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U.S. Department of Energy Zero Energy Ready Home Implementation

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NorthernSTAR

July 2017

Building AMERICA®
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Prepared for:

The National Renewable Energy Laboratory

On behalf of the U.S. Department of Energy's Building America Program

Office of Energy Efficiency and Renewable Energy

15013 Denver West Parkway

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NREL Contract No. DE-AC36-08GO28308

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Prepared under Subcontract No. KNDJ-0-403388-00

July 2017

The work presented in this report does not represent performance of any product relative to regulated minimum efficiency requirements.

The laboratory and/or field sites used for this work are not certified rating test facilities. The conditions and methods under which products were characterized for this work differ from standard rating conditions, as described.

Because the methods and conditions differ, the reported results are not comparable to rated product performance and should only be used to estimate performance under the measured conditions.

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Definitions

ACH50	air changes per hour at 50 pascals
AFUE	annual fuel utilization efficiency
BEopt	Building Energy Optimization
CFL	compact fluorescent lamp
DOE	U.S. Department of Energy
EF	Energy Factor
ERV	energy recovery ventilator
ft^2	square feet
HERS	Home Energy Rating System
HRV	heat recovery ventilator
HSPF	heating seasonal performance factor
HVAC	heating, ventilating, and air conditioning
ICF	insulating concrete forms
kW	kilowatt
LED	light-emitting diode
Low-e	low emissivity
MMBtu	million British thermal units
MMBtu/y	million British thermal units per year
PV	photovoltaic
PVC	polyvinyl chloride
SEER	Seasonal Energy Efficiency Ratio
SHGC	solar heat gain coefficient
ZERH	Zero Energy Ready Home

Executive Summary

Achieving the U.S. Department of Energy (DOE) Zero Energy Ready Home (ZERH) program certification can be challenging for some builders. This report is designed to document the process and outcomes involved in meeting this rigorous standard while helping homebuilders in Climate Zones 5 and 6 in the Upper Midwest achieve ZERH certification.

For this research, local builders volunteered to build at least one ZERH-qualified house. Northern*STAR*, in conjunction with program partner Building Knowledge, Inc., provided technical support to the builders during the design and construction process. In addition, participants had their program questions answered and received technical information about program requirements and critical building components and processes.

Commonly-Found Construction Technique Improvements

The volunteer builders' homes meet or exceed the 2012 International Energy Conservation Code requirements. Typical improvements over theses requirements include:

- Improved infiltration performance
- Increased high-efficacy lighting
- Increased foundation insulation levels
- Energy recovery ventilation.

Energy Modeling

Energy consumption predictions were made using two software tools: REM/Rate™ and BEopt™. REM/Rate was used to generate Home Energy Rating System ratings and verify qualification under DOE ZERH. Detailed inputs used in REM/Rate were used to duplicate the houses as closely as possible in BEopt. Energy model predictions were in close agreement in half of the homes, while they differed significantly in the other half. Modeling limitations were identified to explain the differences, including:

- Geometry that can't be accommodated in BEopt:
    - House plans with geometry including angles other than 90º
    - Unconventional conditioned attics under complex roof shapes that don't include additional exterior wall areas
    - Walk-out basements and other complex basement conditions
    - Certain complex ceiling geometries
    - Half-story upper floors that cantilever beyond the first floor
- Window types that vary within a given elevation (BEopt can model differing window types on different elevations, but not multiple types on one elevation).

Key Conclusions

The two most obvious barriers faced by the builders include overcoming the learning curve about the ZERH program requirements and conveying those requirements to their staff and trade

contractors. The Building America Solution Center was a valuable resource for the builders and designers, especially in addressing the strategies for above-grade wall insulation to maximize performance and minimize risk and cost. Energy modeling also supported a common understanding of the energy impact of design decisions, building components, and energy-consuming devices and systems.

Other barriers to effectively implementing ZERH certification include:

- Heating, ventilating, and air conditioning (HVAC) quality installation:
    - There is a limited availability of credentialed HVAC contractors in most markets to work on ENERGY STAR®-certified projects
    - Our experience demonstrates that even with credentialing, field crews' lack of experience and training often results in HVAC system designs and installations that do not meet the program requirements
- Exterior wall continuous insulation:
    - Placing insulation on the outside of exterior wall assemblies presents challenges for attaching structural deck ledgers while maintaining a thermal break
    - Integration with fenestrations and attaching siding are not practices builders and trade contractors are accustomed to.

It is clear builders can achieve the ZERH certification and will see the performance results in their new homes. At the time this publication was drafted, four qualifying homes were complete, and an additional three were under construction to be completed later in 2016.

To help builders convey the benefits of ZERH homes to homebuyers, realtors, appraisers, and the press, enhanced messaging is needed. Most of the homes presented in this study received enhanced public interest through media events, feature newspaper articles, site tours, and social media posts, demonstrating an increasing acceptance by the public of the benefits of energy-efficient homes. Two builders noted that participating in the ZERH program provided them with a competitive advantage in the marketplace at reasonable construction costs, resulting in extremely satisfied clients who recommend the builders to friends and family.

1 Introduction

The purpose of this project is to document the feasibility of attaining the U.S. Department of Energy (DOE) Zero Energy Ready Home (ZERH) (formerly known as *DOE Challenge Home*) standards in a Midwestern cold climate market (Climate Zones 5 and 6). The aim of DOE's ZERH is to enable the construction of houses that are "so energy efficient, that a renewable energy system can offset all or most of [their] annual energy consumption" (DOE 2015). This goal aligns with DOE's Building America Program goal to reduce home energy use by 30%–50% (compared to 2009 energy codes for new homes) while at the same time not compromising building durability or human health.

DOE ZERH must:

- Comply with ENERGY STAR for homes[1] and the inspection checklists[2] for
  - Thermal enclosure
  - Heating, ventilating, and air conditioning (HVAC) quality installation [contractor and the Home Energy Rating System (HERS)]
  - Water management.
- Feature energy-efficient appliances and fixtures that are ENERGY STAR qualified
- Use high-performance windows that meet ENERGY STAR[3] specifications
- Meet 2012 International Energy Conservation Code levels for insulation. In some states, 2015 International Energy Conservation Code insulation levels are required
- Follow the latest proven research recommendations by installing ducts in conditioned space or using a high-performance alternative as defined in the program specs
- Conserve water and energy through an efficient hot water distribution system that provides rapid hot water to the homeowner
- Provide comprehensive indoor air quality through full certification by the U.S. Environmental Protection Agency's Indoor airPLUS[4] program
- Accomplish savings on the cost of future solar photovoltaic (PV) installations by following the PV-ready checklist[5] for climates with significant solar insolation. This checklist references the U.S. Environmental Protection Agency's solar electric guide.[6]

[1] See http://www.energy.gov/eere/buildings/downloads/energy-star-certified-homes-version-3-rev-07-national-program-requirements.
[2] See http://www.energy.gov/eere/buildings/downloads/energy-star-certified-homes-version-3-rev-07-inspection-checklists-national.
[3] See http://www.energystar.gov/products/building_products/residential_windows_doors_and_skylights.
[4] See http://www.epa.gov/indoorairplus.
[5] See http://www.energy.gov/eere/buildings/downloads/doe-zero-energy-ready-home-pv-ready-checklist.
[6] See http://www.energy.gov/eere/buildings/downloads/renewable-energy-ready-home-solar-photovoltaic-specifications.

This project identifies builders willing to participate in a program that will put them among the top 1% of builders in the region in terms of their ability to profitably build new homes that are a substantial step up in performance relative to the rest of the new home market.

2 Approach

The essential components of this research consisted of marketing the DOE ZERH concept to local builders to solicit volunteers who were willing to build at least one qualified house, answering their questions about the program and providing technical knowledge about program requirements and critical building components and processes, and verifying that the requirements had been met on candidate houses. The approach involved the following steps:

1. Assist builders in understanding the DOE ZERH concept, criteria, and registration.
2. Provide technical support to the builders through plan reviews, technology/product selections, and energy modeling.
3. Document the process and final product using a case study format.
4. Provide short-term monitoring, using utility bill data when possible, to compare actual energy use to design models.

2.1 Volunteer Builders

Amaris Custom Homes of White Bear Lake, Minnesota, committed to constructing 100% of their homes to DOE ZERH requirements. To date, the company has completed three certified homes, one of which is a 2015 Housing Innovation Award winner.

Cobblestone Homes of Saginaw, Michigan, has completed a qualifying home, which was a 2014 Housing Innovation Award winner, and it is currently developing strategies to commit to constructing 100% of their homes to DOE ZERH requirements.

Morrissey Builders of Minneapolis, Minnesota, has experience in constructing certified projects such as homes certified by Minnesota GreenStar, Passive House Institute US Certification, and Leadership in Energy and Environmental Design.

Urban Homeworks of Minneapolis, Minnesota, is a faith-based nonprofit organization that provides dignified housing and creates construction training opportunities by weaving together a network of engaged neighbors and mobilizing volunteers. ZERH is part of the City of Minneapolis's Green Homes North Initiative to build 100 energy-efficient homes throughout five years to revitalize neighborhoods in North Minneapolis. The project is also a training ground for Urban Construction Company and Youthbuild, wherein youth and young adults learn skills and make each trainee a more sought-after asset for employers.

Detailed analyses of the business and building practices for Amaris and Cobblestone Homes are available in VonThoma and Ojczyk (2012).

2.2 Technical Support

2.2.1 *Technical Support from the University of Minnesota*

Pat Huelman and Garrett Mosiman from the University of Minnesota met with builders and their subcontractors on an as-needed basis. These meetings were used to communicate ZERH requirements and to talk through applying the requirements to the builders' home designs.

2.2.2 *Technical Support from HERS Raters*

Building Knowledge, Inc., provided the participating builders with technical support and assistance including verification and testing to meet DOE ZERH program requirements. Building Knowledge is a team lead for DOE's Northern*STAR* Building America Program, and it has been a technical resource for the Building America Program for more than 15 years.

2.3 Energy Modeling

Two energy modeling software packages were used to model each house: REM/Rate, produced by NORESCO, LLC; and Building Energy Optimization (BEopt), a free energy modeling software application produced by the National Renewable Energy Laboratory. REM/Rate is used nationally to certify homes using standards such as DOE ZERH, and it was used during this project to inform decisions during the design and construction process. BEopt is used extensively in DOE's Building America Program, and it was used here to enable comparisons among ZERH projects in this study and other Building America work.

Building Knowledge produced energy models using REM/Rate in the process of generating HERS ratings as a part of the ZERH certification process. Detailed summaries of building characteristics modeled in REM/Rate were used to generate BEopt inputs to ensure that the models were as close as possible to being identical. Models were generated using BEopt 2.3.0.2 and run using the EnergyPlus simulation engine. Three outputs from BEopt are reported: B10 Benchmark source energy use, as-designed source energy use, and as-designed site energy use. As-designed site energy use can be compared directly to REM/Rate site energy use. Note that the two programs allocate end-use energy differently. REM/Rate outputs include four categories: heating, cooling, water heating, and lights/appliances. BEopt outputs also include heating, cooling, and water heating; however, lights/appliances are disaggregated into the categories of large appliances, HVAC fan/pump, lights, vent fan, and miscellaneous. This difference in categorization may account for some of the differences in allocated energy between the models.

Establishing whether or not results are similar between the two tools may be useful for further transfer of knowledge among researchers (using BEopt) and energy raters in the field.

3 DOE ZERH Designs

3.1 Amaris Custom Homes: Saint Paul, Minnesota, Model Home Project

3.1.1 *Basic Project Information*

This 3,542-ft^2, 5-bedroom, 4-bathroom walk-out rambler with finished basement is the first DOE Challenge Home in Minnesota. This home was completed in September, 2013, and it is located in Climate Zone 6.

Figure 1. Amaris Custom Homes: Front elevation of the St. Paul, Minnesota, project

Figure 2. Amaris Custom Homes: Rear elevation of the St. Paul, Minnesota, project

3.1.2 *Technical Characteristics of Typical Construction Practices and DOE ZERH Solutions*

The typical construction practices for Amaris Custom Homes are close to the ZERH requirements.

Table 1. Amaris Custom Homes: Model Home Project

Measure	Typical Construction Practices	ZERH Solution
Infiltration	1.00 ACH50[a]	0.84 ACH50
Cooling Equipment	14 SEER[b]	14.5 SEER
Heating Equipment	Natural gas, 96 AFUE[c]	Natural gas, 96.1 AFUE
Water Heater	Natural gas, 0.90 EF[d]	Natural gas, 0.80 EF
Lighting	50% ENERGY STAR	100% ENERGY STAR CFL[e]/LED[f]
Thermostat	Programmable	Programmable
Dishwasher	ENERGY STAR rated	ENERGY STAR rated
Refrigerator	ENERGY STAR rated	ENERGY STAR rated
Clothes Washer	ENERGY STAR rated	ENERGY STAR rated
Ceiling Insulation	2-in. closed-cell spray foam on lid with R-48 blown fiberglass. Total R-65.5	2-in. closed-cell spray foam on lid with R-48 blown fiberglass. Total R-65.5
Above-Grade Wall Insulation	R-5 continuous exterior insulation, 3-in. closed-cell spray foam in cavity. Total R-24.5	R-5 continuous exterior insulation, 3-in. closed-cell spray foam in cavity. Total R-25
Foundation Insulation	R-10 foundation wall	14-in. ICF,[g] R-25, under slab R-20
Windows	Double-pane, argon-filled; PVC[h]-framed; Low-e[i] windows with U-0.25	Double-pane, argon-filled; PVC-framed; Low-e windows with U-0.25 and 0.49 SHGC[j]
Reduced Lumber from Advanced Framing	2 x 6-in. walls 24-in. on center, open corners and single-ply headers	2 x 6-in. walls 24-in. on center, open corners and single-ply headers
Ventilation	HRV[k]	ERV[l]
Duct Systems	Located within the thermal and air barrier, fully ducted, sealed with mastic	Located within the thermal and air barrier, fully ducted, sealed with mastic
PV	None	12.2 kW[m]

[a] Air changes per hour at 50 pascals
[b] Seasonal energy efficiency ratio
[c] Annual fuel utilization efficiency
[d] Energy Factor
[e] Compact fluorescent lamp
[f] Light-emitting diode
[g] Insulating concrete forms
[h] Polyvinyl chloride
[i] Low-emissivity
[j] Solar heat gain coefficient
[k] Heat recovery ventilator
[l] Energy recovery ventilator
[m] Kilowatt

3.1.3 *Energy Modeling*

Figure 3 shows the energy modeling results for Amaris Custom Homes' St. Paul, Minnesota, project. Predictions of site energy use were nearly identical between the two models: 99 Million British thermal units per year (MMBtu/yr) for BEopt and MMBtu/yr REM/Rate. In addition, predicted PV output is very similar: 46 and 48 MMBtu/yr, respectively. BEopt inputs and HERS information can be found in Appendix A and Appendix B.

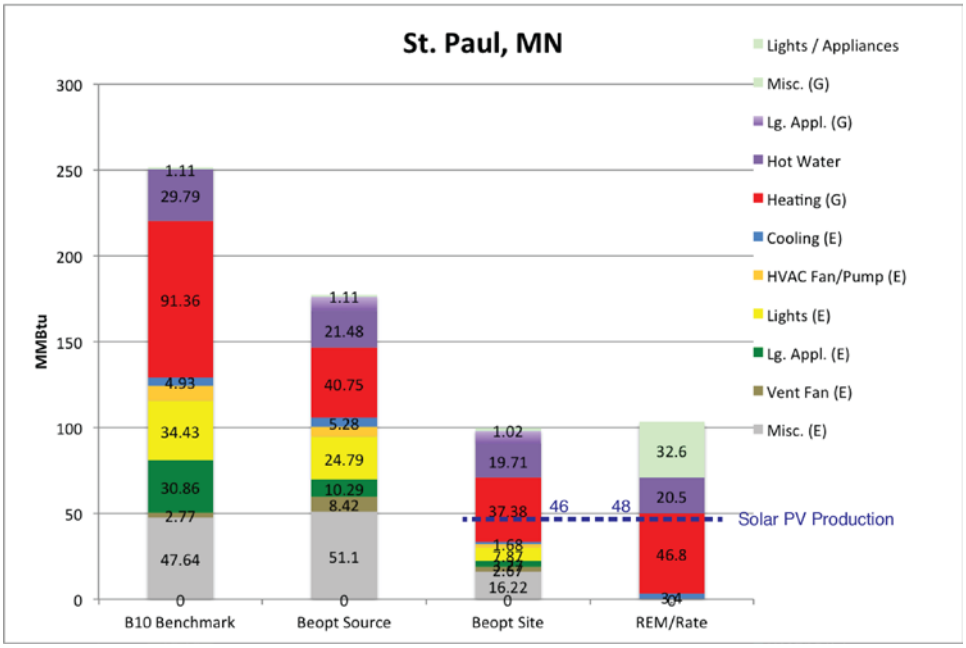


Figure 3. Amaris Custom Homes: Energy modeling results for the St. Paul, Minnesota, project

3.1.4 *Initial Energy Use*

Figure 4 summarizes the actual energy use and predicted energy use as modeled in BEopt. Note that Year 2 energy use does not include data for July 2015, which was not available at the time of publication. Figure 5 and Figure 6 show the first two years broken down by billing period. First-year electric consumption was only slightly higher than modeled. Year 2 appears to be on track to consume less electricity than Year 1 and that of the predicted value. In both years, however, gas consumption was significantly higher than predicted.

Gas consumption roughly follows the pattern predicted in the model; that is, consumption rises during the heating season and declines in warmer months. Consumption in the summer can be primarily attributed to water heating but also to clothes drying and cooking. Electric consumption, however, appears to be consumed in a much more stochastic way, perhaps reflecting the importance of occupant behavior and plug loads to electric energy use.

