Economics of the Net-Zero Energy Residential Test Facility

William Healy
Joshua Kneifel
Eric O'Rear

Engineering Laboratory, National Institute of Standards and Technology
100 Bureau Drive Gaithersburg, MD 20899

Content submitted to and published by:
Energy Design Update
Vol. 38, No. 1
January 2018

U.S. Department of Commerce
Wilbur Ross, Secretary of Commerce

National Institute of Standards and Technology
Walter G. Copan, Director

Three previous articles in EDU discussed energy and indoor air quality performance measured at the National Institute of Standards and Technology's (NIST's) Net-Zero Energy Residential Test Facility (NZERTF) over the course of two years of operation. During the first year of operation under an emulated occupancy profile typical of a four-person American family, the facility achieved an annual energy surplus of 7 %. Operational changes during the second year, including a different thermostat control of the heat pump and a modified ventilation strategy, contributed to a larger surplus of energy generated from the photovoltaic systems, 19 %[1]. To better understand the operation of the facility and understand the differences between year 1 operation and year 2 operation, an Energy Plus model of the house was developed. Another key question for any pursuit of energy efficient housing relates to economics, and modeling can be useful in understanding these questions as well. This article will discuss the modeling efforts, both in terms of energy performance and in developing estimates of the cost-effectiveness of a home built to energy efficient specifications.

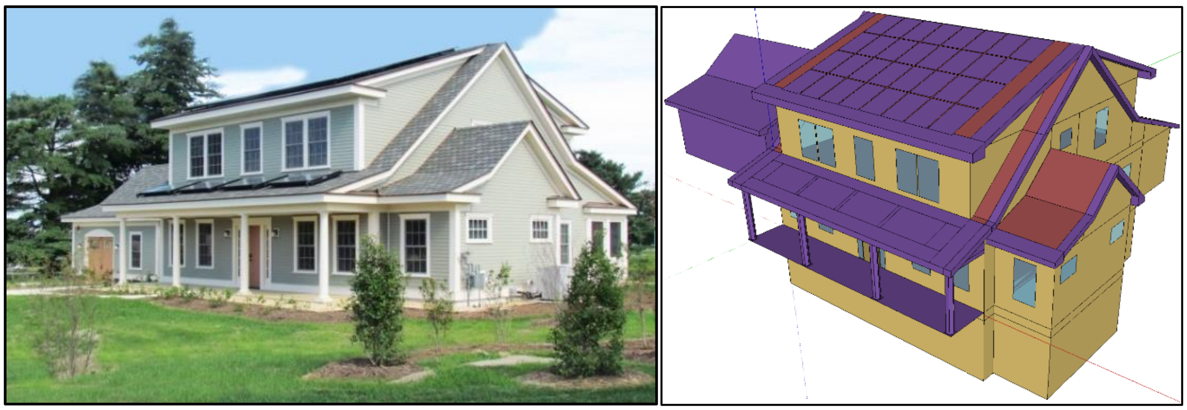

Figure 1: NZERTF (left) and SketchUp 3-D Representation (right)

Modeling Approach

Models of the house were built in both EnergyPlus and TRNSYS.[2] This article will focus on the EnergyPlus modeling (see geometrical model in Figure 1). Details on the modeling approaches are given in Kneifel et al.[3] The model was developed in several stages, initially based on design data (e.g., nameplate ratings of appliances, envelope specifications) and then adjusted to account for the observed performance of various systems. This exercise allowed the team to focus on simulation issues where default energy modeling approaches were challenged when compared to actual operation. The initial, pre-demonstration model using actual meteorological data underestimated the annual energy

[1] A. Hunter Fanney et al., "Small Changes Yield Large Results at NIST's Net-Zero Energy Residential Test Facility," *Journal of Solar Energy Engineering* 139, no. 6 (September 28, 2017): 061009-061009-14, https://doi.org/10.1115/1.4037815.

[2] *Certain commercial software are identified in this paper to foster understanding. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the software are necessarily the best available for the purpose*

[3] Joshua D. Kneifel et al., "Simulated versus Measured Energy Performance of the NIST Net Zero Energy Residential Test Facility Design," March 30, 2015, https://www.nist.gov/publications/simulated-versus-measured-energy-performance-nist-net-zero-energy-residential-test.

consumption by 14 % compared to the measured data (11 156 kWh compared to 12 927 kWh), and overestimated PV production by 5 % (14 222 kWh compared to 13 523 kWh).

