Measuring Performance of Net Zero Homes in New York State

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ABSTRACT

This paper presents the methodology of a measurement and verification (M&V) effort that will be conducted on a census of net zero energy (NZE) homes participating in NYSERDA's Low-Rise Residential New Construction program (Program).

The goal of the evaluation is to establish energy use values and metrics for the in situ performance of twenty-nine Program participant homes. The performance values will be based on on-site M&V, and will determine the load shape of the home, and the generation load shape of the installed renewable systems. The analysis will generate correlations to independent variables and the authors will identify behavioral impacts on performance. Findings will be compared to modeled predictions to assess the effectiveness of the models at predicting net zero performance.

In addition to the on-site M&V, the authors will identify the baseline alternative to an NZE home and the associated incremental costs, based on actual construction cost data. Is the participant baseline alternative to an NZE home a code-compliant home, a highly energy efficient home, or something in the middle? Surveys will be conducted with NZE home owners and builders to identify the likely less-efficient alternative for an NZE home, providing future evaluations with data and context to support baseline characterization in NZE homes.

Introduction

NYSERDA's Low-Rise Residential New Construction program provides technical and financial support for the construction of net zero energy homes. As NYSERDA's programs transition to align with the Clean Energy Fund (CEF), the residential new construction efforts are moving towards market animation activities including technical assistance, training, stake holder networking, and the identification and implementation of pilot opportunities in integrated delivery and performance validation.

As a result of moving away from resource acquisition, it is essential for NYSERDA to have a firm grasp of current performance levels of residential new construction to establish a baseline by which future energy savings can be calculated and progress of technology performance can be tracked over time.

As part of this effort, NYSERDA will assess the actual performance of a census of 29 net zero energy participant homes built in New York between 2008 and 2015. All of the homes have photovoltaic (PV) renewable energy systems installed. The M&V analysis will validate the energy use and energy production of homes that have been deemed net zero ready through REM/Rate modeling software. The Program considers a single family home to be net zero if it achieves a HERS score of 10 as modeled in REM/Rate software by certified providers. The performance of the homes will be compared to the modeled results in order to gauge the accuracy of the Program's HERS rating thresholds in predicting net zero performance. This will allow the Program to adjust the threshold values to ensure participant homes achieve the expected performance. Determining occupant behaviors and their effect on a ZNE building's performance requires extensive and detailed end use energy monitoring (Mahone, Pande, Kasman, & Jones, 2014). Sub-metering of individual end-use circuits and interviews with home owners on occupancy patterns and home use will provide correlations between occupant behavior and energy use. Building size and physical characteristics, climate zone (New York has two), year of construction, and other variables will be used in regression analysis to identify independent variables that drive energy use. Energy end-use break-down and the impact of occupant behavior will allow NYSERDA to modify technical guidance on best practices in construction and the role the occupant plays in achieving net zero energy performance.

In addition to performance measurement, the authors will identify the likely non-NZE alternative that the homeowners would have pursued in lieu of a net zero home. Traditional evaluation often compares an energy efficient system or home to a minimally code complaint system or home. NYSERDA and the authors question whether a minimally code complaint home is the realistic alternative to an NZE home. The authors will conduct interviews with the home owners, as well as with the contractors that built the homes, to identify the motivation behind the pursuit of a NZE home and what home they may have purchased or built if NZE homes were not available.

On-site Measurement and Verification

Simply stated, the intent of the on-site M&V is to capture as many data points as possible without burdening the homeowner. The evaluators are installing current transducers on as many circuits as physical space within the panel allows, considering that the panel must be closed with the cover secured in order to ensure a safe and secure installation. The physical space limitations will prevent the metering of every circuit, and as such the authors have developed a priority list of circuits to meter. The choice to use current rather than power loggers was made primarily because of the space constraint concern, voltage and power factor readings are taken at the time of current transducer installation for use in the final analysis. This list is provided in Table 1.

Table 1. Order of Priority – End-use Circuit Metering

Purpose	Equipment Type	Logging Variable	Logger Interval	Deployment Duration	Priority
Whole-building consumption	HOBO UX120-006M	Amperes	1 hour	6-8 Months	Required
Photovoltaic production	HOBO UX120-006M	Amperes	1 hour	6-8 Months	Required
Heat pump	HOBO UX120-006M	Amperes	1 hour	6-8 Months	Desired
Water heater	HOBO UX120-006M	Amperes	1 hour	6-8 Months	Desired
Supplementary electric heat	HOBO UX120-006M	Amperes	1 hour	6-8 Months	Desired
Space temperature	HOBO pendant temperature/light logger	Temperature (°F)	1 hour	6-8 Months	Desired
Unique loads (hot tub, electric car, etc.)	HOBO UX120-006M	Amperes	1 hour	6-8 Months	As available
Energy recovery fan	HOBO UX120-006M	Amperes	1 hour	6-8 Months	As available
Dryer	HOBO UX120-006M	Amperes	1 hour	6-8 Months	As available
Oven	HOBO UX120-006M	Amperes	1 hour	6-8 Months	As available

