Residential Net Zero Energy: Performance Assessments (2008–2015)

Final Report

03-31-17

Prepared for

The New York State Energy Research and Development Authority

Judeen Byrne, Project Manager

Jonathan Steiner, Project Manager

Prepared by

ERS

120 Water Street, Suite 350

North Andover, MA 01245

Phone: 978-521-2550

NOTICE

CONTENTS

LIST OF TABLES

LIST OF FIGURES

SECTION 1: INTRODUCTION

This report describes the energy performance baseline determination of a group of residential new construction homes in New York State. This effort establishes energy use and energy use per square foot for two performance tiers of residential new construction. The two performance tiers include non-participant market typical and NYSERDA Low-rise Residential New Construction (LRNC) program participant construction.

This Baseline Performance project was conceptualized in the summer of 2015 with the purpose of establishing the actual performance of all net zero performing homes that had participated in the Low Rise Residential New Construction program through June 2015. The original number of homes in the study was 27 (one 3-unit multifamily and 24 single family). However due to attrition, the number dropped to 18 (one 3-unit multifamily and 15 single family). Of the 18 homes, 8 were New York Energy Star Certified Homes and 10 were participants in the Net Zero Tier of the LRNC program. For the purpose of this study all will be collectively referred to as "participant homes". This effort was not intended to be an impact evaluation. No realization rate is generated as part of the analysis, though informative comparisons are made between the metered results and the REM/Rate predicted energy consumption and generation.

The performance of the participant homes was developed by measuring whole home net consumption and solar PV output from the spring of 2016 through early winter 2016. Select end-use circuits were also metered for greater insight into home performance, but data capture on these end uses was not always successful. The metered data was then normalized to various independent variables to develop regression algorithms that modeled the home and photovoltaic (PV) system performance. These algorithms were then used in conjunction with typical meteorological year (TMY3) weather data to calculate their typical annual consumption and solar PV generation.

The on-site measurement and verification found that seven of the 15 single family participant homes were performing at net-zero levels, while the Program had predicted that only two would perform at net-zero levels. On average, these participant homes were found to consume 9% less energy than anticipated in Program modeling estimates.

In addition to performing measurement and verification of energy consumption (M&V) on participant homes, ERS conducted aggregate analysis on a population of REM/Rate files for projects that were included in a recent NYSERDA market baseline study[1]. These homes represent "market typical". The models themselves were not assessed, but instead were reviewed as a population to identify any trends in energy consumption and to establish energy consumption values (kBtu/s.f.[2]) for this tier of construction.

While the information contained in this report is informative, it is important to note that this study represents a small number of homes in a relatively small geographic area, with over 50% of the group having been built by the same contractor. It is therefore important to review the findings within the context of the individual homes and to recognize that the findings are not necessarily representative of net-zero homes at large.

1.1 PROGRAM DESCRIPTION

As NYSERDA's programs transition to align with the Clean Energy Fund (CEF)[3], the residential new construction efforts will move towards market animation activities including technical assistance, training, stakeholder networking, and the identification and implementation of pilot opportunities in integrated delivery and performance validation. As a result of moving away from resource acquisition[4], 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. The performance of the various tiers of efficient construction can be used when comparing efficient homes to a less efficient alternative; establishing performance for several tiers will allow for more nuanced comparisons within a spectrum of performance.

The M&V also sought to provide the Program with in-situ performance information of NZE-performing participant homes. Although finding of this baseline project are distinct to the projects reviewed and are not representative of a larger population of participant or NZE homes, this anecdotal information may be used to help assess whether or not homes participating in the Program are achieving the performance levels anticipated and can help inform the criteria on which the NZE designation is based[5].

[1] Residential Statewide Baseline Study of New York State - July 2015 https://www.nyserda.ny.gov/About/Publications/Building-Stock-and-Potential-Studies/Residential-Statewide-Baseline-Study-of-New-York-State

[2] kBtu/s.f. stands for 1000 Btus per square foot per year. A BTU is defined as amount of heat required to raise the temperature of one pound of liquid water by one degree from 60°to 61°F at a constant pressure of one atmosphere.

[3] The Clean Energy Fund (CEF) is designed to deliver on New York State's commitment to reduce ratepayer collections, drive economic development, and accelerate the use of clean energy and energy innovation.

[4] Resource acquisition in this case refers to efficiency programs that acquire energy savings through technical or financial assistance provided to participants

[5] Qualifying homes must meet a HERS rating score threshold to be considered NZE under Program rules

1.2 SUMMARY OF OBJECTIVES AND METHODS

The primary objectives of this work were to establish energy use for two tiers of construction as detailed in in Table 1-1. Measurement and verification was performed in 2016 for a sample of homes built between 2008 and 2015.

Table 1-1. Objectives and methods

Objective	Purpose	Method
Establish typical range of energy use and energy metrics for non-participant market typical homes - kBtu/s.f.	To provide a reference for the energy consumption of this tier of construction for use and consideration of future Program planning and for the comparison to other tiers of efficient construction	Aggregate analysis of 157 REM/Rate models developed as part of NYSERDA's 2014 Residential Statewide Baseline Study
Establish typical range of energy use and energy metrics for participant homes participating from 2008- June 2015 - kBtu/s.f.	To establish the in-situ performance of participant homes to provide a reference for the energy consumption of this tier of construction for use and consideration of future Program planning and for the comparison to other tiers of efficient construction	On-site measurement and verification of 15 single family homes and one 3-unit multifamily building

The scope of work detailed in the Work Plan was modified early in the planning and execution stages to better align with the ongoing Market Baseline activities, the availability of data, and the existing Program tracking that was in place. Tasks dropped and the reasons for dropping them were:

1. Review of REM/Rate files to assess their viability in establishing energy use and metrics for non-NZE performance for:
    - Code compliant homes[6]
        - Program staff has developed a code compliant model that can be used in REM/Rate when making comparisons to above-code designs. Instead of comparing an above-code design to a deemed or prescribed code-complaint metric, any above-code design is loaded into REM/Rate and de-rated in the model to account for code levels of insulation, infiltration, HVAC system efficiencies, etc. This provides the code complaint basis for future comparison.
    - ENERGY STAR participant homes[7]
        - The ENERGY STAR non-NZE tier was also removed from this effort. Program has historically tracked project level information, and so the effort would include

[6] Based on a NYSERDA developed code reference home

[7] To be based on REM/Rate models developed as part of the LRNC program application process

duplication of some existing information. Additionally, and as with the code compliant tier, current and past versions of ENERGY STAR can be chosen within REM/Rate as the basis of comparison for other designs. This feature of REM/Rate can provide the efficient non-NZE alternative for comparison to other designs.

2. Conduct interviews with home owners and market stakeholders to characterize the baseline alternative to NZE homes. The Impact Baseline team plans to work closely with the Market Baseline team on this effort as both teams are interested in interviewing these groups.

    - The Performance Baseline and Market Baseline efforts did not depend on one another and there was little opportunity for close coordination. The efforts were developed and executed separately from one another. The Baseline Performance team assisted the Market team with outreach since contact had already been established for M&V purposes.

SECTION 2: METHODS

The baseline performance assessment consisted of two distinct efforts; 1) reviewing REM/Rate files from the statewide baseline study to determine market typical energy use and metrics and 2) performing measurement and verification on a group of participant homes to determine as-built performance and energy metrics. The following sections detail the methods used for each task.

2.1 MARKET TYPICAL REM/RATE REVIEW METHODS

NYSERDA transmitted 157 REM/Rate modeling files that were created as part of the 2014 Residential Statewide Baseline Study. These files were simulated in REM/Rate 14 and batch exported to a Microsoft Access database, at which point the data was brought to Microsoft Excel for manipulation and review. Pivot tables and graphing functions were used to examine various independent variables and their relationship to the dependent variables of energy consumption or energy intensity. Excel functions were also used to generate minimums, quartile percentages, maximums, and averages for climate zone and building area in square footage (s.f.) groupings.

The REM/Rate models themselves were not reviewed; the energy consumption estimated by the models was taken to be representative of the homes included in the statewide study.

2.2 PARTICIPANT HOMES MEASUREMENT AND VERIFICATION

The measurement and verification of the participant homes consisted of three primary tasks, each of which is detailed in the following sections

2.2.1 Outreach

Before any M&V could be conducted, the Impact Baseline Team had to make contact with the homeowners to gain permission to visit the home and install metering equipment. Program tracking data did not have contact information for the homeowners, only address, as most of these homes had been submitted to the Program by contractors and developers, not the eventual homeowner. The Impact Baseline Team conducted online public records searches in an attempt to gather current homeowner contact information. This approach was not particularly effective, though some functional contact information was found and used successfully.

As the direct outreach to homeowners had little success, the Impact Baseline Team then reached out to the builders, developers, and architects of these homes to ask for their assistance in contacting the homeowners. This approach was much more effective as these entities were able to provide the team with current contact information and in most cases went so far as to provide an introductory email to the homeowner. The success of this approach is attributed to the fact that the Program has relationships with builders, not homeowners, and to the atypical relationship that existed between the homeowners and the builders. The homeowners and builders were often on a first name basis, and several homeowners allowed the contractor to act as their proxy during the site visit. This level of relationship is different from what the Impact Evaluation Baseline team observed in a recent New Hampshire ENERGY STAR homes evaluation where the builders and homeowners had very little, if any, relationship. The Impact Baseline Team continued outreach until permission for measurement and verification was granted or denied by the homeowner, or after six attempts at contact had been made. Contact attempts were made through a mix of phone calls, emails, knocking on doors, and leaving flyers in mailboxes.

2.2.2 Data collection

Data collection consisted of Program tracking data and REM/Rate files, the installation of metering equipment at the participant home, a survey of occupant characteristics and schedule, and a high-level plug load inventory.

HOBO brand amp loggers and current transducers were installed to monitor energy use of a selection of major subsystems as well as whole home and solar PV systems. The number of end use circuits that were ultimately metered was limited by the physical space in the electric panels, which only allowed for the safe installation of a certain number of current transducers.

