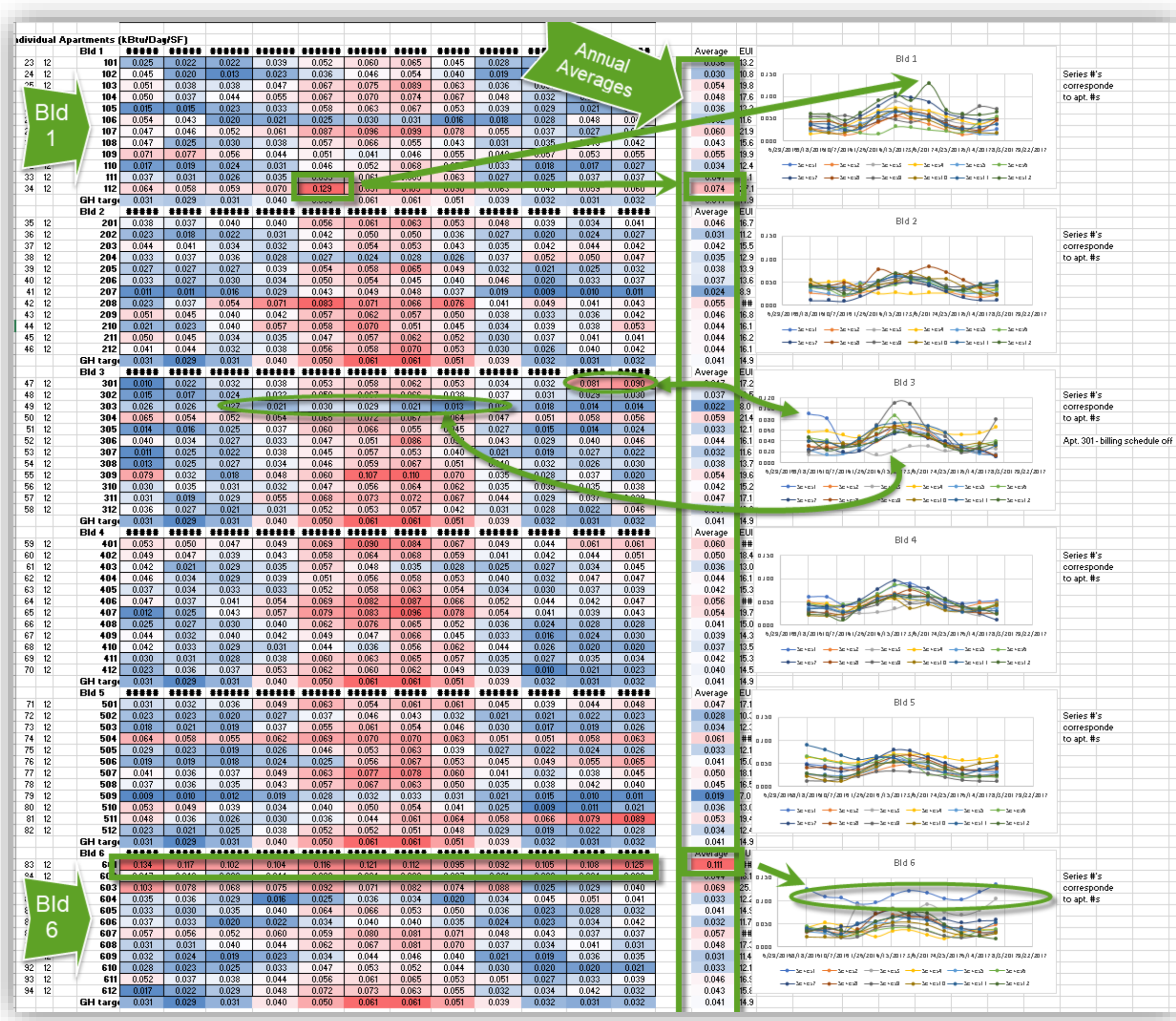
Building use can be broken down further, which is done in more detail in the reports included as part of the appendix. Data collected from the monitored apartments can be disaggregate down to the end use in some cases. Even with only the utility data, high and low users can be identified along with usage outliers.