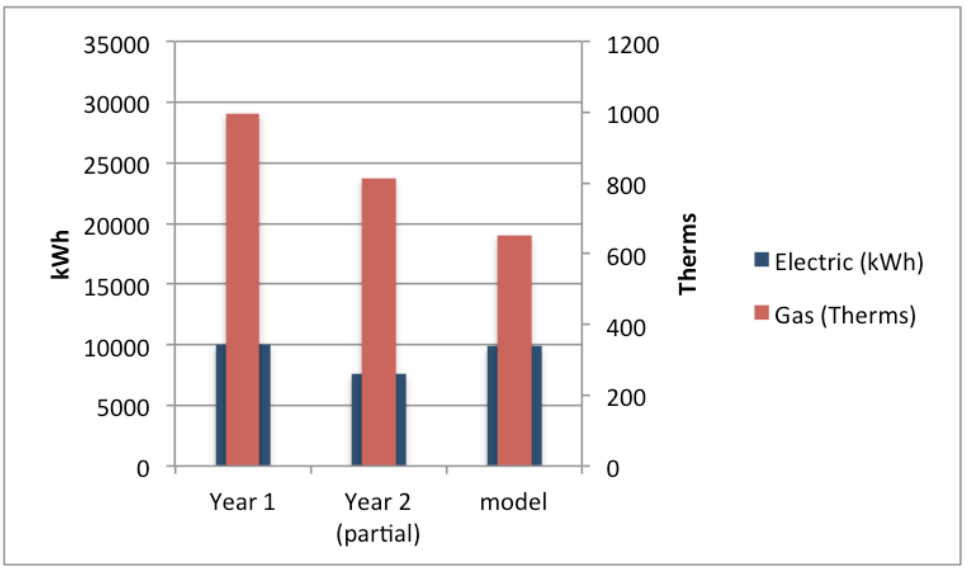


Figure 4. Amaris Custom Homes: Actual compared to modeled annual energy use for the St. Paul, Minnesota, project

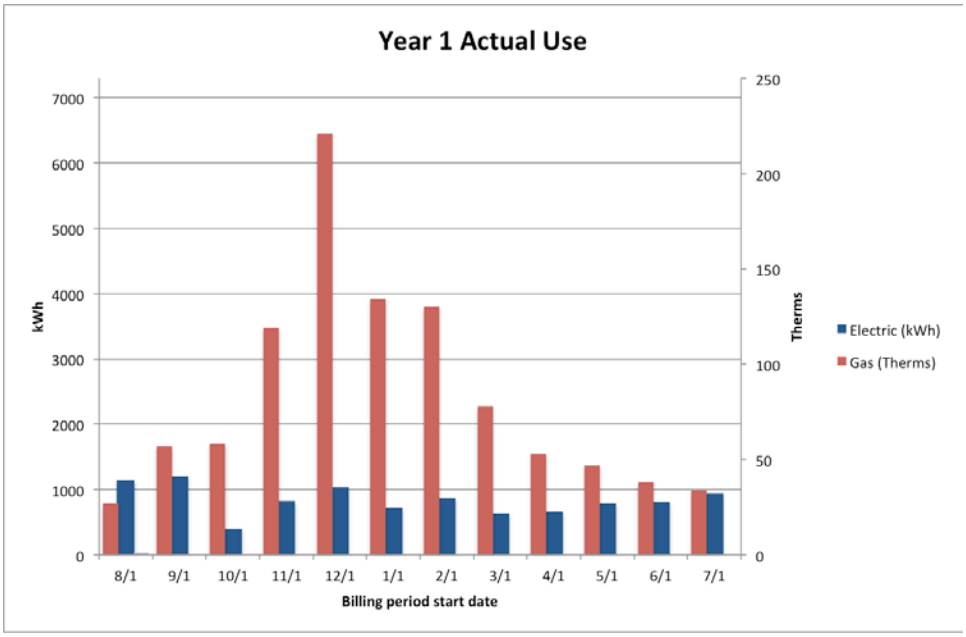


Figure 5. Amaris Custom Homes: Year 1 actual monthly energy use for the St. Paul, Minnesota, project

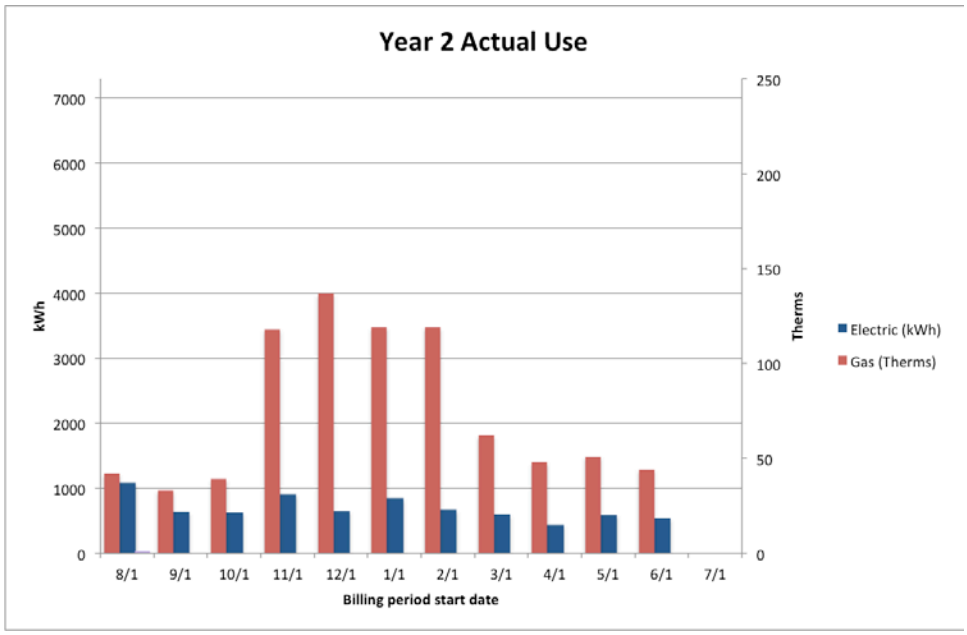


Figure 6. Amaris Custom Homes: Year 2 actual monthly energy use for the St. Paul, Minnesota, project

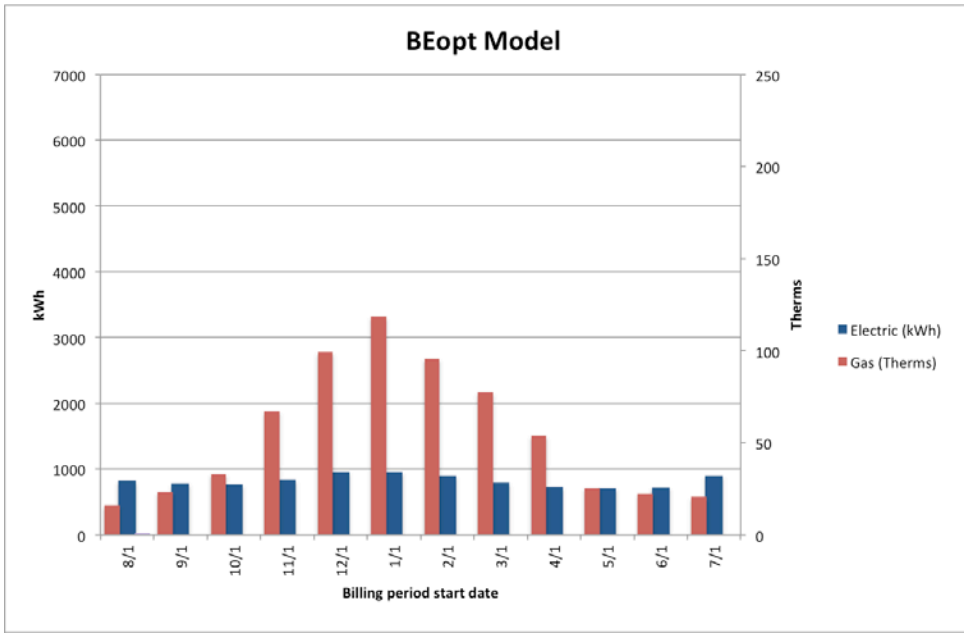


Figure 7. Amaris Custom Homes: Modeled monthly energy use for the St. Paul, Minnesota, project

3.2 Amaris Custom Homes: Bloomington, Minnesota, Project

3.2.1 *Basic Project Information*

This 3,364-ft^2, 4-bedroom, 2½-bathroom, 2-story home with conditioned basement is located in Climate Zone 6.

Figure 8. Amaris Custom Homes: Front elevation of the Bloomington, Minnesota, project

Figure 9. Amaris Custom Homes: Interior of the Bloomington, Minnesota, project

3.2.2 *Technical Characteristics of Typical Construction Practices and DOE ZERH Solutions*

The typical construction practices of Amaris Custom Homes are close to the ZERH requirements. This home could not be certified under the DOE ZERH program. The builder requires the credentialing of the HVAC contractor as part of the project specifications, and it reviews that requirement at the time of the contract bid and award. This requirement was also reviewed at the required pre-construction meeting; however, despite assurances from the HVAC contractor, the qualification was not achieved until after the project was completed. This home meets all other criteria of the DEO ZERH program.

Table 2. Amaris Custom Homes: Bloomington, Minnesota, Project

Measure	Typical Construction Practices	ZERH Solution
Infiltration	1.00 ACH50	0.94 ACH50
Cooling Equipment	14 SEER	14.5 SEER
Heating Equipment	Natural gas, 96 AFUE	Natural gas, 96 AFUE
Water Heater	Natural gas, 0.90 EF	Natural gas, 0.70 EF
Lighting	50% ENERGY STAR	96% ENERGY STAR
Thermostat	Programmable	Programmable
Dishwasher	ENERGY STAR rated	ENERGY STAR rated
Refrigerator	ENERGY STAR rated	ENERGY STAR rated
Clothes Washer	ENERGY STAR rated	ENERGY STAR rated
Ceiling Insulation	2-in. closed-cell spray foam on lid with R-48 blown fiberglass. Total R-65.5	2-in. closed-cell spray foam on lid with R-48 blown fiberglass. Total R-65.5
Above-Grade Wall Insulation	R-5 continuous exterior insulation, 3-in. closed-cell spray foam in cavity. Total R-24.5	R-5 continuous exterior insulation, 3-in. closed-cell spray foam in cavity. Total R-24.5
Foundation Insulation	R-10	R-10
Windows	Double-pane, argon-filled; PVC-framed; Low-e windows with U-0.25	Double-pane, argon-filled; PVC-framed; Low-e windows with U-0.24 and 0.16 SHGC
Reduced Lumber from Advanced Framing	2 x 6-in. walls 24-in. on center, open corners and single-ply headers	2 x 6-in. walls 24-in. on center, open corners and single-ply headers
Ventilation	HRV	HRV
Duct Systems	Located within the thermal and air barrier, fully ducted, sealed with mastic	Located within the thermal and air barrier, fully ducted, sealed with mastic

3.2.4 *Energy Modeling*

Figure 10 shows the energy modeling results for Amaris Custom Homes' Bloomington, Minnesota, project. Predictions of site energy use were nearly identical between the two models: 102 MMBtu/yr for BEopt and 101 MMBtu/yr REM/Rate. BEopt inputs and HERS information can be found in Appendix C and Appendix D.

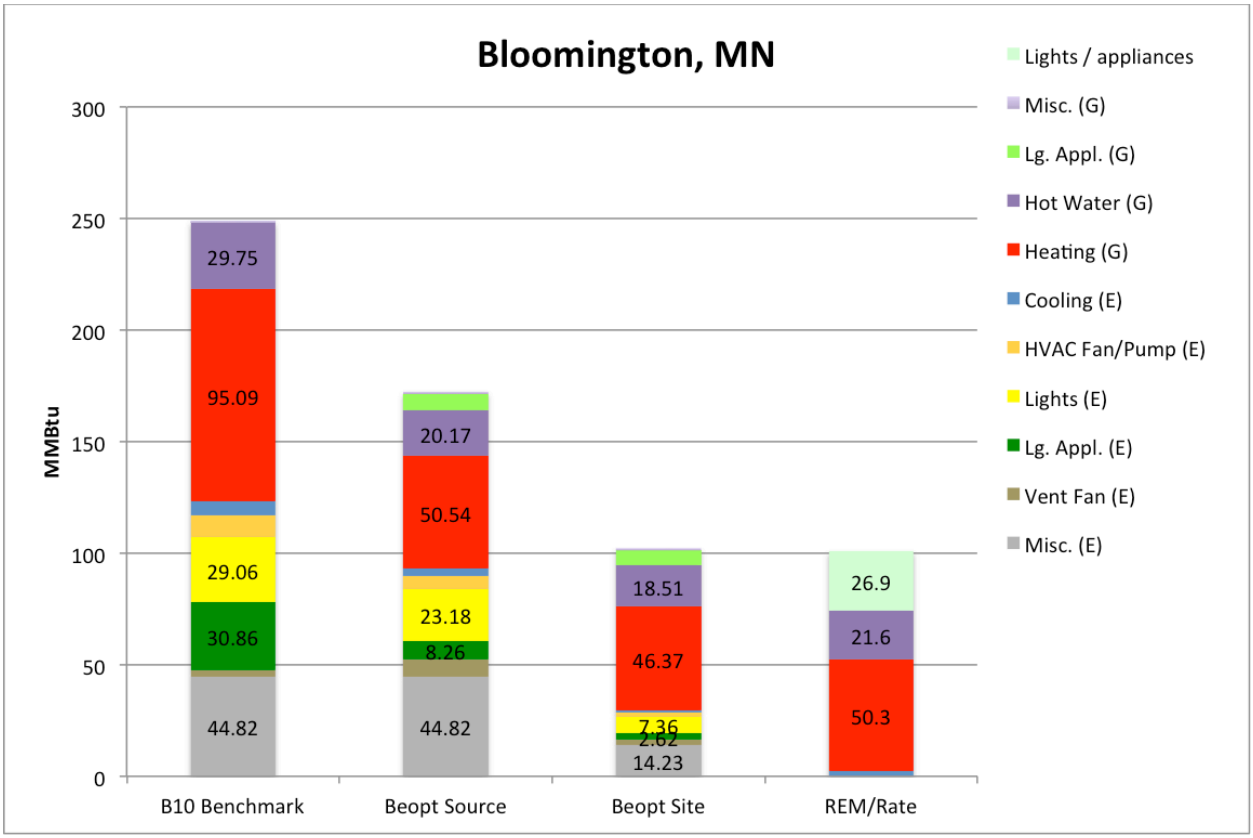


Figure 10. Amaris Custom Homes: Energy modeling results for the Bloomington, Minnesota, project

3.3 Amaris Custom Homes: Vadnais Heights, Minnesota, Project

3.3.1 *Basic Project Information*

This 1,882-ft^2, 3-bedroom, 2-bathroom, 1-story slab-on-grade home is located in Climate Zone 6. Amaris Custom Homes was notified on August 4, 2015, that this home was a 2015 Housing Innovation Award winner. The Housing Innovation Award application for this home is located in Appendix E.

Figure 11. Amaris Custom Homes: Front elevation of the Vadnais Heights, Minnesota, project

Figure 12. Amaris Custom Homes: Rear elevation with solar panels of the Vadnais Heights, Minnesota, project

3.3.3 *Technical Characteristics of Typical Construction Practices and DOE ZERH Solutions*

The typical construction practices of Amaris Custom Homes are close to the ZERH requirements.

Table 3. Amaris Custom Homes: Vadnais Heights, Minnesota, Project

Measure	Typical Construction Practices	ZERH Solution
Infiltration	1.00 ACH50	1.64 ACH50
Cooling Equipment	14 SEER	14.5 SEER
Heating Equipment	Natural gas, 96 AFUE	Natural gas combination boiler, 95% efficient
Water Heater	Natural gas, 0.90 EF	Natural gas combination boiler, 95% efficient
Lighting	50% ENERGY STAR	100% ENERGY STAR LED
Thermostat	Programmable	Programmable
Dishwasher	ENERGY STAR rated	ENERGY STAR rated
Refrigerator	ENERGY STAR rated	ENERGY STAR rated
Clothes Washer	ENERGY STAR rated	ENERGY STAR rated
Ceiling Insulation	2-in. closed-cell spray foam on lid with R-48 blown fiberglass. Total R-65.5	2-in. closed-cell spray foam on lid with R-48 blown fiberglass. Total R-65.5
Above-Grade Wall Insulation	R-5 continuous exterior insulation, 3-in. closed-cell spray foam in cavity. Total R-24.5	R-5 continuous exterior insulation, 3-in. closed-cell spray foam in cavity. Total R-24.5
Foundation Insulation	R-10	Under slab R-10
Windows	Double-pane, argon-filled; PVC-framed; Low-e windows with U-0.25	Double-pane, argon-filled; PVC-framed; Low-e windows with U-0.25 and 0.16 SHGC
Reduced Lumber from Advanced Framing	2 x 6-in. walls 24-in. on center, open corners and single-ply headers	2 x 6-in. walls 24-in. on center, open corners and single-ply headers
Ventilation	HRV	HRV
Duct Systems	Located within the thermal and air barrier, fully ducted, sealed with mastic	Located within the thermal and air barrier, fully ducted, sealed with mastic

3.3.5 *Energy Modeling*

Figure 13 shows the energy modeling results for Amaris' Homes Vadnais Heights, Minnesota, project. Predictions of site energy use differed between the two models: 85 MMBtu/yr for BEopt and 71 MMBtu/yr REM/Rate. This may be because the actual house geometry, which includes significant portions of the plan that do not intersect at right angles, could not be modeled correctly in BEopt. In addition, window type varied not only by orientation (which can be accommodated in BEopt) but also within each orientation. BEopt inputs and HERS information can be found in Appendix E and Appendix F.

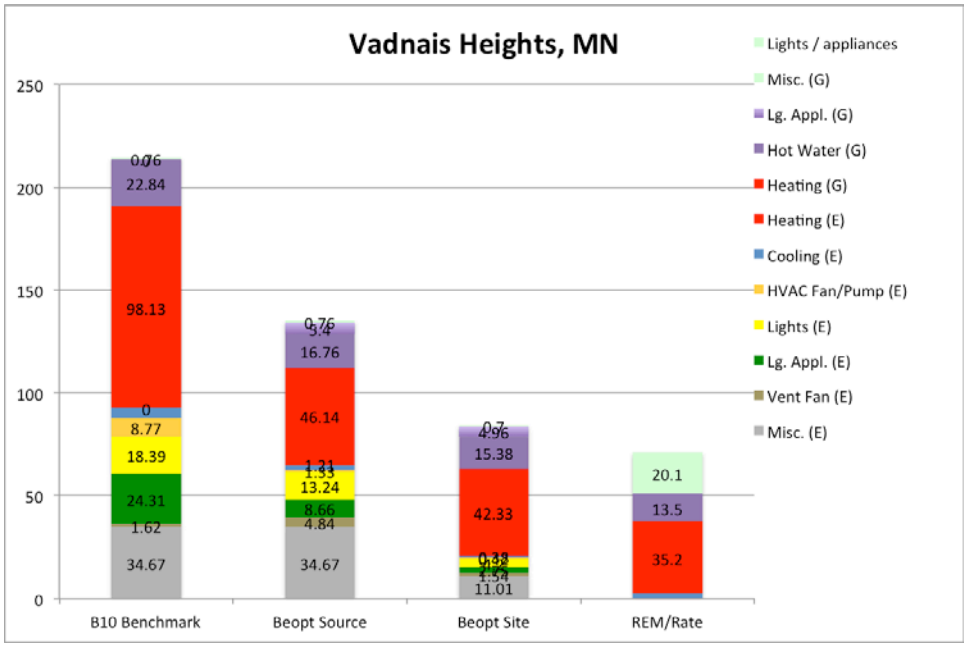


Figure 13. Amaris Custom Homes: Energy modeling results for the Vadnais Heights, Minnesota, project

3.5 Amaris Custom Homes: Apple Valley, Minnesota, Project

3.5.1 *Basic Project Information*

This 3,716-ft^2, 4-bedroom, 3½-bathroom, 1-story home with finished basement is located in Climate Zone 6. Lot orientation precluded additional solar panels to achieve full ZERH for the home.