Metering was generally performed from the spring of 2016 through early winter of 2016. Two homeowners did not want to extend metering into the winter season and requested that meters be removed during the late summer site visits that were conducted to refresh batteries and download the data captured to date. Metering intervals were generally 1 hour, and some were reduced to 15 minutes in homes where metering was extended into the winter. Table 2-1 provides a summary of data collection points.

Table 2-1. Summary of data points collected

Data point	Attempts - # of homes	Full metering period used - spring-early winter	Partial metering period used - spring-early fall	Partial metering period used - late summer - early winter	No data	Impact
Whole home net	18 (15 single family and one 3-unit multifamily)	16	2	0	0	Limited cold weather data on two homes where owner opted not to extend metering
Solar PV output	15 single family	5	2	6	2	Solar performance was modeled for two homes based on installed PV array and measured performance of other PV arrays of that size
Heat pump	15 single family	2	0	5	8	Limited heat pump end use data
Domestic hot water	15 single family	1	1	3	10	Limited DHW end use data
Well pump	3 single family	0	0	0	3	Well pump power draw was too small to accurately record on CTs
Electric vehicle	2 single family	2	0	0	0	None

Issues with data capture or reliability are detailed in the following points:

- Whole home net – Two homes were only metered during the spring to early fall period.
- Solar PV output – In some instances, a portion of the solar data came back corrupt. In these cases, sufficient data existed for the remaining portions of the data to model solar PV output across the full range of solar insolation experienced at a site.
- End use energy use – Numerous metered end-uses experienced partial or full data loss. These data losses fall into three general categories.
    - ❑ Partial data loss – This generally occurred when multiple leads were run through one current transducer in an attempt to reduce the number of CTs in an electric panel. It appears that the leads were out of phase with one another and effectively canceled each other out. In many cases this was discovered and corrected during the 2nd meter deployment in late summer/early fall and reliable data was captured from that point forward allowing for modeling of that end-use.
    - ❑ Full data loss – This occurred where two leads were run through one current transducer. This primarily impacted the monitoring of heat pumps.

- ❑ Loads too small to be captured on deployed meters – Some loads were too small to be accurately captured with the current transducers deployed. In some cases the energy use of the equipment was so infrequent that it was of no value to the analysis. This is primarily associated with domestic hot water heating equipment (where frequency of use was very low due to the geothermal system providing the DHW) and well pumps (where the load was too small to be accurately captured).

The full or partial loss of end-use data does not impact the overall assessment of whole home consumption or PV output, but does limit the number of instances where reliable end-use data was captured.

To mitigate future metering issues, each lead within in a panel should be run through its own current transducer, particularly if the equipment makes use of both 120V legs within the panel. Once current transducers are installed, the equipment should then be brought under load to validate the installation of the meter and the readings provided.

2.2.3 Analysis

Analysis activities included site level and aggregate level data review.

2.2.3.1 Site level analysis

The analysis methodology consisted of regressing metered data against various independent variables to identify strong correlations on which an 8,760-hourly model could be built. The independent variables that showed the closest and most consistent correlation to energy use were outdoor air enthalpy (Btu/lb.) and time of day. The analysis of each site occurred according to the following process:

- Metered data was downloaded, cleaned, and organized into hourly values. The metered amp data was then converted to kW data with spot measured voltage and power factor readings.
- The clean data was then regressed against independent variables including:
    - ❑ NOAA historic weather data for the relevant time periods and weather station locations
    - ❑ Historic solar insolation data as purchased from Solar Data Warehouse for the time period of metering for the locations of Brooklyn, Buffalo, and Poughkeepsie.
    - ❑ Time of day
    - ❑ Day of the week
- Regressions were reviewed to identify the numerical models that best fit the data based on R^2 values and engineering judgement.

- Selected regression algorithms were then used with typical meteorological year (TMY3) data to calculate whole home energy consumption, solar PV output, and end-use energy consumption where possible.

2.2.3.2 Aggregate analysis

The energy consumption, production, and end use values and metrics were compiled in an Excel spreadsheet for manipulation and review. Similar to the market typical review approach, though with different raw data, pivot tables and Excel functions were used to group and analyze the participant site level data to identify trends and/or patterns in energy use, energy intensity, and solar PV system performance.

SECTION 3: RESULTS, FINDINGS AND RECOMENDATIONS

This section presents the findings of the research.

3.1 AGGREGATE ANALYSIS OF REM/RATE MARKET TYPICAL HOMES

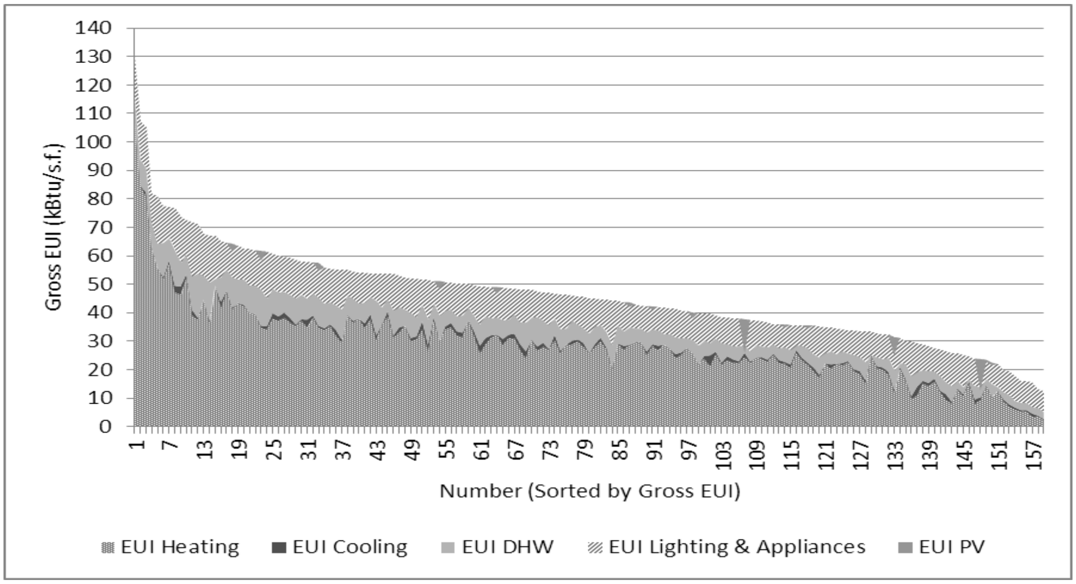
The homes reviewed were all single family[8], and were built between 2009-2015. There was no data within the files to indicate if the year built was indicative of new construction or gut rehab. Data was analyzed to determine total site energy use intensity (EUI) expressed as kBtu/s.f.

The data yields a wide range of EUI values, as would be expected in a baseline study that includes efficient homes as well as minimally code compliant homes. The size and geographic location of the home also plays a role in its total energy consumption.

A graphical representation of the entire population reviewed is presented in Figure 3-1. The projects are sorted by energy intensity along the x-axis, with the most energy intensive on the left, and the least energy intensive on the right. The values on the x-axis represent the cumulative count of sites. EUI consumption values for end uses are plotted and stacked in order to illustrate total EUI, and the contribution of each end-use on total energy consumption. Gross EUI is defined as the total on-site energy consumption, irrespective of on-site generation.

[8] NYSERDA provided 157 REM/Rate model files from the 2014 Residential Statewide Baseline study for use in the review. Data from the files was exported to a database for review and analysis.

Figure 3-1. Gross EUI values of market typical homes



What can be observed in the above graph is the large contribution of heating, and lighting and appliances energy use in terms of overall energy use.

Table 3-1 presents a summary of basic home characteristics and total and end-use energy intensities by climate zone[9].

Table 3-1. Home characteristics and energy intensities sorted by climate zone

Market Typical Population Statistics				
	Zone 4	Zone 5	Zone 6	Total
Basic Data				
Number of Homes in Sample	9	107	41	157
Avg. Conditioned Area	3,356	2,724	2,621	2,733
Avg. Number Bedrooms	3.0	3.4	3.0	3.3
Percentage Homes with Solar PV	11%	12%	5%	10%
Modeled Performance and End Use Breakdown				
Avg. Gross EUI (kBtu/SF)	30.7	48.0	44.3	46.0
Avg. Net EUI (kBtu/SF)	29.5	47.6	44.2	45.7
Percent Heating Energy	52%	62%	63%	62%
Percent Cooling Energy	5%	2%	1%	2%
Percent Domestic Hot Water Energy	13%	14%	12%	13%
Percent Lighting & Appliances Energy	31%	22%	24%	23%

[9] Climate zones are geographical areas with distinct climates. The climate zones referenced are defined by ASHRAE. They are used in this report to identify weather related energy use trends for the different climate zones in New York.

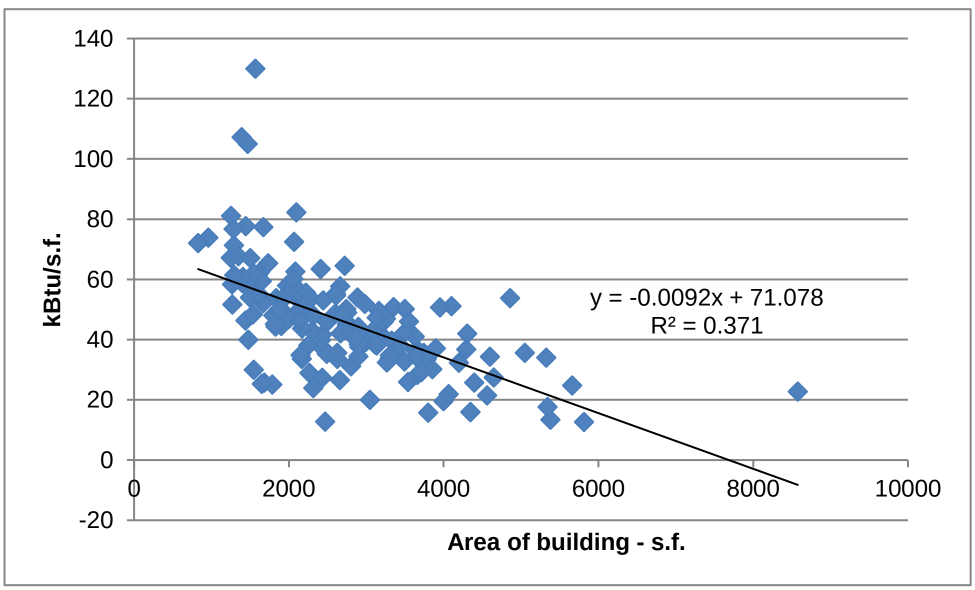
The end use breakdown in Table 3-1 illustrates that over 50% of the energy use is associated with space heating, and as would be expected, that the percent of energy use associated with heating increases in colder climates (5 & 6). Table 3-2 presents the same information but sorted by area of the home. As energy use changes with climate zone, it also varies based on the size of the home.

