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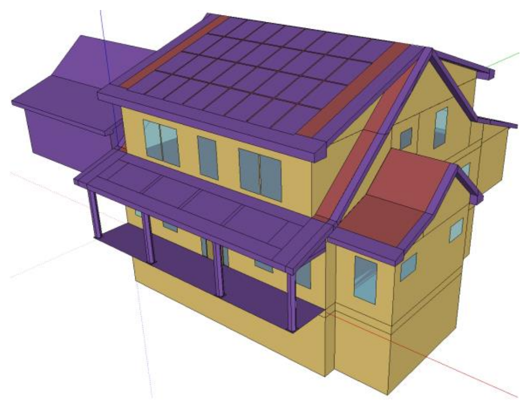

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Abstract

The National Institute of Standards and Technology (NIST) received funding through the American Recovery and Reinvestment Act (ARRA) to construct a Net Zero Energy Residential Test Facility (NZERTF). The initial goal of the NZERTF is to demonstrate that a net-zero energy residential design can "look and feel" like a typical home in the Gaithersburg area. The demonstration phase of the project intends to demonstrate that the operation of the house does perform at "net zero," or produces as much electricity as it consumes over an entire year. The NZERTF began the demonstration phase in July 2013 and will be completed in June 2014.

The purpose of this report is to compare the life-cycle cost performance of the NZERTF design to a comparable Maryland code-compliant building design using the results of EnergyPlus (E+) whole building energy simulations, local utility electricity rate schedules, and a contractor report estimating the associated construction costs. The combination of initial construction costs and future energy costs are used to estimate the total present value costs of constructing and operating the NZERTF relative to the Maryland code-compliant house design. The NZERTF is more costly to build, but saves the home owner money in energy costs and increases the market value of the home at resale. Assuming the NZERTF is purchased with a 30-year mortgage at 4.5 % and a 20 % down payment, the home owner would realize net savings of $41 714, or a 5.6 % adjusted internal rate of return.

Keywords

Net zero energy construction; energy efficiency; residential building; whole building energy simulation

Preface

This study was conducted by the Applied Economics Office (AEO) in the Engineering Laboratory (EL) at the National Institute of Standards and Technology (NIST). The study is designed to compare the life-cycle cost performance of the NZERTF design to a comparable Maryland code-compliant building design using the results of *EnergyPlus* (*E+*) whole building energy simulations and a contractor report estimating the associated construction costs. The intended audience includes researchers in the residential building sector concerned with net zero energy residential performance.

Disclaimer

The policy of the National Institute of Standards and Technology is to use SI units in all of its published materials. Because this report is intended for the U.S. construction industry that uses U.S. customary units, it is more practical and less confusing to include U.S. customary units as well as metric units. Measurement values in this report are therefore stated in metric units first, followed by the corresponding values in U.S. customary units within parentheses.

Acknowledgements

The author wishes to thank everyone involved in the NZERTF project. A special thanks to the team at Multinational Group, LCC for their hard work on the contract that developed the construction cost estimates used in this report. Thank you to everyone for their advice and recommendations for the writing of this report, including Dr. David Butry and Dr. Robert Chapman of EL's Applied Economics Office, Dr. Hunter Fanney of EL's Energy and Environment Division, and Dr. Nicos S. Martys of EL's Materials and Structural Systems Division.

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List of Acronyms

Acronym	Definition
AEO	Applied Economics Office
ARRA	American Recovery and Reinvestment Act
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BA	Building America
BSC	Building Science Corporation
BTP	Building Technology Program
CFL	compact fluorescent
COP	Coefficient of Performance
DHW	Domestic Hot Water
DOE	Department of Energy
E+	EnergyPlus
EERE	Energy Efficiency and Renewable Energy
EL	Engineering Laboratory
ELA	Effective Leakage Area
HERS	Home Energy Rating System
HRV	Heat Recovery Ventilator
HSPF	Heating Seasonal Performance Factor
HVAC	Heating, Ventilating, and Air Conditioning
IAQ	Indoor Air Quality
IECC	International Energy Conservation Code
MRR	Maintenance, Repair, and Replacement
NIST	National Institute of Standards and Technology
NREL	National Renewable Energy Laboratory
NZERTF	Net Zero Energy Residential Test Facility
OC	On Center
PV	Photovoltaic
SEER	Seasonal Energy Efficiency Ratio
SHGC	Solar Heat Gain Coefficient
VT	Visible Transmittance

1 Introduction

1.1 Background and Purpose

The National Institute of Standards and Technology (NIST) received funding through the American Recovery and Reinvestment Act (ARRA) to construct a Net Zero Energy Residential Test Facility (NZERTF). The initial goal of the NZERTF is to demonstrate that a net-zero energy residential design can "look and feel" like a typical home in the Gaithersburg area. The demonstration phase of the project intends to demonstrate that the operation of the house does perform at "net zero," or produces as much electricity as it consumes over an entire year. The NZERTF began the demonstration phase in July 2013 and will be completed in June 2014.

The purpose of this report is to compare the life-cycle cost performance of the NZERTF design to a comparable Maryland code-compliant building design using the results of *EnergyPlus* (*E+*)[1] whole building energy simulations and a contractor report estimating the associated construction costs. The use of life-cycle cost analysis is important because the cost flows associated with the NZERTF design and a Maryland code-compliant house design are different, with the NZERTF design realizing greater initial costs, but lower (negative) annual energy costs. By accounting for all costs associated with both building designs for the home owner's investment time horizon, it is possible to allow a direct comparison of the economic performance across designs.

1.2 Approach

The Department of Energy's (DOE) Energy Efficiency and Renewable Energy (EERE) Building Technologies Program (BTP) is responsible for funding research at the national laboratories for the Building America (BA) program. The BA program has been at the forefront of research of low-energy single-family housing design through a variety of outlets, including the BA Best Practices Series, case studies for new construction and retrofits, and technical reports and fact sheets.[2] Hendron and Engebrecht (2010) defines the BA house protocols to be implemented when simulating house energy performance, which are used to supplement the NZERTF architectural specifications.

Kneifel (2012) documents the assumptions made to create a whole building energy simulation model in the *E+* simulation software estimating the energy performance of the NZERTF design. The geometry, building envelope, and hard-wired lighting design as well as some energy performance requirements are based on the specifications defined by the NZERTF project's architectural firm, Building Science Corporation (BSC).[3] Based on the BSC specifications, the contractor selected interior equipment and lighting to meet those specifications. Occupant behavior assumptions for the NZERTF design are defined based on the operation during the

[1] Department of Energy (2013)
[2] Building America (2013)
[3] Building Science Corporation (2009)

NZERTF's demonstration phase currently in progress as documented in Omar and Bushby (2013). For some operating conditions, the model uses assumptions defined in Hendron and Engebrecht (2010). Additional documents that assist the model design are *American Society of Heating, Refrigerating and Air-Conditioning Engineers* (*ASHRAE) 90.2-2007*, *ASHRAE 62.2-2010*, and the *ASHRAE Fundamentals Handbook*.

Kneifel (2013) uses the *E+* simulation defined in Kneifel (2012) to estimate the energy performance of the NZERTF design and a comparable Maryland code-compliant design. The energy efficiency requirements defined in 2012 International Energy Conservation Code (IECC) for residential buildings are used to determine the Maryland code-compliant design. Each of the energy efficiency measures is removed from the NZERTF design simulation model, one-by-one, to reach the minimum requirements for 2012 IECC in Gaithersburg, Maryland (Climate Zone 4).

Matlock (2013) was a government contracted report completed by Multinational Group, LCC that documented the approach used to estimate the costs of constructing the NZERTF and a comparable Maryland code-compliant design. Multinational Group hired a LEED-certified contractor to create a bid as though it was a private sector project in Maryland being built to meet both the NZERTF design as being operated during the demonstration phase (proving net zero energy performance over an entire year) as well as minimum Maryland code-compliance (2012 IECC). The cost estimates for each house design were delivered to NIST in spreadsheet form with the report. This report uses the energy performance results estimated in Kneifel (2013) and the line item cost estimates in Matlock (2013) to estimate energy and cost performance of the NZERTF relative to the same house built to meet Maryland residential code, which is based on 2012 IECC for residential buildings.

2 Energy and IAQ Performance

In order to determine the economic benefits of increased energy efficiency for the NZERTF design, it is necessary to compare the energy savings relative to the current design (2012 IECC). This chapter describes the E+ simulation assumptions and estimated energy and indoor environment performance of the NZERTF design and 2012 IECC designs.

2.1 Assumptions

The NZERTF design improves energy efficiency of five aspects of the building envelope listed in Table 2-1, Table 2-2, and Table 2-3: framing, wall, roof, fenestration, and infiltration. The NZERTF is constructed using “advanced framing,” which uses 2”x6” 24” on center (OC) framing instead of the common practice of 2”x4” 16” OC framing. The thicker framing allows for greater levels of insulation within the wall cavity while decreasing the amount of wood required for framing the house, making it easier to increase the thermal performance of the building envelope.

Table 2-1 Framing and Insulation

Insulation	NZERTF	2012 IECC – Zone 4
Framing	2”x6” 24” OC	2”x4” 16” OC
Exterior Wall (Cavity/Cavity + External Wall)	- /R-20+24	R-20/R-13+5
Basement Wall	R-22	R-10
Roof	R-45+30	R-49 or R-45+4

Note 1: Wall Cavity R-Value + Continuous R-Value
Note 2: Basement Floor Insulation is the same for both designs

The 2012 IECC wall insulation requirement for a city located in IECC Climate Zone 4 is R-20 in the wall cavity or R-13 in the wall cavity and R-5 of rigid insulation. The NZERTF uses advanced framing and adds an additional R-24 of rigid insulation to the R-20 in the wall cavity. The basement wall requirement for 2012 IECC is R-10 of rigid insulation while the NZERTF adds R-12 to the interior of the basement wall. The 2012 IECC design with typical framing uses blown-in insulation on the attic floor to reach R-49 of continuous insulation. The 2012 IECC design with advanced framing uses R-45 blown-in insulation in the rafters with R-4 rigid insulation on the exterior of the roof. The NZERTF roof construction uses the R-45 insulation in the rafters and adds rigid insulation to the exterior roof to reach an additional R-30.

The fenestration surface construction materials for windows are defined based on three parameters: U-factor, Solar Heat Gain Coefficient (SHGC), and Visible Transmittance (VT). This approach allows the rated window performance to be modeled while simplifying window “materials” and “constructions” in the simulation. The window parameters can be seen in Table

2-2, and are based on the minimum requirements specified in 2012 IECC and the BSC window specifications.[4]

Table 2-2 Window Specifications

Field	Units	NZERTF	2012 IECC – Zone 4
U-Factor	W/m^2-K	1.14	1.99
SHGC		0.25	0.35
VT		0.40	0.40

The maximum envelope air leakage rate in the 2012 IECC allowed for residential structures in Climate Zone 4 is 3 air changes per hour at 50 Pa. The air tightness of the NZERTF was measured at 0.61 air changes per hour at 50 Pa using a blower door test.[5] These results, shown in Table 2-3, are converted into effective leakage area (ELA) for the simulations and then split between the 1st floor and 2nd floor based on fraction of volume.[6]

Table 2-3 Infiltration Rates

Air Leakage	NZERTF	2012 IECC
Air Changes at 50 Pa	0.61	3.00
ELA – 1st Floor (cm^2)	98.8	403.6
ELA – 2nd Floor (cm^2)	90.2	368.1

Table 2-4 shows that the NZERTF design implements energy efficiency measures in the lighting, heating, ventilation, and air conditioning (HVAC), and domestic hot water (DHW) systems, and installs a solar thermal hot water system and solar photovoltaic system. The 2012 IECC requires 75 % of all light fixtures to be high efficiency. All lighting fixtures in the NZERTF design are high efficiency.

[4] These parameters assume no difference in performance of the windows regardless of the window type (awning or double hung).
[5] Everyday Green (2012)
[6] The ELA should have been split based on the fraction of surface area for each floor, not volume. However, this should not make a significant difference in the results.

Table 2-4 Electrical and Mechanical Systems

Building System	Component	NZERTF	2012 IECC-based System
Lighting	Light Bulbs	100 % Efficient Lighting	75 % Efficient Lighting
HVAC	Air Conditioning	Heat Pump (SEER 15.8)	Heat Pump (SEER 13.0)
	Heating	Heat Pump (HSPF 9.05)	Heat Pump (HSPF 7.7)
	Ventilation/Outdoor Air	Heat Recovery Ventilator	Min. Outdoor Air (0.04 m^3/s)
DHW	Water Heater Tank	Heat Pump Water Heater	Electric Water Heater
Solar	Solar Thermal System	2 Panel with 80 gallon	None
	Solar PV System	10.2 kW	None

* SEER = Seasonal Energy Efficiency Ratio
** HSPF = Heating Seasonal Performance Factor

The 2012 IECC design assumes a federal minimum efficiency heat pump with continuous outdoor air of 0.04 m^3/s.[7] The NZERTF design replaces the minimum efficiency heat pump with a high-efficiency heat pump, and adds a dedicated outdoor air system with a heat recovery ventilator (HRV). The NZERTF design replaces the electric water heater with a thermal efficiency of 0.98 for the element in the 2012 IECC design with a heat pump water heater with a coefficient of performance (COP) of 2.6 and electric backup with thermal efficiency of 0.98 for the element. Additionally, the NZERTF design installs two solar thermal panels and 80 gallon storage tank to preheat water entering the heat pump water heater. The NZERTF design installs the largest possible solar photovoltaic (PV) system (10.2 kW) based on the surface areas of the roof.