Some of the discrepancy occurred because of unexpected faulty operation of equipment or data gaps at the facility. After adjusting for those faults, the largest discrepancies between the model and the measured data arose in the annual heating and cooling energy consumption (-1960 kWh, negative sign meaning that the model underestimated consumption compared to measured results), plug loads/appliances (+718 kWh), and the combination of the heat pump water heater and the solar thermal preheat system (-484 kWh and -243 kWh, respectively). The overestimate of the plug loads/appliances was largely due to conservative estimates of the efficiency of the clothes washer and the dishwasher, with model predictions amounting to 151 % and 194 %, respectively, of the actual consumption of those appliances. The original model underestimated the refrigerator's energy consumption by 74 kWh, likely due to the energy consumption of the ice maker, which was not accounted for in the EnergyGuide rating at the time the refrigerator was labeled.

Water heating consumption was originally underestimated for a number of reasons. The first reason was that hot water consumption was more than originally modeled, partly due to larger consumption by the clothes washer and dishwasher than expected and also due to more hot water being delivered to fixtures to meet the desired delivery temperature. Measured data on the heat pump water heater suggested that its performance was not accurately captured with manufacturer-supplied data, partly due to different operating regimes than those under which the unit was tested. The energy consumption by the solar pumps was underestimated due to incorrect default flow rates included in the original model. Additionally, a default assumption of zero heat loss from piping connecting the solar panels to the hot water storage tank introduced errors.

The largest discrepancy occurred for the space heating and cooling estimates. Greater differences were seen in the heating months (December through March) than during the cooling months. Measured data suggested that default component parameters in EnergyPlus led to a larger Coefficient of Performance for the heat pump than observed. Another challenge in modeling the installed heat pump was that it was difficult to properly model the dedicated dehumidification cycle of the unit. It was modeled as a stand-alone dehumidifier, but differences in actual operation were inevitable. The largest challenge in modeling the two-speed heat pump was in setting the proper control algorithms to transition between low speed, high speed, and resistance operation. The installed thermostat used a time-based criterion to shift to resistance heating, whereas the original model based the mode selection on ability to meet capacity. For this reason, resistance heat was used much more than anticipated by the model, and the actual energy consumption by the HVAC system was greater than expected by the model.

The adjusted model was based on improved knowledge of the operation of the components of the house and predicted the annual energy consumption with a difference of 4.2 % and the energy production within 2 % of the measured results. After these adjustments, the model was then used to estimate performance under other conditions and as a basis for economic analyses.

Cost estimation

To perform a life cycle cost analysis, cost data were collected for all components of the house. Estimates were compiled of total construction costs if the house were built in a typical subdivision in Maryland to various levels of efficiency, from compliance to the Maryland residential building energy code at the time of study (based on IECC 2015) to the as-built home that went beyond net-zero operation. Kneifel and O'Rear present details of the methodology and the costs that were compiled[4]. Data were compiled from several sources, resulting in a range of construction costs. It is estimated that the home built to be compliant with the Maryland building code would cost $519,000 (cost of land is not included). If it were built to the design of the NZERTF as used in the first two years of operation, the average incremental first cost across the multiple estimates is $126,000, with the building envelope and building systems accounting for approximately half the additional costs each. It should be noted that this number does not include any government or other incentives for installation of efficient equipment. Additionally, the average installed cost of residential solar photovoltaic systems has dropped from the $3.90/W used in this study to under $3.00/W in early 2017, which would reduce the installed cost by over $10,000.[5] Assuming a 30-year mortgage at a 4.88% interest rate with 20 % down payment, the incremental monthly mortgage payment of the NZERTF compared to a Maryland Code Compliant home is between $400/month and $800/month. The largest drivers behind the increased costs are the improved building envelope to achieve the high R-values and low air leakage rate and the addition of the photovoltaic system. Collecting data from multiple sources, however, demonstrated the large uncertainty in these numbers, and the study also highlighted the dramatic drop in prices for photovoltaics that is moving the needle on the economic feasibility of net-zero homes.