Table 3-2. Home characteristics and energy intensities sorted by building area (s.f.)

Market Typical Population Statistics					
Square Footage Range	**<2000**	**2000-2999**	**3000-3999**	**4000+**	**Total**
Basic Data					
Number of Homes in Sample	46	56	35	20	157
Avg. Conditioned Area	1,550	2,468	3,470	4,893	2,733
Avg. Number Bedrooms	2.8	3.3	3.5	4.0	3.3
Percentage Homes with Solar PV	13%	5%	11%	15%	10%
Modeled Performance and End Use Breakdown					
Avg. Gross EUI (kBtu/SF)	60.1	46.3	38.1	28.1	46.0
Avg. Net EUI (kBtu/SF)	59.6	46.0	37.6	28.0	45.7
Percent Heating Energy	62%	63%	62%	58%	62%
Percent Cooling Energy	2%	2%	3%	3%	2%
Percent Domestic Hot Water Energy	14%	13%	12%	11%	13%
Percent Lighting & Appliances Energy	22%	22%	23%	28%	23%

Table 3-2 above indicates that total EUI decreases with an increase in total building area. This is due to fixed loads (such as the energy consumed by a refrigerator) being distributed over a larger area in the calculation, resulting in a lower EUI. This is further illustrated in Figure 3-2.

Figure 3-2. Energy use intensity versus area of building



While EUI decreases with an increase in building area, total energy use increases with an increase in building area as shown in Figure 3-3.

Figure 3-3. Total energy use versus area of building

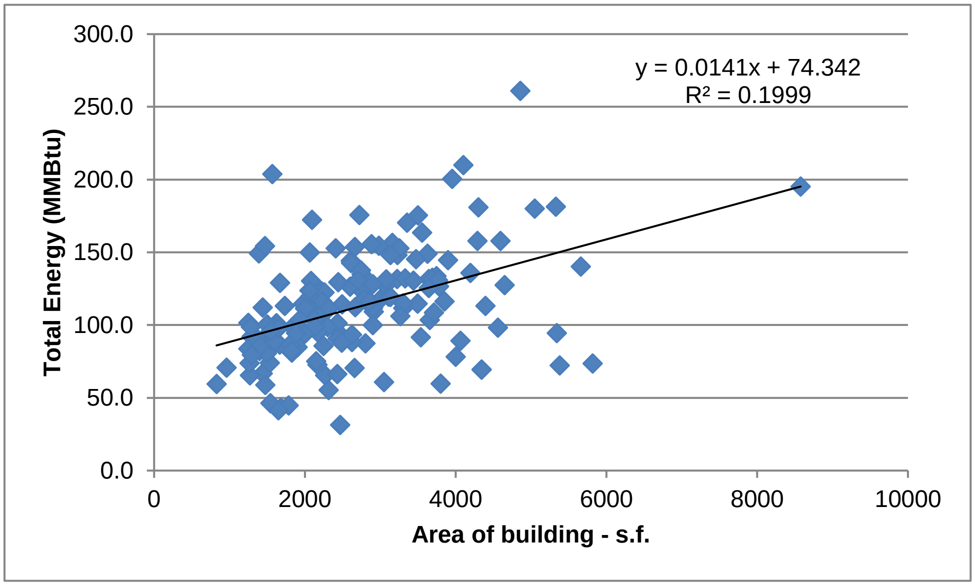


Table 3-3 provides a summary of the ranges and average EUI values for the market typical home tier of construction. Additional break-downs and comparisons are provided in Appendix A.

Table 3-3. Summary of EUI ranges and averages for typical market homes

Value	Min	25th percentile	75th percentile	Max	Average
Total EUI - kBtu/s.f.	12.7	35.5	54.4	130.0	**46.4**
Heating EUI - kBtu/s.f.	2.2	21.7	35.0	107.8	**28.7**
Cooling EUI - kBtu/s.f.	0.0	0.4	1.4	3.8	**0.9**
DHW EUI kBtu/s.f.	0.0	4.4	8.0	15.6	**6.2**
Lights, appliances - kBtu/s.f.	6.6	8.8	11.9	19.2	**10.5**

3.2 ANALYSIS OF PARTICIPANT HOME PERFORMANCE

This section provides the results of the M&V activities performed on 15 single family homes and one 3-unit multifamily home. Current readings (amps) were measured for whole home net consumption and for solar PV output at hourly intervals from spring 2016 through early winter 2016. Two homeowners requested the meters be removed in early-fall and did not permit extending the metering period into the winter. Spot measurements of voltage and power factor were also made. In addition to whole home net energy[10] and solar PV system output, select end-uses metering was attempted where possible[11]. End-use metering was not always successful as further detailed in Section 3.

Seven of the 15 single family homes were found to be performing at net zero levels[12]. Of those seven, two were part of the ENERGY STAR program, and five were part of the Net Zero Tier of the LRNC program. The original REM/Rate models predicted that two of the homes would perform at net zero levels. A less rigorous analysis was performed on the 3-unit multi-family due to issues accessing sub-panels for metering, but a partial utility analysis performed on the available data strongly suggests the one multi-family building in the group is not achieving net zero performance levels.

3.2.1 Single family home findings

Nine of the population of 24 either declined to participate or were unresponsive to outreach. This section provides aggregate findings for the 15 single family homes that did receive M&V.

The heating fuel for all 15 homes in the M&V group is electricity, as they are all served by either ground source or air source heat pumps. An overview of the homes is provided in the following bullet points:

- Construction completed between 2008 – 2015
- Size range from 756 – 4,382 SF
- Infiltration range from 0.14 – 3.3 ACH_{50}
- One contractor built 50%+ of program homes
- 11 (75%) ground source heat pumps (GSHP) and 4 (25%) air source heat pumps (ASHP)
- Electric domestic hot water, typically preheated via GSHP or solar thermal
- Lighting predominantly CFL and LED
- All homes generate electricity with PV arrays

Table 3-4 provides an overview of Program tracking data on the population of single family projects, sorted by building area. This data was extracted from the REM/Rate models created as part of the LRNC program application process.

---

[10] Net energy is the total energy of the site including the impact of renewables. A site can be a net-producer where they generate more electricity than they use in a year, or they can be a net consumer where they consume more energy than they produce in a year.

[11] Space constraints within the panel dictated the extent to which end use circuits could be metered

[12] A net zero home produces at least as much energy as it consumes over the course of a year through the use of on-site renewables.

Table 3-4. Program tracking data - Average participant home characteristics and estimated performance[1]

Site	Year	Square feet	REMRate consumed - kWh	REMRate solar production - kWh	REMRate net - kWh	EUI - kBtu/s.f.	PV array nameplate rating	Tracking HERS index
ENERGY STAR	2011	2,892	12,975	(11,026)	1,950	15.5	9.1	6
Net Zero Tier	2014	2,403	9,878	(7,920)	1,958	15.7	6.5	8
All sites	2013	2,620	11,255	(9,300)	1,954	15.6	7.7	7

[1]Findings are distinct to the projects reviewed and are not representative of a larger population of NZE homes

REM/Rate modeling estimated that two of the homes would achieve net zero performance. Table 3-5 compares the average total on-site consumption as determined through the measurement and verification activities to the average total on-site consumption estimated in the REM/Rate models. On average, the homes performed approximately 9% better than anticipated.

Table 3-5. Comparison of average M&V total consumption to REM/Rate modeled total consumption[1]

Site	M&V consumed - kWh	REM/Rate consumed - kWh	Difference
ENERGY STAR	11,824	12,975	-9%
Net Zero Tier	10,041	11,075	-9%
All sites	10,992	12,088	-9%

[1]Findings are distinct to the projects reviewed and are not representative of a larger population of NZE homes

*3.2.1.1 **Measured consumption in excess of modeled consumption***

Two homes yielded consumption values that were notably larger than anticipated by REM/Rate. In both instances, the excess of energy use can be understood when the characteristics and behavior of the occupants are considered.

One of the homes was larger with three bedrooms and a higher number of occupants, most of whom occupied the building nearly all hours of the day. REM/Rate calculates lighting and appliance loads based on total area of the building and does not consider the number of bedrooms or the number of occupants, nor does it attempt to estimate miscellaneous plug loads. Therefore, the REM/Rate model would predict similar lighting and appliance loads for sites that are similar in size but does not account for greater connected plug load or diversity in occupant loads and schedules.

This illustrates a shortcoming with REM/Rate modeling for net zero homes; as the envelope performance of the homes increases and a greater percent of the modeled energy use and therefore total energy use, is attributed to lights and appliances, the accuracy with which those loads are estimated becomes more important. Without a way to control for variance in occupancy and miscellaneous loads (including the unknown impact of plug loads), REM/Rate will not be able to accurately predict plug load differences between similar homes with different occupancy rates or densities.

The other home is using approximately 250% more energy for space conditioning than estimated in the REM/Rate model. This site is an outlier in terms of both heating distribution equipment and the occupants' desire for very warm conditions, both of which explained the increase in total energy and space condition energy consumption as compared to the REM/Rate model.