2.2 Total Electricity Consumption

Figure 2-1 shows that constructing to the NZERTF design specification leads to a predicted 16 242 kWh (60 %) reduction in annual electricity use relative to constructing to meet residential 2012 IECC requirements for Climate Zone 4 (10 742 kWh versus 26 983 kWh). The solar PV system installed on the NZERTF is estimated to produce 15 471 kWh, resulting in the NZERTF

[7] Low air leakage rates without including mechanical ventilation of outdoor air into the house could lead to concerns over indoor air quality. Therefore, 2012 IECC requires that any house with an air leakage rate of less than 3 air changes per hour must include mechanical ventilation that meets either the International Residential Code or International Mechanical Code. The Maryland state energy code for residential buildings requires a minimum ventilation rate that is equivalent to those defined in the *ASHRAE 62.2-2010*. Since the HRV system is designed to meet ASHRAE 62.2 requirements, the mechanical ventilation rate for the simulations without the HRV system is assumed to be equivalent to those rates. The heat pump fan is used to supply a constant outdoor air flow, and the associated electricity consumption is captured in the “HVAC Fan” category.

producing 4731 kWh more than it consumes.

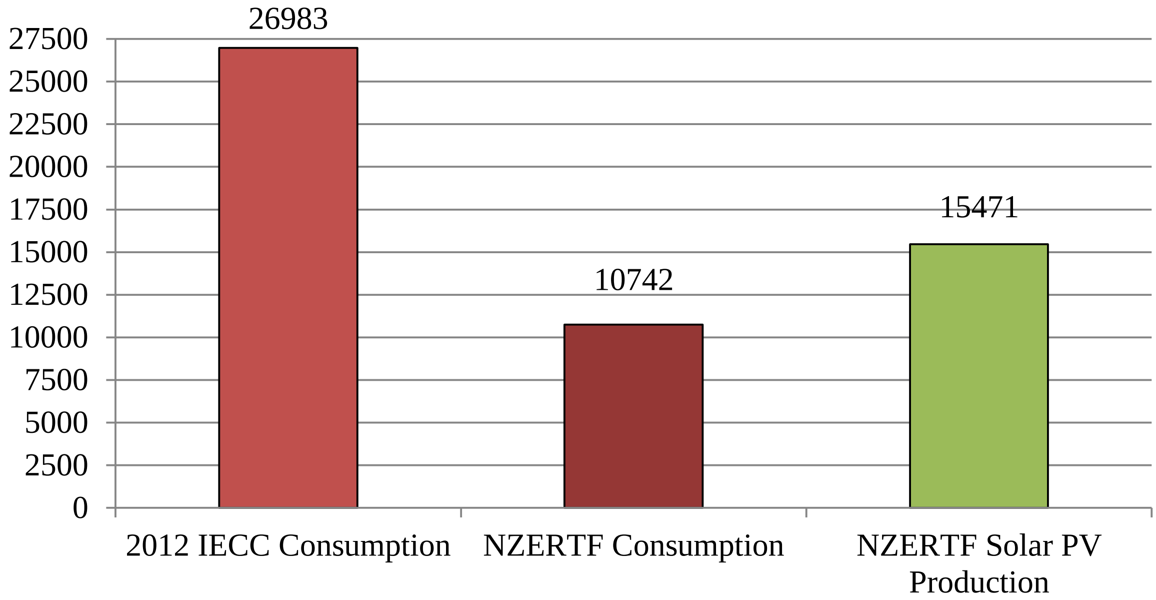

Figure 2-1 Predicted Annual Electricity Consumption and Production by Building Design

Figure 2-2 compares the monthly consumption for the NZERTF design and 2012 IECC design. The NZERTF design consumes less electricity in each month, and realizes greater reductions relative to the IECC design during the coldest months (November through March).

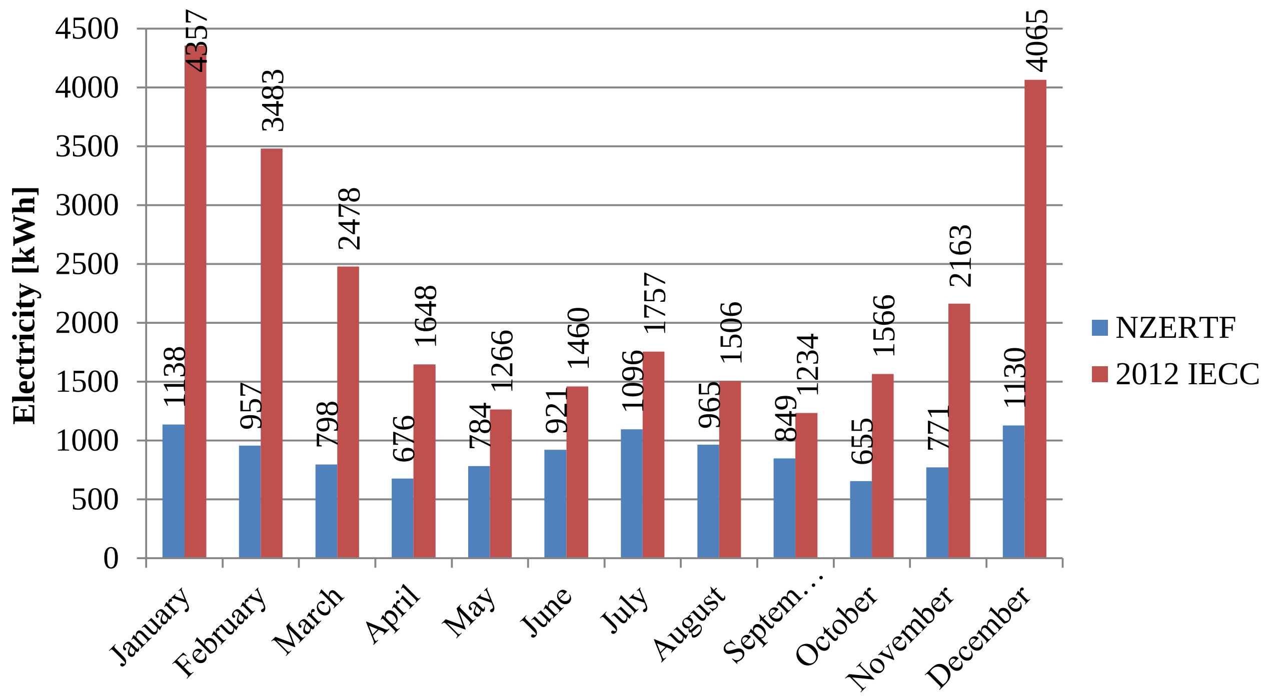

Figure 2-2 Monthly Electricity Consumption by Building Design

Figure 2-3 shows the solar PV production and consumption by the NZERTF design by month. As would be expected, the summer months are when the most energy is produced while the winter months are when production lags. However, even with the varying monthly production, ten of the twelve months realize greater production of electricity than is consumed by the NZERTF design.

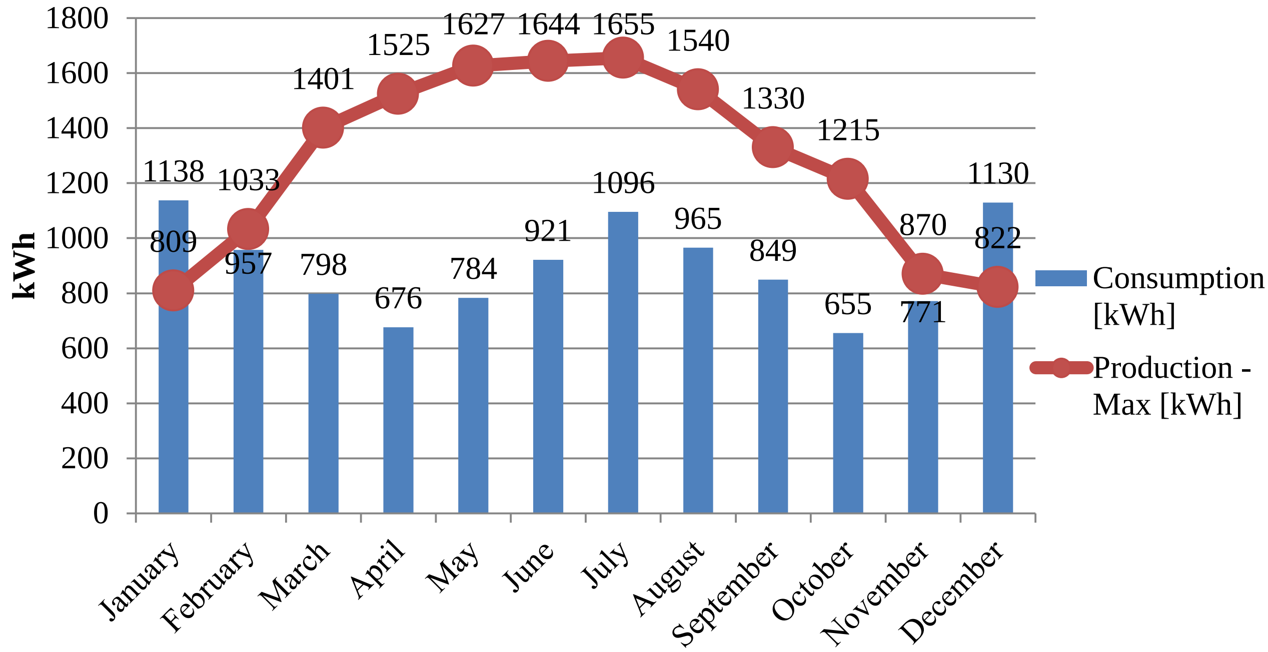

Figure 2-3 Monthly Electricity Consumption and Production (kWh) for NZERTF Design

2.3 Interior Environment

An important aspect of building performance is the indoor environmental conditions. Given the unique characteristics of the NZERTF (high insulation, low infiltration, and mechanical ventilation control), there are concerns that the comfort levels in the house will not meet target levels. There are a number of ways in which to compare indoor environment performance using the temperature and humidity levels inside the house. This report measures indoor environment performance using *ASHRAE Standard 55-2010*, which defines an approach to estimate a range of conditions (temperature and relative humidity) under which an occupant is "comfortable." Figure 2-4 shows the number of hours for which the conditions are considered "not comfortable" according to *ASHRAE 55* by month for the 2012 IECC and NZERTF design.[8] For both designs, the winter months lead to more "uncomfortable" conditions, and the 2nd floor realizes a greater number of hours in "uncomfortable" conditions. The NZERTF design has significantly fewer hours for which the thermal comfort is not maintained relative to the 2012 IECC design.

[8] These results are outputs from the *E+* model for the simple approach of calculating acceptable indoor environment levels, which are based on combinations of operative temperature and humidity ratio. The calculations allow maximum flexibility in the insulation value of clothes worn by the occupant, which estimates the insulation value of summer clothes and winter clothes to be 0.078 m^2K/W (0.5 Clo) and 0.155 m^2K/W (1.0 Clo), respectively. A Clo is the amount of insulation that allows a person at rest to maintain thermal equilibrium in an environment at 21°C (70°F) in a room ventilated at 0.1 m/s (0.33 ft/s) of air movement. For additional details, see the *E+* documentation and *ASHRAE 55-2010*.