Because this data is readily available and can be a useful tool to the owner for diagnostics, forecasting, and early response, several of the tools used in this analysis were provided to the owner. One of the primary tools is a spreadsheet analysis that allows the owner to import data provided by the utility (in its raw, unformatted version) and will then automatically parse the data into the appropriate billing periods, compare it with the predicted energy use, and creates a color coded set of tables and charts that can be used to identify outliers.

The following screenshot is taken from this tool. Outliers can be easily identified by their color intensity (red is high usage), by unusual usage patterns (look at the circled use for apartment 601 for example), and from the graphs to the right of the tables. For demonstration purposes some of the more typical outlier types have been highlighted in green in the screenshot.

Figure 11: Screenshot of netZero Village Utility Analysis Tool Provided to Owner

Screenshot of spreadsheet tool provided to owner with specific features and methods of use highlighted in green text and markup icons.



3 Conclusions

3.1 Answers to initial project questions

3.1.1 Primary Goals

Goal 1: Provide early warning, identify potential obstacles, and provide possible solutions to achieving net zero energy performance.

The measurement and verification process was built around this primary goal of not only verification, but active intervention should it be required. Although some modification was required due to the extended duration of this project, the initial expectation of analysis at early stages of each season of use was successful in identifying issues and ensuring that outlier apartments were checked for excessive use and correctable issues resolved.

Each stage of analysis was supported by a site visit to investigate outliers and identify common traits of over- and under-performing spaces. There were several instances where early warning of issues was provided. Advice was also offered on unexpected trends, which appeared and could impact energy use.

An example of this is the discovery that many of the occupants installed and were operating their own internet connections, despite building-wide internet supplied by the owner. On investigation, it was noted that the most cited reason for maintaining independent internet connections was to maximize connection speed. As the owner was directly paying for the electric use of all these independent modems, it was suggested that an upgrade to the central internet speed might be a cost-effective investment.

Goal 2: Assess the performance of the heating system and control strategy from both a comfort and efficiency perspective.

The comfort aspects were demonstrated during the period when apartments were occupied without a fully functional backup heating system installed. Efficiency of the system was demonstrated through dedicated logging of the systems, temperature-based analysis, and overall energy use of all the apartments.

Goal 3: Identify potential design improvements for use in Phase I, Phase II, and beyond.

Early in the project, two major design unknowns were evaluated. The two open questions were as follows: (1) whether the single-head heat pump would adequately satisfy the apartments, and if not, what level of backup was required; and (2) what capacity would be required from the solar thermal domestic hot water system. Item 1, that a single head heat pump system would provide adequate heat distribution, was confirmed to the owner's satisfaction through a season of heating without either backup system. Item 2, domestic hot water capacity under peak demands, was tested during the commissioning and verified to be adequate under most expected conditions. Installing eGauge sensors on the domestic hot water elements to track how the backup domestic hot water heaters were being used was part of the original scope,[29] but was not implemented during the initial phases of the project. Monitoring was added at later stages, and it was determined through monitoring and a measurement and control system added by the solar thermal contractor, that backup electric domestic hot water heating capacity could be halved from what was installed in the first phases.

Another finding that partially impacted design of future stages was the discovery of a previously unknown issue with the use of eGauge units to monitor energy use. Two key factors were discovered and passed on to the owner for integration into future aspects of the project:

1. eGauge unit accuracy was observed to be impacted by measurement of non-standard loads and possibly by PV system interference.
2. eGauge sensor readings can be transmitted over CAT5 cable, up to 100 feet. This was an integral part of the M&V design. Because of the project's unique location (adjacent to a high-power radio transmitter), longer cable runs were susceptible to interference. Sensor extensions were not used in later stages.

Although a stated goal of the M&V was to influence design decisions made for Phase II of the project, the delays in installation of sensors were such that installation of the apartment-level eGauges was only completed after construction had moved beyond the point of making many design alterations on Phase II. These lessons are still applicable to a second net zero facility being built by the owner in the same general location.

Goal 4: Demonstrate through defensible methods that the building has (or has not) achieved net zero energy performance.

Utility data presented earlier in this report has conclusively shown that Phase I buildings as a group produced more energy than they consumed.

Goal 5: Attempt to identify reasons for net zero energy performance success or shortfall.