Figure 14. Amaris Custom Homes: Front elevation of the Apple Valley, Minnesota, project

Figure 15. Amaris Custom Homes: Roof with solar panels of the Apple Valley, Minnesota, project

3.5.2 *Technical Characteristics of Typical Construction Practices and DOE ZERH Solutions*

The typical construction practices of Amaris Custom Homes are close to the ZERH requirements.

Table 4. Amaris Custom Homes: Apple Valley, Minnesota, Project

Measure	Typical Construction Practices	ZERH Solution
Infiltration	1.00 ACH50	0.66 ACH50
Cooling Equipment	14 SEER	14.5 SEER
Heating Equipment	Natural gas, 96 AFUE	Natural gas, 98 AFUE
Water Heater	Natural gas, 0.90 EF	Electric, 0.91 EF
Lighting	50% ENERGY STAR	100% ENERGY STAR
Thermostat	Programmable	Programmable
Dishwasher	ENERGY STAR rated	ENERGY STAR rated
Refrigerator	ENERGY STAR rated	ENERGY STAR rated
Clothes Washer	ENERGY STAR rated	ENERGY STAR rated
Ceiling Insulation	2-in. closed-cell spray foam on lid with R-48 blown fiberglass. Total R-65.5	2-in. closed-cell spray foam on lid with R-48 blown fiberglass. Total R-65.5
Above-Grade Wall Insulation	R-5 continuous exterior insulation, 3-in. closed-cell spray foam in cavity. Total R-24.5	R-5 continuous exterior insulation, 3-in. closed-cell spray foam in cavity. Total R-25
Foundation Insulation	R-10	Under Slab R-10
Windows	Double-pane, argon-filled; PVC-framed; Low-e windows with U-0.25	Double-pane, argon-filled; PVC-framed; Low-e windows with U-0.26 and 0.18 SHGC
Reduced Lumber from Advanced Framing	2 x 6-in. walls 24-in. on center, open corners and single-ply headers	2 x 6-in. walls 24-in. on center, open corners and single-ply headers
Ventilation	HRV	HRV
Duct Systems	Located within the thermal and air barrier, fully ducted, sealed with mastic	Located within the thermal and air barrier, fully ducted, sealed with mastic

3.5.4 *Energy Modeling*

Figure 16 shows the energy modeling results for Amaris Custom Homes' Apple Valley project. Predictions of site energy use were closely aligned between the two models: 110 MMBtu/yr for BEopt and 115 MMBtu/yr REM/Rate. Models were also closely aligned in predictions of PV production: 54 MMBtu/yr and 54 MMBtu/yr, respectively. BEopt inputs and HERS information can be found in Appendix G and Appendix H.

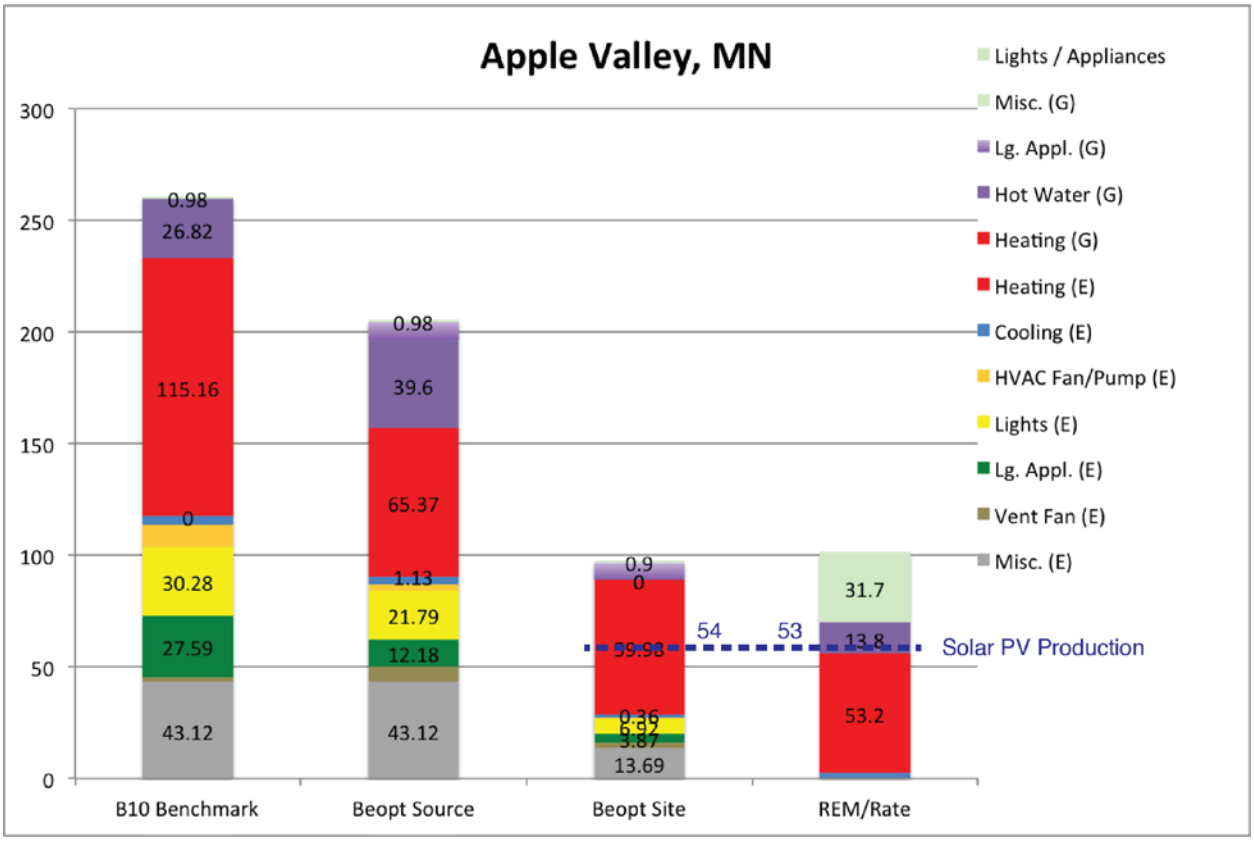


Figure 16. Amaris Custom Homes: Energy modeling results for the Apple Valley, Minnesota, project

3.7 Amaris Custom Homes: White Bear Township, Minnesota, Project

3.7.1 *Basic Project Information*

This 1,654-ft^2, 3-bedroom, 2-bathroom, 1-story home with conditioned crawl space is located in Climate Zone 6.

Figure 17. Amaris Custom Homes: Front elevation of the White Bear Township, Minnesota, project

Figure 18. Amaris Custom Homes: Spray foam walls and energy heel truss of the White Bear Township, Minnesota, project

3.7.2 *Technical Characteristics of Typical Construction Practices and DOE ZERH Solutions*

The typical construction practices of Amaris Custom Homes are close to the ZERH requirements. This home could not be certified under the DOE ZERH program. The builder requires the credentialing of the HVAC contractor as part of the project specifications, and it reviews that requirement at the time of the contract bid and award. This requirement was also reviewed at the required pre-construction meeting; however, despite assurances from the HVAC contractor, the qualification was not achieved until after the project was completed. This home meets all other criteria of the DEO ZERH program.

Table 5. Amaris Custom Homes: White Bear Township, Minnesota, Project

Measure	Typical Construction Practices	ZERH Solution
Infiltration	1.00 ACH50	0.91 ACH50
Cooling Equipment	14 SEER	14.5 SEER
Heating Equipment	Natural gas, 96 AFUE	Natural gas, 96 AFUE
Water Heater	Natural gas, 0.90 EF	Natural gas, 0.80 EF
Lighting	50% ENERGY STAR	79% ENERGY STAR
Thermostat	Programmable	Programmable
Dishwasher	ENERGY STAR rated	ENERGY STAR rated
Refrigerator	ENERGY STAR rated	ENERGY STAR rated
Clothes Washer	ENERGY STAR rated	ENERGY STAR rated
Ceiling Insulation	2-in. closed-cell spray foam on lid with R-48 blown fiberglass. Total R-65.5	2-in. closed-cell spray foam on lid with R-48 blown fiberglass. Total R-65.5
Above-Grade Wall Insulation	R-5 continuous exterior insulation, 3-in. closed-cell spray foam in cavity. Total R-25	R-5 continuous exterior insulation, 3-in. closed-cell spray foam in cavity. Total R-25
Foundation Insulation	R-10	R-10
Windows	Double-pane, argon-filled; PVC-framed; Low-e windows with U-0.25	Double-pane, argon-filled; PVC-framed; Low-e windows with U-0.25 and 0.16 SHGC
Reduced Lumber from Advanced Framing	2 x 6-in. walls 24-in. on center, open corners and single-ply headers	2 x 6-in. walls 24-in. on center, open corners and single-ply headers
Ventilation	HRV	HRV
Duct Systems	Located within the thermal and air barrier, fully ducted, sealed with mastic	Located within the thermal and air barrier, fully ducted, sealed with mastic

3.7.3 *Energy Modeling*

Figure 19 shows the energy modeling results for Amaris Custom Homes' White Bear Township, Minnesota, project. Predictions of site energy use were nearly identical between the two models: 76 MMBtu/yr for BEopt and 77 MMBtu/yr REM/Rate. BEopt inputs and HERS information can be found in Appendix I and Appendix J.

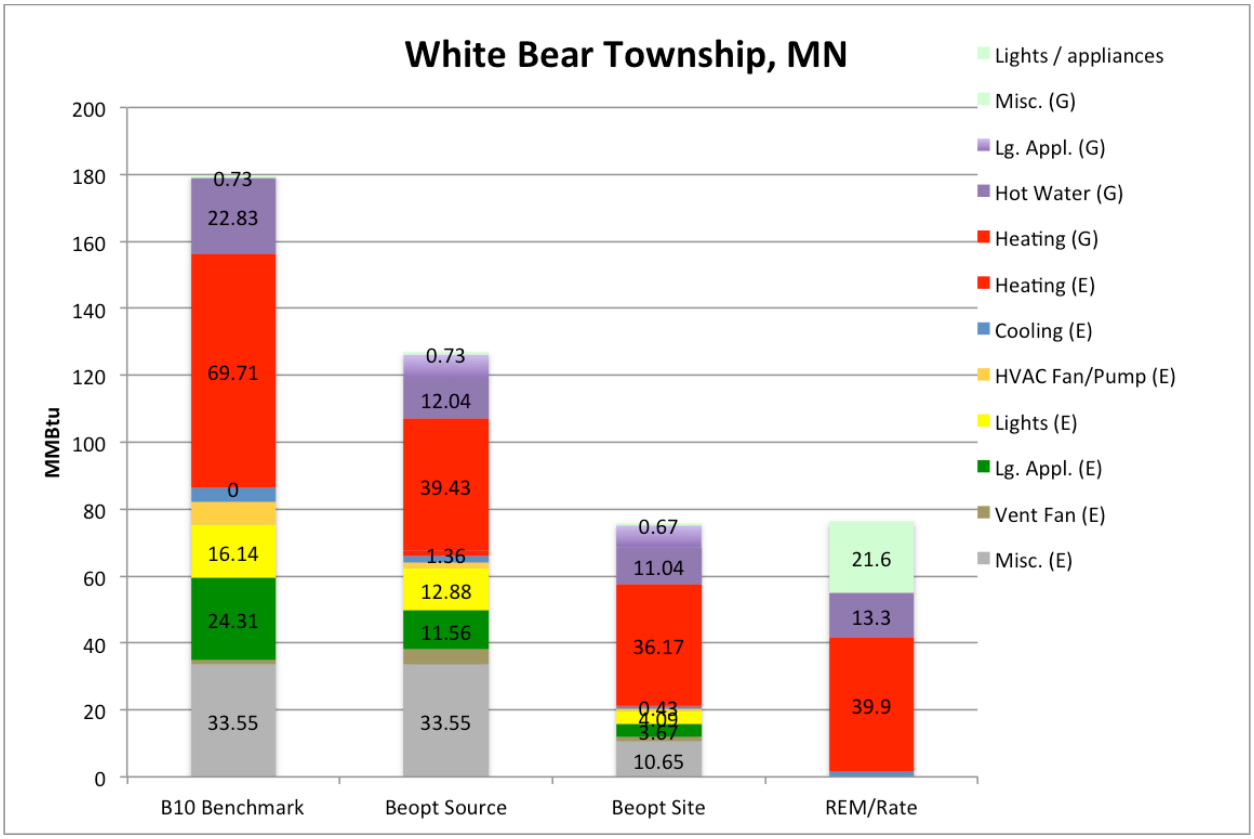


Figure 19. Amaris Custom Homes: Energy modeling results for the White Bear Township, Minnesota, project

3.8 Amaris Custom Homes: Mound, Minnesota, Project

3.8.1 *Basic Project Information*

This 3,537-ft^2, 4-bedroom, 3½-bathroom, 1-story home with finished basement is located in Climate Zone 6.

Figure 20. Amaris Custom Homes: Advanced frame wall with spray foam insulation of the Mound, Minnesota, project

3.8.2 *Technical Characteristics of Typical Construction Practices and DOE ZERH Solutions*

The typical construction practices of Amaris Custom Homes are close to the ZERH requirements. This home could not be certified under the DOE ZERH program. The builder requires the credentialing of the HVAC contractor as part of the project specifications, and it reviews that requirement at the time of the contract bid and award. This requirement was also reviewed at the required pre-construction meeting; however, despite assurances from the HVAC contractor, the qualification was not achieved until after the project was completed. This home meets all other criteria of the DEO ZERH program.

Table 6. Amaris Custom Homes: Mound, Minnesota, Project

Measure	Typical Construction Practices	ZERH Solution
Infiltration	1.00 ACH50	1.58 ACH50
Cooling Equipment	14 SEER	14.5 SEER
Heating Equipment	Natural gas, 96 AFUE	Natural gas, 95 AFUE
Water Heater	Natural gas, 0.90 EF	Natural gas, 0.80 EF
Lighting	50% ENERGY STAR	100% ENERGY STAR
Thermostat	Programmable	Programmable
Dishwasher	ENERGY STAR rated	ENERGY STAR rated
Refrigerator	ENERGY STAR rated	ENERGY STAR rated
Clothes Washer	ENERGY STAR rated	ENERGY STAR rated
Ceiling Insulation	2-in. closed-cell spray foam on lid with R-48 blown fiberglass. Total R-65.5	R-49 blown fiberglass
Above-Grade Wall Insulation	R-5 continuous exterior insulation, 3-in. closed-cell spray foam in cavity. Total R-25	R-5 continuous exterior insulation, 3-in. closed-cell spray foam in cavity. Total R-25
Foundation Insulation	R-10	R-29.5
Windows	Double-pane, argon-filled; PVC-framed; Low-e windows with U-0.25	Double-pane, argon-filled; PVC-framed; Low-e windows with U-0.28 and 0.29 SHGC
Reduced Lumber from Advanced Framing	2 x 6-in. walls 24-in. on center, open corners and single-ply headers	2 x 6-in. walls 24-in. on center, open corners and single-ply headers
Ventilation	HRV	HRV
Duct Systems	Located within the thermal and air barrier, fully ducted, sealed with mastic	Located within the thermal and air barrier, fully ducted, sealed with mastic

3.8.3 *Energy Modeling*

Figure 21 shows the energy modeling results for Amaris Custom Homes' Mound, Minnesota, project. Predictions of site energy use differed significantly between the two models: 115 MMBtu/yr for BEopt and 106 MMBtu/yr REM/Rate. It appears that differences in predicted heating energy use were largely responsible for this. This house included plan features that produced errors in the BEopt simulation due to an inability to resolve the roof. The file was sent to the BEopt development team, which modified the geometry to enable the model to run. In addition, the house includes a partial second story under a complex roof shape that could not be correctly modeled in BEopt. This resulted in significant additional exterior wall surface that is not present in the actual design or the REM/Rate model. BEopt inputs and HERS information can be found in Appendix K and Appendix L.

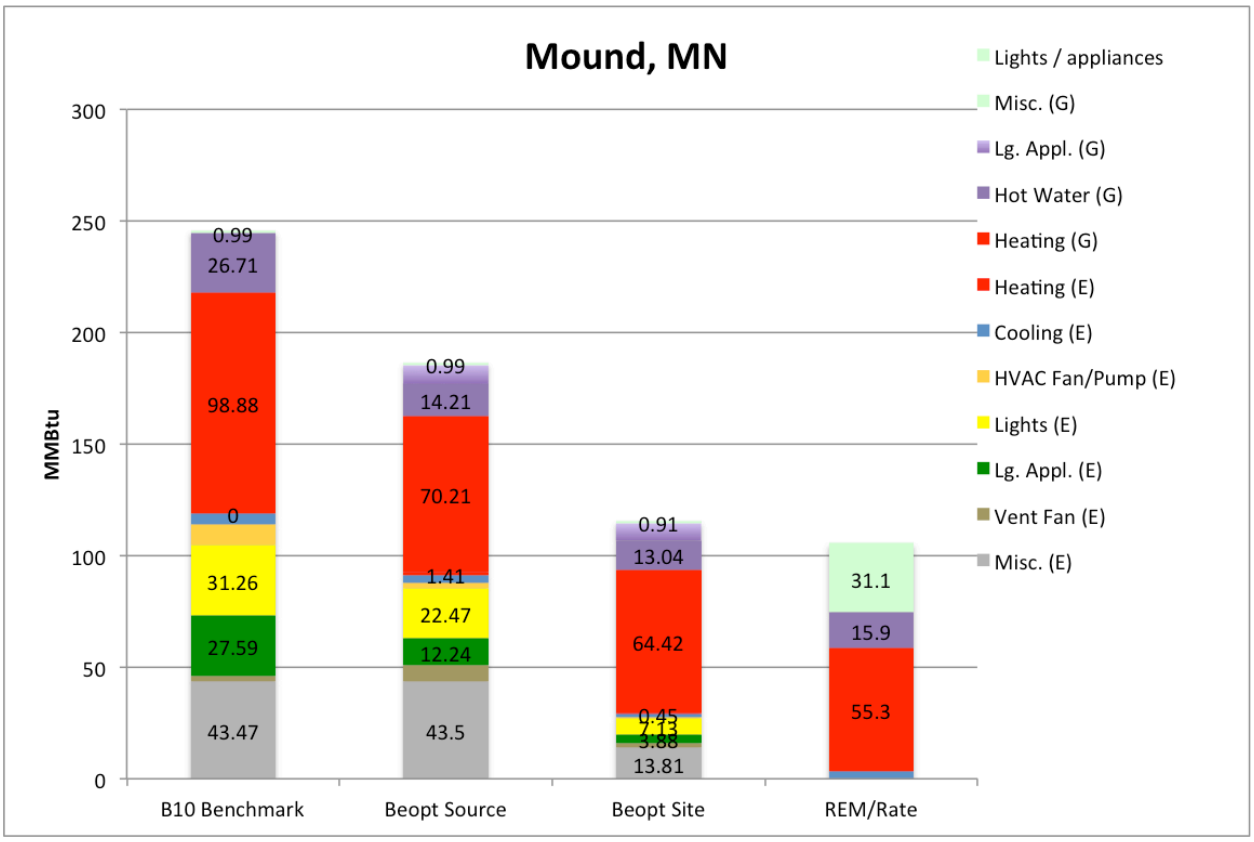


Figure 21. Amaris Custom Homes: Energy modeling results for the Mound, Minnesota, project

3.9 Amaris Custom Homes: Stillwater, Minnesota, Project

3.9.1 *Basic Project Information*

This 2,927-ft2, 4-bedroom, 2½-bathroom, 2-story home with conditioned basement is located in Climate Zone 6.