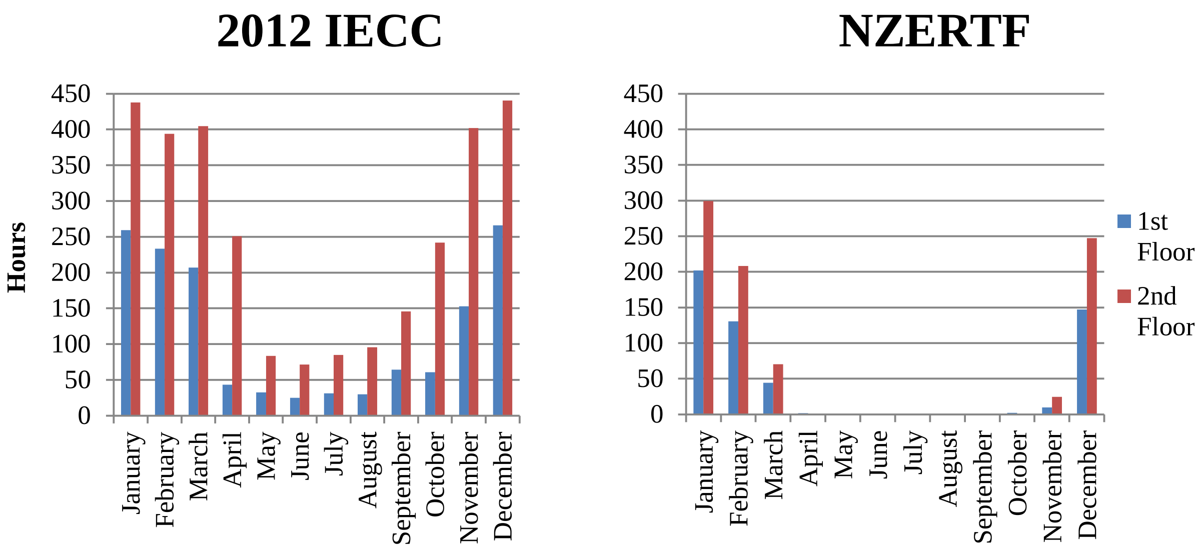

Figure 2-4 Simple *ASHRAE 55-2010* Not Comfortable for 2012 IECC and NZERTF Designs - Hours

3 Construction Cost Data

One of the deliverables for NIST's contract with Multinational Group was a summary cost estimate for the NZERTF and 2012 IECC designs. This chapter will describe the approach used to develop the cost estimate summaries, discuss the cost estimate for each building design, and explain the necessary adjustments to the estimates that are required to calculate the construction costs for homes built in the private sector for typical residential occupancy for both the NZERTF and 2012 IECC designs.

3.1 Cost Estimate Approach

The Construction Cost Summary (Matlock, 2013) estimates the overall costs and work hours for the construction of the NIST NZERTF if built in the private residential market in Gaithersburg, Maryland. Its key purpose is to determine the differences between the NZERTF as built and a comparable house built to code in the state of Maryland. This task was a collaborative effort with VESTA Building Industries a residential LEED certified contractor that is an expert in energy efficient residential construction.

All costs in the Construction Cost Summary include labor and materials as well as mark-up for subcontractor tasks. However, based on the contractor's experience and verification with several other contractors, we were able to estimate subcontractor timelines and approximate crew sizes to complete the tasks. The assumptions made in developing the Construction Cost Summary are made based on the following sources:

- Contractor and subcontractor quotes
- Contractor and subcontractor information on time for task completion
- Contractor and subcontractor information on how many laborers required for task completion
- VESTA Building Industries' professional experience with sub-contracting
- Multinational Group's research via the internet for supplemental cost and time estimations

The quotes for sub-contracted tasks were acquired by contacting sources in the DC/Maryland area. For the tasks that the contractor was responsible, the costs were based on wages in Ann Arbor, Michigan and adjusted accordingly to reflect the wage differences between Michigan and Maryland. On average, the wage gap between Ann Arbor and Baltimore, Maryland was negligible. However, due to the proximity of Gaithersburg to Washington, D.C. Multinational Group determined that the wages were to be increased by 2 % to ensure wages were not underestimated. All general contractor tasks were described in detail to determine the number of people required and the number of days/labor hours. Table 3-1 shows examples of the labor details reported for each task, including the number of workers, number of hours worked and the training required to perform the task.

Table 3-1 Examples of Labor Details by Task

Task	# Persons	Skill Level	Hours
Rough Framing	5	Lead Carpenter (1) General Labor (4)	1000
Exterior Siding	3	Lead Carpenter (1) General Labor (2)	240
Drywall Installation	6	General labor	130
Flooring	4	General labor	110
Electrical Finishes	2	Licensed Electrician (1) General Labor (1)	20

3.2 Construction Cost Estimates

Table A-1 included in the Appendix A shows the construction cost estimate for the construction of the NZERTF as built, including all the duplicative and monitoring systems (geothermal loops, high, velocity ductwork, electrical system for monitoring, etc). Table 3-2 shows that the difference in the NZERTF and 2012 IECC design estimates is $314 787, of which $46 883 is overhead and profit mark-up for the builder.[9] The category with the most significant builder's cost difference is "Building Systems" ($163 250 or 61 %), which includes HVAC, electrical, solar PV, and hot water heating systems. "Insulation" accounts for the next highest percentage at 13 % ($34 800) followed by "Rough Framing" ($20 898 or 7.8 %) and "Miscellaneous" ($20 200 or 7.5 %). No other category is over 4 % of the builder's cost.

[9] Table A-2 shows the more detailed subcategory differences for these categories.

Table 3-2 Initial Construction Cost Differences and Reasons by Category

Category	NZERTF	2012 IECC	Difference	Reason for Difference
PRECONSTRUCTION	**$3430**	**$3230**	**$200**	NZERTF has more detail, which increases design cost. Permitting may be based on total construction cost, which is higher with NZERTF.
HEAVY EQUIPMENT	**$2750**	**$2200**	**$550**	Additional components and stages of construction.
FOUNDATION and EXCAVATION	**$29 628**	**$22 050**	**$7578**	Additional foundation and drainage material and labor costs
UTILITY CONNECTIONS	**$6000**	**$6000**	**$0**	Same requirements
CONCRETE	**$14 528**	**$10 400**	**$4128**	Additional insulation under foundation, in-floor radiant heating system, and extra care in garage concrete work.
ROUGH FRAMING	**$85 598**	**$64 700**	**$20 898**	More steps and attention to detail. Additional insulation materials. Much of the cost increase in the NIST home is due to the air-sealing details. Garage insulated for monitoring system.
BUILDING SYSTEMS	**$214 750**	**$51 500**	**$163 250**	Duplicative HVAC ductwork creates complex "work arounds" for plumbing and electrical systems. HRV system, in-floor radiant heating, geothermal loops. High performance electrical equipment for monitoring.
EXTERIOR FINISHES	**$83 900**	**$74 100**	**$9800**	Cost increase for NIST in this section is mainly due to the additional complexity of attaching siding and higher cost windows.
INSULATION	**$41 300**	**$6500**	**$34 800**	Additional high priced insulation, in some cases double thickness and meticulous application of tape to seal. Insulation of garage.
PORCHES AND DECKS	**$2000**	**$2000**	**$0**	Same design
INTERIOR FINISHES[10]	**$173 450**	**$166 950**	**$6500**	Basement drywall and installation details are the cause of the increase for code built above NIST home.
LANSCAPING	**$0**	**$0**	**$0**	No landscaping included in the cost estimates.
MISCELLANEOUS	**$30 750**	**$10 550**	**$20 200**	Miscellaneous cost higher due to overall higher costs for NZERTF. Offsets risk for contractor for issues with nonstandard processes and applications.
Builder's Cost	**$688 084**	**$420 180**	**$267 904**	
Builder's Overhead and Profit @ 17.5%	**$120 415**	**$73 532**	**$46 883**	
TOTAL	**$808 499**	**$493 712**	**$314 787**	

These cost differences initially appear to be excessively high for any typical homebuyer to consider as an economically viable option. However, there are adjustments to these costs that are required to correctly represent the cost associated with this house as though it is built for actual occupancy by a home owner in the private sector.

3.3 Adjustments to Cost Estimates

In order to compare the costs of building the two houses in the private sector (typical residential subdivision), the additional costs not associated with the house (i.e., duplicative system costs) as

[10] Interior finishes are based on medium-end quality products to better represent typical construction. The additional cost of using high-end/luxury finishes would be the same across both the NZERTF and 2012 IECC designs, and therefore, will not impact the life-cycle cost analysis.

it is being operated should be excluded from the estimate. These costs are related to building systems and construction of the garage. The subcategories for "Building Systems" are shown in Table 3-3. The italicized line items are costs associated with systems not in operation during the demonstration phase of the NZERTF, and should not be included in the costs related to the NZERTF for this analysis because these systems would not be installed in a private sector construction project. Additionally, the added costs related to the more complex "work-arounds" for plumbing and electrical systems around these duplicative systems as well as the electrical system for monitoring the house would not be incurred. Therefore the additional costs for "Plumbing Rough," "Electrical Rough," "Electrical Finish," and "HVAC Finish" should be removed from the cost estimate. The solar PV system included in the Construction Cost Summary is based on a different system than the system installed on the NZERTF. The difference in costs for the two systems is $7000. These adjustments decrease total costs for "Building Systems" by $102 750, leaving $112 000 for total building system costs or a $60 500 difference from the 2012 IECC design.

Table 3-3 Construction Cost Adjustments to Building Systems by Subcategory

Category	NZERTF	2012 IECC	Initial Difference	NZERTF Adjusted	New Difference
Plumbing Rough	$16 500	$12 000	$4500	$12 000	$0
HVAC Rough	**$23 000**	**$13 500**	**$9500**	**$23 000**	**$9500**
Interior ductwork and Equipment Air to Air	$15 000		$15 000	$0	$0
High Velocity Ductwork and equipment	$6500		$6500	$0	$0
Heat Recovery Ventilation system	**$12 000**		**$12 000**	**$12 000**	**$12 000**
Geothermal loops	$37 000		$37 000	$0	$0
Multi split heat pump system	$18 750		$18 750	$0	$0
Electrical Rough	$16 500	$11 000	$5500	$11 000	$0
Fire Suppression	$10 000	$10 000	$0	$10 000	**$0**
Solar PV System	**$28 000**		**$28 000**	**$35 000**	**$35 000**
Solar Thermal - 80 Gallon 2 panel system	**$4000**		**$4000**	**$4000**	**$4000**
Solar Thermal - 120 Gallon 4 Panel system	$6000		$6000	$0	$0
Plumbing Finish	$1500	$1500	$0	$1500	$0
HVAC finish	$2000	$1500	$500	$1500	$0
Electrical Finish	$18 000	$2000	$16 000	$2000	$0
BUILDING SYSTEMS - TOTAL	**$214 750**	**$51 500**	**$163 250**	**$112 000**	**$60 500**
Note: In-floor radiant heating system is included in the "Concrete" cost category.					

Similarly, there are costs within other categories that would not occur in a house construction in the private sector. In particular, the garage has been built as a laboratory for monitoring the performance of the NZERTF, which required insulating with closed-cell spray foam insulation and greater care in constructing the structure (framing and concrete). The costs for installing the in-floor radiant heating system in the basement slab, which is not being used during the demonstration phase, is included in the “Concrete” category. These additional costs are captured in the categories/sub-categories shown in Table 3-4 and total $8026.

Table 3-4 Other Construction Cost Adjustments

Category	Subcategory	NZERTF	2012 IECC	Difference
Concrete	Basement Concrete	$8500	$5000	$3500
	Garage – Concrete	$2028	$1800	$228
Rough Framing	Garage – Materials	$2400	$2200	$200
	Garage – Labor	$2298	$1200	$1098
Insulation	Garage – Roof (closed cell insulation)	$3500	$0	$3500
Total				**$8026**

Table 3-5 shows the costs differences for each category, which have shifted dramatically from the initial cost estimates, shown in Table 3-2. “Building Systems” still accounts for the greatest cost difference, but it has been significantly reduced (44 % of builder’s cost). “Insulation” is now 23 % of builder’s cost while “Rough Framing” and “Miscellaneous” are 14 % and 15 %, respectively.

Table 3-5 Adjusted Construction Cost Differences by Category

Category	Initial Difference	New Difference
PRECONSTRUCTION	$200	$200
HEAVY EQUIPMENT	$550	$550
FOUNDATION and EXCAVATION	$7578	$7587
UTILITY CONNECTIONS	$0	$0
CONCRETE	**$4128**	**$400**
ROUGH FRAMING	**$20 898**	**$19 600**
BUILDING SYSTEMS	**$163 250**	**$60 500**
EXTERIOR FINISHES	$9800	$9800
INSULATION	**$34 800**	**$31 300**
PORCHES AND DECKS	$0	$0
INTERIOR FINISHES	$6500	$6500
LANSCAPING	$0	$0
MISCELLANEOUS	$20 200	$20 200
Builder's Cost	**$267 904**	$138 457
Builder's Overhead and Profit @ 17.5%	**$46 883**	$24 230
TOTAL	**$314 787**	**$162 687**
Percent of Total Costs for 2012 IECC Design	**64 %**	**33 %**

After controlling for all these additional costs related to constructing the NZERTF as a test facility instead of a house constructed for basic residential occupancy, the cost difference between the two building designs is greatly diminished. Table 3-5 shows that the builder's cost difference was decreased from $267 904 to $138 457. Lowering the builder's cost also lowers the builder's overhead and profit mark-up, leading to costs reductions for the home purchaser of $162 687.

One last item to consider is the risk-related costs in the "Miscellaneous" category. The builder included an additional $20 000 in the estimate to cover any unforeseen issues related to the "non-standard processes and applications" and higher costs of the NZERTF. These costs currently exist in the short term, but in the long-run should diminish and eventually disappear as the builder becomes more familiar with the new processes and applications. Therefore, these costs are associated with the learning curve related to net zero energy residential construction.

4 Future Costs

The cost performance of the two building designs are impacted by the initial construction costs, operating energy costs, maintenance, repair, and replacement (MRR) costs of building components, and the resale/residual value of the house at the end of the study period. This chapter will analyze the costs for both house designs for each of these factors, and calculate the life-cycle costs for owning and operating both houses for a 10-year study period).