This project was very successful at meeting its target, including a few instances where performance varied from expectations. This bears repeating with some context, as the standard of meeting expectations is not often considered to be exceptional. In this case, it is better to have accurately predicted and achieved, rather than significantly exceeded the desired building performance.[30]

This project also took a very methodical, cost-based look at which measures to install, comparing each potential improvement over a code-compliant building with the incremental cost of installing additional solar. One consequence of that approach is that very few measures were taken to extremes. The final design was built around many smaller component parts, each contributing to the energy goals, rather than centered around a few larger, more aggressive measures.[31] This appears to have resulted in a more stable project, where there are few if any critical components.[32]

There were some deviations from expected use levels. In general, the apartment usage was slightly higher than anticipated, but this was balanced by greater than expected solar PV generation. One of the key characteristics of the M&V approach was the addition of a follow-up site visit after each round of analysis. These visits were focused on any atypical usage observed during the analysis and involved inspecting apartments that fell in the top or bottom 10% of usage.

Ultimately these visits were very useful in investigating the higher than expected apartment usage. One of the discoveries made was that high-apartment use was somewhat tied to higher than average plug loads and electronics, but also strongly tied to occupancy patterns. Apartments where two residents worked opposite shifts (day shift and night shift) tended to have higher use, as did some apartments occupied by recent retirees, who were in the apartment a greater proportion of the time. These sorts of observations would not have been possible with off-site monitoring alone.

3.1.2 Secondary Goals

Secondary Goal 1: Providing feedback regarding the Low-rise Residential New Construction program, including performance standards and minimum performance thresholds.

The project did not appear to have any issues meeting efficiency goals or program requirements, nor did it encounter financial hardship caused by participation in the program. It did require more direct involvement of the building owner/developer. This resulted in a higher standard of construction build quality and greater attention to details throughout the process.

The building spent an extended period of time in the design phase, with the design and modeling teams and installation contractors all involved in selecting the most cost-effective ways to reach net zero. This resulted in decisions being made to install some less efficient envelope components because the cost-benefit ratio of installing extra solar capacity was more beneficial. The building site was also taken into consideration, and building orientation played a role in determining where and how big windows were, as well as how windows would be shaded.

Although this approach to building exceeds the level of effort displayed by many of the projects entering the program, it is certainly reproducible. One of the best indications of the success of this project is the ongoing construction of a second similar project and the completion of the second phase of building, which added seven more buildings to Phase I.

Secondary Goal 2: Act as a demonstration project for several progressive design strategies and technologies.

The design strategies and technologies are as follows:

- Single-head ductless mini-split heat pumps in the living room of apartments with multiple bedrooms
- Heating control strategies for low-load spaces
- Passive design strategies
- Behavioral modification through accountability at the dwelling unit level

Single-head ductless mini-split heat pumps were successfully demonstrated to be a viable option for well-insulated and well-sealed buildings such as these. One key factor in this success is that the building envelope was fully tested as part of the project construction, ensuring that each space was truly well sealed.

As part of the M&V, it was confirmed that backup heat was not used excessively, but beyond that there were few chances to see the system in operation.[33] The backup control system was designed, installed, and programmed entirely by the owner. Because the single-head heat pump was able to provide sufficient heat to all, or nearly all, of the apartments implementing the backup heat control system was not given a high priority and it was only installed and active for the last year of the M&V period.

Passive design strategies were a conservative success. These design features were intended to reduce heating and cooling loads during the winter and summer months. The following table shows the deviation of the average energy use intensity (EUI) metric for all apartments from the predicted use over a certain month. Red cells indicate months when more energy than predicted was used, blue indicates months when less energy was used.

Figure 12. Average Apartment EUI Deviation

Average EUI deviation from prediction for all apartments presented as average kBtu/ft2/day over each month billing period.

	7/20/2017	6/20/2017	5/20/2017	4/20/2017	3/20/2017	2/16/2017	1/19/2017	12/19/2016	11/17/2016	10/19/2016	9/20/2016	8/19/2016	
Average monthly deviation	0.007	0.005	0.002	0.001	0.005	-0.001	0.002	0.000	-0.002	0.000	0.005	0.008	kBtu/Day/SF

Although there is a clear trend towards greater than predicted energy use in the summer, there are two important factors to note: (1) space temperature setpoint did not have a significant correlation with high summer energy use in the apartments analyzed; and (2) apartments generally tended to have higher than anticipated plug loads, which will in turn generate heat within the apartments, reducing heating use and increasing cooling use.