Table 3-5 above is modified in Table 3-6 to show the relative performance of the group without the two outlier sites discussed above.

Table 3-6. Comparison of average M&V total consumption to REM/Rate modeled total consumption with outlier site breakout[1]

Site type	M&V consumed - kWh	REM/Rate consumed - kWh	Difference
Non-outlier sites	9,957	11,997	-17%
Outlier sites	17,718	12,680	42%

[1]Findings are distinct to the projects reviewed and are not representative of a larger population of NZE homes

On average and excluding the two outlier homes, as a group the homes performed approximately 17% better than anticipated.

*3.2.1.2 **Review of solar PV performance***

The M&V activities found that actual solar output had a strong correlation to historic total insolation data[13] (w/m^2) and that REM/Rate estimates of solar PV generation aligned well with measured values.

Measured solar output vs. REM/Rate estimated output

Table 3-7 compares the average calculated annual solar output based on metered data and analysis to the average annual output estimated by REM/Rate.

Table 3-7. Average measured solar PV output vs. REM/Rate estimated solar PV output[1]

Site	M&V solar output - kWh	REM/Rate solar output - kWh	Difference
ENERGY STAR	(10,647)	(11,026)	-3%
Net Zero Tier	(9,599)	(8,927)	8%
All sites	(10,158)	(10,046)	1%

[1]Findings are distinct to the projects reviewed and are not representative of a larger population of NZE homes

[13] Insolation is the amount of solar radiation an area receives, defined as watts per square meter (w/m^2)

On average, the homes generated approximately 1% more electricity than anticipated by the REM/Rate models.

Correlation between solar PV array output and historic solar insolation data

In order to assess PV performance, the measured output had to be compared to some independent variable. For this effort, the independent variable that provided the best R^2 value when regressed against PV output was total solar insolation. Recent historic solar insolation data could not be found by the Impact Baseline Team within the public domain. Typical solar insolation data in available as part of TMY3 data, but not recent historic data that coincided with the period of metering.

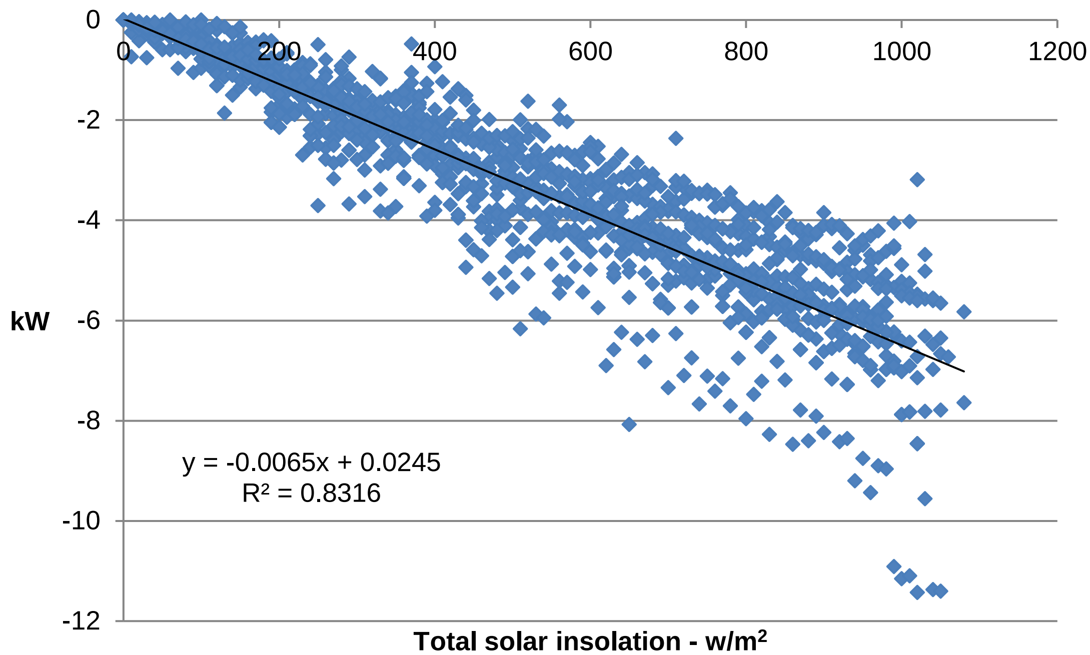
Since historical location-specific solar insolation data was needed to perform the analysis, the Impact Baseline Team purchased a data set from Solar Data Warehouse[14], who provides recent historic solar insolation data gathered from various public and private sources. The purchased data has since been transferred to NYSERDA for possible use on other efforts.

The output of the PV arrays regressed well against the historic total insolation data, typically producing R^2 values[15] above 0.9 for a given site. The correlation remains when the insolation and output data is considered for the group of homes. Figure 3-4 plots the solar insolation to PV array output for the homes as a group.

[14] Two potential sources of data were found, Solar Data Warehouse, and Solar Anywhere[14]. Solar Data Warehouse provided the data required at a lower cost. www.solardatawarehouse.com and www.solardataanywhere.com

[15] In a regression analysis, the R^2 value provides an indication of how well the independent variable correlates to the dependent variable. An R^2 of 1 indicates a perfect relationship between the two variables, and R^2 of 0 would indicate that there is no relationship between the two variables.

Figure 3-4. Solar insolation vs. PV array output for all measured participant homes[1]



[1]Findings are distinct to the population reviewed and are not representative of a larger population of NZE homes

Grid utilization

All the homes reviewed had photovoltaic systems installed. During daylight hours, these systems generate electricity to offset on-site use, and any excess generation is exported to the grid. These homes often generate more electricity than they consume during daylight hours.

All of the homes reviewed except one are net exporters of energy during peak periods as defined by the New York State Technical Resource Manual (TRM)[16]. Even homes that do not reach net zero levels of performance on an annual basis were found to be net exporters during peak demand periods[17].

On average, the home demand during the peak period was -2.4 kW. In other words, during the peak period each home was contributing 2.4 kW of supply to the grid, in addition to offsetting the load being consumed on site, which was typically 1 kW during the peak period.

16 http://www3.dps.ny.gov/W/PSCWeb.nsf/96f0fec0b45a3c6485257688006a701a/72c23decff52920a85257f1100671bdd/$FILE/ATTESQKL.pdf/TRM%20-%20Version%204.0-April%202016.pdf

17 Peak demand describes a period of time when electrical power demand from the grid is expected to be notably higher than the average demand. cycles.

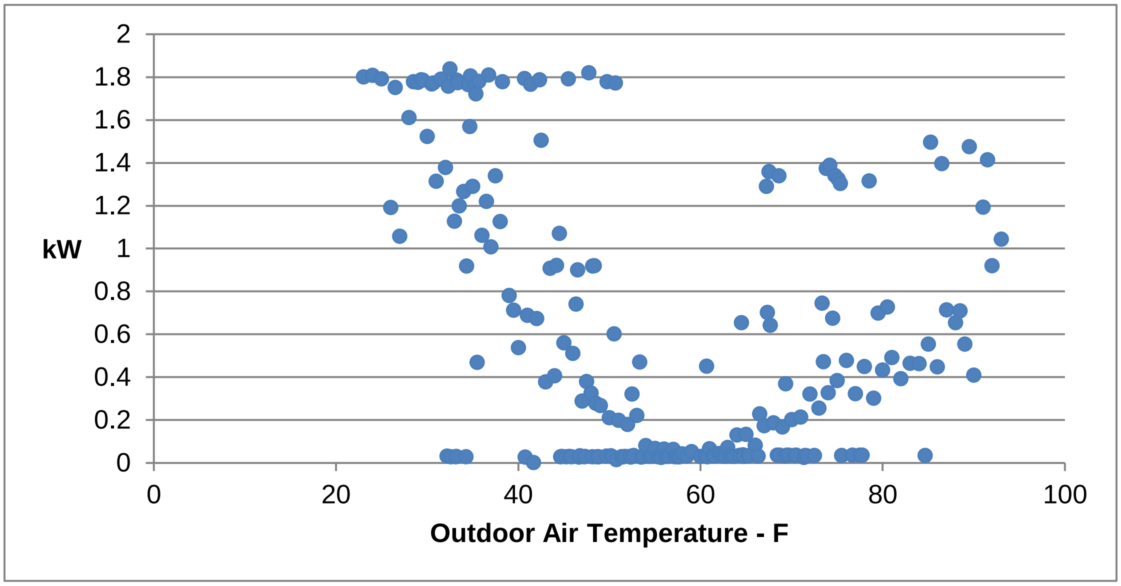
3.2.1.3 Heat Pump Performance

Though successful data capture on heat pumps was limited, some observations can be made regarding the performance of the systems reviewed.

- Most of the systems reviewed (74%) were geothermal ground source heat pump (GSHP) systems. The remaining systems were air source heat pump systems
- The GSHP systems were tied into the domestic hot water systems and provided the majority of domestic hot water based on the metering of the DHW systems.
- The GSHP systems ran infrequently on an hourly basis, and drew little power based on hourly averages. When outdoor temperatures were at their hot and cold extremes, both run time and power draw increased.