Figure 22. Amaris Custom Homes: Front elevation of the Stillwater, Minnesota, project

3.9.2 *Technical Characteristics of Typical Construction Practices and DOE ZERH Solutions*

The typical construction practices of Amaris Custom Homes are close to the ZERH requirements.

Table 7. Amaris Custom Homes: Stillwater, Minnesota, Project

Measure	Typical Construction Practices	ZERH Solution
Infiltration	1.00 ACH50	1.87 ACH50
Cooling Equipment	14 SEER	15.0 SEER
Heating Equipment	Natural gas, 96 AFUE	Natural gas, 96 AFUE
Water Heater	Natural gas, 0.90 EF	Natural gas, 0.70 EF
Lighting	50% ENERGY STAR	90% ENERGY STAR
Thermostat	Programmable	Programmable
Dishwasher	ENERGY STAR rated	ENERGY STAR rated
Refrigerator	ENERGY STAR rated	ENERGY STAR rated
Clothes Washer	ENERGY STAR rated	ENERGY STAR rated
Ceiling Insulation	2-in. closed-cell spray foam on lid with R-48 blown fiberglass. Total R-65.5	2-in. closed-cell spray foam on lid with R-48 blown fiberglass. Total R-65.5
Above-Grade Wall Insulation	R-5 continuous exterior insulation, 3-in. closed-cell spray foam in cavity. Total R-24.5	R-5 continuous exterior insulation, 3-in. closed-cell spray foam in cavity. Total R-24.5
Foundation Insulation	R-10	R-10
Windows	Double-pane, argon-filled; | PVC-framed; Low-e windows with U-0.25	Double-pane, argon-filled; PVC-framed; Low-e windows with U-0.30 and 0.25 SHGC
Reduced Lumber from Advanced Framing	2 x 6-in. walls 24-in. on center, open corners and single-ply headers	2 x 6-in. walls 24-in. on center, open corners and single-ply headers
Ventilation	HRV	HRV
Duct Systems	Located within the thermal and air barrier, fully ducted, sealed with mastic	Located within the thermal and air barrier, fully ducted, sealed with mastic

3.9.3 *Energy Modeling*

Figure 23 shows the energy modeling results for Amaris Custom Homes' Stillwater, Minnesota, project. Predictions of site energy use differed significantly between the two models: 136 MMBtu/yr for BEopt and 115 MMBtu/yr REM/Rate. It appears that differences in predicted heating energy use were largely responsible for this. This house included design features that could not be modeled in BEopt. Most significantly, the design includes a walk-out basement. Therefore, the BEopt model included more above-grade exterior wall than the actual design. BEopt inputs and HERS information can be found in Appendix M and Appendix N.

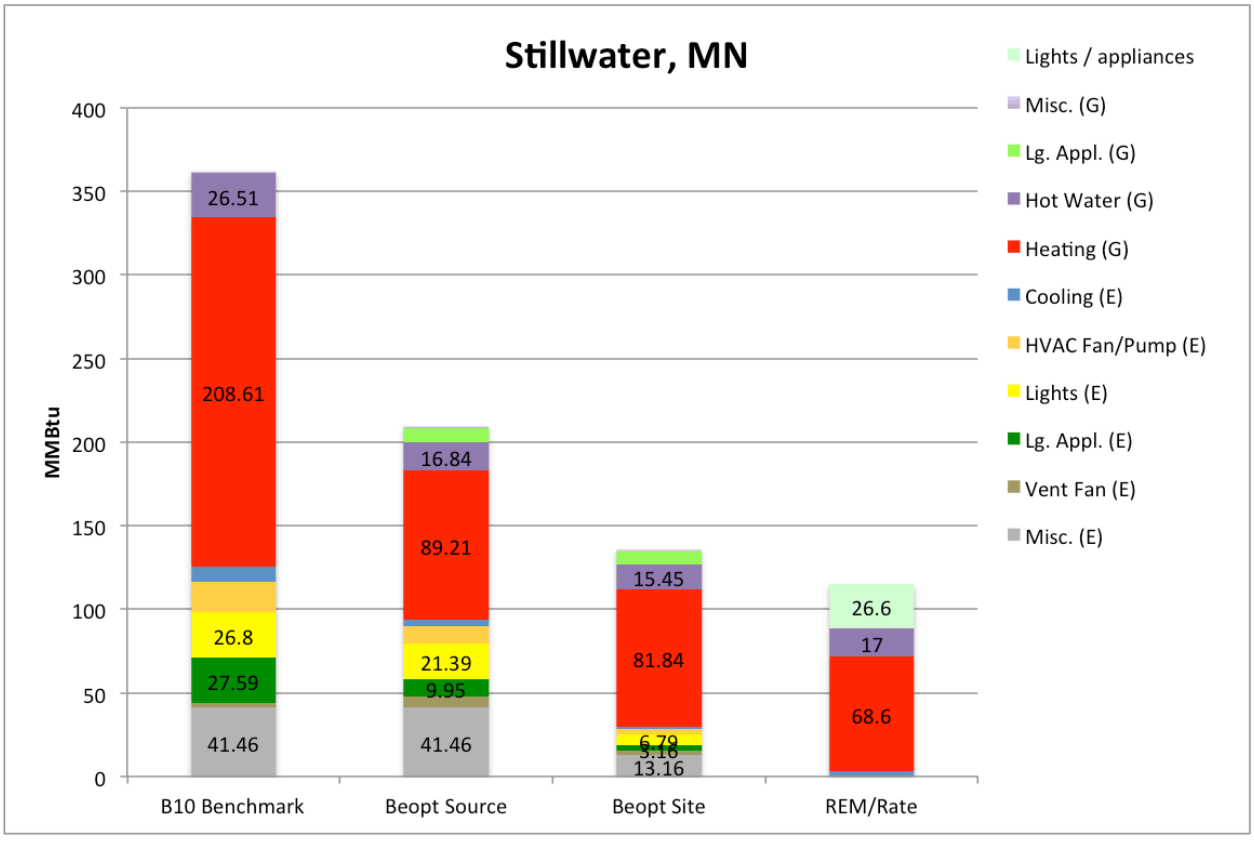


Figure 23. Amaris Custom Homes: Energy modeling results for the Stillwater, Minnesota, project

3.10 Cobblestone Homes: Midland, Michigan, Project

3.10.1 *Basic Project Information*

This 4,008-ft^2, 4-bedroom, 3½-bathroom, 1-story home with finished basement is located in Climate Zone 5. This home was a DOE ZERH 2014 Housing Innovation Award winner. (See Appendix O.)

3.10.2 *Technical Characteristics of Typical Construction Practices and DOE ZERH Solutions*

Table 8. Cobblestone Homes: Midland, Michigan, Project

Measure	Typical Construction Practices	ZERH Solution
Infiltration	3.0 ACH50	1.65 ACH50
Cooling Equipment	13 SEER	13 SEER
Heating Equipment	Natural gas, 96 AFUE	Natural gas, 96 AFUE
Water Heater	Natural gas, 0.63 EF	Natural gas, 0.63 EF
Lighting	90% ENERGY STAR	90% ENERGY STAR
Thermostat	Programmable	Programmable
Dishwasher	ENERGY STAR rated	ENERGY STAR rated
Refrigerator	ENERGY STAR rated	ENERGY STAR rated
Clothes Washer	ENERGY STAR rated	ENERGY STAR rated
Ceiling Insulation	R-49	R-49
Above-Grade Wall Insulation	R-20.6	R-20.6
Foundation Insulation	R-10	R-11.5, with R-5 under slab
Windows	Double-pane, Low-e windows with U-0.28 and 0.28 SHGC	Double-pane, Low-e windows with U-0.28 and 0.28 SHGC
Ventilation	HRV	ERV
Duct Systems	Located within the thermal and air barrier, sealed	Located within the thermal and air barrier, fully ducted, sealed

A unique feature of this home is the 1.4 kW of PV roof tiles. The PV tiles are made of a flexible material that has the same dimensions and thickness as asphalt shingles. Rather than sit-on-top panels, the tiles are integrated with the shingles as part of the roofing layer. The home's roof structure and orientation on the lot were designed to allow room for up to 891 ft^2 of PV tiles.

Figure 24. Cobblestone Homes: Front elevation of the Midland, Michigan, project

Figure 25. Pat Huelman from the Northern*STAR* Building America team at the Cobblestone Innovation event

3.10.3 *Energy Modeling*

Figure 26 shows the energy modeling results for Cobblestone Homes' Midland, Michigan, project. Predictions of site energy use were nearly identical between the two models: 104 MMBtu/yr for BEopt and 102 MMBtu/yr REM/Rate. In addition, PV output predictions were identical, at 6 MMBtu/year. BEopt inputs and HERS information can be found in Appendix O and Appendix P.

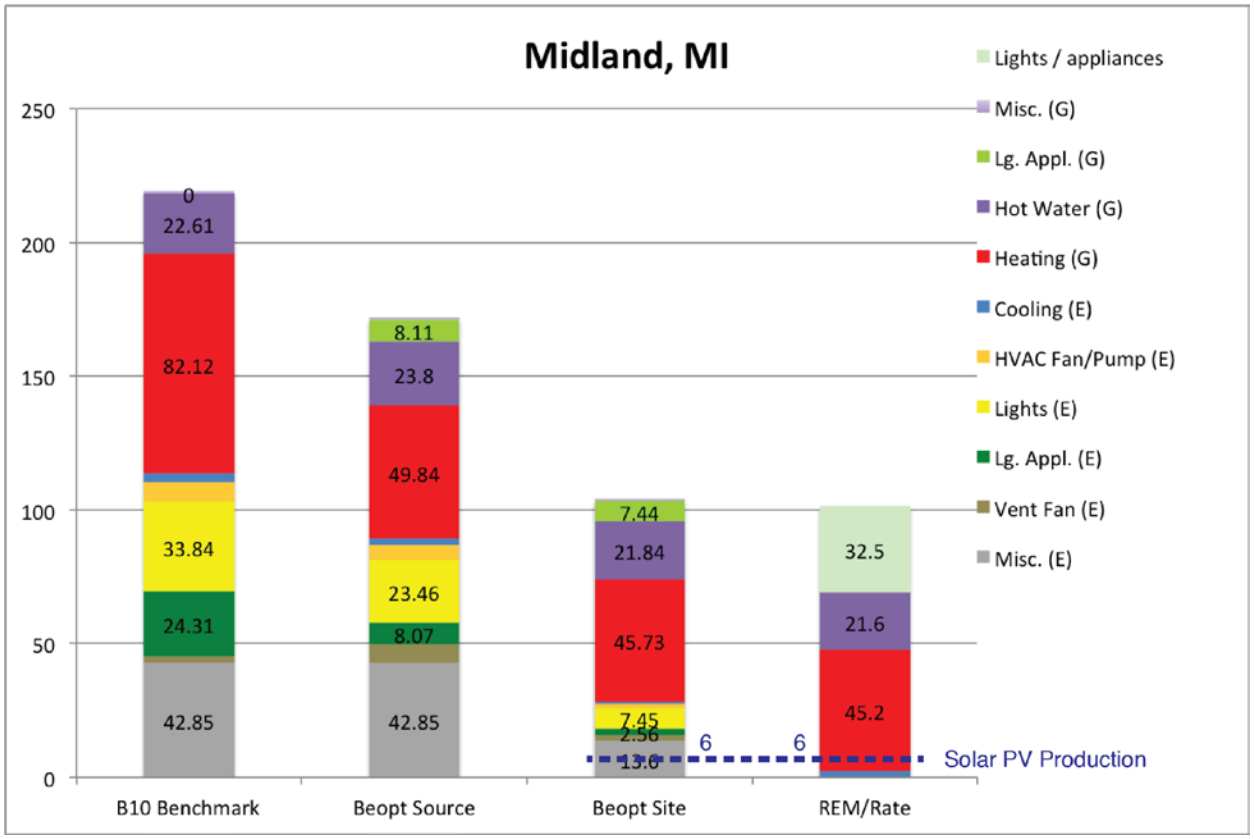


Figure 26. Cobblestone Homes: Energy modeling results for the Midland, Michigan, project

3.11 Morrissey Builders: Lake Elmo, Minnesota, Project

3.11.1 *Basic Project Information*

This 2,930-ft^2, 3-bedroom, 2½-bathroom, 2-story home is currently under construction, and it is located in Climate Zone 6.

Figure 27. Morrissey Builders: Solar panel installation of the Lake Elmo, Minnesota, project

This client-driven, highly sustainable home is expected to receive the following third-party certifications: Leadership in Energy and Environmental Design for Homes, Minnesota GreenStar, ENERGY STAR, Indoor airPLUS, and ZERH.

The client's vision is for an energy-efficient, locally-sourced, green home wherein the clients can age in place. The goals are to get it as close to net zero energy as possible and to use the house as an educational tool.

The home's preliminary HERS Index is 8. The preliminary (mid-construction) blower door test result is 0.3 ACH50.

The project team conducted two project tours: one on April 8, 2015, for students of the University of Minnesota and one on June 25, 2015, as an open house various residential building disciplines. The project was also a the topic of a two-hour panel discussion at the American Institute of Architects convention in Minnesota on November 13, 2015.[7]

[7] See project website for more information: https://olsonlakehouse.wix.com/brink.

3.11.2 *Technical Characteristics of Typical Construction Practices and DOE ZERH Solutions*

Figure 28. Morrissey Builders: Exterior wall assembly of the Lake Elmo, Minnesota, project

Specifications include wood furring strips for attaching siding, 3 in. of mineral wool insulation, and weather-resistive barrier over ½-in. of fiberboard structural sheathing. The 2 x 6-in. exterior stud wall (bearing wall) is filled with dense-packed cellulose held in by netting. Half-inch oriented strand board is the interior air barrier. The 2 x 4-in. interior stud wall is the chase for wiring, plumbing, and HVAC ductwork.

Table 9. Morrissey Builders: Lake Elmo, Minnesota, Project

Measure	Typical Construction Practices	ZERH Solution
Infiltration	2.0 ACH50	0.3 ACH50
Cooling Equipment	13.5 SEER	19.25 SEER
Heating Equipment	Natural gas, 95 AFUE	Electric, 10,00 HSPF[a]
Water Heater	Natural gas, 0.70 EF	Electric, 2.75 EF
Lighting	N/A	100% ENERGY STAR CFL/LED
Thermostat	Programmable	Programmable
Dishwasher	ENERGY STAR rated	ENERGY STAR rated
Refrigerator	ENERGY STAR rated	ENERGY STAR rated
Clothes Washer	ENERGY STAR rated	ENERGY STAR rated
Ceiling Insulation	R-45	R-81: 4-in. exterior continuous insulation; 16-in. dense-packed cellulose
Above-Grade Wall Insulation	R-25	R-49: 3-in. exterior continuous insulation; double-stud wall with dense-packed cellulose
Foundation Insulation	R-22 ICF	R-41: 3-in. exterior continuous insulation on top of 11¾-in. ICF, below slab R-30
Windows	Double-pane, low-e windows with U-0.29 and 0.29 SHGC	Double-pane, low-e, argon-filled windows with U-0.18 and selective SHGC based on orientation
Ventilation	HRV	ERV
Duct Systems	Located within the thermal and air barrier, fully ducted, sealed with mastic	Located within the thermal and air barrier, fully ducted, sealed with mastic

[a] Heating seasonal performance factor

3.11.3 *Energy Modeling*

Figure 29 shows the energy modeling results for Morrissey Builders' Lake Elmo, Minnesota, project. Predictions of site energy use differed significantly between the two models: 80 MMBtu/yr for BEopt and 58 MMBtu/yr REM/Rate. Differences in predicted heating energy use appear to be largely responsible for this difference. This house included design features that could not be modeled in BEopt. Most significantly, the design includes a walk-out basement. Therefore, the BEopt model allocated all the glazing on the south and east orientations to a single floor. This resulted in a model with a glaze area of approximately 75%. The design also includes complex ceiling geometries that could not be faithfully represented in the BEopt model. Predictions for PV production were very similar, at 35 MMBtu/yr and 37 MMBtu/yr for the BEopt and REM/Rate, respectively. BEopt inputs and HERS information can be found in Appendix Q and Appendix R.