There is a general shift over the entire year (increased cooling use, decreased heating use) that is typical of higher plug loads, instead of increased heating and cooling use. Conversely there are increases in both peak summer and winter use, which would be typical of higher HVAC use and heat loss. Based on that the conclusion is that the project's heat loss and gain[34] performance was very similar to that predicted by the energy model. Since the model included energy credits for passive design strategies, this indicates these features performed as expected.

Two of the more significant innovations implemented as passive design strategies at the site include slatted window awnings, which allow more light in the winter while blocking it in the summer;[35] and site/orientation specific use of windows to control window-to-wall ratio, maximize light penetration into the space, and take advantage of passive solar principles.

The final strategy evaluated was an attempt to influence occupant behavior through the anonymous display of each apartment's energy usage. There are a few aspects of this system that should be addressed.

The first is that the system was not fully implemented when the buildings were first occupied. This would ideally give us a pre- and post-implementation period that could be analyzed. Unfortunately, there was a delay in implementation caused by delays in installation of the measurement system, which was needed to provide us that data. While there was access to utility bills for both periods, the day-to-day usage of the apartments is variable enough and the amount of savings expected small enough (5% decreases to select plug loads and lighting), there was no clear impact on usage observed in the utility bills.

Simple reductions in plug loads and lighting use were not the only predicted impact from the interactive energy use display. A secondary, indirect effect was predicted to result in a 1–2°F reduction in space temperature setpoints in the apartments. The proposed backup heat control and space temperature monitoring system being installed by the owner, which would have allowed measuring this effect had not yet been implemented and any direct impacts on the temperature were not able to be verified.

As a final caveat to the occupant behavior modification attempts, the building already tends to attract tenants predisposed toward living in an energy-efficient manner.[36] The potential behavioral modification savings available in this pool of occupants will be less than in a set of less energy conscious tenants.

Although there was limited success explicitly confirming savings due to the behavior modification efforts,[37] the ready access to usage data has proven to be useful not only for the tenants, but also to the owner and maintenance staff, who are able to identify equipment malfunctions and abnormal energy use in buildings through these displays.[38]

Secondary Goal 3: Collaborate with the project's developer and design team members, including the Passive House consultant, contractors, and HERS Rater, as well as with NYSERDA and the Conservation Services Group and other involved parties, to share and collect data for use in assessment and validation of the predictive models created for the project.

Usage data, as well as the tools used to collect and analyze the project data, has been made available to NYSERDA and to the owner. In addition, several collaborative efforts, including a group presentation and support for several others, have been completed based on the measurement and verification data. Lessons learned regarding the modeling effort are also included in the following section.

3.2 Lessons Learned

3.2.1 eGauge Units

Despite using units rated as "Revenue Grade," this entire class of smart metering solution has problems. In brief, the eGauge measurements are based on high-frequency sampling of amperage, which is then converted into an energy consumption value based on the voltage of the system (actually a wave and is measured at one point in the system). Many new high-efficiency devices have a disruptive effect on the voltage's normal sine wave pattern. When the wave is shifted, or altered from a regular sine pattern, the sampled amperage readings are not correctly matched to the corresponding voltage. This skews the energy consumption readings, depending on what devices are in use and how the wave has been shifted.

This is an issue that is just now starting to be recognized as a problem in the M&V and smart meter industry. An example of this is a study published in the IEEE Electromagnetic Compatibility Magazine.[39] The article[40] reported finding deviations of as much as 500% from actual usage for smart meters measuring certain end uses, such as LEDs. Perhaps more telling than the deviation from actual usage is that these results were collected from meters that met all legal and certification requirements for accuracy.

Moving forward, with the understanding that both smart meters and high-efficiency devices[41] are becoming more common, the recommendation is that all smart meter results be compared with and verified against a known baseline before use in an analysis. This can be as simple as confirming aggregated data from a space matches the utility data collected for that space over the same period.

3.2.2 Modeling Cautions

Overall, the energy model and predictions for energy use were close to the energy use recorded from the site. There were two significant differences that should be considered when creating future models:

1. The modeled space temperatures were slightly ambitious for the apartment spaces. Despite the well-sealed and insulated envelope, it is optimistic to assume, as the model did, that residents who are not paying heating and cooling costs will maintain their apartments at 68°F–69°F in the winter and 75°F–76°F in the summer.[42]
2. Occupant plug load use is higher than anticipated and expected to continue growing. Because this is such a large factor in low-energy-use buildings, and the increase in plug loads is growing quickly, it is recommended that allowances for plug load energy use increases be built into models (similar to estimates on inflation or ROI calculations).