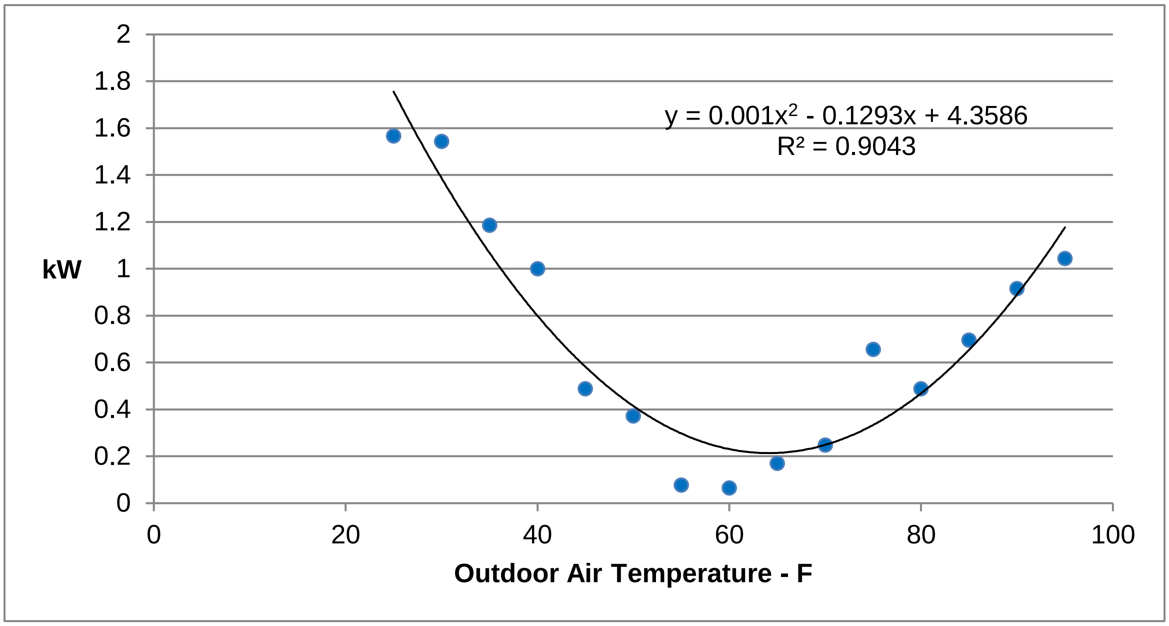
Figure 3-5 plots the typical metered power draw of a GSHP system. The plot is based on the hourly average of the metered date.

Figure 3-5. Typical GSHP weather correlation



Arranging the data in Figure 3-5 into discreet five-degree temperature bins and averaging the input power in those temperature bins provides better clarity on the relationship between GSHP input power and ambient conditions. This plot is presented in Figure 3-6.

Figure 3-6. Typical GSHP weather correlation – 5-degree temperature bins



A clear trend exists where power draw increase during the hottest and coldest hours. The increase in power is largely attributable to building envelope losses and gains since the performance of a GSHP system is not heavily influenced by outdoor conditions as the energy heat source (or heat sink) is the earth, the temperature of which remains nearly constant.

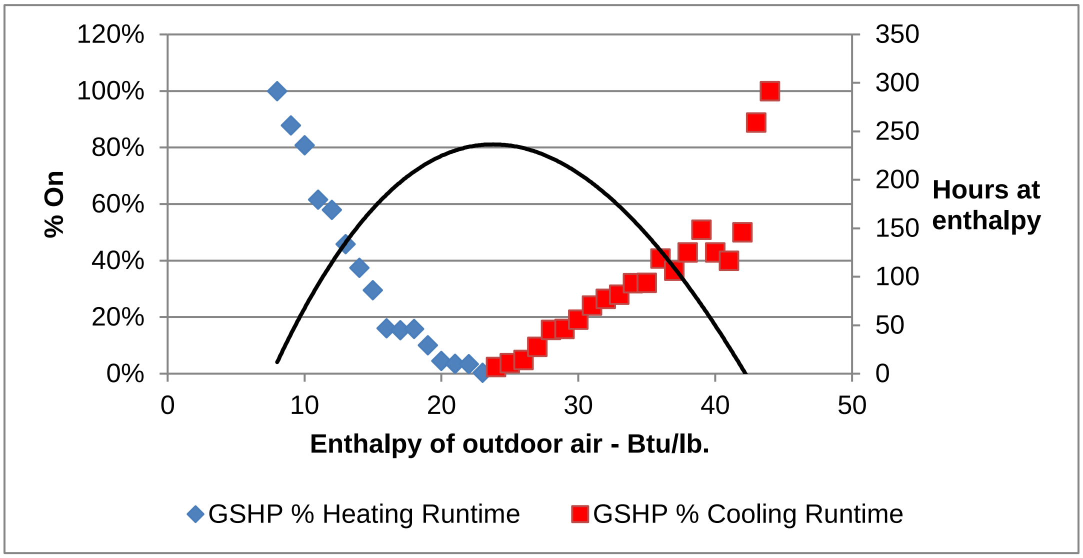
Figure 3-7 plots the run time based on binned[18] enthalpy[19] values, and the number of hours at a given enthalpy bin. The large arc represents the count of hours at a given outdoor air enthalpy bin. What can be seen in this plot is that for the majority of the outdoor air conditions experienced over the course of a year, the GSHP system runs less than 40% of the time.

---

[18] "Binning" refers to separating value into discreet groups. For example, the temperatures of 71, 72, and 73 could all be placed in the 70 degree "bin", while 76 and 77 may be placed in the 75 degree "bin"

[19] Enthalpy is a measurement of energy contained in the air, expressed in Btu/lb. of air. Outdoor air enthalpy can be used in a regression in lieu of, or in addition to, outdoor air temperature

Figure 3-7. Run time and hours at enthalpy bins



3.2.1.4 Additional energy metrics and summary of findings

This section includes a collection of figures comparing the dependent variables of total energy consumption, EUI, or solar array output to various independent variables such as area of the building or modeled energy consumption. Figures of additional comparisons are included in Appendix A.

Figure 3-8 compares the evaluated kWh consumption against the REM/Rate modeled predicted consumption. If projects performed exactly as modeled, the points would all fall directly on the diagonal line. This diagonal line represents a realization rate of 1. Data points below the diagonal line indicate less energy use then predicted, and points above the line indicate greater energy use than anticipated.

Figure 3-8. Evaluated vs. modeled consumption[1]

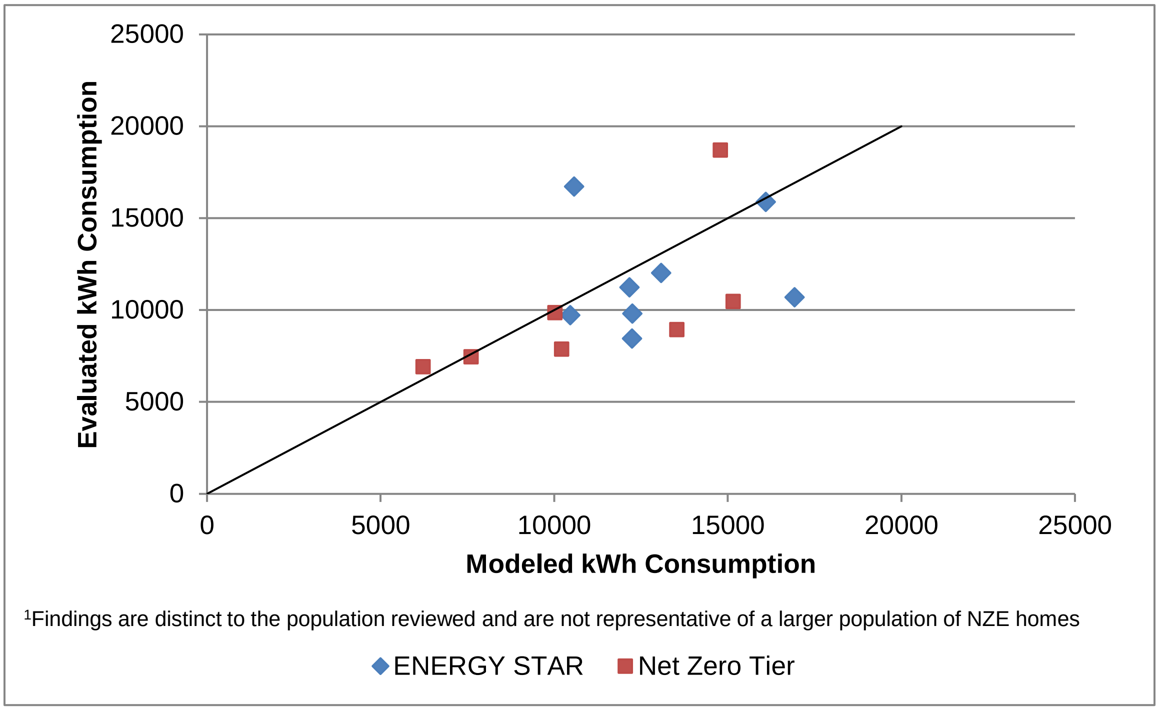
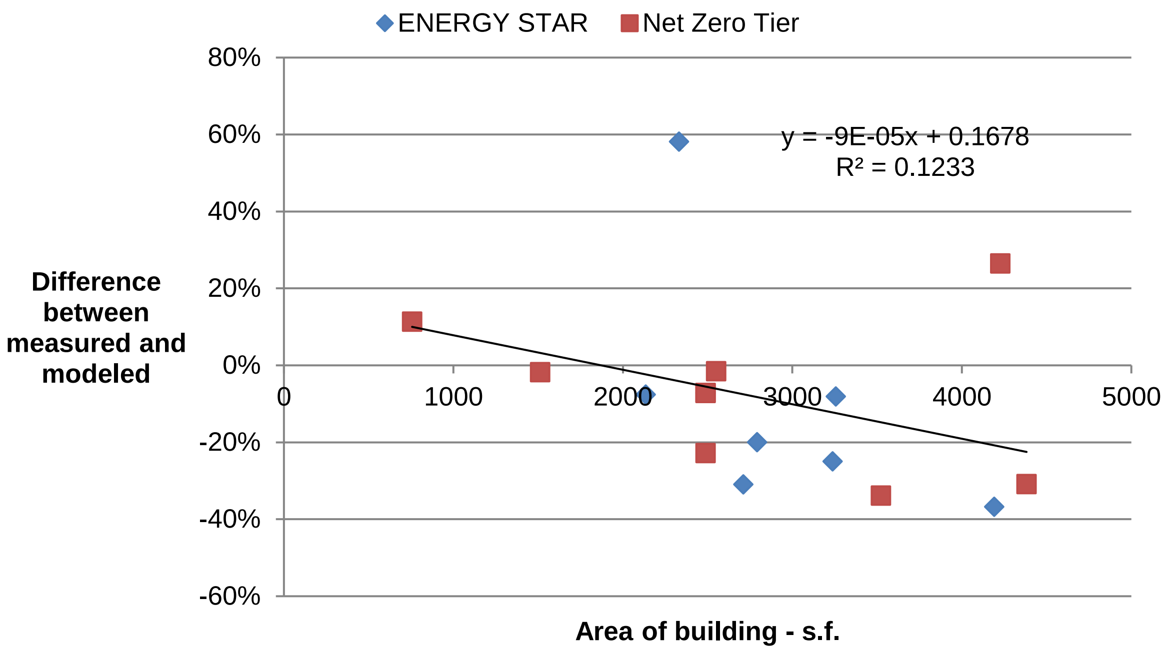


Figure 3-8 demonstrates that most of the homes are consuming the same or less energy than predicted in REM/Rate models. The two points farthest above the vertical line are the sites discussed in Section 2.2.1.1.