4.1 Electricity Costs

Calculating the annual energy costs for each design requires the monthly energy consumption and electricity rate schedule. Table 4-1 shows the PEPCO standard rate schedule for residential customers in Montgomery County. The components of the rate schedule are constant across months of the year except for the generation charge, which is 8.8¢/kWh for June through September and 8.6¢/kWh for October through May estimates net metering monthly.

Table 4-1 PEPCO Electricity Rate Schedule

PEPCO Standard Offer - Residential	Rate Schedule Components
Generation (June-Sept.)*	0.08789/kWh
Generation (Oct.-May)*	0.08592/kWh
Transmission	0.0069/kWh
Gross Transmission Receipts Tax	2.0408 %
Distribution Service (Flat Rate)	7.39/moth
Distribution Service (Per kWh)	$0.04137/kWh
Delivery Tax	0.00062/kWh
MD Environmental Surcharge	0.00015/kWh
Montgomery County Surcharge	0.0119037/kWh
Administrative Charge	0.003/kWh
EmPower MD Charge	0.001813/kWh
Demand Resource Surcharge	-0.00007/kWh
Total Cost per kWh (June-Sept.)	*15.4 ¢/kWh*
Total Cost per kWh (Oct.-May)	*15.2 ¢/kWh*
Total Lump Sum Cost	*$7.39/month*
Note: Does not included Procurement Adjustment Cost, Universal Service Charge, Bill Stabilization Adjustment, or RGGI Rate Credit	

After combining the cost rates, the total marginal cost of electricity consumption is 15.4¢/kWh for June through September and 15.2¢/kWh for October through May. There is also a monthly lump sum distribution charge of $7.39. PEPCO determines net metering consumption on a monthly basis. Any excess production is carried over as a credit and applied to the next month's consumption. In the case of the NZERTF design, cumulative excess production continues to increase across most of the year. In this case, the consumer receives a payment from PEPCO for any excess production before the end of April. The rate of payment is the 12-month average marginal generation charge (8.66¢/kWh) multiplied by the excess production accumulated over the previous 12 months.

Table 4-2 shows monthly net consumption for both house designs. Based on the rate schedule and excess production credit, the NZERTF design leads to negative annual electricity costs (-$320.96) while the 2012 IECC design leads to annual electricity costs of $4205.17. In total, the NZERTF design decreases annual electricity costs relative to the 2012 IECC design by $4526.13.

Table 4-2 Estimated Electricity Costs

Month	2012 IECC Consumption	Total Cost	NZERTF Net Consumption	Total Cost
January	4357	$662.33	329	$7.39
February	3483	$529.39	-76	$7.39
March	2478	$376.71	-603	$7.39
April	1648	$250.52	-848	-$402.25
May	1266	$192.38	-843	$7.39
June	1460	$224.83	-722	$7.39
July	1757	$270.58	-560	$7.39
August	1506	$231.89	-575	$7.39
September	1234	$190.08	-481	$7.39
October	1566	$241.18	-560	$7.39
November	2163	$328.71	-99	$7.39
December	4065	$617.90	308	$7.39
Total	26 983	$4205.17	-4730	-$320.96

Costs are calculated monthly based on the PEPCO rate schedule.
Net metering credit is applied in April and is calculated taking excess production for those 12 month multiplied by the 12-month average generation charge (8.66 ¢/kWh).
Does not include any financial incentives such as production tax credits.

Energy prices tend to rise over time. In order to control for this increase, the residential electricity price escalation rate estimates for the South Census Region are used to adjust future electricity costs.[11] The average escalation rate for year 25 through year 30 is used for all years beyond 30 years.

[11] Annual Supplement

4.2 Maintenance, Repair, and Replacement Costs

The initial construction costs and operating energy costs are not the only costs associated with a house. Building components will require regular maintenance and repair throughout a house's lifetime, including inspections and repairs to HVAC and DHW equipment. Some building components have a limited useful life. HVAC equipment may last anywhere from 10 to 30 years. Solar PV systems are warrantied for 25 years. The cost of replacing these systems should be included when considering the total cost of ownership for a home.

For simplicity, we assume that maintenance and repair costs will be the same for similar systems because it would be expected that the higher performing "off-the-shelf" equipment in the NZERTF would maintain its performance as well as more conventional technologies used in the 2012 IECC design. Any costs that are identical across alternatives can be excluded from the analysis because the differences in costs are all that matters for life-cycle cost analysis. The maintenance costs for the solar PV, solar hot water, and HRV systems are assumed to be negligible for the initial 10 years of building operation.

4.3 Residual Value

There have been few studies to date that have considered the market value of an energy efficiency rating or "green" rating in the single-family residential sector. There have been studies that have estimated the percentage premium for green ratings in the residential sector. Brounen and Kok (2011) estimate a 10 % premium for higher energy efficiency homes in the Netherlands. Dashtrup et al (2012) finds home with solar panels sell for about a 3.5 % premium. Aroul and Hansz (2012) find a sale premium of 2.1 % to 2.4 % for homes in Texas rated as green, which included a Home Energy Rating System (HERS) rating of 83. The premium is greater in a jurisdiction that has a mandatory green building program (3.0 % to 4.7 %) relative to one with a voluntary program (0.2 % to 1.1 %). Kok and Kahn (2012) finds that a house with a certified green home label sell for a 9 % premium (+/- 4 %), on average, for a subset of homes in California. The premium is enough to more than offset the costs of constructing the homes to meet the rating systems. The effect is driven by the homes with an Energy Star label (statistically significant 14.5 % premium) while the effect of LEED and GreenPoint Rated homes is statistically insignificant. The green rating systems could be insignificant in the model due to the smaller sample size or the ratings have not yet gained recognition in the market due to uncertainty in the related benefits. For example, the same green rating could imply different levels of energy efficiency, which leads to different realized energy cost savings. These studies are all looking at homes with marginally better energy efficiency (<30 %), which makes it difficult to compare to market value of a net zero energy home.

In order to estimate the premium for the NZERTF design, it is necessary to determine an incremental value placed on the next unit of energy savings. Two studies have determined a relationship between energy cost savings and market valuation of a home. Nevin and Watson

(1998) shows that for every dollar saved in energy efficiency, a house sells for an additional $20, or annual fuel savings is discounted at the prevailing after-tax mortgage interest rate. Research from the commercial sector has led to similar results. Eichholtz et al (2009) estimates commercial buildings with Energy Star ratings realize premiums (one dollar of energy savings annually leads to an increase in market value of 18.32 – capitalization rate of about 5.5 %). In summary, a rational homebuyer is willing to pay more for a home up to the point where the additional after-tax monthly mortgage costs are equal to the average monthly energy cost savings.

Based on this market approach, our study will calculate the additional resale value as the addition to the purchase price that leads to an increase in the monthly mortgage payments equivalent to the average monthly energy cost savings for the last year of the study period. The last year is used because energy prices escalate over time, and the new homeowner will value the home based on energy prices at the time of purchase. Tax effects are excluded from this analysis to minimize the complexity of the calculations.

Life-cycle costing methodology states that the residual value of an investment should be calculated as a linear function of the initial investment costs and the remaining life of the investment as shown in the formula below:

$$Residual\ Value = Investment\ Cost * \frac{(Lifetime - Study\ Period)}{Lifetime}$$

Both the life-cycle costing methodology, ASTM Standard Practice E917, for estimation of residual value and a market approach based on Nevin and Watson (1998) are considered in this study while calculating market value of home resale.

5 Financial Incentives

There are a variety of financial incentives available at the federal, state, and electric utility levels for residential renewable energy technology installation and electricity production as well as energy efficient home construction. The combination of these financial incentives can significantly impact the cost performance relative to the Maryland code-compliant design.

Table 5-1 shows the financial incentives available for the NZERTF design. At the federal level, there is a renewable equipment income tax credit worth 30 % of the installed cost of a solar PV or solar thermal system. For the two systems installed in the NZERTF design, the total upfront federal tax credit is $11 700.

Table 5-1 Energy Efficiency and Renewable Energy System Financial Incentives

	Description	Incentive	Type	$Value
Federal	Renewable Equipment Income Tax Credit	30 % of installed cost	Solar PV Installation	$10 500
		30 % of installed cost	Solar Hot Water Installation	$1200
State	Energy Efficiency Rebate Program	$1000	Solar PV Installation	$1000
		$500	Solar Hot Water Installation	$500
	Solar Renewable Energy Credits (SRECs)	80 % of SACP[12]	Solar PV Production	$26 802
			Solar Water Heater Production	$5024
Utility	EnergyStar for New Homes	Varies based on HERS Rating	Efficient Home Construction	$1600

The State of Maryland offers a flat rebate for the installation of solar PV ($1000) and solar thermal systems ($500) as well as a renewable energy production incentive based on solar renewable energy credits (SRECs). SRECs are earned from production of solar energy, both solar PV and solar hot water. Power producers buy these SRECs from the homeowner to meet requirements under Maryland's Renewable Energy Portfolio Standard. For Level I renewable energy producers (producers with systems under 10 kW), the purchase of SRECs must take place in a single, upfront payment of the present value of the SRECs over the lifetime of the contract discounted using the federal secondary credit interest rate as of January of the year in which the

[12] 15-month average price per certificate (February 2013 through April 2014). Source: https://gats.pjm-eis.com/gats2/PublicReports/SolarWeightedAveragePrice.

contract is signed (1.25 % in January 2014).[13] Assuming a contract is signed for the remainder of the legislative life through 2028, the present value of the SRECs for the solar hot water and solar PV combined is $31 826.

The local utility (PEPCO) participates in the EnergyStar for New Homes program and offers a rebate for up to $1600 depending on its Home Energy Rating System (HERS) rating. Since the NZERTF design is net zero, it qualifies for the entire $1600 rebate.

All of these financial incentives are received upfront when the house is completed, which assists in offsetting some of the additional construction costs of reaching the net zero design. In total, the homeowner receives $46 626.

[13] Even though the system is technically rated at 10.2 kW, it is assumed that the system qualifies as a Level I system to simplify the analysis.

6 Analysis

There will be two cost analysis approaches considered in this chapter: payback period and life-cycle cost analysis. Payback period is a simplistic comparison of the initial investment costs and future cost savings while life-cycle costing is a more rigorous and complete analysis approach.

6.1 Payback Period

The construction costs have been described in detail in Chapter 3. In summary, the cost of constructing the 2012 IECC design is $493 712 while the construction costs for the net zero energy house design are $656 398, which is a difference of $162 687. In Section 4.1, the annual energy cost savings is estimated to be $4526. The simple payback approach calculates how many years it will take for the future cost savings to offset the initial investment costs (all in nominal dollars). Let's initially exclude any financial incentives available to homeowners. Assuming the buyer purchases the home outright, the simple payback period is the investment costs ($162 687) divided by the annual cost savings ($4526), or 36 years.

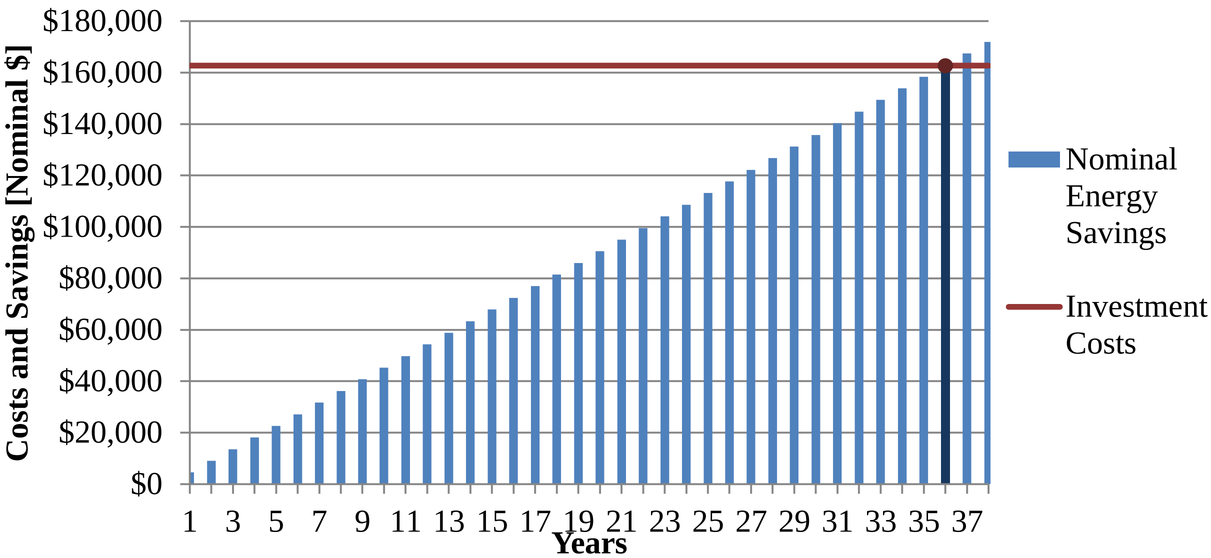

Figure 6-1 Simple Payback Period – All Cash Purchase

A more typical home purchasing approach is to finance most of the home purchase. The most common financing option for a new home purchase is the 30-year fixed-rate mortgage. For simplicity, let's assume the purchaser makes a 20 % down payment, which eliminates mortgage insurance. The difference in down payments between the net zero energy home design and the 2012 IECC design is $32 537. Assuming a 4.375 % interest rate makes the additional monthly mortgage payment (principal and interest) $650 greater for the net zero energy design, which makes the additional annual mortgage payments $7800.[14] The extra annual mortgage costs are 72 % higher than the energy cost savings of $4526. Not only does the net zero energy house cost more upfront ($32 537), but the homeowner's monthly costs (mortgage payment plus average energy costs) are higher by $273. The homeowner does not begin to see annual savings greater than annual costs until the 30 year mortgage is entirely paid off. It takes another 29 years (59 years in total) for the savings to offset the costs.