3.2.3 Factors for Success

There were many factors involved in the success of this project, including continued and early involvement by NYSERDA and a shared interest by all parties in finding practical, innovative and cost-effective solutions to problems. Many of the concrete manifestations of these decisions and efforts are noted earlier in this report and most are shared by other projects attempting to reach net zero energy targets.

A few of these factors stood out as being particularly well executed, critical to the project's success, or playing a more significant role in this project than usual. These may not have been explicitly stated and are worthy of additional emphasis. In brief, these factors include the following:

- Involved project team
- Significant and sustained onsite presence
- Commitment to net zero use from the start, but flexibility in methods of achievement
- Innovative project financing
- Clear and measurable project goals and targets

Again, it is worth noting that these elements will not independently ensure project success. However, they are good indicators of a successful project and areas in which this project excelled.

Endnotes

[1] Energy Use Intensity – measured in kBtu/SF/year. Typical apartment average EUI of 78.8 is based on Portfolio Manager/Energy Star published data: https://portfoliomanager.energystar.gov/pdf/reference/US%20National%20Median%20Table.pdf

This reference was based on the 2016 release, available on request from Portfolio Manager support staff

Additional ratings and averages can be found online: https://www.eia.gov/consumption/commercial/reports/2012/energyusage/

[2] Excluding contributions from Solar PV

[3] Phase II added seven additional apartment buildings, bringing the complex total to 13 apartment buildings.

[4] All apartments are individually metered

[5] With a boost option to increase flow to 33 CFM

[6] based on utility bills

[7] Installation of eGauge units was included as part of the owner's scope of work. Several units were installed and checked as part of the commissioning task; however, installation in the remaining buildings lagged for a considerable period following the initial visits and analysis.

[8] Building 2 analysis included two fully wired and monitored apartments, and selective monitoring and analysis of typical end loads in as many as 10 other apartments to establish a baseline usage profile for a typical apartment.

[9] Already needed to establish the baseline sample on different end-uses and appliances

[10] By comparison, without the owner's system much of the end-use data would have been severely curtailed, and a significant increase in sampling would have been necessary to accomplish the M&V at a reasonable cost.

[11] Both meters are revenue grade measurement devices, meaning the readings should be very similar

[12] The number of issues discovered was remarkably low; based on experience with similar projects one or more significant operational issues would be expected in a building of this size and type.

[13] End-use logging refers to the logging of multiple individual loads, such as refrigerators, lights, living room plugs, etc. within select apartments. Apartment level logging is the monitoring of total apartment use, similar to what would be billed by a utility company.

[14] The initial visit was conducted based on utility data with the understanding that eGauge apartment level data would soon be available, and that early analysis and action was desirable to prevent high-energy use from a few easily corrected issues to skew project performance.

[15] Inventory was aborted after the occupant was found asleep.

[16] Bulb counts were not done in apartments where the occupant was present.

[17] Window AC units, electric space heaters, etc. Visit was performed mid-December of the first winter; however, weather for the season was unusually mild.

[18] To test if errors were due to an installation issue, the issue first had to be identified using a month of utility data versus the same month of eGauge data. The owner then had to investigate and correct any discovered wiring or setup issues within the next billing period. A third full billing period was required to determine if the issue was resolved.

[19] Installation of the eGauge units was initially by the owner had been largely performed by an intern. Once issues were first identified the owner went through and re-inspected all units; however, there were still a few lingering concerns about installation. This visit was intended to conclusively rule out any issues with installation from further troubleshooting.

[20] Although some technical support was available, the level of support anticipated was not provided as a snow storm forced many of the manufacturer's workers to stay home, leaving them with a skeleton staff the day of the visit.

[21] The eGauge sampling method takes repeated sample measurements of a power wave to calculate the amount of energy used. A recently discovered issue with this method of energy metering is that certain high efficiency systems alter the shape of this power wave. This can result in measurements as much as 500% off from actual use (see http://sciencebulletin.org/archives/10940.html for a discussion of this from a recent Dutch study).

[22] The owner had not been aware that the lights were used at all, or that they were incandescent.

[23] Full implementation of the system lagged for roughly a year after occupants first moved in.