The better than anticipated performance of the homes illustrates another relationship apparent in the data for this group: as the home size increase, the actual energy consumption goes down in relation to the modeled performance. In other words, the larger the home, the greater the difference between measured vs. modeled performance, with measured energy use being less than modeled. This data is plotted in Figure 3-9. A negative percentage indicates less actual energy use then modeled in REM/Rate.

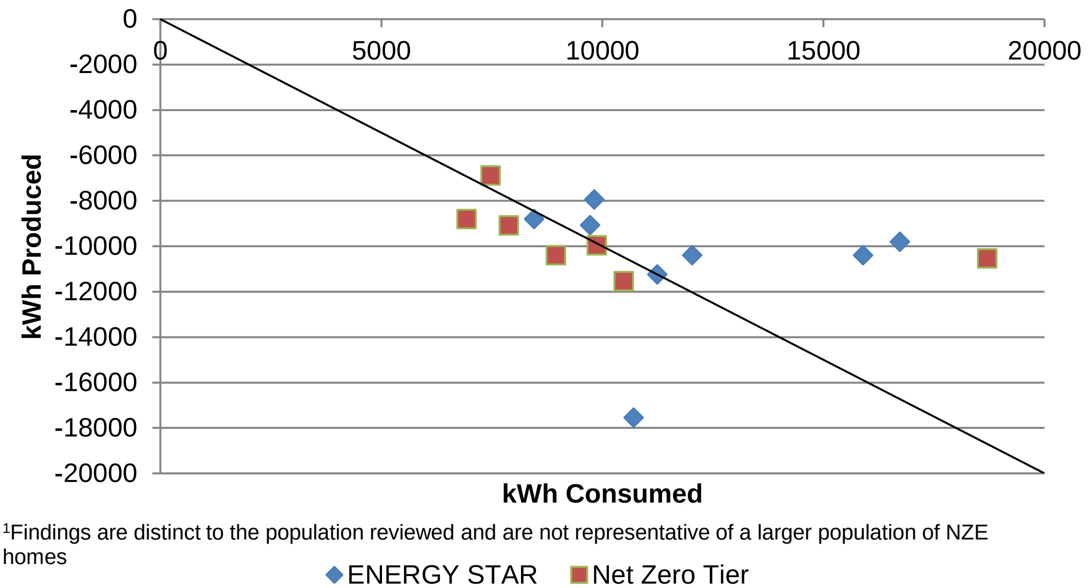
Figure 3-9. Difference in measured vs. modeled performance compared to area of home[1]



[1]Findings are distinct to the population reviewed and are not representative of a larger population of NZE homes

Figure 3-10 provides a plot of measured kWh consumption vs. measured PV output. The diagonal line represents an ideal where the home generates as much as it consumes and is exactly net zero. Homes above and to the right of this line are net energy consumers, and homes below and to the left of this line are net energy producers.

Figure 3-10. Measured consumption vs. measured PV generation (in kWh)[1]



[1]Findings are distinct to the population reviewed and are not representative of a larger population of NZE homes

Table 3-8 provides a summary of the findings expressed as kBtu/s.f.

Table 3-8. Summary of home performance[1]

	Area - s.f.	Consumption EUI - kBtu/s.f.	Production EUI - kBtu/s.f.	Net EUI - kBtu/s.f.
ENERGY STAR	2,892	15	(12)	2.8
Net Zero Tier	2,776	14	(14)	(0.7)
REM/Rate Market Typical Homes - Avg.	2,733	46.0	(0.3)	45.7

[1]Findings are distinct to the projects reviewed and are not representative of a larger population of NZE homes

The information in Table 3-8 above is revised to exclude the two outlier homes, and this information is presented in Table 3-9.

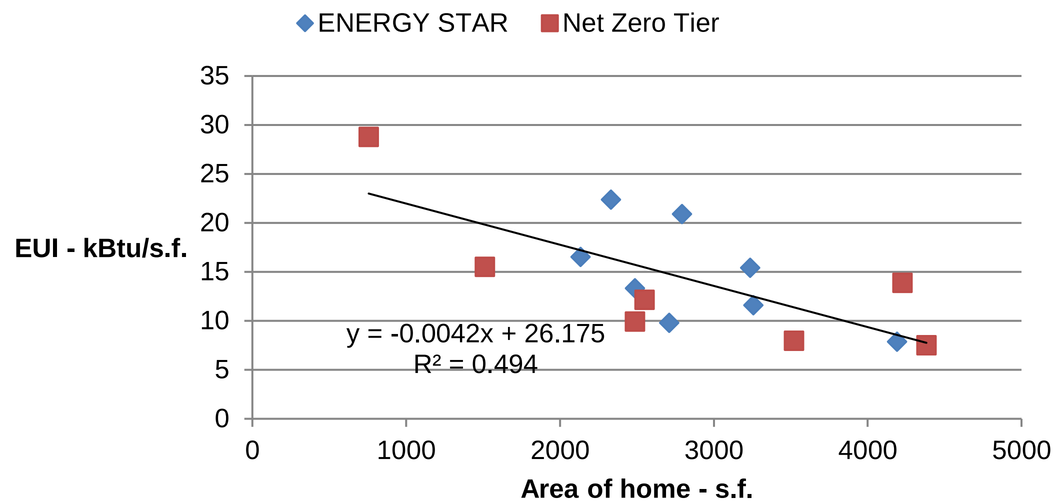
Table 3-9. Summary of home performance excluding outlier sites[1]

	Area - s.f.	Consumption EUI - kBtu/s.f.	Production EUI - kBtu/s.f.	Net EUI - kBtu/s.f.
ENERGY STAR	2,972	14	(12)	1.9
Net Zero Tier	2,535	14	(15)	(1.8)
REM/Rate Market Typical Homes - Avg.	2,733	46.0	(0.3)	45.7

[1]Findings are distinct to the projects reviewed and are not representative of a larger population of NZE homes

While the tables above demonstrate a clear difference in the average EUI values between participant and market typical homes, it is important to note that EUI (kBtu/s.f.) is a function of building area. The greater the denominator of the equation (the area of the home), the smaller the apparent EUI for a given amount of energy consumption. It is also important to note that EUI values for a given home are best used to compare the performance of that home to one of a similar size, though substantial variance can still exist due to differences in number of occupants, their schedules, and their behavior. Figure 3-11 illustrates the downward trend in EUI with an increase in building area.

Figure 3-11. Energy intensity (kBtu/s.f.) vs. building area[1]



[1]Findings are distinct to the population reviewed and are not representative of a larger population of NZE homes

This trend can be attributed in part to the fact that these homes had on average 2.6 occupants regardless of the size of the home. Therefore, the EUI calculation effectively spreads the fixed loads associated with occupants (heat gain due to occupants, lighting and appliances, etc.) over a larger area (larger denominator) resulting in a lower EUI value.

This same trend is observed within the market typical group in Figure 3-2.

3.2.2 Multifamily review

One three-unit multifamily building was included in the review. The home participated in the net zero tier of the LRNC program. The panel configurations at the 3-unit multifamily only allowed for measurement of whole unit net energy consumption. Net energy consumption at the meter is very difficult to interpret without corresponding solar data as it is not clear for any given hour whether the energy being measured is being provided by the grid or being exported to the grid. The Impact Baseline Team planned to use utility data to triangulate the measured data, but limited utility data was available for use and was insufficient to definitively determine if the home performed at net zero levels. More research and metering of individual unit sub-panels are necessary to clarify the annual performance of this home.

3.3 KEY FINDINGS

The key findings are summarized below. However, the findings are distinct to the population reviewed and are not representative of a larger population of participant or NZE homes.

- The participant homes in the group generally performed better than estimated in the REM/Rate models.

- The homes completed under the Net Zero Tier, on average, perform at the net zero level. The homes completed under the ENERGY STAR program, on average, perform just above net zero performance.
- The REM/Rate models, and specifically the process that Program uses to modify REM/Rate model for solar predictions to align with values calculated by the contractor for the NY-SUN Program, predict solar PV output well and serve as a good tool for predicating solar PV array generation.
- In this group of homes, the REM/Rate models tended to overestimate energy use, and there is an apparent relationship between the difference between measured and modeled performance and the size of the home as shown in Figure 3-6 above. As the homes get larger, the measured use goes down in relation to the modeled use. If this trend is representative, REM/Rate models will tend to understate the energy use of homes under 2,000 s.f. and overestimate the energy use of homes greater than 2,000 s.f.
- Occupant density and behavior have an undeniable, though difficult to quantify, impact on energy use. As building envelopes and mechanical equipment efficiencies become asymptotic[20] in terms of performance, greater emphasis will need to be placed on educating owners on the use and operation of the home, including temperature set-points[21] and the impact of plug loads in order to achieve even greater levels of performance.
- HERS index for NZE designation – Current Program rules use a HERS value of 10 as the threshold to qualify as an NZE project. A higher HERS Index indicates more energy use, a lower HERS index indicates less energy use. In theory, a HERS Index of 0 indicates a home that will perform at net zero levels. The review found the average modeled HERS value for homes that achieved net zero performance was 6.8. There were two homes originally modeled with a HERS index of 9 that achieved net zero performance. Based on these values, the current target HERS index of 10 is a reasonable threshold and predictor for NZE designation.
- Grid utilization – Although not all homes performed at net zero levels on an annual basis, all but one home were net exporters of electricity during peak demand periods. This is attributable in

[20] An asymptotic line is one that approaches a given limit, but never touches it. In this context, asymptotic refers to the diminishing returns of increased envelope performance or improved mechanical equipment efficiencies. The envelopes and mechanical systems in the participant homes are so efficient, that further improvement of these systems will only generate minor improvements in performance.