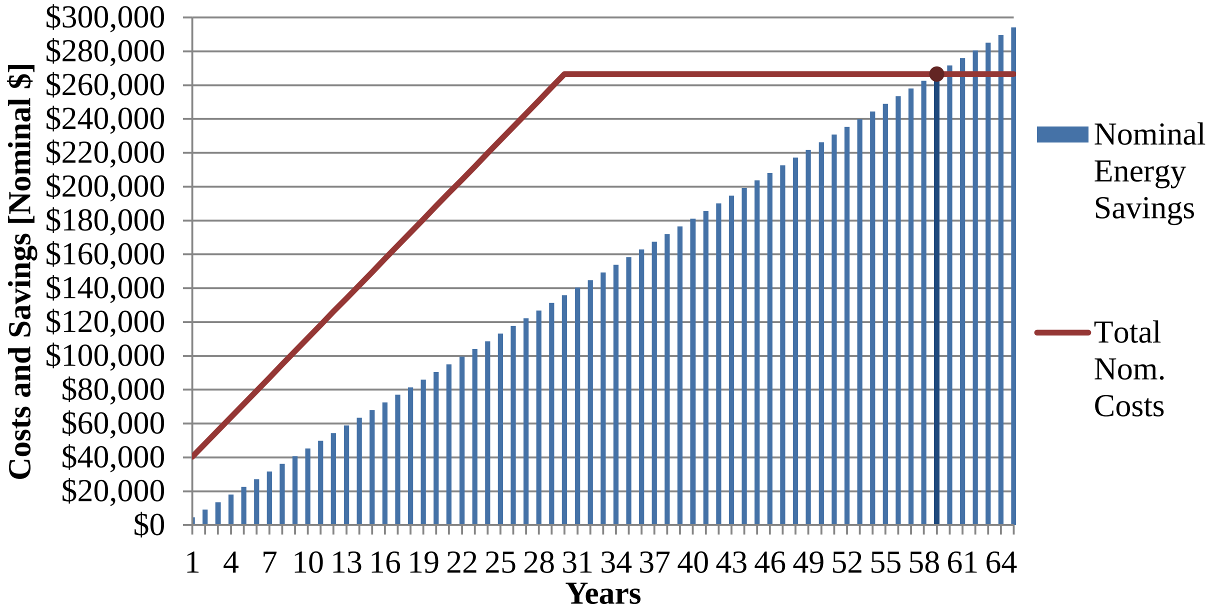

Figure 6-2 Simple Payback Period – 30-Year Mortgage

If currently available federal, state, and utility financial incentives are included in the analysis, the cost savings in the first year are increased by $46 626 due to rebate and grant programs and the value of state-level Solar Renewable Energy Credits (SRECs) associated with the solar PV and solar hot water system production. Figure 6-3 shows the combined cost savings from the financial incentives and energy cost savings, which first offset the initial investment costs of an all cash purchase in Year 26, which is 10 years sooner than if the financial incentives are not included in the analysis.

[14] Market rate for jumbo mortgage with 20 % down for Rockville-Wheaton area of Maryland as of April 30, 2014. Source: http://www.bankrate.com/calculators/mortgages/mortgage-calculator.aspx.

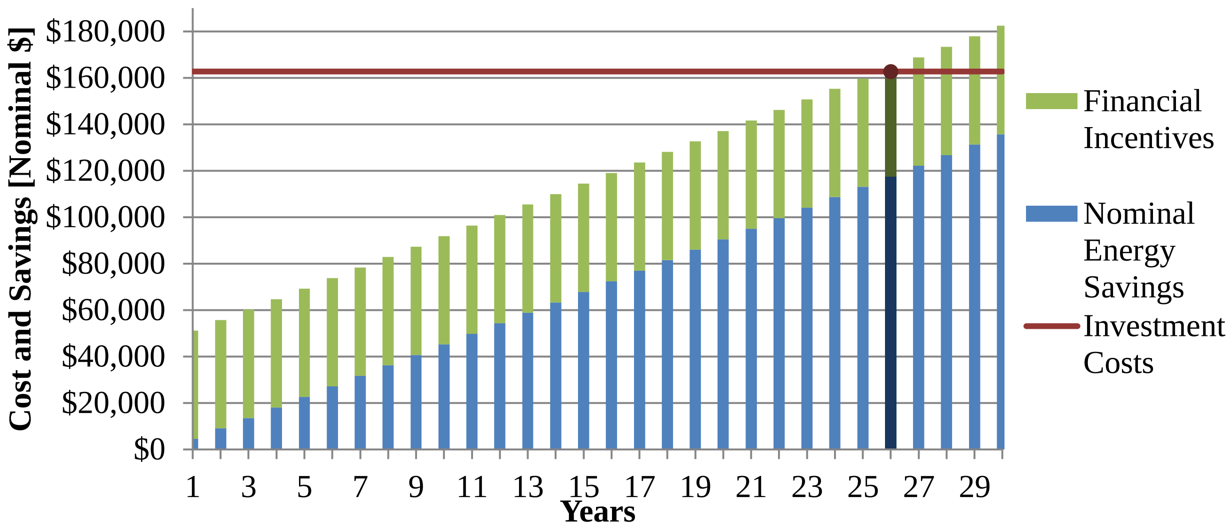

Figure 6-3 Simple Payback Period with Financial Incentives – All Cash Purchase

In the case of a financed home purchase (a 30-year fixed-rate mortgage with 20 % down payment), including in the financial incentives makes the interpretation of the results more nuanced. The financial incentives ($46 626) are greater than the additional down payment ($32 537), which leads to a payback period of one year. The savings are greater than the costs until Year 5, at which point the annual costs are greater than the annual savings until the mortgage is paid off in Year 30. It takes another 19 years until the total savings offsets the total costs again in Year 49.

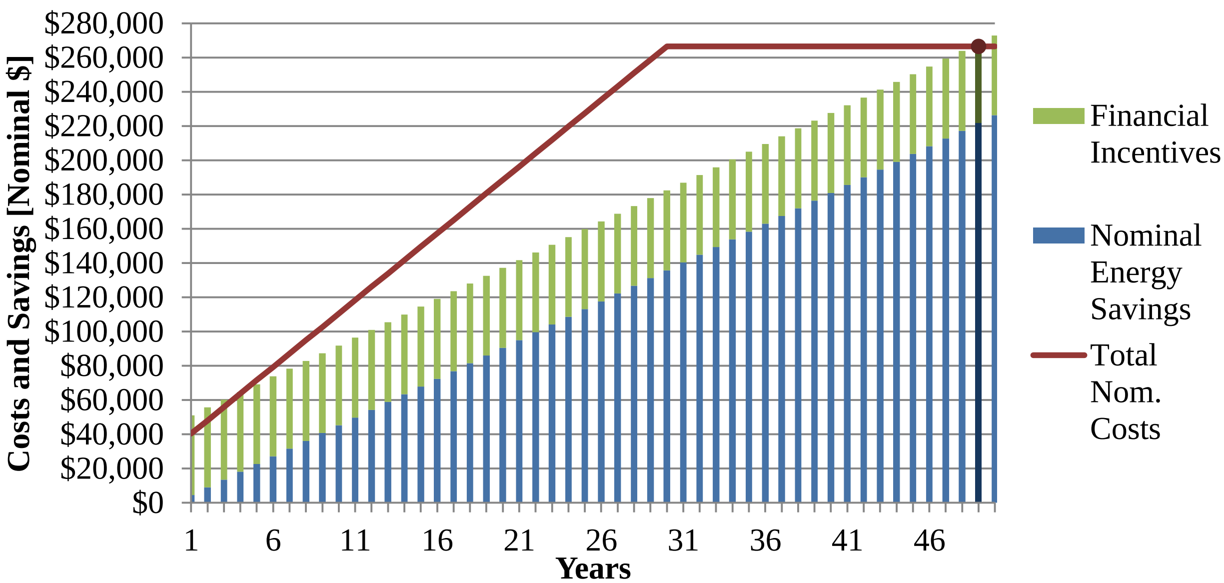

Figure 6-4 Simple Payback Period with Financial Incentives – 30-Year Mortgage

The simple payback approach does not take into account the time value of money. In order to do so, the future costs and savings must be discounted into present value terms. In this case we will assume the discount rate is equal to the mortgage interest rate to estimate the discounted payback period. Assuming an outright purchase, it takes 85 years for the financial incentives and present value energy cost savings to offset the initial investment costs, nearly 30 additional years relative to the simple payback period approach.

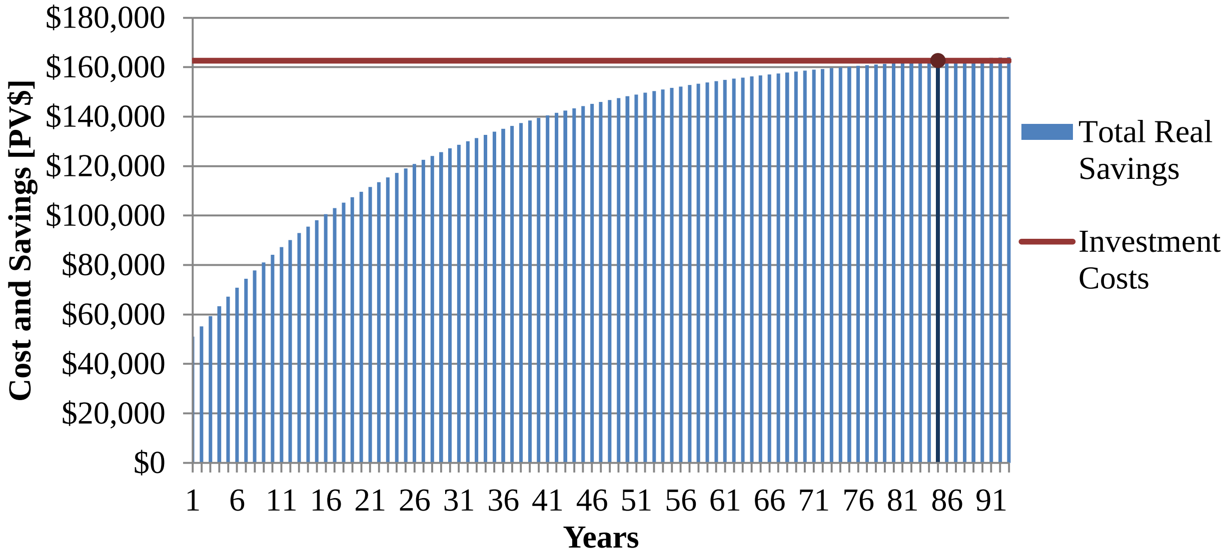

Figure 6-5 Discounted Payback Period with Financial Incentives – All Cash Purchase

Similar to the non-discounted results for a financed home purchase, using a strict definition of the discounted payback period leads to a discounted payback of one year. However, since the annual mortgage costs are greater than the annual energy cost savings, the total costs become greater than the total savings starting in year 6. The costs remain higher throughout the life of the mortgage plus an additional 50 years (80 years in total) for the financial incentives and present value energy cost savings to offset the initial investment costs, which is 31 years greater than the simple payback period approach.