Measurement of any fossil fuel burning appliance is not in the scope. This is due to the use of heat pumps (both air source and ground source) for space heating and domestic hot water (DHW) in almost all the homes; one home in the group uses natural gas for space heating, one uses natural gas for domestic hot water, and one home's heat pump system has propane fired back-up. Natural gas and propane utility data will be collected for these three homes and will be analyzed in conjunction with weather data and occupant behavior patterns to assess the energy use associated with fossil fuels in these homes.

While on-site, the evaluators will conduct a brief survey with the homeowners to understand the occupant population (number of occupants, age of occupants) and how the home is used. As energy use associated with HVAC and lighting is reduced through efficient design and technology, behavioral factors such as plug loads, and occupant density and schedule play a greater role in dictating overall energy use. A stated by Brandemuehl and Field (Brandemuehl & Field, 2011) "The rise in importance of these variables [occupant behavior variables] shows that, once a builder has optimized the envelope and building systems, the unpredictable loads generated by the occupants gain greater influence than in a house whose envelope-driven loads dominate the consumption profile". Preliminary results from on-site surveys indicate that net-zero home owners in this study may be disinclined to modify their behavior in pursuit of energy savings; 75% of those surveyed to date stated that they did not make an effort to shut off lights, or set back thermostats as the purchase of a net-zero home would mitigate the need for energy conscious behaviors as related to the use of the home. The population of homes measured as part of this effort include near identical homes that are across the street from one another, with one home owner consciously modifying their behavior to improve their energy use, and the other home owner consciously ignoring energy saving behaviors. With near identical construction and occupant demographics, the impact of different occupant attitudes and behaviors will be illustrated in the difference in energy use between these two homes; the circuit end-use metering will allow further isolation of behavioral impacts on the energy use of specific systems. Questions on occupant behavior include:

- How many people live in the house?
- What are the ages of the occupants?
- Does the home have uses beyond that of a dwelling (home office, other)?
- How often is auxiliary heating and cooling equipment like a space heater or a window A/C unit used?
- What are the typical weekday and weekend occupancy patterns and usage?
- What are the space temperature set-points and schedules?
- Have there been any additions or alternations to the home since its construction?
- What uncommon equipment is present in the building, such as electric cars, battery storage, swimming pool, hot tub, driveway heater, or other?

An on-site survey of plug loads and lighting loads is conducted to further assist in the identification of end-use energy allocation and the impact of occupant behavior on energy use.

Data Analysis

Data for the analysis will come from three primary sources. The three individual data sets will be used to develop a holistic picture of energy use and to support and modify the findings associated with the individual data sets.

On-site M&V Data

On-site data, as captured per the previous section, will be used to determine the performance of the home during the metered period and will constitute the foundation on which end use allocations are built. At a minimum, on-site M&V data will establish total energy use and total energy production from the PV system. Barring any unforeseen physical space limitations in the panel, the evaluators also expect to meter an additional four circuits, prioritized per discussions on home use with the occupants and Table 1. This data will be normalized to several variables including ambient conditions and occupant schedules in order to extrapolate the data out to an annual analysis based on typical meteorological year (TMY3) weather data and site-specific occupant loads.

Utility Data

A minimum 12 months of utility data will be gathered, and will include the metering period. The utility data will be used to tune the annual analysis that is generated through the on-site data and will be particularly useful in triangulating home performance outside of the metering period.

As previously described, utility data will be the sole source of data for fossil fuel consumption. Since fossil fuels serve only one end-use in each of the three homes that use fossil fuels (one space heating, one DHW, and one back-up heating), the associated energy use is easily allocated to its proper end-use. Estimated load shapes will be built based on occupant surveys, appliance nameplate rating, and the utility records.

Owner Data

Many of the owners have been tracking their energy use through their own meters for years. The analysts are using this data to supplement the above and to look at the long term performance of those homes where this data is available. One home has seven years of daily consumption and production data. This data will provide valuable insight into changes in performance over time due to equipment degradation, or the impact of step changes in occupant behavior on energy use, such as the addition of, or growth of, children over a 7 year time span.

This data is valuable, but we cannot ensure the calibration of owner meters or the accuracy of owner supplied data, and so this data will remain as supplementary to the on-site evaluator and utility data. Evaluators will compare evaluation metered data to homeowner data when available to assess the validity of the owner tracked data.