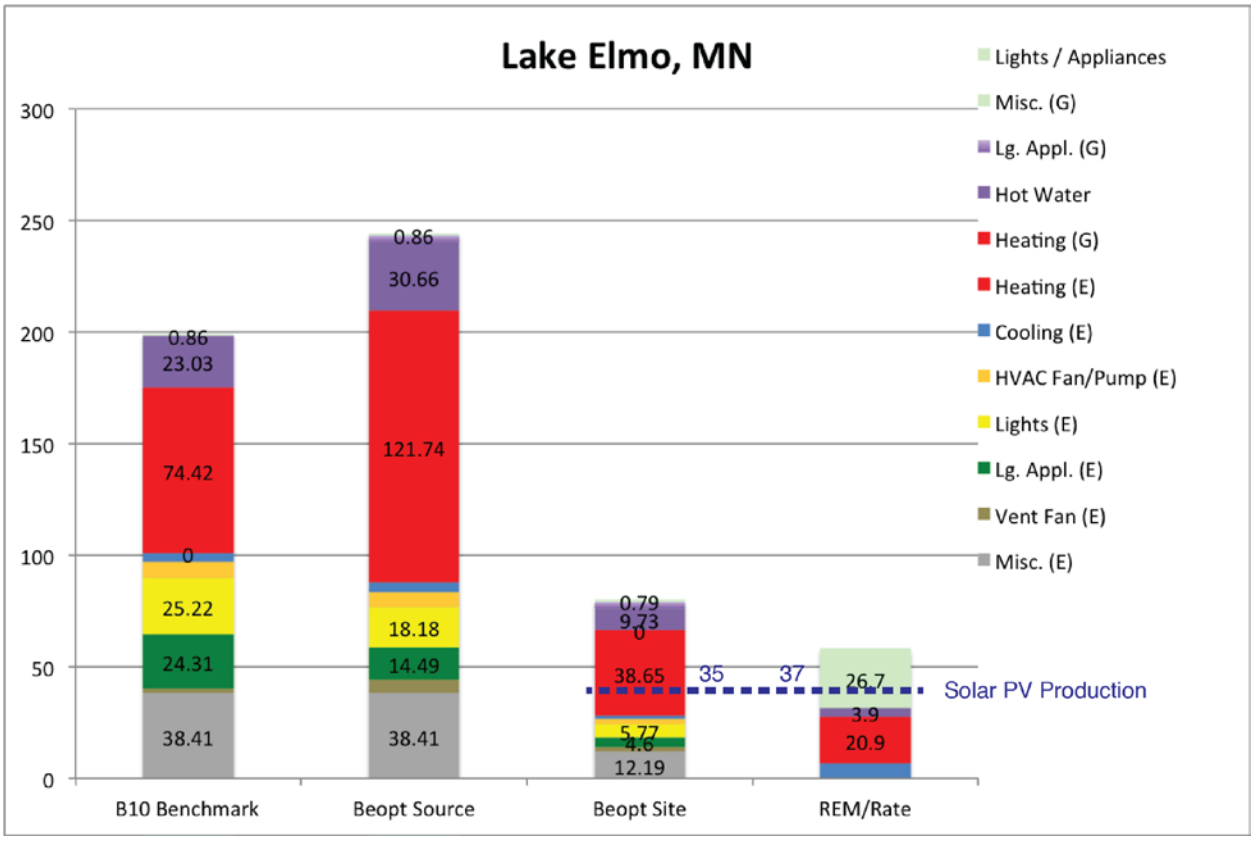


Figure 29. Morrissey Builders: Energy modeling results for the Lake Elmo, Minnesota, project

3.12 Urban Homeworks: North Minneapolis, Minnesota, Project

3.12.1 *Basic Project Information*

This 2,115-ft^2, 3-bedroom, 2½-bathroom, 2-story home with finished basement is currently under construction, and it is located in Climate Zone 6

The target HERS Index for this home is 55. The home's preliminary HERS Index is 41.

Figure 30. Urban Homeworks: Front elevation of the North Minneapolis, Minnesota, project

3.12.2 *Technical Characteristics of Typical Construction Practices and DOE ZERH Solutions*

Table 10. Urban Homeworks: North Minneapolis, Minnesota, Project

Measure	Typical Construction Practices	ZERH Solution
Infiltration	3.0 ACH50	2.0 ACH50
Cooling Equipment	13 SEER	13 SEER
Heating Equipment	Natural gas, 95 AFUE	Natural gas, 96 AFUE
Water Heater	Natural gas, 0.70 EF	Natural gas, 0.96 EF
Lighting	N/A	100% ENERGY STAR CFL/LED
Thermostat	Programmable	Programmable
Dishwasher	ENERGY STAR rated	ENERGY STAR rated
Refrigerator	ENERGY STAR rated	ENERGY STAR rated
Clothes Washer	ENERGY STAR rated	ENERGY STAR rated
Ceiling Insulation	R-45	R-75 dense-packed cellulose
Above-Grade Wall Insulation	R-21	R-25: 2.5-in. exterior continuous insulation; fiberglass batt cavity
Cantilevered Floor	R-38	R-66 dense-packed cellulose
Foundation Insulation	R-10	R-20: 13-in. ICF, below slab R-10
Windows	Double-pane, low-e windows with U-0.29 and 0.29 SHGC	Double-pane, low-e windows with U-0.27 and 0.180 SHGC
Ventilation	HRV	HRV
Duct Systems	Located within the thermal and air barrier	Located within the thermal and air barrier, fully ducted, sealed with mastic

Figure 31. Urban Homeworks: Expanded polystyrene continuous insulation with embedded polypropylene attachment studs of the North Minneapolis, Minnesota, project

Figure 32. Urban Homeworks: ICF foundation, closed-cell spray foam at rim joist, and sealed ductwork located within the thermal enclosure of the North Minneapolis, Minnesota, project

3.12.3 *Energy Modeling*

Figure 33 shows the energy modeling results for Urban Homeworks' North Minneapolis, Minnesota, project. Predictions of site energy use differed significantly between the two models: BEopt and REM/Rate. It appears that differences in predicted heating energy use and water heating energy use were largely responsible for this. This house included design features that could not be modeled in BEopt. The design is a simple gable story-and-a-half, with the second floor cantilevering beyond the first floor on the east and west elevations. BEopt cannot model this geometry. The model could have been created as a story-and-a-half with no cantilever or a two-story with a cantilever. The latter option was selected to capture the effect of the interzonal floor that occurs at the cantilever. However, this resulted in significantly more surface area than the actual house and REM/Rate model. BEopt inputs and HERS information can be found in Appendix S and Appendix T.

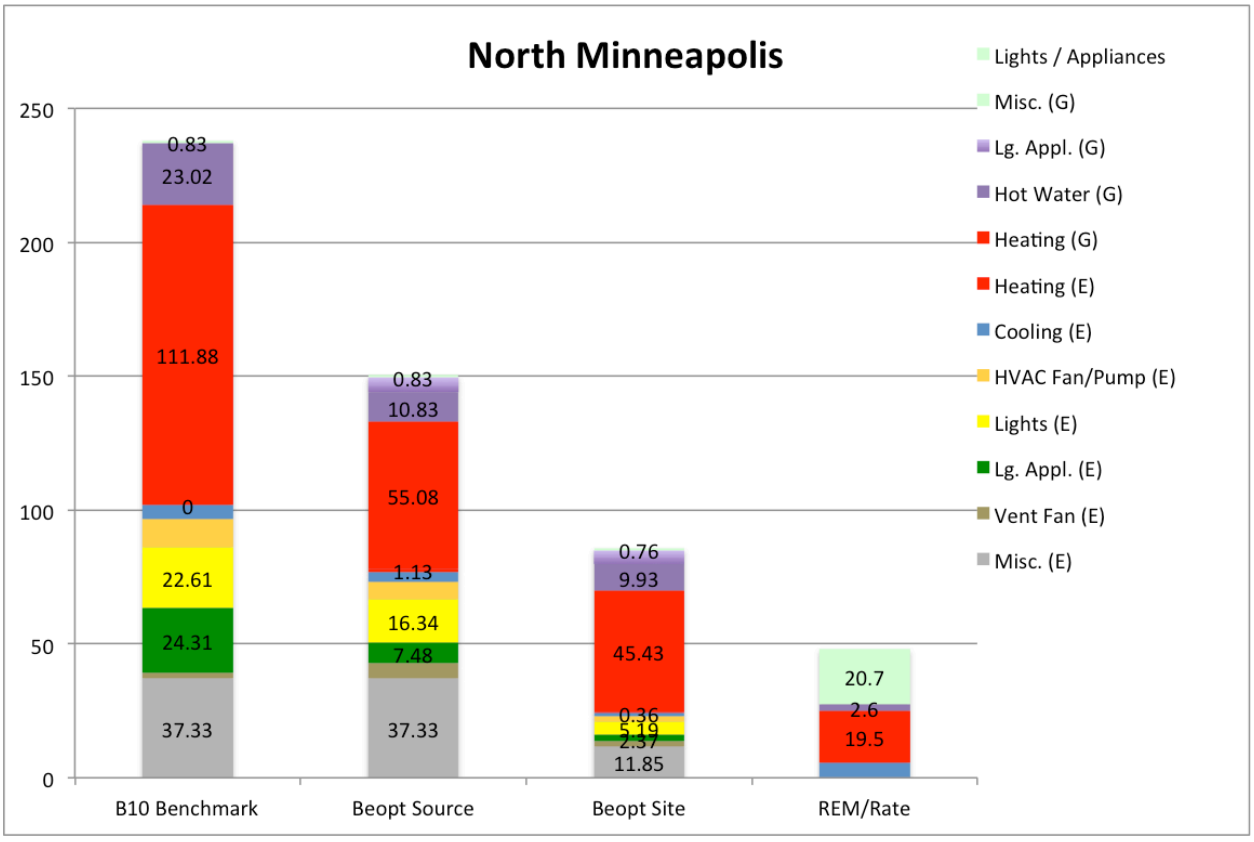


Figure 33. Urban Homeworks: Energy modeling results for the North Minneapolis, Minnesota, project

4 Analysis

4.1 Barriers

4.1.1 *HVAC System Quality Installation*

HVAC system quality installation continues to be a challenge for homebuilders in achieving ZERH certification. Currently, there are only 18 credentialed HVAC contractors in the state of Minnesota (compared to 14,000 licensed residential contractors). Many of these contractors obtained their credentials to meet the Enterprise Green Communities ENEGY STAR criteria that are mandatory for state-funded affordable-housing projects. Additionally, our experience demonstrates that even with the credentialing, field crews' lack of experience and training often results in HVAC system designs and installations that do not meet the program requirements. Specific items that require corrective action include Manual J and D calculations and the sealing of ducts, filter compartments, and furnace cabinets.

4.1.2 *Exterior Wall Continuous Insulation*

4.1.2.1 Morrissey Builders

Morrissey Builders chose to install the fiber cement siding to furring strips attached through the mineral wool continuous insulation to the wall framing. The builder encountered detail challenges at structural elements (i.e., deck ledgers) and fenestrations that required unique solutions to minimize thermal bridging and address the extra thickness of the insulation and furring while maintaining the architectural detailing.

4.1.2.2 Urban Homeworks

The exterior siding style chosen by the architect for the Urban Homeworks project required horizontal strapping on top of the expanded polystyrene continuous insulation embedded polypropylene studs. The additional material and labor costs were not anticipated, and future projects would use traditional siding to take advantage of the embedded studs. The builder chose to install the windows directly to the exterior structural sheathing, which required exterior trim extensions that were not noted on the plans.

4.2 Market Opportunities

4.2.1 *Amaris Custom Homes*

As a result of Amaris Custom Homes' experience in participating in the ZERH program and the positive reaction they received from prospective clients, Amaris Custom Homes is planning on offering a guarantee of zero energy bills for their new homes.[8]

Additionally, Amaris Custom Homes offered a guarantee of no net energy bills for the first 10 years for its 2015 Builders Association of the Twin Cities Fall Parade of Homes ZERH model home.[9]

4.2.2 *Cobblestone Homes*

Cobblestone Homes has had previous experience with the DOE Challenge Home program and appreciates the enhanced marketing opportunities available with the DOE ZERH program.

4.2.3 *Morrissey Builders*

Morrissey Builders is enthusiastic about being a catalyst in the Twin Cities, Minnesota, area and in Wisconsin on building toward zero energy homes through retrofits and new construction.

4.2.4 *Urban Homeworks*

The mission of Urban Homeworks includes innovative approaches to building new, green, energy-efficient, sustainable housing on vacant lots that builds area market value, boosts the local housing market, and increases confidence of current owners.

[8] See http://www.startribune.com/homebuilder-pruban-s-aim-is-a-house-without-an-energy-bill/309904841/.
[9] See http://www.prweb.com/releases/2015/09/prweb12938548.htm.

5 Conclusion

The volunteer builders' homes featured in this report already provide high-performance criteria that meet or exceed the 2012 International Energy Conservation Code requirements as a result of the builders previous involvement in programs such as ENERGY STAR for Homes, Leadership in Energy and Environmental Design for Homes, Enterprise Green Communities, GreenStar, and Passive House Institute US. Participating in the DOE ZERH program provided an additional framework for the volunteer builders to apply the competencies in energy-efficient construction that they have already developed.

Problems encountered by the builders mainly centered on issues with HVAC quality installation and exterior wall continuous insulation. The most obvious barriers faced by the builders is overcoming the learning curve about the ZERH program requirements and conveying those requirements to their staff and trade contractors as well as to the field crews accomplishing the program requirements. This is exemplified by the three homes that met the technical requirements of the ZERH program but could not be qualified for certification under the program because of the HVAC contractor's unfamiliarity with the credentialing process.

The Building America Solution Center proved to be a valuable resource for the builders and designers especially in addressing the strategies for above-grade wall insulation that would maximize performance and minimize risk and cost.

Energy modeling results were generally very closely aligned in cases where house designs could be accurately represented in BEopt. This suggests that the underlying algorithms in both BEopt and REM/Rate support a common understanding of the energy impact of design decisions, building components, and energy-consuming devices and systems. In cases when building geometry was unable to be modeled in BEopt, however, significant divergence in energy use predictions occurred.

Issues regarding building geometry modeling were encountered while using BEopt on several house designs because of their complexity. Building geometry is automatically generated by BEopt based on building footprint and some menu-driven choices such as roof shape (hip/gable), roof pitch, and eave dimension. This feature makes entering the building geometry for most house designs quick and efficient. However, features such as portions of a house plan that don't intersect at right angles, complex mixes of conditioned and unconditioned spaces in attics, walk-out basements, and complex roof forms either cannot be modeled or cause the application to report errors. When geometries cannot be modeled, the modeler is forced to devise proxy ways of modeling the condition in question or to conclude that the physical inaccuracy is not likely to significantly affect the modeling results. In this project, one error was generated due to a complex roof form; BEopt development staff offered an alternative geometrical solution in a timely fashion that enabled the model to run without errors. For most house designs, the geometry generation performed by BEopt is likely to be adequate. However, in the future, overrides may have to be enabled or other alternate methods developed to allow for more faithful modeling of conditions such as those listed above.

Most of the homes presented in this study have also received enhanced public interest through media events, feature newspaper articles, site tours, and social media posts that demonstrates an increasing acceptance by the public of the benefits of energy-efficient homes.

It is clear that builders can achieve the ZERH certification and will see the performance results in their new homes. We covered the many reasons why more builders should pursue this type of building. However, we also observed some potential barriers that could be addressed in future projects. These barriers include:

- There is a strong resistance to change the building envelope. It seems radical and risky to build a high-performance wall that is too different from traditional 2 x 6-in. stud framing.
- Placing insulation on the outside of exterior wall assemblies presents challenges for attaching structural deck ledgers while maintaining a thermal break as well as integration issues with fenestrations and siding attachment.
- Qualified HVAC contractors able to meet the ENERGY STAR criteria are not common in the Minnesota and Michigan markets.
- Some builders tell us they are burned out on "programs." It takes energy and time to redesign and retool to meet the varying requirements. They also question whether the outcome is enough to be a real selling point.

When marketing ZERH, there needs to be enhanced messaging to assist builders in conveying the benefits of ZERH homes to the homebuyers, realtors, appraisers, and press.

Figure 34. Sam Rashkin, chief architect of DOE, at the Cobblestone Homes DOE Innovation event

References

VonThoma, E., and C. Ojczyk. 2012. *Practices and Processes of Leading High Performance Home Builders in the Upper Midwest.* Golden, CO: National Renewable Energy Laboratory.

Appendix A: Amaris Custom Homes—St. Paul, Minnesota, Project HERS Reports and Challenge Home Certification

Home Energy Rating Certificate

BUILDING KNOWLEDGE

1017 Oak Bluff Circle
St. Paul, MN

5 Stars Plus
Projected Rating
HERS Index: 41

General Information

Conditioned Area	3542 sq. ft.	House Type	Single-family detached
Conditioned Volume	33237 cubic ft.	Foundation	Conditioned basement
Bedrooms	5		

Mechanical Systems Features

Heating:	Fuel-fired air distribution, Natural gas, 96.1 AFUE.
Integrated Htg/DHW:	Natural gas, Htg eff 0.95 CAafue. DHW eff 0.80 CAef.
Cooling:	Air conditioner, Electric, 14.5 SEER.
Duct Leakage to Outside	5.00 CFM25.
Ventilation System	Balanced: ERV, 80 cfm, 84.0 watts.
Programmable Thermostat	Heat=Yes; Cool=Yes

Building Shell Features

Ceiling Flat	N/A	Slab	R-20.0 Edge, R-20.0 Under
Sealed Attic	N/A	Exposed Floor	R-30.0
Vaulted Ceiling	R-65.5	Window Type	U:0.25, SHGC:0.49
Above Grade Walls	R-25.0	Infiltration Rate	Htg: 464 Clg: 464 CFM50
Foundation Walls	R-25.0	Method	Blower door test

Lights and Appliance Features

Percent Interior Lighting	100.00	Range/Oven Fuel	Natural gas
Percent Garage Lighting	100.00	Clothes Dryer Fuel	Natural gas
Refrigerator (kWh/yr)	1374.00	Clothes Dryer EF	2.75
Dishwasher Energy Factor	0.79	Ceiling Fan (cfm/Watt)	0.00

Registry ID	
Rating Number	
Certified Energy Rater	Patrick O'Malley
Rating Date	8/29/13
Rating Ordered For	Ray Pruban

Estimated Annual Energy Cost

Use	MMBtu	Cost	Percent
Heating	45.5	$418	24%
Cooling	3.6	$96	5%
Hot Water	23.1	$208	12%
Lights/Appliances	33.6	$785	45%
Photovoltaics	-0.0	$-0	-0%
Service Charges		$240	14%
Total	**105.7**	**$1747**	**100%**

Criteria

This home meets or exceeds the minimum criteria for the following:

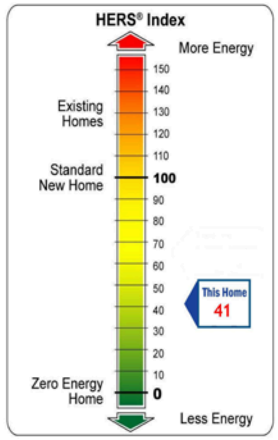
EPA ENERGY STAR Version 2 Home
EPA ENERGY STAR Version 2.5 Home
2006 International Energy Conservation Code
2009 International Energy Conservation Code

Building Knowledge, Inc.
PO Box 1376
Burnsville, MN 55337
952-944-5605
www.buildingknowledge.com

BUILDING KNOWLEDGE

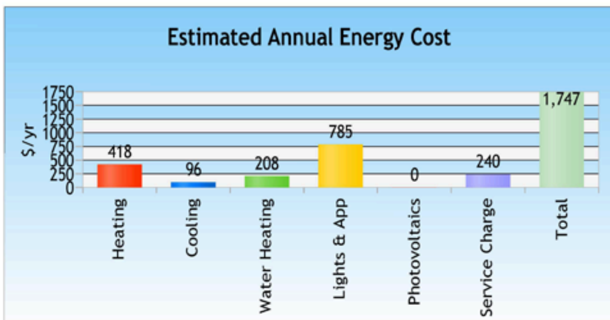
The Home Energy Rating Standard Disclosure for this home is available from the rating provider.
REM/Rate - Residential Energy Analysis and Rating Software v14.3
This information does not constitute any warranty of energy cost or savings.