The code-compliant home is modeled to consume 23,555 kWh over the course of a typical year, while the NZERTF is modeled to be a net exporter of 2,566 kWh. At an average electricity rate in Maryland of $0.14 per kWh, the NZERTF is projected to save $3,657 per year in electricity costs in the current year compared to a code-compliant version. A holistic approach to evaluate the cost-effectiveness of energy efficiency investments is life cycle costing, which accounts for the present value of all the costs associated with a building over the entire study period of interest (e.g., length of home ownership). Looking at the life cycle costs of each house at the conditions listed above over a 10-year study period, the NZERTF has higher present value life cycle costs compared to the Maryland code-compliant house ($159,000 and $147,000, respectively). A few points regarding these life cycle costs should be noted, however. First, the analysis does not consider any potential incentives for energy efficient or renewable generation equipment, including the 30 % federal tax credit for solar photovoltaics that would offset nearly the entire $12,000 differential in life cycle costs. Second, as shown in the BIRDS database[6], there are other combinations of components and equipment that would result in a lower life cycle cost than the baseline case. The combination with the lowest LCC would, for example, not include photovoltaics. This combination would achieve a life cycle cost reduction of $6,000 relative to the baseline and would reduce energy consumption by 24%. If one were interested in maintaining the same LCC as the baseline home, a reduction in energy consumption of 86 % from the baseline could be achieved. Net-zero operation could be achieved with an increase in LCC of $2,392 over the 10-year study period, showing that the NZERTF includes additional energy efficiency measures that increase life cycle costs by approximately $10,000. Finally, as previously noted, the continued decrease in the cost of photovoltaics is changing these break-even points at a rapid pace, quickly moving photovoltaics into being one of the

---

[4] Joshua D. Kneifel and Eric G. O'Rear, "Net-Zero Energy Residential Building Component Cost Estimates and Comparisons," Special Publication, October 4, 2016, https://dx.doi.org/10.6028/NIST.SP.1207.

[5] EnergySage, "Solar Marketplace Intel Report: H2 2016 – H1 2017," September 2017. https://www.energysage.com/data/#reports

[6] Joshua Kneifel, "BIRDS: Building Industry Reporting and Design for Sustainability," accessed December 14, 2017, http://ws680.nist.gov/Birds/Home/Index.

most cost-effective methods to reduce net energy consumption. Table 1 summarizes some of these key economic results.

Table 1: Energy and Economic Performance - NZERTF relative to Maryland Code Compliant Design

NZERTF vs MD Code-Compliant Construction	**Value**	**Unit**
Average Initial Cost Premium	126,000	$
BIRDS Life Cycle Cost Premium (10-year study period)	12,000	$
Annual Energy Savings	26,121	kWh
Annual Energy Cost Savings (Initial year assuming $0.14 per kWh)	3,657	$
Additional Federal Tax Credit (not included in numbers above)	$11,981	$

Life Cycle Assessment

The modeling also contributed to environmental life cycle assessments (LCAs) of the NZERTF and related designs to assess the environmental impact across a range of impact categories (e.g., climate change potential, ozone depletion, water use). Once again, details on the comparison of the environmental impact of a range of options based on the NZERTF can be found at the BIRDS website. The 12 environmental impact categories evaluated in BIRDS can be combined into a single Environmental Impact Score (EIS) using a normalized weighted average based on environmental preferences discussed at a NIST LCA workshop. The EIS is reduced by 51% for the NZERTF compared to a Maryland code-compliant design. Impact reductions are observed in categories directly related to electricity production (e.g., CO_2 production, acidification, smog), while impacts increase in some categories associated with the inputs required for the additional materials and equipment incorporated into the NZERTF to reach net zero energy performance.

Conclusions

In addition to providing valuable data on residential home energy and indoor air quality performance, the NZERTF has led to valuable information on cost-effectiveness of net-zero energy homes. The BIRDS database, available at http://ws680.nist.gov/Birds/Home/Index, can be used for in-depth analysis of building design alternatives that may lead to more efficient housing. While the first cost of the NZERTF exceeded that of a Maryland code-compliant home by over $100,000, the future energy cost savings and resale value premium of energy efficiency and solar photovoltaic features make it cost-competitive for new home construction to move towards, and potentially reach, net-zero operation over a common home occupancy time horizon (10 years).