[21] Temperature set-points refer to the thermostat settings of the homes.

part because of the low cooling requirements of these homes due to their high-performance envelopes, and due to the fact that peak demand periods coincide with times of the year where there is high solar insolation and therefore PV system output.

APPENDIX A: ADDITIONAL AGGREGATE ANALYSIS PLOTS

This Appendix presents additional scatter plots of data with a description of the plot and observations of trends where appropriate.

Market Typical Scatter Plots

This section presents a selection of scatter plots from the aggregate review of REM/Rate market typical homes[22].

Figure A-1 compares the area of the home to the total annual energy consumption (electricity and fuel) against the area of the home. Energy use trends upward with an increase in building size. What can also be seen in the plot is great variability of energy use for any given size of home. This is further illustrated by the low R^2 value of the linear trend line. While there is a correlation between the size of the home and its energy use, other factors, like occupant density and schedules, play a substantial role.

Figure A-1. Market Typical Total Energy Consumption versus Area of Building

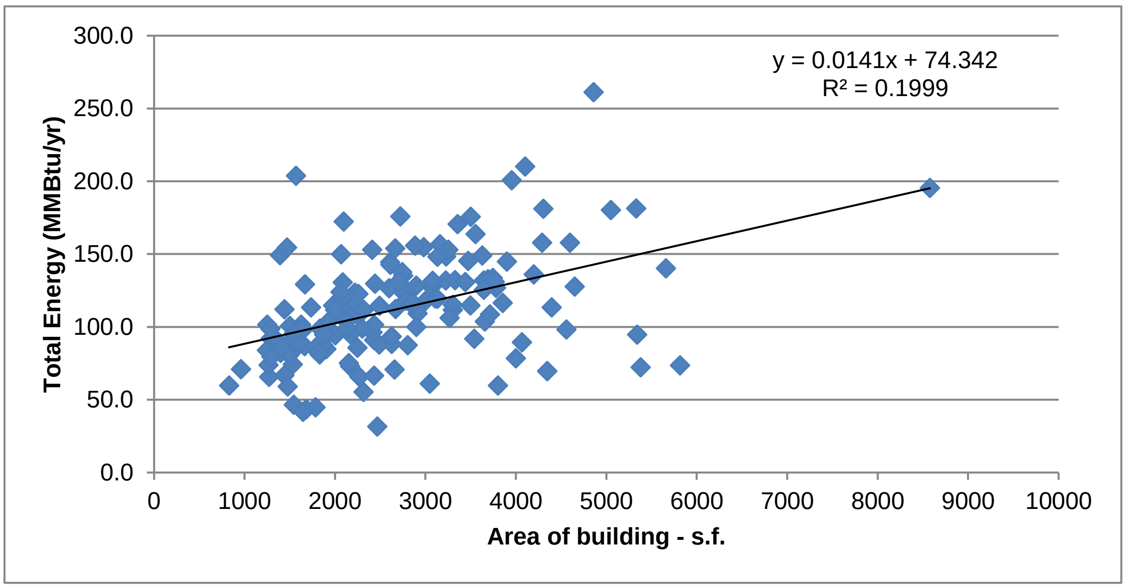
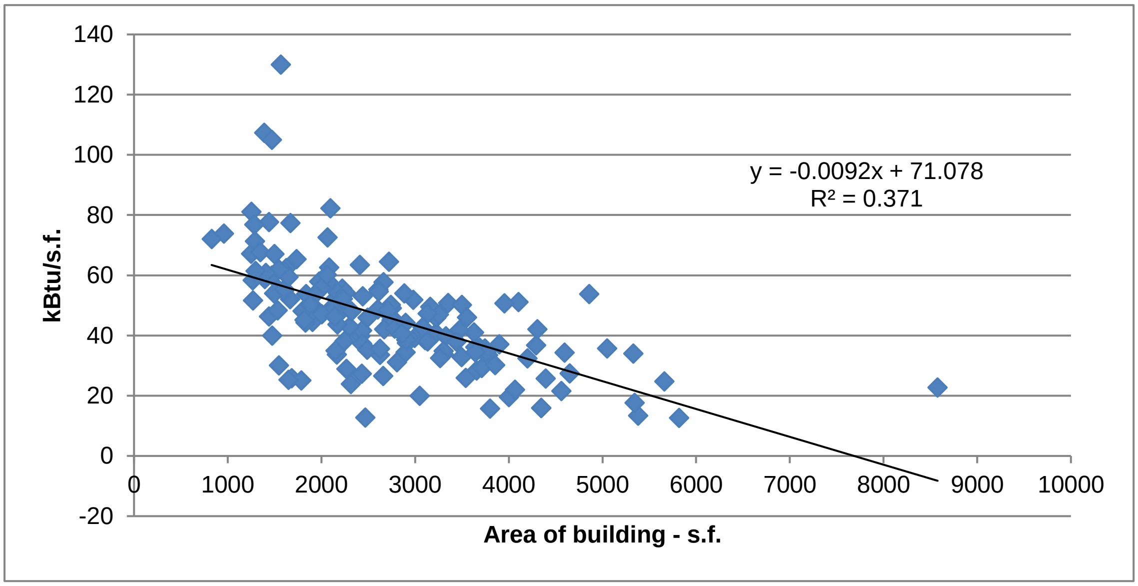


Figure A-2 compares the energy use normalized to building area. The normalized energy use is referred to as energy use intensity (EUI) and is expressed as kBtu/s.f. EUI values trend down as building area increases. As discussed in Section 2.2.1.4, this is due to fixed energy loads (loads unrelated to the size of the home, such as a refrigerator) being normalized over a greater area.

[22] Residential Statewide Baseline Study of New York State - July 2015
https://www.nyserda.ny.gov/About/Publications/Building-Stock-and-Potential-Studies/Residential-Statewide-Baseline-Study-of-New-York-State

Figure A-2. Market typical EUI versus area of building



Similar to Figure A-1, Figure A-3 plots total energy use against area of the building, but in Figure A-3 the homes are further grouped by climate zone. Trend lines are included for Zone 5 and Zone 6 which demonstrate different behavior with respect to building area. For this group of homes, those in Zone 5 tend to use more energy with an increase in building area than those in Zone 6. It is not clear why this is the case; the difference in ambient conditions between Zone 5 and 6 does not explain the difference in the trend line, therefore there are others factors at play outside of ambient weather conditions.

Figure A-3. Market Typical Energy Use versus Area of Building by Climate Zone

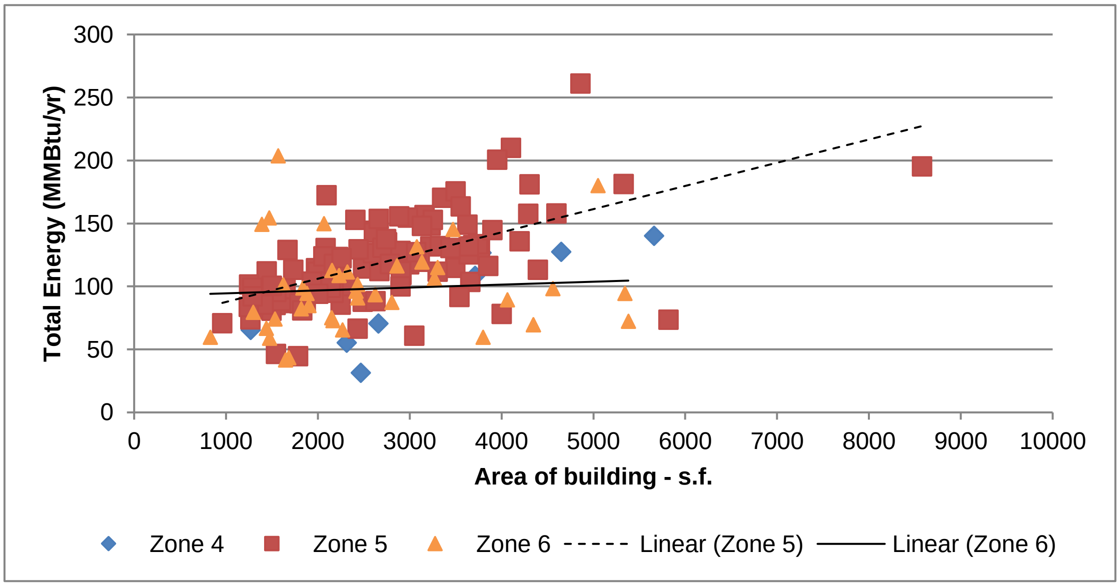
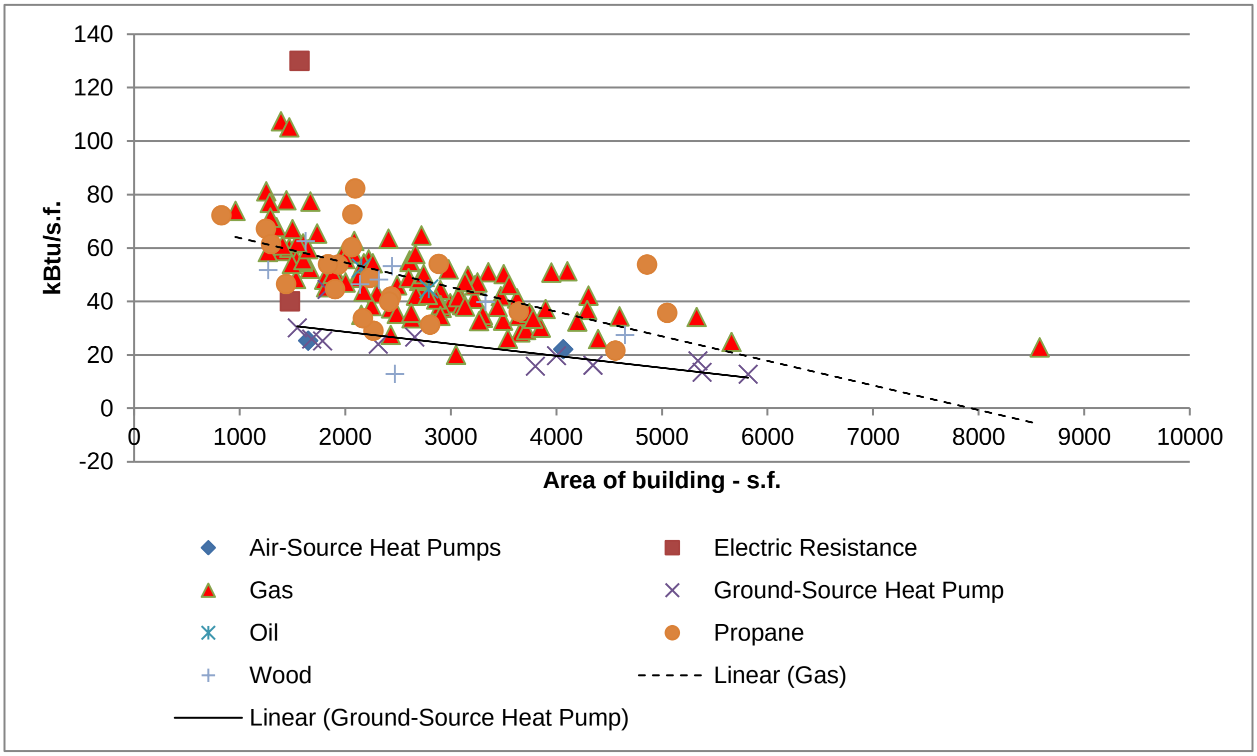