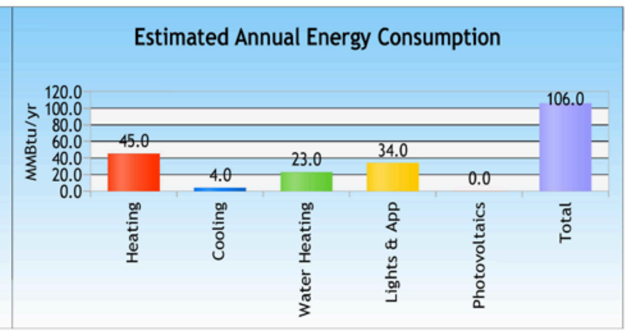
HOME PERFORMANCE WITH ENERGY STAR



ENERGY RATING CERTIFICATE

BUILDING KNOWLEDGE





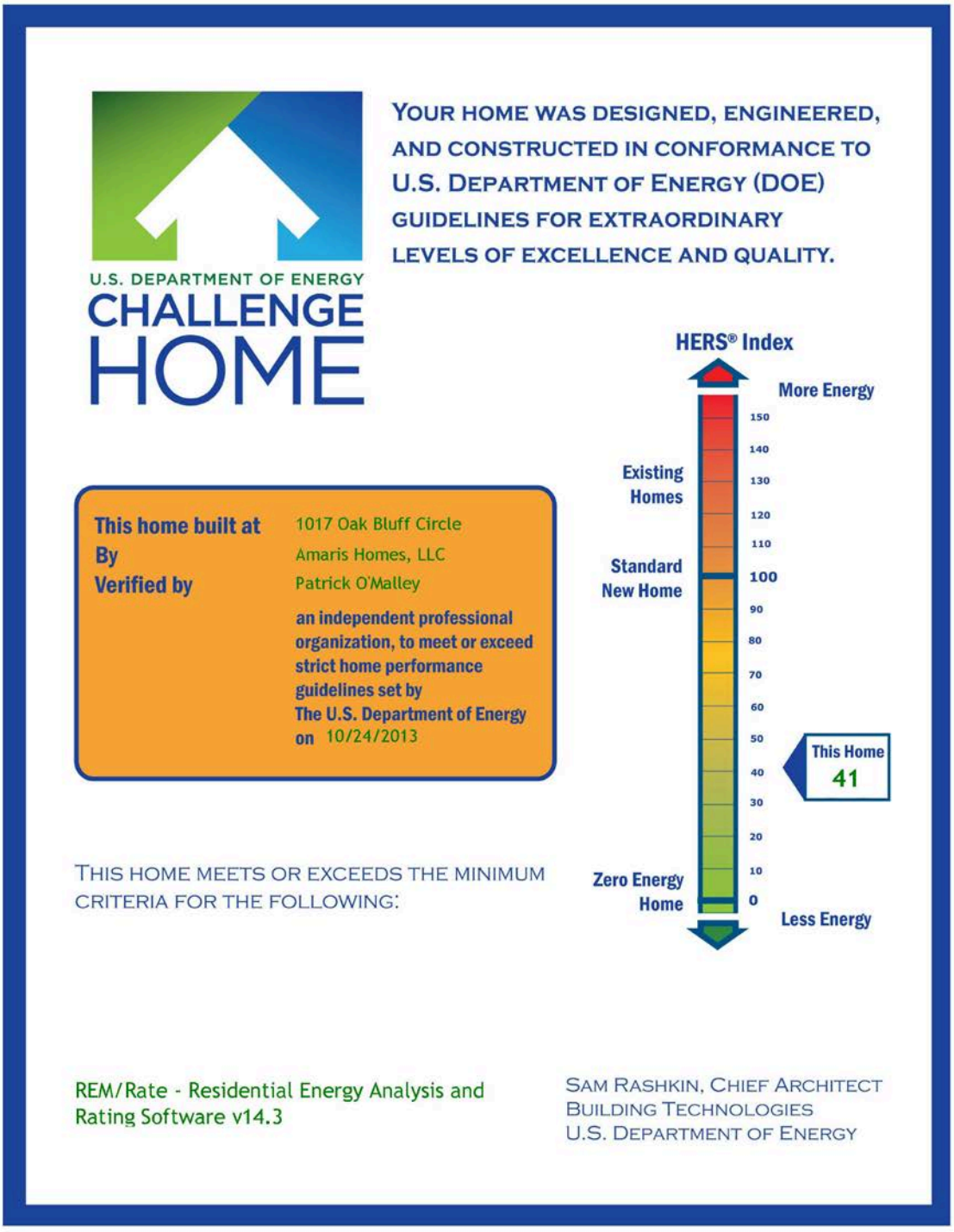
Address	1017 Oak Bluff Circle St. Paul, MN	Annual Estimates* Electric(kWh): 9166	Building Knowledge, Inc. PO Box 1376	
House Type	Single-family detached	Natural gas(Therms): 744	Certified Rater	Patrick O'Malley
Cond. Area	3542 sq. ft.	C02 emissions(Tons): 11	Rater ID	9377462
Rating No.		Annual Savings**: $2388	Registry ID	
Issue Date	September 06, 2013		Rating Date	8/29/13
Certification	Verified			

* Based on standard operating conditions

** Based on a HERS 130 Index Home

REM/Rate - Residential Energy Analysis and Rating Software v14.3

This information does not constitute any warranty of energy cost or savings. © 1985-2013 Architectural Energy Corporation, Boulder, Colorado.
The Home Energy Rating Standard Disclosure for this home is available from the rating provider.



DOE Challenge Home Verification

Energy Performance	
House Type	**DOE Challenge Home Builder Partner ID#**
Single-family detached	505
Year built	**Square footage of Conditioned Space including Basement**
2013	3542.0
Number of Bedrooms	**Square footage of Conditioned Space without Basement**
4	3542.0
Site address (if not available, list the site Lot #)	**Registered Builder**
1017 Oak Bluff Circle	Amaris Homes, LLC
St. Paul	**Certified Rater**
MN,	Patrick O'Malley
HERS Index without On-site Generation	**Date of Rating**
41	9/13/13
HERS Index with On-site Generation	**Rating Software**
41	REM/Rate - v14.3
HERS Index of the Target Home using size adjustment factor	**Estimated annual energy costs($)**
49	1713
Estimated annual energy use	**Estimated annual energy savings**
Electric: 8979 kWh \ Natural Gas: 726 Therms	Electric: 3146 kWh \ Natural gas: 1332 Therms
Energy cost rates	**Estimated annual emissions reductions**
Electric: 0.09 $/kWh \ Natural Gas: 0.90 $/Therms	CO2: 10.2 tons / SO2: 6.7 lbs / NOx: 25.3 lbs

DOE Challenge Home Certification

As the certified Rater for this house, I certify this house meets/complies with all mandatory requirments of the DOE Challenge home guidelines, including the following:

X	Compliance with all ENERGY STAR Qualified Homes Version 3 requirements and checklists
X	Compliance with Mandatory Fenestration Requirements
X	Compliance with Mandatory Insulation Requirements
X	Compliance with Mandatory Duct Location Requirements
X	Compliance with Mandatory Appliance Requirements
X	Compliance with Mandatory Lighting Requirements
X	Compliance with Mandatory Fan Efficiency Requirements
X	Compliance with Mandatory Indoor Air Quality Requirements
X	Compliance with Mandatory Renewable Energy Ready Solar Electric Requirements
X	Compliance with Mandatory Renewable Energy Ready Solar Hot Water Requirements
	This home was qualified via sampling in lieu of testing, in accordance with allowable sampling provisions as stated in the DOE Challenge Home National Program Requirements

Optional Compliance for Builder Recognition

I further certify that the following also apply to this house:

YES	NO	DON'T KNOW	Optional Home Builder Commitments for Recognition

*Certification under the DOE Challenge Home permits limited exceptions to full compliance with Indoor airPLUS. Builders seeking the Indoor airPLUS label must achieve full compliance with the Indoor airPLUS Verification Checklist.

REM/Rate - Residential Energy Analysis and Rating Software v14.3
This information does not constitute any warranty of energy cost or savings.

DOE Challenge Home Verification

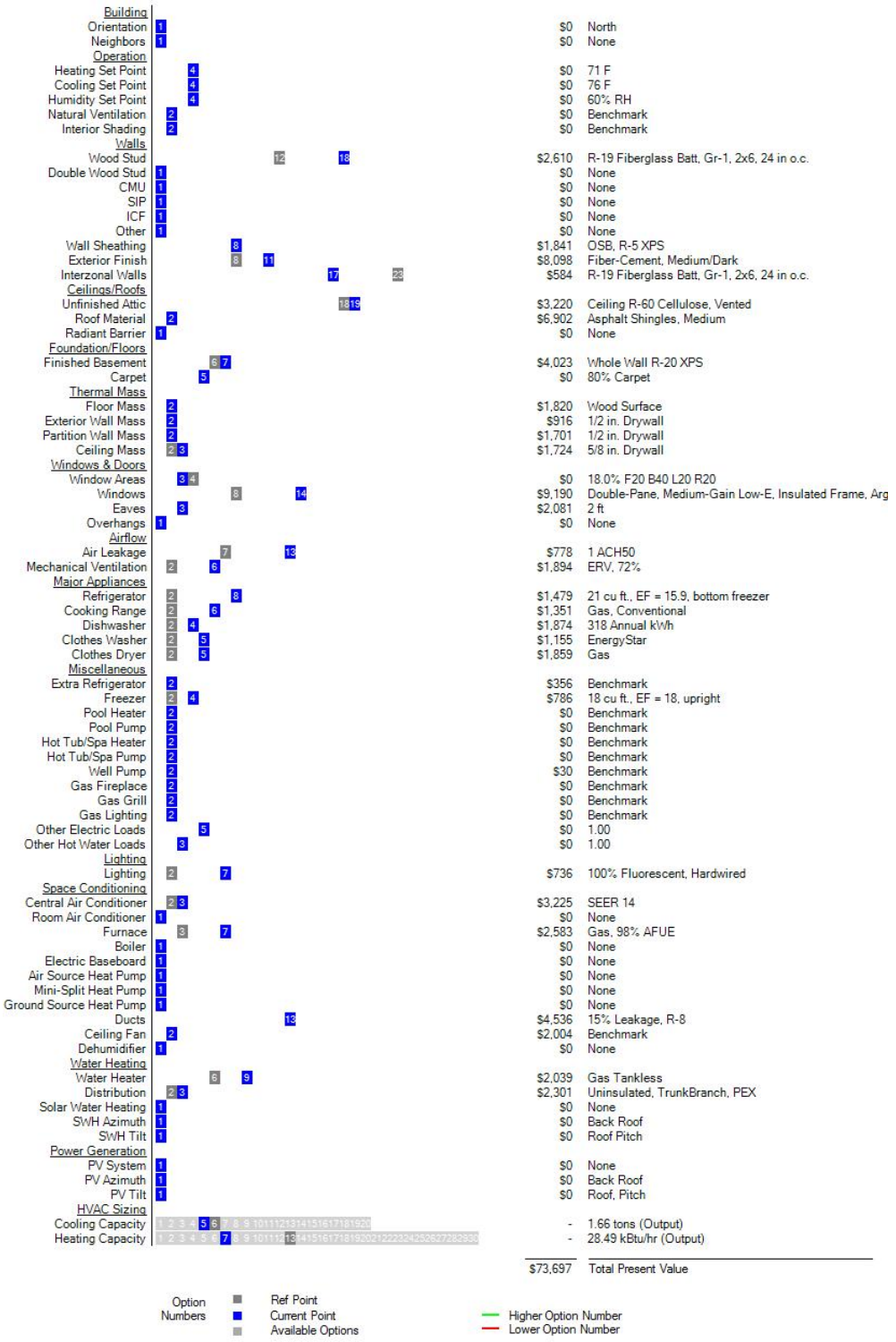
Optional Compliance for Builder Recognition

I further certify that the following also apply to this house:

YES	NO	DON'T KNOW	Optional Home Builder Commitments for Recognition
	X		Certified under the EPA Indoor airPLUS Program*
	X		Certified under the EPA WaterSense for New Homes Program
	X		Certified under the IBHS Fortified for Safer Living Program
	X		Followed the DOE Challenge Home Quality Management Guidelines
X			The buyer of this home signed a waiver giving DOE Challenge Home access to utility bill data for one year

*Certification under the DOE Challenge Home permits limited exceptions to full compliance with Indoor airPLUS. Builders seeking the Indoor airPLUS label must achieve full compliance with the Indoor airPLUS Verification Checklist.

Appendix B: Amaris Custom Homes—St. Paul, Minnesota, Project BEopt Input



Appendix C: Amaris Custom Homes—Bloomington, Minnesota, Project HERS Reports

Home Energy Rating Certificate

BUILDING KNOWLEDGE

4210 West 108th Street
Bloomington, MN 55437

5 Stars Plus
Confirmed
HERS Index: 41

Registry ID	**293748617**
Rating Number	
Certified Energy Rater	Patrick O'Malley
Rating Date	6/4/14
Rating Ordered For	Lenny & Rebecca Klevan Schmitz

General Information

Conditioned Area	3364 sq. ft.	House Type	Single-family detached
Conditioned Volume	32502 cubic ft.	Foundation	Conditioned basement
Bedrooms	4		

Mechanical Systems Features

Heating:	Fuel-fired air distribution, Natural gas, 95.0 AFUE.
Cooling:	Air conditioner, Electric, 14.5 SEER.
Water Heating:	Conventional, Natural gas, 0.70 EF, 50.0 Gal.
Duct Leakage to Outside	5.00 CFM25.
Ventilation System	Balanced: HRV, 71 cfm, 75.0 watts.
Programmable Thermostat	Heat=Yes; Cool=Yes

Building Shell Features

Ceiling Flat	R-65.5	Slab	R-0.0 Edge, R-10.0 Under
Sealed Attic	NA	Exposed Floor	R-30.0
Vaulted Ceiling	NA	Window Type	U-Value: 0.240, SHGC: 0.160
Above Grade Walls	R-24.5	Infiltration Rate	Htg: 510 Clg: 510 CFM50
Foundation Walls	R-10.0	Method	Blower door test

Lights and Appliance Features

Percent Interior Lighting	96.00	Range/Oven Fuel	Natural gas
Percent Garage Lighting	100.00	Clothes Dryer Fuel	Natural gas
Refrigerator (kWh/yr)	365.00	Clothes Dryer EF	2.67
Dishwasher Energy Factor	0.00	Ceiling Fan (cfm/Watt)	0.00

Estimated Annual Energy Cost

Use	MMBtu	Cost	Percent
Heating	50.3	$468	29%
Cooling	2.2	$58	4%
Hot Water	21.6	$195	12%
Lights/Appliances	26.9	$635	40%
Photovoltaics	-0.0	$-0	-0%
Service Charges		$240	15%
Total	**101.0**	**$1596**	**100%**

Criteria

This home meets or exceeds the minimum criteria for the following:

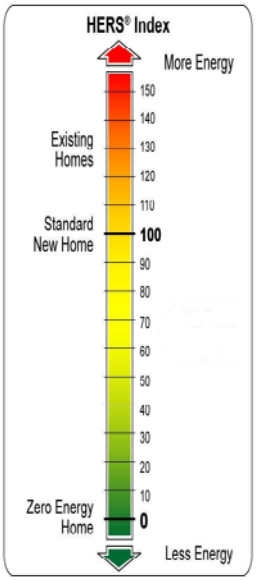
EPA ENERGY STAR Version 2 Home
EPA ENERGY STAR Version 2.5 Home
2006 International Energy Conservation Code
2009 International Energy Conservation Code
2012 International Energy Conservation Code

Building Knowledge, Inc.
PO Box 1376
Burnsville, MN 55337
952-944-5605
www.buildingknowledge.com

BUILDING KNOWLEDGE

The Home Energy Rating Standard Disclosure for this home is available from the rating provider.
REM/Rate - Residential Energy Analysis and Rating Software v14.4.1
This information does not constitute any warranty of energy cost or savings.

HOME PERFORMANCE WITH ENERGY STAR



ENERGY RATING CERTIFICATE

BUILDING KNOWLEDGE

BUILDING KNOWLEDGE

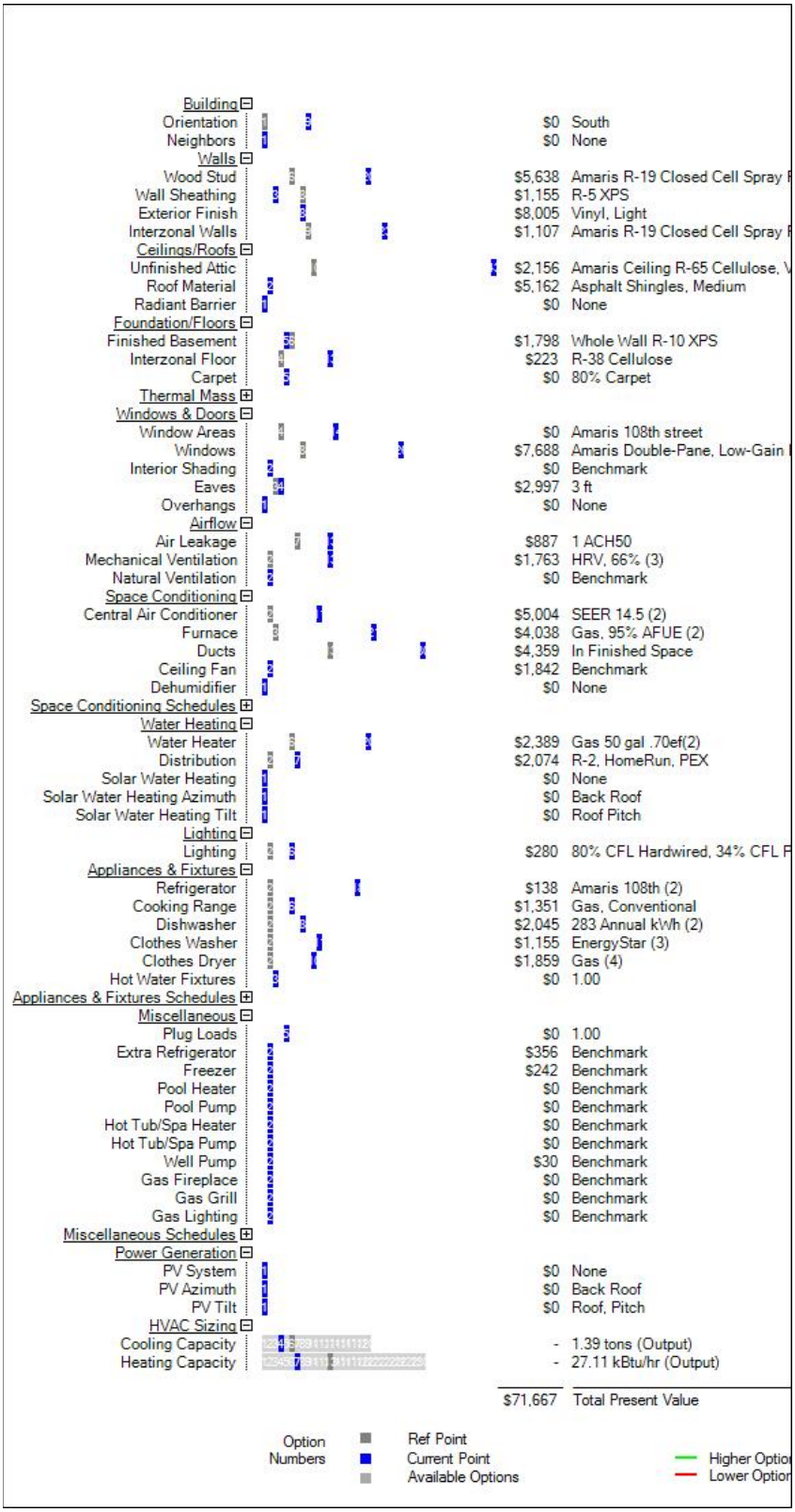
8617

Rating Date 6/4/14

REM/Rate - Residential Energy Analysis and Rating Software v14.4.1

The Home Energy Rating Standard Disclosure for this home is available from the rating provider.