Putting it all together

With all of this data in hand, the authors will generate gross and net[1] energy use intensity (EUI) values, expressed in kBTU/sf as calculated at the site. This unit serves as the basic measure of performance. These values provide an understanding of how well the home performs compared to other homes. The net EUI value allows NYSERDA to identify whether their current HERS rating threshold for net zero performance accurately predicts whether a building will perform as intended. The ratio of gross to net EUI will also be considered to identify the most expedient path to net zero performance. Is it more cost effective to have a moderately efficient home with greater renewable capacity, or a very efficient home with little renewable capacity? This has direct implications on program design.

While the above analysis provides NYSERDA with the basic result of identifying whether or not participant homes perform at net zero levels; the gross and net EUI values, normalized only to building area, provides little insight into the driving forces of energy use and aren’t particularly useful in advancing the understanding of net zero performance or in revising best practices for NZE builders and home owners.

In order to provide a more nuanced view of the data, the evaluators are performing an intensive investigation, looking for correlations between energy use and numerous independent variables, not just gross building area. This aggregate analysis will help the Program better understand the impacts of home use, systems, and occupant behavior on energy use. A selection of metrics that will be analyzed is presented in Table 2.

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[1] Gross EUI values take into account only energy consumption. Net EUI values consider total consumption, and total output of the PV system.

Table 2. Selection of Energy Use Metrics

Metric	Purpose
$\frac{kBTU_{gross}}{sf}$	Total energy use normalized to building area. Provides an overall picture of building performance, before on-site generation is considered
$\frac{kBTU_{net}}{sf}$	Net energy use normalized to building area. Provides an overall picture of building performance, after on-site generation is considered
$\frac{kBTU}{occupant}$	Total energy use normalized to number of occupants. Allows for the assessment of occupant density on energy use
$\frac{kBTU}{occupant_{avg\ age}}$	Total energy use normalized to average age of occupant. Allows for the assessment of occupant age on energy use
$\frac{kBTU_{occupied}}{sf}$	Total energy use normalized to building area for occupied periods. Provides an overall picture of building performance when occupied
$\frac{kBTU_{unoccupied}}{sf}$	Total energy use normalized building area for unoccupied periods. Provides an overall picture of building performance when unoccupied
$\frac{kBTU}{watts_{plug\ load}}$	Total energy use normalized to the total wattage of plug loads. Allows for the assessment of plug loads on total energy use
$\frac{kBTU_{cooling}}{watts_{plug\ load}}$	Cooling energy use normalized to the total wattage of plug loads. Allows for the assessment of the interactive effects of plug loads on cooling energy use
$\frac{kBTU_{heating}}{watts_{plug\ load}}$	Heating energy use normalized to the total wattage of plug loads. Allows for the assessment of the interactive effects of plug loads on heating energy use

Baseline Survey

In addition to determining the overall performance of these net zero homes and analyzing the nuances of design and behavior that drive their energy use, the evaluators will identify the likely less-efficient alternative that the owners would have pursued in lieu of a net zero home through interviews with the home owners and the builders. For the purpose of identifying savings, a baseline must be identified to which the as-built performance can be compared. The evaluators postulate that the likely less-efficient alternative is not a code complaint home; which is the least efficient home you can legally build. Through surveys the evaluators will identify if the likely alternative is a code-complaint home, a typical market home as defined by a recently completed NYSERDA baseline study, or a highly efficient non-NZE home. The builders of these homes will also be providing incremental cost information to identify the extent of additional first costs associated with net zero construction.

Current Status and Next Steps

On-site measurement began in March of 2016 and the metering equipment will be left in place for six months. The 2016 ACEE Summer Study oral presentation will include updates on the number of successfully recruited sites, data and interpretations from the home owner survey on building use, and the results of the utility and historical home owner metered data analysis.

This robust and detailed evaluation of net zero homes in New York will determine the accuracy with which current REM/Rate modeling protocols can predict net-zero home performance and will provide insight into the driving forces of energy use in net zero homes with an emphasis on occupant demographics and behavior. Home energy consumption and PV system generation are analyzed to identify the relationship between efficiency and generation capacity.

Works Cited

Brandemuehl, M. J., & Field, K. M. (2011). Effects of Variations of Occupant Behavior on Residentail Building Net Zero Energy Performance. *Proceedings of Building Simulation 2011*. Sydney: 12th Conference of International Building Performance Simulation Association.

Mahone, D., Pande, A., Kasman, R., & Jones, D. (2014). An Evaluation Framework for Residentail Zero Net Energy Buildings. *2014 ACEEE Summer Study of Energy Efficiency in Buildings.* Pacific Grove: America Council for and Energy-Efficient Economy.