24 Because this data was all being collected by this control system, and expected to be available for the analysis, only two supplemental temperature sensors were installed as part of the M&V approach.

25 Hobo data loggers were available and brought to the site to be used as a backup during the January 2017 visit; however the owner had recently completed installation of the backup/transfer system and committed to providing temperature data from that system instead (the owner was not comfortable installing data loggers in the apartments at that point). Multiple follow up attempts were made to gain access to this temperature data, but the data was not easily transferable and the owner eventually deployed Hobo data loggers to give us summer usage data.

26 Although this measurement may lack the precision of some third party metering systems the quantity of units deployed and quality assurance procedures mandated by the public service commission ensure a reasonable standard of accuracy is upheld by meters supplied by utilities.

27 Building 3 was slightly above zero net usage, with 193 kWh of overall use; however, the amount of overshoot is within margins of error and primarily due to a non-365 day year of use being analyzed. Because of the utility billing schedule does not perfectly align with monthly, or even annual periods, the analysis period is slightly skewed. When fitted to the period included in the utility bills the predicted use that would achieve net zero is anything under 1,590 kWh.

28 When compared with an equivalent billing period, the six buildings performed even better, using roughly 25,500 kWh less than anticipated

29 The M&V sensor installation plan was based on a base plan of systems being monitored that would be installed and provided by the owner. As noted previously, this installation was significantly delayed. Additionally, the eGauges intended for use on common area loads were at first co-opted to measure the solar PV production. The solar PV contractor was contractually bound to provide its own set of eGauges for monitoring of the PV system, but failed to comply with that aspect of the contract and the owner decided not to push for it. As part of the M&V, some of the remaining surplus eGauge units were reconfigured to monitor a few of the hot water heaters.

30 Excess generation, in this instance, would mean the project was not as cost-effective as it could have been, and wasted resources on solar PV that could have been directed elsewhere

31 Less aggressive measures also tended to have more reasonable and attainable performance targets, instead of requiring absolute peak efficiency of the installed systems. Something that also likely played a part in the nearly universal success of all measures.

32 Although there were few chances to observe system failures, the stability observation is based around the one failure of the solar PV serving Building 4. In this project the PV systems were the closest thing to a ‘critical’ system, and the failure on one building for a month (including time to diagnose and correct) was not enough to prevent the project from achieving its performance target.

33 Several factors limited the ability to analyze the backup heating system effectiveness. The late date of final installation prevented relocating end-use sensors to applicable systems so there were only two independently monitored baseboard systems. This direct monitoring of the systems was one part of the M&V approach, and baseboard use from the apartment total usage would also be discernable. Excessive usage was checked for and not noted as part of the utility bill analysis. See appendix section 5.12 for more details on end-use analysis.

The other aspect was that the control system provided by the owner was going to be completely accessible and would provide runtime, space temperatures in the bedroom and living room. Given this data was expected to be readily available for every apartment, it was decided at the beginning of the project not to invest resources in duplicate monitoring of these points. Unfortunately the data recorded by the owner’s system was only accessible from the site, only set up to extend back a single day, and for practical use was unavailable (to the point that Hobo data loggers were deployed to collect apartment temperature data instead of trying to extract that information from the control system).

34 Heat loss and gain due to envelope components, before accounting for any internal heat sources, etc.

35 Light is allowed through at varying levels depending on the spacing of the awning slats and elevation of the sun, which varies seasonally.

36 This interest in energy efficiency was expected due to the targeted marketing of the building to these clients, and was confirmed through discussions with the residents during site visits.

37 An aspect of the project that would be hard to directly quantify in ideal circumstances.

[38] The best measure of this usefulness is that the owner is planning on continuing to install these systems in future projects.

[39] This study came out in Q4 of 2016, a few months after issues were noted with the eGauge units deviating from utility meter readings.

[40] (Leferink, Keyer and Melentjev 2016). News article summarizing this article available: http://sciencebulletin.org/archives/10940.html

[41] Which alter the power signal.

[42] Space temperature assumptions documented in energy report—assumed to be the primary impact of energy-use feedback. The level of energy savings proposed for the behavioral modification is similar to what Taitem recommends as a maximum modeled impact from implementing outdoor reset and installing apartment level controls (see 2/6/2014 MPP tech tip on this subject prepared by Taitem).

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