Appendix D: Amaris Custom Homes—Bloomington, Minnesota, Project BEopt Inputs



Appendix E: Amaris Custom Homes—Vadnais Heights, Minnesota, Project HERS Reports and ZERH Certification

Home Energy Rating Certificate

549 Fisher Circle
Vadnais Heights, MN 55127

5 Stars Plus
Confirmed
HERS Index: 22

Registry ID	**397859593**
Rating Number	
Certified Energy Rater	Patrick O'Malley
Rating Date	3/5/15
Rating Ordered For	Peter Helgeson & Sharon Lorain

General Information

Conditioned Area	1882 sq. ft.	House Type	Single-family detached
Conditioned Volume	17724 cubic ft.	Foundation	Slab
Bedrooms	3		

Mechanical Systems Features

Air-source heat pump:	Electric, Htg: 8.7 HSPF. Clg: 14.5 SEER.
Integrated Htg/DHW:	Natural gas, Htg eff 0.95 CAafue. DHW eff 0.80 CAef.
Duct Leakage to Outside	18.00 CFM25.
Ventilation System	Balanced: HRV, 75 cfm, 70.0 watts.
Programmable Thermostat	Heat=Yes; Cool=Yes

Building Shell Features

Ceiling Flat	R-65.5	Slab	R-10.0 Edge, R-10.0 Under
Sealed Attic	NA	Exposed Floor	NA
Vaulted Ceiling	NA	Window Type	U-Value: 0.250, SHGC: 0.160
Above Grade Walls	R-24.5	Infiltration Rate	Htg: 486 Clg: 486 CFM50
Foundation Walls	NA	Method	Blower door test

Lights and Appliance Features

Percent Interior Lighting	100.00	Range/Oven Fuel	Natural gas
Percent Garage Lighting	100.00	Clothes Dryer Fuel	Natural gas
Refrigerator (kWh/yr)	768.00	Clothes Dryer EF	2.67
Dishwasher Energy Factor	0.00	Ceiling Fan (cfm/Watt)	0.00

Estimated Annual Energy Cost

Use	MMBtu	Cost	Percent
Heating	34.8	$398	60%
Cooling	1.9	$49	7%
Hot Water	13.4	$120	18%
Lights/Appliances	19.9	$453	68%
Photovoltaics	-22.4	$-599	-90%
Service Charges		$240	36%
Total	**47.5**	**$663**	**100%**

Criteria

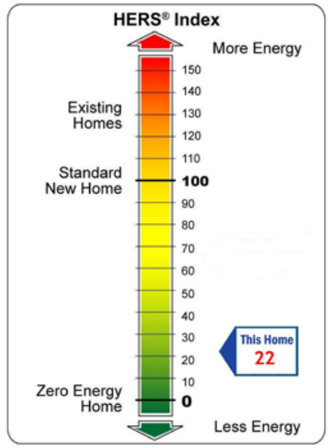
This home meets or exceeds the minimum criteria for the following:
EPA ENERGY STAR Version 3 Home
2009 International Energy Conservation Code

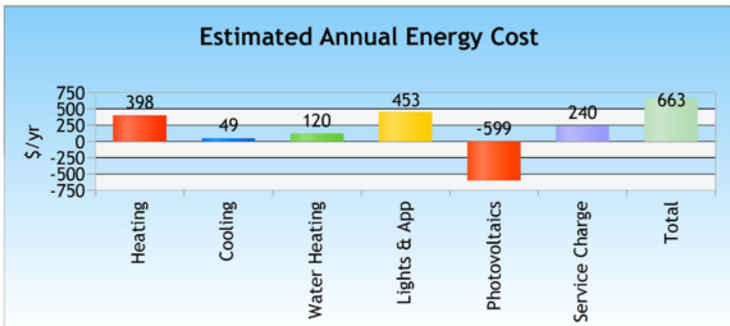
Building Knowledge, Inc.
PO Box 1376
Burnsville, MN 55337
952-944-5605
www.buildingknowledge.com

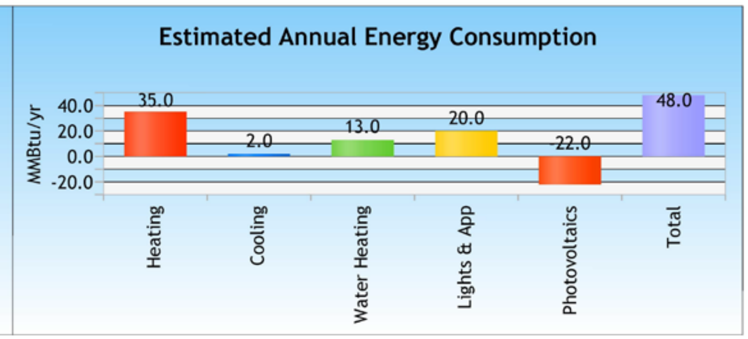
REM/Rate - Residential Energy Analysis and Rating Software v14.5.1

The Home Energy Rating Standard Disclosure for this home is available from the rating provider.

HERS PERFORMANCE ENERGY RATING CERTIFICATE







Address	549 Fisher Circle Vadnais Heights, MN 55127
House Type	Single-family detached
Cond. Area	1882 sq. ft.
Rating No.	
Issue Date	March 09, 2015
Certification	Verified

Annual Estimates*
Natural gas(Therms): 477
C02 emissions(Tons): 3
Annual Savings**: $1917

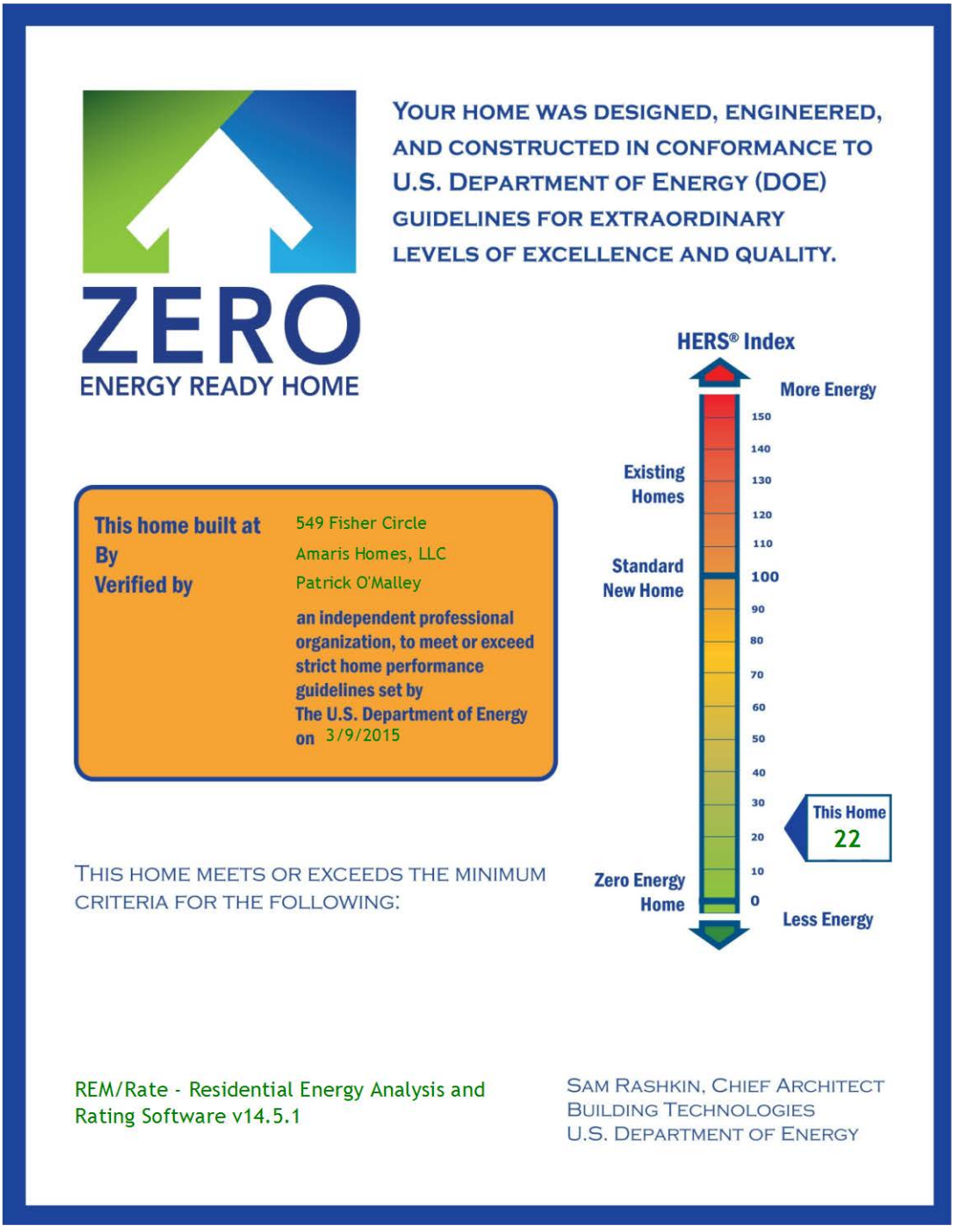
* Based on standard operating conditions
** Based on a HERS 130 Index Home

Building Knowledge, Inc.
PO Box 1376

Certified Rater	Patrick O'Malley
Rater ID	9377462
Registry ID	397859593
Rating Date	3/5/15

REM/Rate - Residential Energy Analysis and Rating Software v14.5.1

The Home Energy Rating Standard Disclosure for this home is available from the rating provider.



DOE Zero Energy Ready Home

Optional Compliance for Builder Recognition

I further certify that the following also apply to this house:

YES	NO	DON'T KNOW	Optional Home Builder Commitments for Recognition
	X		Certified under the EPA WaterSense for New Homes Program
	X		Certified under the IBHS Fortified for Safer Living Program
	X		Followed the DOE Zero Energy Ready Home Quality Management Guidelines
	X		The buyer of this home signed a waiver giving DOE Zero Energy Ready Home access to utility bill data for one year

*Certification under the DOE Zero Energy Ready Home permits limited exceptions to full compliance with Indoor airPLUS. Builders seeking the Indoor airPLUS label must achieve full compliance with the Indoor airPLUS Verification Checklist.

DOE Zero Energy Ready Home

Energy Performance	
House Type	**DOE Zero Energy Ready Home Builder Partner ID#**
Single-family detached	33
Year built	**Square footage of Conditioned Space including Basement**
2014	1882.0
Number of Bedrooms	**Square footage of Conditioned Space without Basement**
3	1882.0
Site address (if not available, list the site Lot #)	**Registered Builder**
549 Fisher Circle	Amaris Homes, LLC
Vadnais Heights	**Certified Rater**
MN, 55127	Patrick O'Malley
HERS Index without On-site Generation	**Date of Rating**
47	3/5/15
HERS Index with On-site Generation	**Rating Software**
22	REM/Rate - v14.5.1
HERS Index of the Target Home using size adjustment factor	**Estimated annual energy costs($)**
62	663
Estimated annual energy use	**Estimated annual energy savings**
Electric: -65 kWh \ Natural Gas: 477 Therms	Electric: 9032 kWh \ Natural gas: 614 Therms
Energy cost rates	**Estimated annual emissions reductions**
Electric: 0.09 $/kWh \ Natural Gas: 0.90 $/Therms	CO2: 10.0 tons / SO2: 19.2 lbs / NOx: 24.4 lbs

DOE Zero Energy Ready Home Certification

As the certified Rater for this house, I certify this house meets/complies with all mandatory requirments of the DOE Zero Energy Ready home guidelines, including the following:

X	Compliance with all ENERGY STAR Qualified Homes Version 3 requirements and checklists
X	Compliance with Mandatory Fenestration Requirements
X	Compliance with Mandatory Insulation Requirements
X	Compliance with Mandatory Duct Location Requirements
X	Compliance with Mandatory Appliance Requirements
X	Compliance with Mandatory Lighting Requirements
X	Compliance with Mandatory Fan Efficiency Requirements
X	Compliance with Mandatory EPA Indoor airPLUS
X	Compliance with Mandatory Renewable Energy Ready Solar Electric Requirements
X	Compliance with Mandatory Renewable Energy Ready Solar Hot Water Requirements
	This home was qualified via sampling in lieu of testing, in accordance with allowable sampling provisions as stated in the DOE Zero Energy Ready Home National Program Requirements

Optional Compliance for Builder Recognition

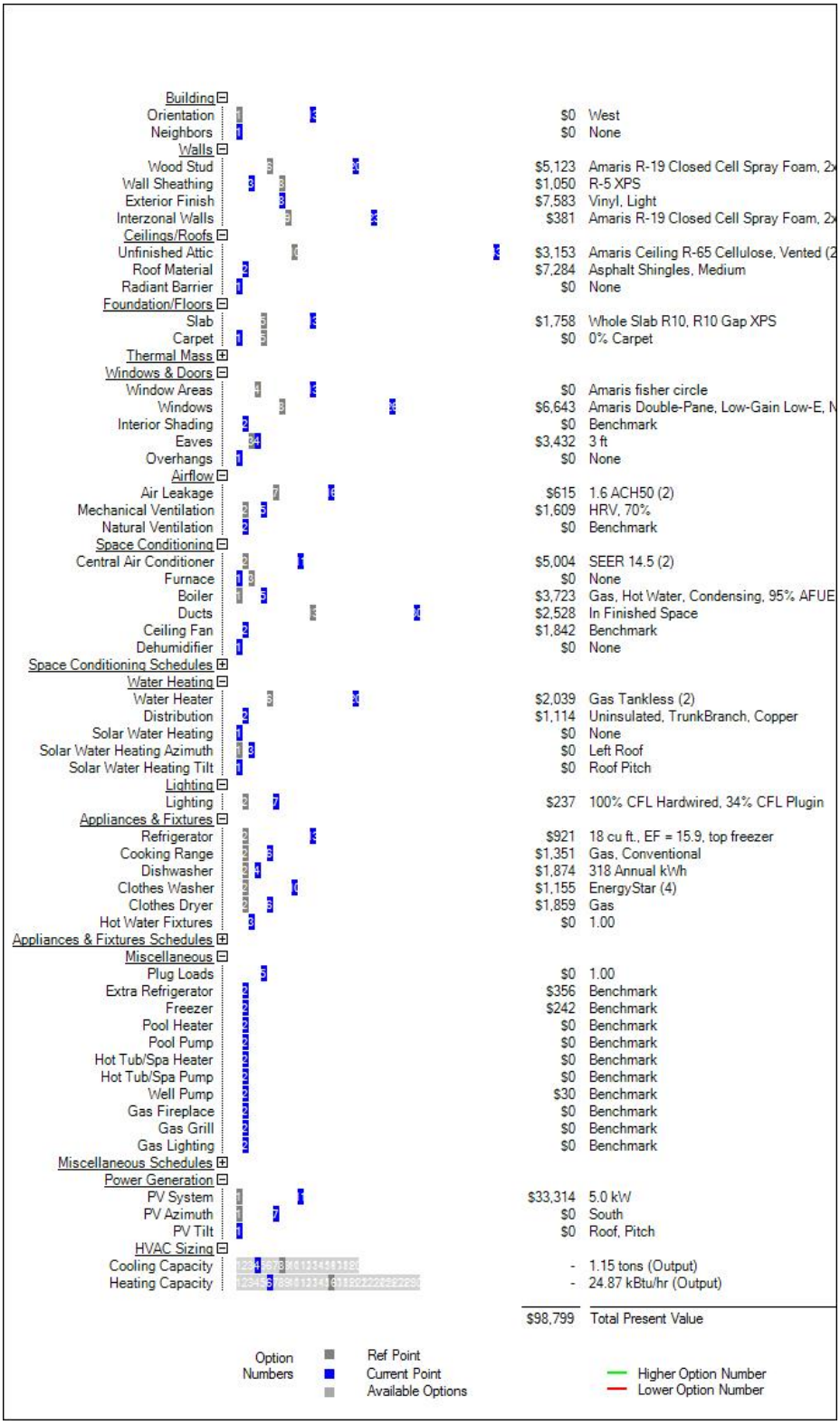
I further certify that the following also apply to this house:

YES	NO	DON'T KNOW	Optional Home Builder Commitments for Recognition

*Certification under the DOE Zero Energy Ready Home permits limited exceptions to full compliance with Indoor airPLUS. Builders seeking the Indoor airPLUS label must achieve full compliance with the Indoor airPLUS Verification Checklist.

REM/Rate - Residential Energy Analysis and Rating Software v14.5.1
This information does not constitute any warranty of energy cost or savings.