Figure A-4 is similar to Figure A-2, but groups the homes by heating system type. One item of note is the lower EUI values and shallower slope of the trend line associated with GSHP systems (solid trend line) when compared to the trend line for a gas fired heating systems (dashed trend line). This is likely attributable to the high efficiencies of GSHP systems and the calculation of EUI being at the site level as opposed to the source level.

Figure A-4. EUI versus area of building, grouped by heating system

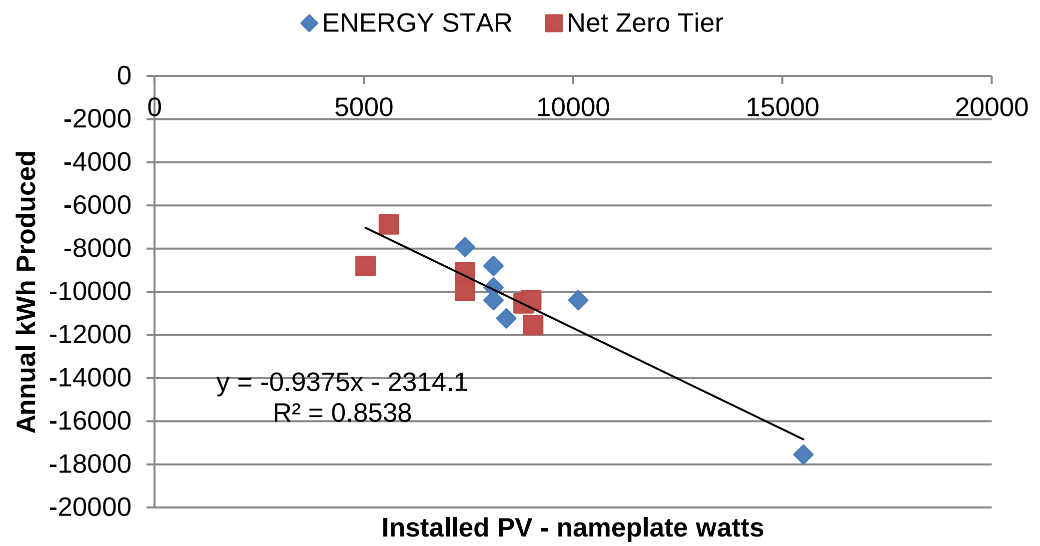


Participant Home Scatter Plots

This section presents a selection of additional scatter plots from the aggregate review of the participant homes.

Figure A-5 compares the measure output of the PV system to the manufacturer's nameplate rating of the installed system array. As PV array nameplate rating increases, the annual output of the system also increases.

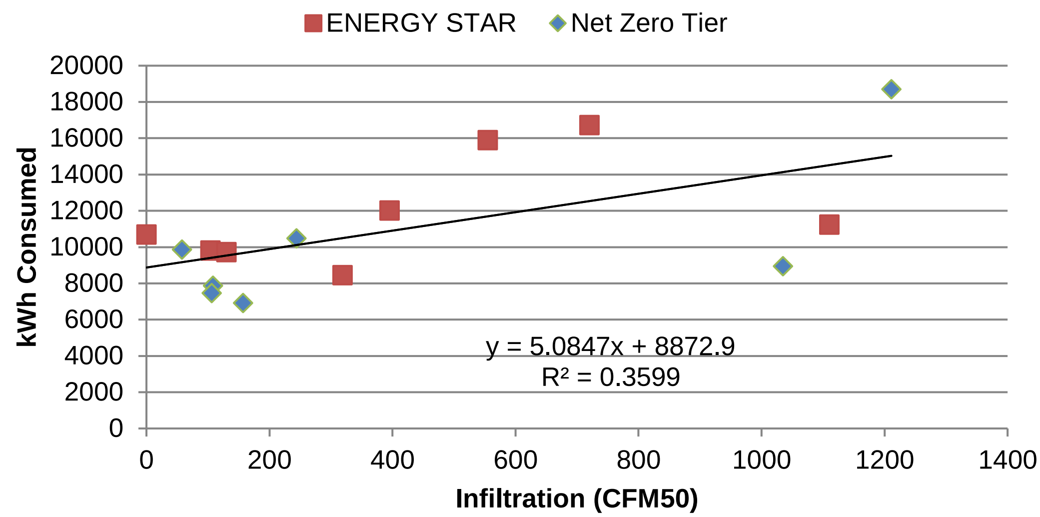
Figure A-5. Annual kWh production compared to PV array nameplate rating[1]



[1]Findings are distinct to the population reviewed and are not representative of a larger population of NZE homes

Figure A-6 compares the measure annual consumption of the homes to the results of the blower door depressurization test conducted as part of the Program project verification process. There is a correlation between the levels of infiltration and the annual energy use, and this aligns with intuition and basic thermodynamics; as more outdoor air is brought in through infiltration, more energy is required to condition that air to meet heating or cooling set-points. Also apparent is a high degree of variability in energy use for a given infiltration rate. From this we can conclude that infiltration rates are one variable impacting energy use but are not the only variable.

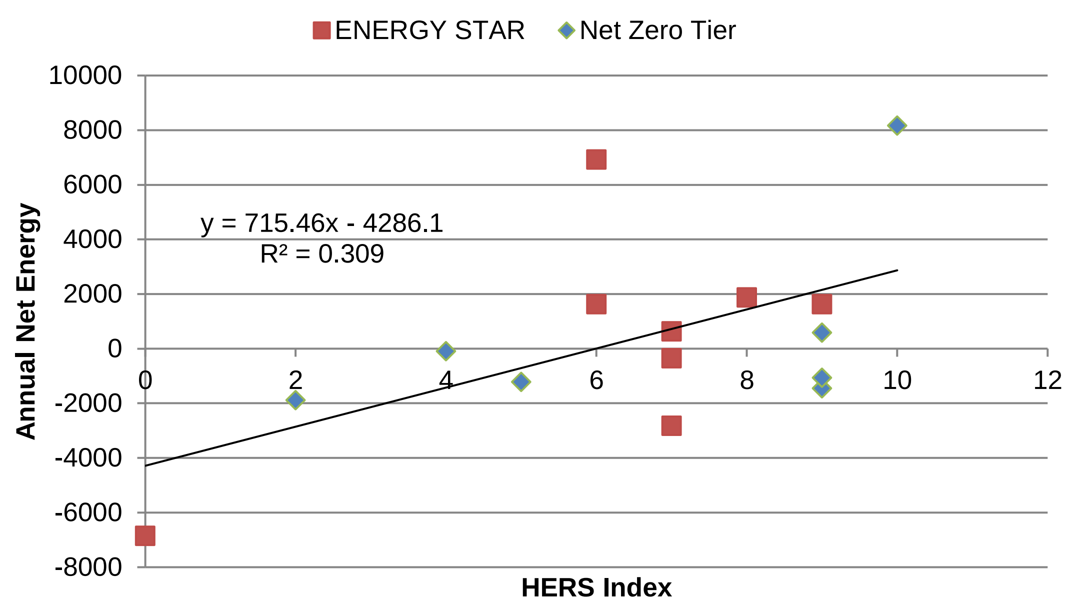
Figure A-6. Annual kWh consumption compared to blower door infiltration results[1]



[1]Findings are distinct to the population reviewed and are not representative of a larger population of NZE homes

Figure A-7 plots annual net energy use (net energy includes the impact of PV array output) against the HERS index calculated as part of the original project review. This plot graphically supports the finding that a target HERS index of 10 is a good threshold for participating in the net zero tier of the LRNC program.

Figure A-7. Annual Net Energy Use Compared to HERS Index[1]



[1]Findings are distinct to the population reviewed and are not representative of a larger population of NZE homes

Figure A-8 compares the measure annual energy use to the number of occupants. One home was occupied for only a few days a month, and so was considered to have zero occupants for the purpose of this comparison. Energy use increases with an increase in the number of occupants, but the R^2 value is low indicating that there are other factors besides the number of occupants that dictates energy use.

Figure A-8. Annual energy consumption versus number of occupants[1]