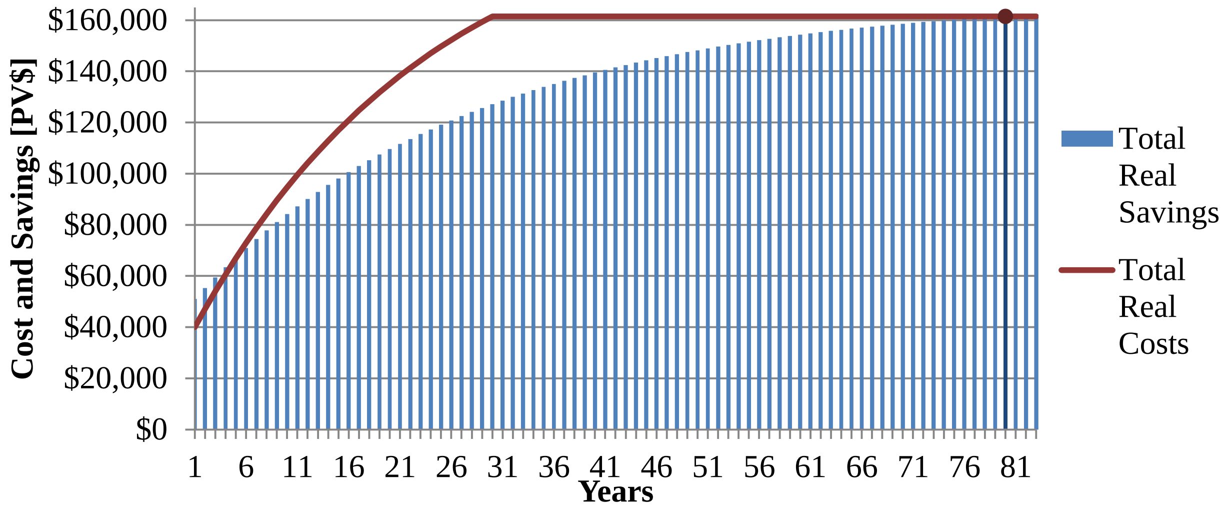

Figure 6-6 Discounted Payback Period with Financial Incentives – 30-Year Mortgage

The simple and discounted payback period approaches are limited in their usefulness and the above example shows the limitations of using payback period to determine a project's economic feasibility. If strictly followed, selecting the net zero energy design would have had a simple payback and discounted payback period of one year. As has been shown, this approach would miss any benefits and costs that occur after the payback period, which are important to the homeowner. In order to capture all the related benefits and costs associated with the house, it is appropriate to use a more rigorous approach.

6.2 Life-Cycle Cost Analysis

Consider the complexity of the decision for the homebuyer. The net zero energy home costs an additional $162 687. If the homebuyer finances the home with a 30-year fixed-rate mortgage with a 20 % down payment at 4.375 %, the additional monthly mortgage payment (principal and interest) is $650 or $7800 annually.[15] The extra annual mortgage costs are 72 % higher than the energy cost savings of $4526. Not only does the NZERTF cost more upfront ($32 537), but the homeowner's monthly costs (mortgage payment minus average energy cost savings) are higher by $273. For perspective, in order to make the combination of mortgage payment and energy bill equivalent for the two homes would require a mortgage interest rate premium subsidy of almost 1.0 % for the NZERTF (see Figure 6-7).

[15] Market rate for jumbo mortgage with 20 % down for Rockville-Wheaton area of Maryland as of April 30, 2014. Source: http://www.bankrate.com/calculators/mortgages/mortgage-calculator.aspx.

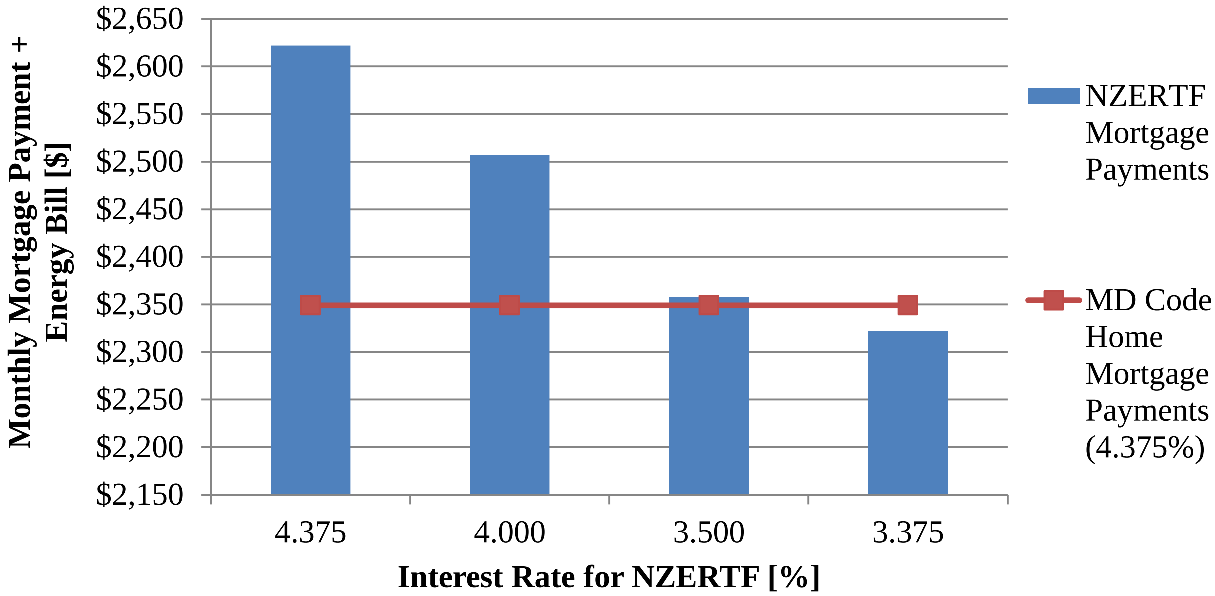

Figure 6-7 Monthly Cost to the Homeowner by Home Design and Interest Rate

However, financial incentives more than offset the higher down payment ($46 626 versus $32 537). The homeowner walks away from closing with an additional $14 809, but has monthly costs (mortgage payment plus energy bill) that are $273 greater than the Maryland code-compliant home. The homeowner's investment time horizon of interest (study period) could significantly impact the owner's decision-making process. Additionally, two other important values must be considered: differences in maintenance, repair, and replacement costs of house components and the difference in resale value of the house. Both of which are impacted by the homeowner's selected study period. It is important to use a well-documented, industry-accepted methodology in order to account for the variety of costs related to the house.

The life-cycle cost methodology, as defined in ASTM Standard Practice E917, considers all costs related to the house over the selected study period, whether it is construction costs, operating costs, or resale value at the end of the study period. The following analysis will vary the study period from 1 year to 100 years because there is a diverse distribution of homeowners. Figure 6-8 shows that 15 years is the approximate half-life of homeownership, where 50.2 % of homeowners are still living in the house (i.e. survival rate). After 20 years, the rate at which homeowners move out of the house (i.e. attrition rate) is relatively constant with an average attrition rate of 2.2 % and a range of 1.5 % to 2.7 %. Assuming this rate of attrition from 31 years forward, there will be 0.1 % of homeowners in their home after 60 years, although there are sure to be outliers that remain in the same home for longer. This study will focus on 30 years or fewer because approximately 65 % of all homeowners live in a home for 30 years or less.

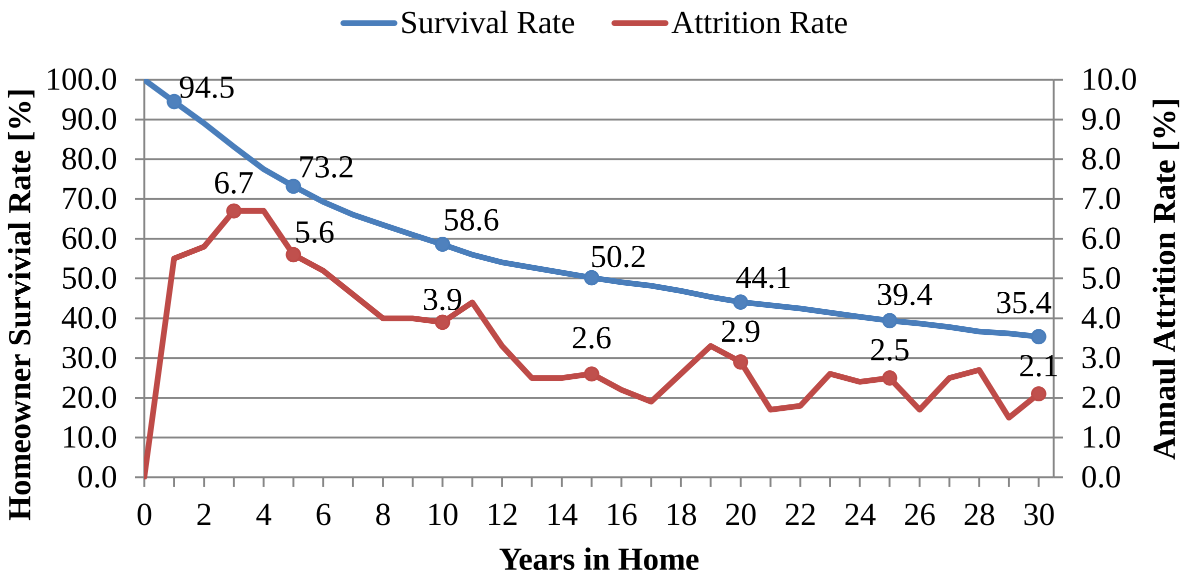

Figure 6-8 Annual Survival Rate of U.S. Single-Family Home Ownership[16]

In order to simplify the analysis, initially assume that the homeowner remains in their home or assumes there is no home price appreciation, the higher performing building design will not fetch a higher resale price relative to the Maryland code-compliant design (no resale value), and the maintenance, repair, and replacement costs are comparable between the two building designs.[17] Figure 6-9 shows the life-cycle cost analysis for 8 study periods from 1 year to 100 years. For a study period 5 years or less, the homeowner realizes net savings in present value life-cycle costs because the upfront financial incentives are enough to offset the higher down payment and future monthly costs (mortgage payments and energy bill) for the first 5 years. However, by the end of year 6 the homeowner realizes net costs, which continue to increase until the mortgage is paid in full after 30 years. At which time the energy cost savings lowers present value net costs until net cost savings is realized in about year 85. Based on these results, it is better for the homeowner to buy the net zero energy home if the homeowner expects to move sometime in the first 5 years, but is not cost-effective for any longer study periods. In the worst case (30 years study period), the additional present value costs is equivalent to a mark-up of 7.0 % relative to the Maryland code compliant design to get a net zero energy, LEED platinum certified, high-performance house.

[16] Emrath (2013)
[17] This assumption is reasonable for approximately the first 15 years because most building systems can continue to work that long, and general maintenance costs will be relatively comparable except for the solar thermal system.

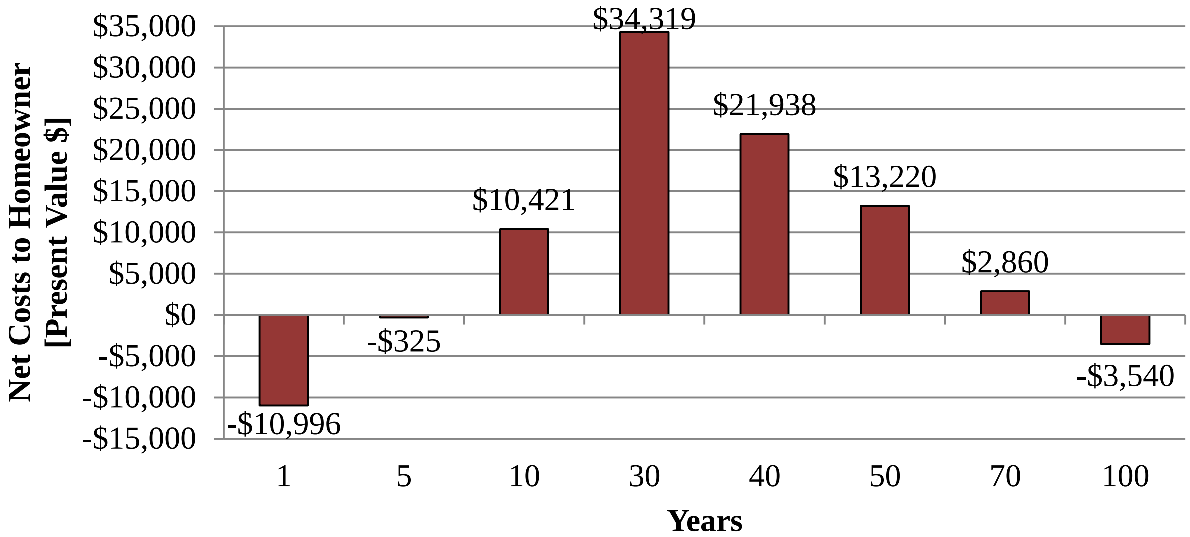

Figure 6-9 Net Costs to Homeowner by Study Period (No Resale Value)

Since most homeowners will sell their home at some point, it is important to consider any potential additional resale value (residual value) of the net zero energy house relative to the Maryland code-compliant home. As was discussed in Section 4.3, there are two approaches considered in calculating residual value. Life-cycle cost methodology takes a functional life approach, assuming a linear depreciation of the residual value based on the initial additional costs, discounted to present value terms. The residual value in this case decreasing over time due to fewer years of usable life for the building and discounting of the residual value back to present value terms. The market approach estimates the additional value of the house to be the discounted present value of the future energy cost savings. The present value of the residual in this case only decreases due to discounting.

Figure 6-10 shows the residual value estimated using both approaches across 8 study periods from 1 year to 100 years. Assuming a house useful life of 100 years, the LCC method leads to a residual value double that from the market approach in year 1 ($154 309 versus $72 814).[18] Both values decrease as the study period increases, with the LCC method residual value decreasing at a faster rate. The residual values are approximately the same by year 40 and the LCC method has a lower residual value after 40 years. The two residual value approaches lead to different results, but similar interpretations.

[18] The market approach leads to similar results to those found in Nevin and Watson (1998): for every $1 saved in energy costs, the homebuyer will pay an extra $16.80 in Year 0.

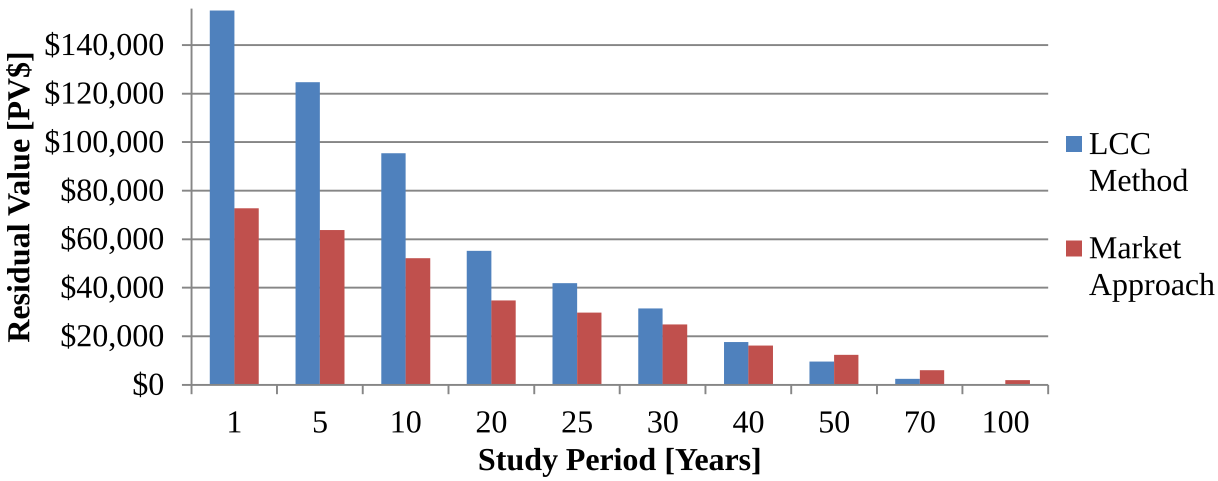

Figure 6-10 Residual Value by Estimation Approach by Study Period

Figure 6-11 shows the net present value costs to the homeowner across 8 study periods from 1 year to 100 years for the two approaches to estimating the residual value. Once the residual value has been included in the life-cycle cost analysis, the net zero energy home becomes more cost-effective over all study periods relative to the life-cycle costs without residual value shown in Figure 6-9. The homeowner realizes present value net cost savings for both residual value approaches for a 1-year, 5-year, 10-year, and 20-year study period, which includes 56 % of all home ownerships. Using the market approach, the homeowner realizes present value costs of $775 over a 25 year study period while the LCC residual value approach leads to net cost savings of $11 230. The homeowner realizes net present value costs for year 30, year 40, and year 50 because the decrease in the discounted value of the residual value is greater than the present value of the energy cost savings. Although it is important to note that the net present value costs for either approach across those 3 study periods range from $879 to $9411, which is equivalent to a 0.2 % to 1.9 % mark-up of the cost of the Maryland code-compliant home ($493 712). So in the worst case scenario, the homeowner is paying the equivalent of a 2 % mark-up for a net zero energy, LEED platinum certified, high-performance home.

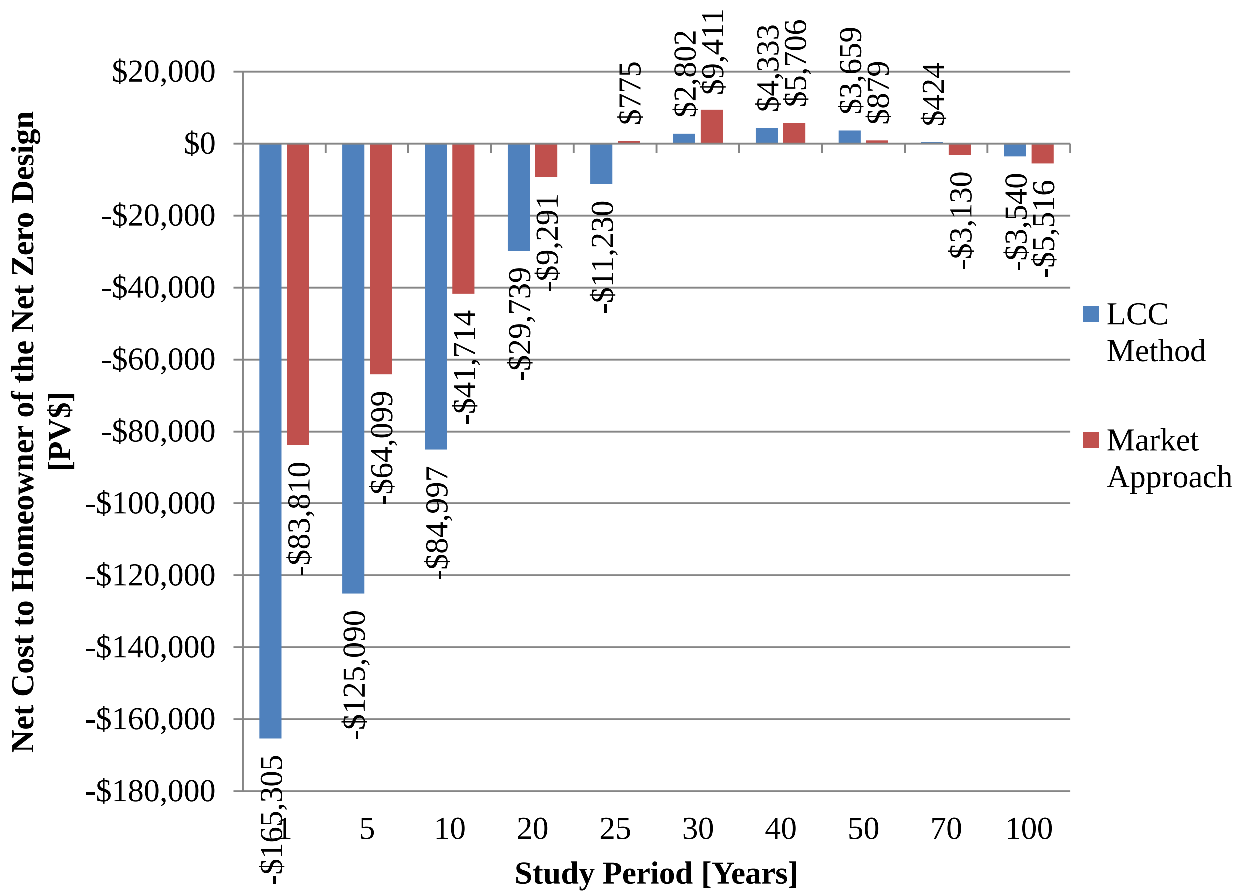

Figure 6-11 Net Costs to Homeowner by Study Period (Including Resale Value)

Let's consider a common homeowner example in detail. Table 6-1 shows the present and future cost comparison of the two designs for a home owner that plans to live in the house for 10 years. This could be representative of a first-time home buyer that will eventually want to move to a larger home or perhaps changes locations due to a career-related move. The present value of the additional down payment minus the financial incentives is -$14 089. The present value of 10 years' worth of mortgage payments minus the energy cost savings is $ 24 510. In total, the additional present value costs to the home owner over the 10-year study period is $10 421. However, at the end of the 10 years, the home owner sells the house and recoups some of the initial additional investment costs. Depending on the residual value estimation approach, the present value net cost savings in life-cycle costs to the home owner is either $41 714 or $84 997.[19]

[19] ASTM Standard E1074

Table 6-1 Life-cycle Cost Comparison: 20 % Down Payment, 4.5 % Discount Rate, 10-Year Study Period

Cost Category	Year Occurred	Discount Factors	Δ Cost	PV Δ Cost
Down Payment	0	1.000	$32 537	$32 537
Financial Incentives	0	1.000	$46 626	$46 626
Mortgage Payments	Annual	7.91	$7800	$62 100
Energy Cost Savings	Annual	8.31	$4526	$37 590
Residual Value - LCC Methodology	10	0.644	$137 658	$95 418
Residual Value – Market Approach	10	0.644	$89 850	$52 134
Net Savings to Home Owner				**$41 714 to $84 997**
Note: No equipment will be replaced in the initial 10 years of operation.				

In making investment decisions, the homeowner may prefer to compare the return on investment to other investment options. Let's assume that the investment cost to the home owner is the higher initial down payment (I). The sum of all financial incentives and future benefits and costs will be treated as net cost savings. Additional mortgage payments (M) are a negative cost savings while energy cost savings (E), financial incentives (F), and residual value (R) are positive cost savings. The ratio of present value net future cost savings to initial investment costs, which is the savings-to-investment ratio or SIR, is calculated using the following formula:

$$SIR = \frac{(E + F + R - M)}{I}$$

Based on the formula, the SIR is calculated to be 1.28 to 2.61, which means the home owner receives a total return on investment over the 10 years of 28 % and 161 %, respectively.[20]

The SIR can be used to calculate an adjusted internal rate of return or AIRR, which is the estimated annualized return on investment the home owner realizes assuming a given reinvestment rate (i) for the study period (n).[21] In this case the reinvestment rate is assumed to be equal to the discount rate or 4.375 %. The formula for calculating the AIRR is the following:

$$AIRR = (1 + i) * (SIR)^{1/n} - 1$$

Based on this formula, the AIRR is estimated to be 5.6 % and 14.9 %, respectively.[22]

These calculations do not account for a number of factors that will impact costs. There is assumed to be no maintenance, repair, and replacement (MRR) cost differences between the two buildings. All equipment is assumed to have at least a 10-year lifespan and, therefore, no

[20] ASTM Standard Practice E964
[21] ASTM Standard Practice E1057
[22] The reinvestment rate is assumed to be the mortgage interest rate of 4.5 %.

replacement costs will occur during the study period. The relative home values are assumed fixed, which ignores any changes in the housing market. Also excluded from the analysis are any home insurance, property tax, and income tax implications. Home insurance may be more expensive due to the higher market value of the home, but more energy efficient homes may receive a premium discount. The state of Maryland exempts many energy efficiency and renewable energy home investments, which should alleviate most, if not all, of the property tax implications. Including the itemized deduction for a home will lower the after-tax mortgage payments because the homeowner is getting some of the mortgage payment returned, and increase the residual value estimate because a lower effective discount rate increases the value of future energy cost savings. The magnitude of the effects will depend on a variety of other factors, including income levels, filing status, and other tax deductions. There is also no value placed on the LEED platinum rating and related "green" features, which would vary significantly across homebuyers.

7 Limitations

This study has a number of limitations related to the whole building energy simulations and cost data and assumptions. Whole building energy simulation software is limited in its abilities to estimate real world energy performance because it is difficult to control for all potential variables that can impact the thermal conditions in a building. There may be discrepancies between the *E+* model and the actual NZERTF design. Electrical equipment consumption may be overestimated or underestimated dependent on whether equipment operates as simulated. Air infiltration may not be accurately estimated in the *E+* model. Building components may not perform at the manufacturer specifications, such as solar photovoltaic, heating, ventilation, and air conditioning, and domestic hot water systems). Actual weather varies from year to year while the simulation uses “typical” weather patterns, which may lead to over or under-consumption to maintain the building’s desired indoor conditions. These concerns are currently being addressed through extensive monitoring of the NZERTF under actual weather conditions to determine where the discrepancies are between the simulation model and the measured performance and adjust the model in order to better replicate measured performance.

There are limitations to the cost analysis in this study. The cost estimates are based on data from one contractor and cannot account for the variation that may occur in the marketplace across contractor project bids. A lack of reliable maintenance, repair, and replacement rates and cost data make it difficult to account for all the cost differences throughout a building’s lifetime, particularly after 15 years. The life-cycle cost analysis excludes a variety of factors that may have significant impacts on the cost-effectiveness of the NZERTF design. In general, this study took a conservative approach to estimating the life-cycle cost performance of the NZERTF: home value appreciation, mortgage income tax deductions, and the economic value associated with the non-energy related sustainability aspects of the home are excluded from the analysis. Each of these factors is expected to have a positive effect on the life-cycle cost-effectiveness of the net zero energy, LEED Platinum home design.

8 Discussion and Future Research

This study analyzes the life-cycle cost performance of the Net Zero Energy Residential Test Facility (NZERTF) relative to an identical house built to meet the Maryland residential energy code, which is based on 2012 IECC. Life-cycle cost analysis requires information on both initial construction costs as well as any future costs associated with operation of the building and maintenance, repair, and replacement (MRR) activity.

Whole building energy simulation software (*E+*) is used to estimate the annual electricity consumption of both the net zero energy and 2012 IECC designs. The net zero energy design leads to a reduction of 60 % in energy consumption relative to the 2012 IECC design while doing a better job at maintaining a "comfortable" indoor environment for the occupants. If the net zero energy design were to be compared to an older edition of IECC, the percentage reduction would be even larger because the goal for 2012 IECC was to be 30 % more efficient than 2006 IECC.

The life-cycle cost analysis is not simple for the homeowner to understand. The net zero energy design is approximately 33 % ($162 687) more expensive to construct than the 2012 IECC design due to its complex construction design (additional insulation, tighter air leakage control, HRV system, solar systems, etc.). However, the net zero energy design is projected to reduce electricity costs by $4526 annually ($4205 in consumption costs plus net metering sales to the utility of $321). Additionally, there are state and federal financial incentives that can offset a portion of the upfront costs. There is also evidence to suggest the more energy efficient design of the net zero energy home increases its market value at the time of resale (i.e., residual value).

If the homeowner finances the home with a 30-year mortgage with a 20 % down payment at 4.375 %, the financial incentives are greater than the additional funds needed for the down payment. However, the additional costs from the mortgage payments are greater than the energy cost savings, the equivalent of a 1 % mortgage rate premium. As a result, the length of time the homeowner intends to live in the house has a significant impact on the life-cycle cost-effectiveness of investing in the net zero energy home instead of the Maryland code-compliant home.

Assuming a 10-year study period, 20 % down payment, 4.5 % discount rate/mortgage rate/reinvestment rate, and the market-based resale value estimate, the net life-cycle cost savings of constructing and operating the net zero energy home are $41 714, which is an adjusted internal rate of return (AIRR) of 5.6 %. Not only does the net zero energy design have lower energy consumption (actually it produces more than it consumes) and improve indoor comfort levels for the occupants, it also provides a positive return on investment to the home owner.

The analysis in this study is limited in scope and scale, and future research should consider a number of factors. More in-depth economic analysis should be completed to consider all costs associated with the building (e.g. differences in MRR costs). Incremental cost analysis of different combinations of the components implemented in the NZERTF should be considered in order to search for the more cost-effective building design for home owners. The NZERTF is set up to test a number of different component and system configurations, such as geothermal heat pumps and high-velocity duct systems. These alternative configurations should be analyzed to determine if any of them are more cost-effective than the current operation of the NZERTF. The construction cost data is based on a single contractors cost estimate. It would be beneficial to receive similar bids from a subset of the home builders in Maryland and the surrounding states to determine a median cost and the potential variation in costs of constructing additional homes in the region to meet the energy performance of the NZERTF design. Appraisers should be consulted in order to determine the additional value placed on energy efficient, net zero energy, and LEED certified homes in the current market.

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Appendix A Construction Cost Data by Category and Subcategory

Table A-1 Construction Cost Estimate by Building Design

Category	NZERTF COST	MD CODE COST
PRECONSTRUCTION	**$3430**	**$3230**
HEAVY EQUIPMENT	**$2750**	**$2200**
Telelift	$2000	$1800
Crane	$0	$0
Misc Tools	$750	$400
FOUNDATION and EXCAVATION	**$29 628**	**$22 050**
Excavation	$1800	$1800
Stone	$4000	$1500
Drainage	$1800	$750
Sand	$0	$0
Foundation Installation	$20 000	$16 500
Backfill	$1528	$1000
Final Grade	$500	$500
UTILITY CONNECTIONS	**$6000**	**$6000**
Disconnect	$0	
Electrical	$1000	$1000
Gas/Propane	$2000	$2000
Water	$1500	$1500
Sewer	$1500	$1500
CONCRETE	**$14 528**	**$10 400**
Basement Concrete	$8500	$5000
Basement Floor Insulation	$1500	$1100
Garage Concrete	$2028	$1800
Driveway	$0	$0
Sidewalk	$0	$0
Sonatubes	$800	$800
Porch/other	$1700	$1700
ROUGH FRAMING	**$85 598**	**$64 700**
Exterior Wall framing Labor	$13 550	$7000
Interior Wall/Floor framing Labor	$5500	$5500
Roof Framing Labor	$19 000	$13 950
Trusses/Rafter material	$4500	$4500
Rough Materials		$30 000
Exterior Walls	$14 000	
Interior Wall/Floor	$10 000	
Roof	$14 000	
Garage Materials	$2400	$2200
Garage Labor	$2298	$1200
Beam Materials	$350	$350
BUILDING SYSTEMS	**$214 750**	**$51 500**
Rough		
Plumbing Rough	$16 500	$12 000
HVAC Rough	$23 000	$13 500
Interior ductwork and Equipment Air to Air	$15 000	
High Velocity Ductwork and equipment	$6500	
Heat Recovery Ventilation system	$12 000	
In-floor radiant (incl in concrete work)		
Geothermal loops		
Horizontal Loop	$10 500	
Slinky Loop	$10 500	
Vertical Loop	$16 000	
Multi split heat pump system	$18 750	
Electrical Rough	$16 500	$11 000
Fire suppression	$10 000	$10 000
Solar Systems		
PV	$28 000	$0
HW	see below	$0
80 Gallon 2 panel system	$4000	
120 Gallon 4 Panel system	$6000	
Finishes		
Plumbing finish	$1500	$1500
HVAC finish	$2000	$1500

Electrical Finish	$18 000	$2000
Fireplace	$0	
Security System	$0	
EXTERIOR FINISHES	**$83 900**	**$74 100**
Windows and doors	$33 000	$22 000
Window Wells	$1200	$1200
Door Other	$0	$0
Garage Doors	$6500	$6500
Siding	$23 000	$23 000
Siding other	$0	$0
Exterior painting	$8000	$8000
Cultured stone	$4200	$4200
Roofing	$8000	$8000
Eavestrough	$0	$1200
INSULATION	**$41 300**	**$6500**
Roof	$15 800	$2500
Exterior Walls	$10 500	$2000
Air Barrier Membrane	$4300	$0
Open cell spray foam	$2500	$1500
Foundation/Basement walls	$4700	$500
Garage roof (closed cell)	$3500	$0
PORCHES AND DECKS	**$2000**	**$2000**
Porch Fixed	$0	
Screened porch	$2000	$2000
Deck	$0	
INTERIOR FINISHES	**$173 450**	**$166 950**
Drywall	$17 000	$10 500
Wall Tile	$15 000	$15 000
Flooring		
Wood	$24 000	$24 000
Tile	$18 000	$18 000
Cabinets		
Cabinet Material	$12 000	$12 000
Cabinet Installation	$3000	$3000
Vanities	$3000	$3000
Vanity Installation	$350	$350
Kitchen Countertop	$9000	$9000
Vanity Tops	$1200	$1200
Shelving	$0	$0
Interior Painting	$9500	$9500
Interior Design	$0	$0
Appliances	$14 000	$14 000
INTERIOR TRIM		
Trim Material	$25 000	$25 000
Trim other		
Trim Installation Labor	$7000	$7000
Interior Doors Material	$10 000	$10 000
Interior Doors Labor	$1200	$1200
Other Trim Material	$0	$0
Other Trim Labor	$0	$0
Shower Doors and Mirrors	$4200	$4200
LANSCAPING	**$0**	**$0**
Retaining Walls	$0	$0
Sod/Hydroseed	$0	$0
Miscellaneous	$0	$0
MISCELLANEOUS	**$30 750**	**$10 550**
Demolition	$0	
Disposal/Recycle	$900	$700
ORDER DUMPSTER		
REMOVE DUMPSTER		
Final Cleanup	$850	$850
Garage Chair lift	$4000	$4000
Miscellaneous	$25 000	$5000
Builder's Cost	**$688 084**	**$420 180**
Builder's Overhead and Profit @ 17.5%	**$120 415**	**$73 532**
TOTAL	**$808 499**	**$493 712**

Table A-2 Construction Cost Differences by Category and Subcategory[23]

Category	NZERTF COST	MD CODE COST	COMPARISON
PRECONSTRUCTION	**$3430**	**$3230**	NZERTF has more detail, which increases design cost. Permitting may be based on total construction cost, which is higher with NIST home.
Permits and Design			
HEAVY EQUIPMENT	**$2750**	**$2200**	Additional components and stages of construction.
Telelift	$2000	$1800	
Misc Tools	$750	$400	
FOUNDATION and EXCAVATION	**$29 628**	**$22 050**	
Stone	$4000	$1500	Additional drainage material (gravel/stone)
Drainage	$1800	$750	Roof drip drainage and gravel bed not included in code built house
Foundation Installation	$20 000	$16 500	Extra work due to drainage and insulation
Backfill	$1528	$1000	Roof drip drainage and gravel bed.
CONCRETE	**$14 528**	**$10 400**	
Basement Concrete	$8500	$5000	In floor heating system (additional planning and labor).
Basement Floor Insulation	$1500	$1100	Additional insulation in the foundation
Garage Concrete	$2028	$1800	Additional cost due to extra care with regard to labor.
ROUGH FRAMING	**$85 598**	**$64 700**	More steps and attention to detail. Much of the cost increase in the NIST home is due to the air-sealing details.
Exterior Wall framing Labor	$13 550	$7000	Extra care to assure proper fits and seals for additional insulation.
Roof Framing Labor	$19 000	$13 950	Extra care to assure proper fits and seals for additional insulation.
Rough Materials		$30 000	
Exterior Walls	$14 000		Additional Cost due to extra insulation materials for insulation
Interior Wall/Floor	$10 000		
Roof	$14 000		Additional Cost due to extra insulation materials for insulation
Garage Materials	$2400	$2200	Additional framing costs due to additional insulation
Garage Labor	$2298	$1200	Extra care to assure proper fits and seals for additional insulation.
BUILDING SYSTEMS	**$214 750**	**$51 500**	
Rough			
Plumbing Rough	$16 500	$12 000	Extensive ductwork leads to additional "work arounds" required for the plumbing.
HVAC Rough	$23 000	$13 500	Cost of HVAC system
Interior ductwork and Equipment Air to Air	$15 000		Extensive ductwork leads to additional "work arounds". Also additional air handler/gas furnace.
High Velocity Ductwork and equipment	$6500		Requires lots of Plenum work to improve performance.
Heat Recovery Ventilation system	$12 000		Included an HRV system for appropriate outdoor air flow.
In-floor radiant (incl in concrete work)			In-floor radiant heating in the basement.
Geothermal loops			Note: This has been discounted assuming all three excavations done together to conserve costs.
Horizontal Loop	$10 500		
Slinky Loop	$10 500		
Verticle Loop	$16 000		

[23] Excludes categories and subcategories that have the same costs for the NZERTF and Maryland code-compliant design.

Multi split heat pump system	$18 750		Typically done post-construction
Electrical Rough	$16 500	$11 000	Several “work arounds” with HVAC and Plumbing. Additional wiring for several HVAC systems. Additional costs comes from the higher performance items (breakers, etc.).
Solar Systems			
PV	$28 000		LG 300W MONO X panels. The performance will be between 10-15% below the SunPower panels. These are the next best panels on the market at the best price. SunPower with a $7000 cost up on average.
80 Gallon 2 panel system	$4000		Solar water heating on NIST house not in typical house construction.
120 Gallon 4 Panel system	$6000		Solar water heating on NIST house not in typical house construction.
Finishes			
HVAC finish	$2000	$1500	Additional HVAC equipment.
Electrical Finish	$18 000	$2000	Several “work arounds” with HVAC and Plumbing. Additional wiring for several HVAC systems. Additional costs comes from the higher performance items (breakers, etc.).
EXTERIOR FINISHES	**$83 900**	**$74 100**	Cost increase for NIST in this section is mainly due to the additional complexity of attaching siding.
Windows and doors	$33 000	$22 000	Pella Triple pane SunDefence LowE with Argon. NZERTF used Serious Materials Windows, which are no longer available.
Eavestrough	$0	$1200	Not needed in NZERTF due to drip drainage system.
INSULATION	**$41 300**	**$6500**	NIST home increase cost due mostly to the cost of the polyisocyanurate. Additional increased cost due to air-sealing membrane and insulation of areas not typically insulated.
Roof	$15 800	$2500	Additional high priced insulation, in some cases double thickness and meticulous application of tape to seal
Exterior Walls	$10 500	$2000	Additional high priced insulation, in some cases double thickness and meticulous application of tape to seal
Air Barrier Membrane	$4300	$0	Additional high priced insulation, in some cases double thickness and meticulous application of tape to seal
Open cell spray foam	$2500	$1500	Additional high priced insulation, in some cases double thickness and meticulous application of tape to seal
Foundation/Basement walls	$4700	$500	Additional high priced insulation, in some cases double thickness and meticulous application of tape to seal
Garage roof (closed cell)	$3500	$0	Additional high priced insulation, in some cases double thickness and meticulous application of tape to seal
INTERIOR FINISHES	**$173 450**	**$166 950**	Basement drywall and installation details are the cause of the increase for code built above NIST home.
MISCELLANEOUS	**$30 750**	**$10 550**	Miscellaneous cost increased due to overall cost increase for NIST. Nonstandard processes and applications also increase Miscellaneous account.
Disposal/Recycle	$900	$700	
Miscellaneous	$25 000	$5000	Risk mark-up due to cost of materials and required expertise.