Appendix F: Amaris Custom Homes—Vadnais Heights, Minnesota, Project BEopt Inputs



Appendix G: Amaris Custom Homes—Apple Valley, Minnesota, Project HERS Reports and ZERH Certification

Home Energy Rating Certificate

BUILDING KNOWLEDGE

4879 Dominica Way
Apple Valley, MN 55124

5 Stars Plus
Confirmed
HERS Index: 13

Registry ID	**969625909**
Rating Number	
Certified Energy Rater	Patrick O'Malley
Rating Date	6/8/15
Rating Ordered For	Tyler Matthews & Jessica Shu

General Information

Conditioned Area	3716 sq. ft.	House Type	Single-family detached
Conditioned Volume	53334 cubic ft.	Foundation	Conditioned basement
Bedrooms	4		

Mechanical Systems Features

Heating:	Fuel-fired air distribution, Natural gas, 98.0 AFUE.
Water Heating:	Conventional, Electric, 0.91 EF, 50.0 Gal.
Air-source heat pump:	Electric, Htg: 9.0 HSPF. Clg: 16.5 SEER.
Duct Leakage to Outside	5.00 CFM25.
Ventilation System	Balanced: HRV, 80 cfm, 76.0 watts.
Programmable Thermostat	Heat=Yes; Cool=Yes

Building Shell Features

Ceiling Flat	R-65.5	Slab	R-0.0 Edge, R-10.0 Under
Sealed Attic	NA	Exposed Floor	NA
Vaulted Ceiling	R-45.0	Window Type	U-Value: 0.260, SHGC: 0.180
Above Grade Walls	R-25.0	Infiltration Rate	Htg: 586 Clg: 586 CFM50
Foundation Walls	R-10.0	Method	Blower door test

Lights and Appliance Features

Percent Interior Lighting	100.00	Range/Oven Fuel	Natural gas
Percent Garage Lighting	100.00	Clothes Dryer Fuel	Natural gas
Refrigerator (kWh/yr)	956.00	Clothes Dryer EF	2.75
Dishwasher Energy Factor	0.00	Ceiling Fan (cfm/Watt)	0.00

Estimated Annual Energy Cost

Use	MMBtu	Cost	Percent
Heating	53.2	$720	98%
Cooling	2.8	$76	10%
Hot Water	13.8	$369	50%
Lights/Appliances	31.7	$744	101%
Photovoltaics	-52.7	$-1413	-192%
Service Charges		$240	33%
Total	**48.8**	**$736**	**100%**

Criteria

This home meets or exceeds the minimum criteria for the following:

EPA ENERGY STAR Version 2 Home
EPA ENERGY STAR Version 2.5 Home
EPA ENERGY STAR Version 3 Home
EPA ENERGY STAR Version 3.1 Home
2006 International Energy Conservation Code
2009 International Energy Conservation Code

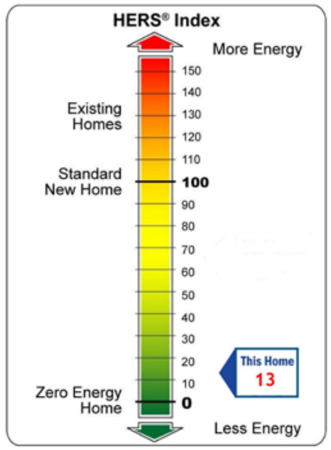
Building Knowledge, Inc.
PO Box 1376
Burnsville, MN 55337
952-944-5605
www.buildingknowledge.com

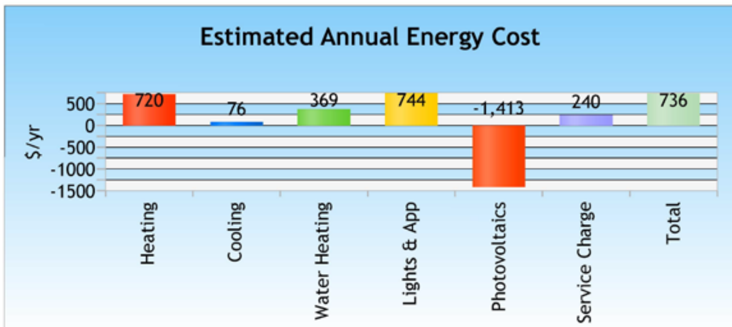
REM/Rate - Residential Energy Analysis and Rating Software v14.5.1

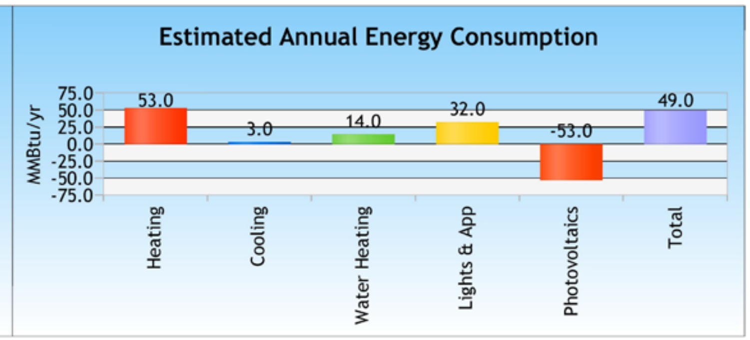
This information does not constitute any warranty of energy cost or savings. © 1985-2014 Architectural Energy Corporation, Boulder, Colorado.
The Home Energy Rating Standard Disclosure for this home is available from the rating provider.

HERS PERFORMANCE ENERGY RATING CERTIFICATE

BUILDING KNOWLEDGE







Address	4879 Dominica Way Apple Valley, MN 55124	Annual Estimates*		Building Knowledge, Inc. PO Box 1376	
		Electric(kWh):	976		
House Type	Single-family detached	Natural gas(Therms):	454	Certified Rater	Patrick O'Malley
Cond. Area	3716 sq. ft.	C02 emissions(Tons):	3	Rater ID	9377462
Rating No.		Annual Savings**:	$4444	Registry ID	969625909
Issue Date	July 09, 2015			Rating Date	6/8/15
Certification	Verified				

* Based on standard operating conditions

** Based on a HERS 130 Index Home

REM/Rate - Residential Energy Analysis and Rating Software v14.5.1

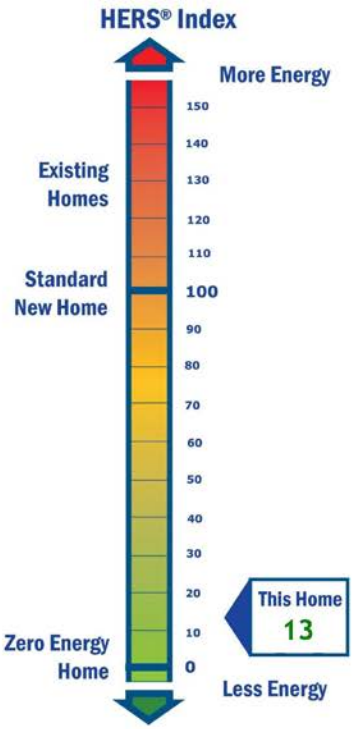
The Home Energy Rating Standard Disclosure for this home is available from the rating provider.

ZERO ENERGY READY HOME

YOUR HOME WAS DESIGNED, ENGINEERED, AND CONSTRUCTED IN CONFORMANCE TO U.S. DEPARTMENT OF ENERGY (DOE) GUIDELINES FOR EXTRAORDINARY LEVELS OF EXCELLENCE AND QUALITY.

This home built at	4879 Dominica Way
By	Amaris Homes, LLC
Verified by	Patrick O'Malley

an independent professional organization, to meet or exceed strict home performance guidelines set by The U.S. Department of Energy on 7/9/2015



THIS HOME MEETS OR EXCEEDS THE MINIMUM CRITERIA FOR THE FOLLOWING:

REM/Rate - Residential Energy Analysis and Rating Software v14.5.1

SAM RASHKIN, CHIEF ARCHITECT
BUILDING TECHNOLOGIES
U.S. DEPARTMENT OF ENERGY

DOE Zero Energy Ready Home

Energy Performance	
House Type	**DOE Zero Energy Ready Home Builder Partner ID#**
Single-family detached	505
Year built	**Square footage of Conditioned Space including Basement**
2015	3716.0
Number of Bedrooms	**Square footage of Conditioned Space without Basement**
4	3716.0
Site address (if not available, list the site Lot #)	**Registered Builder**
4879 Dominica Way	Amaris Homes, LLC
Apple Valley	**Certified Rater**
MN, 55124	Patrick O'Malley
HERS Index without On-site Generation	**Date of Rating**
46	6/8/15
HERS Index with On-site Generation	**Rating Software**
13	REM/Rate - v14.5.1
HERS Index of the Target Home using size adjustment factor	**Estimated annual energy costs($)**
49	736
Estimated annual energy use	**Estimated annual energy savings**
Electric: 976 kWh \ Natural Gas: 454 Therms	Electric: 30572 kWh \ Natural gas: 570 Therms
Energy cost rates	**Estimated annual emissions reductions**
Electric: 0.09 $/kWh \ Natural Gas: 0.90 $/Therms	CO2: 24.8 tons / SO2: 64.8 lbs / NOx: 60.1 lbs

DOE Zero Energy Ready Home Certification

As the certified Rater for this house, I certify this house meets/complies with all mandatory requirments of the DOE Zero Energy Ready home guidelines, including the following:

X	Compliance with all ENERGY STAR Qualified Homes Version 3 requirements and checklists
X	Compliance with Mandatory Fenestration Requirements
X	Compliance with Mandatory Insulation Requirements
X	Compliance with Mandatory Duct Location Requirements
X	Compliance with Mandatory Appliance Requirements
X	Compliance with Mandatory Lighting Requirements
X	Compliance with Mandatory Fan Efficiency Requirements
X	Compliance with Mandatory EPA Indoor airPLUS
X	Compliance with Mandatory Renewable Energy Ready Solar Electric Requirements
X	Compliance with Mandatory Renewable Energy Ready Solar Hot Water Requirements
	This home was qualified via sampling in lieu of testing, in accordance with allowable sampling provisions as stated in the DOE Zero Energy Ready Home National Program Requirements

Optional Compliance for Builder Recognition

I further certify that the following also apply to this house:

YES	NO	DON'T KNOW	Optional Home Builder Commitments for Recognition

*Certification under the DOE Zero Energy Ready Home permits limited exceptions to full compliance with Indoor airPLUS. Builders seeking the Indoor airPLUS label must achieve full compliance with the Indoor airPLUS Verification Checklist.

REM/Rate - Residential Energy Analysis and Rating Software v14.5.1
This information does not constitute any warranty of energy cost or savings.

DOE Zero Energy Ready Home

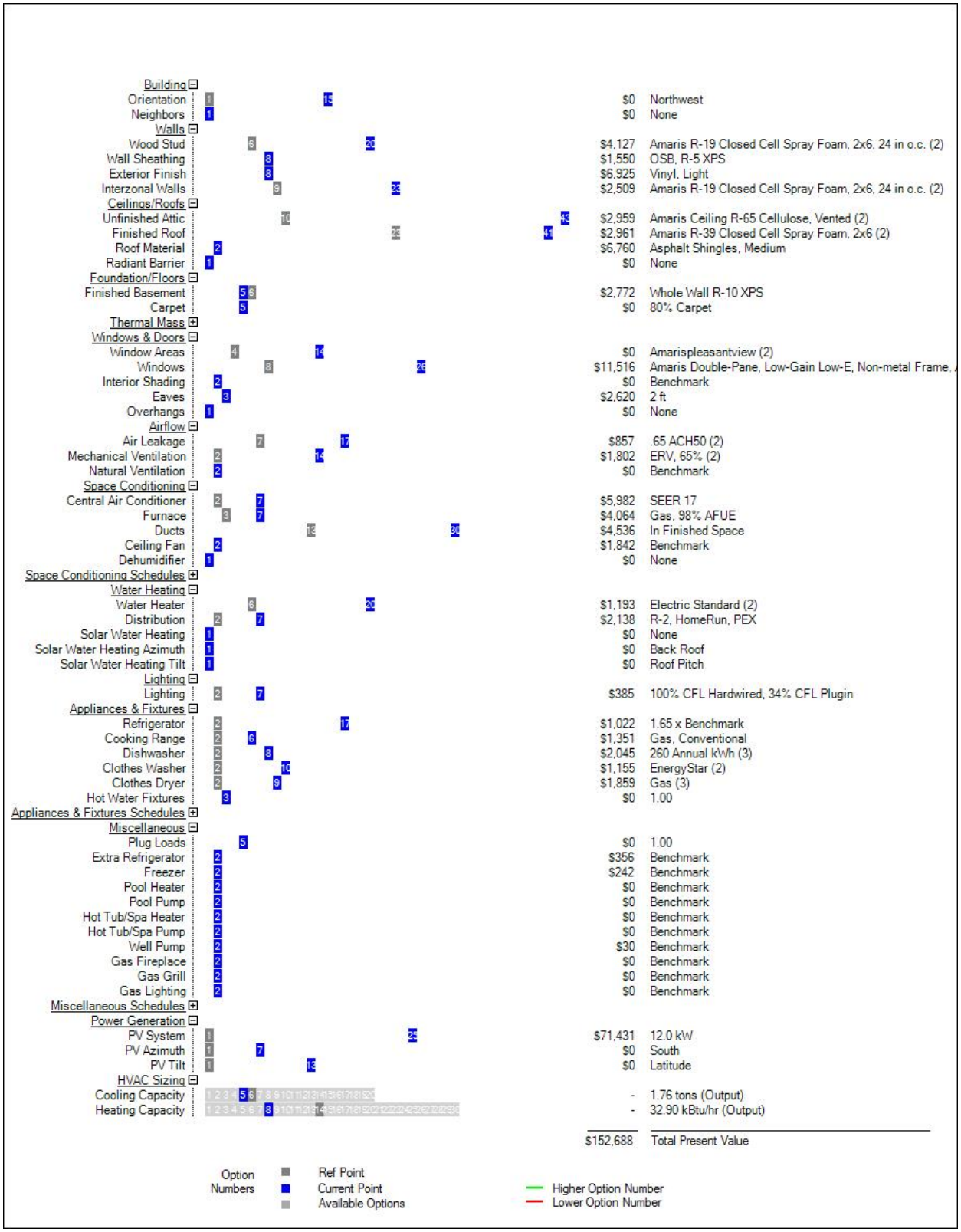
Optional Compliance for Builder Recognition

I further certify that the following also apply to this house:

YES	NO	DON'T KNOW	Optional Home Builder Commitments for Recognition
	X		Certified under the EPA WaterSense for New Homes Program
	X		Certified under the IBHS Fortified for Safer Living Program
	X		Followed the DOE Zero Energy Ready Home Quality Management Guidelines
X			The buyer of this home signed a waiver giving DOE Zero Energy Ready Home access to utility bill data for one year

*Certification under the DOE Zero Energy Ready Home permits limited exceptions to full compliance with Indoor airPLUS. Builders seeking the Indoor airPLUS label must achieve full compliance with the Indoor airPLUS Verification Checklist.

Appendix H: Amaris Custom Homes—Apple Valley, Minnesota, Project BEopt Inputs



Appendix I: Amaris Custom Homes—White Bear Township, Minnesota, Project HERS Reports

Home Energy Rating Certificate

BUILDING KNOWLEDGE

5941 Otter View Trail
White Bear Lake, MN 55110

5 Stars Plus
Confirmed
HERS Index: 43
Efficient Home Comparison: 57% Better

Registry ID	103374497
Rating Number	
Certified Energy Rater	Patrick O'Malley
Rating Date	10/22/14
Rating Ordered For	Laura Phelan & Kris Thornwall

General Information

Conditioned Area	1654 sq. ft.	House Type	Single-family detached
Conditioned Volume	24148 cubic ft.	Foundation	Conditioned crawl space
Bedrooms	3		

Mechanical Systems Features

Integrated Htg/DHW:	Natural gas, Htg eff 0.95 CAafue. DHW eff 0.80 CAef.
Cooling:	Air conditioner, Electric, 14.5 SEER.
Duct Leakage to Outside	5.00 CFM25.
Ventilation System	Balanced: ERV, 65 cfm, 70.0 watts.
Programmable Thermostat	Heat=Yes; Cool=Yes

Building Shell Features

Ceiling Flat	NA	Slab	R-0.0 Edge, R-10.0 Under
Sealed Attic	NA	Exposed Floor	NA
Vaulted Ceiling	R-65.5	Window Type	U-Value: 0.260, SHGC: 0.210
Above Grade Walls	R-25.0	Infiltration Rate	Htg: 365 Clg: 365 CFM50
Foundation Walls	R-10.0	Method	Blower door test

Lights and Appliance Features

Percent Interior Lighting	79.00	Range/Oven Fuel	Natural gas
Percent Garage Lighting	100.00	Clothes Dryer Fuel	Natural gas
Refrigerator (kWh/yr)	709.00	Clothes Dryer EF	2.75
Dishwasher Energy Factor	0.00	Ceiling Fan (cfm/Watt)	0.00

Estimated Annual Energy Cost

Use	MMBtu	Cost	Percent
Heating	39.9	$361	29%
Cooling	1.7	$45	4%
Hot Water	13.3	$120	10%
Lights/Appliances	21.6	$486	39%
Photovoltaics	-0.0	$-0	-0%
Service Charges		$240	19%
Total	**76.5**	**$1252**	**100%**

Criteria

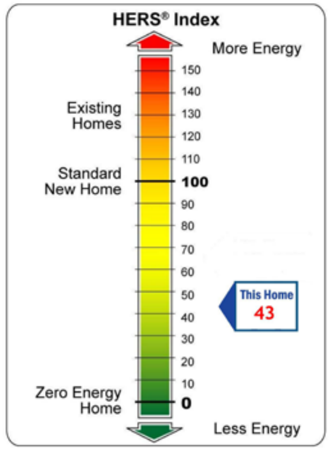
This home meets or exceeds the minimum criteria for the following:
EPA ENERGY STAR Version 3 Home
2006 International Energy Conservation Code
2009 International Energy Conservation Code

Building Knowledge, Inc.
PO Box 1376
Burnsville MN 55337
952-944-5605
www.buildingknowledge.com

REM/Rate - Residential Energy Analysis and Rating Software v14.5.1

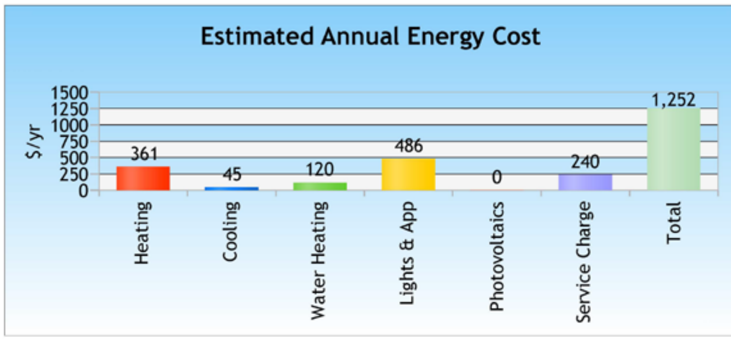
The Home Energy Rating Standard Disclosure for this home is available from the rating provider.

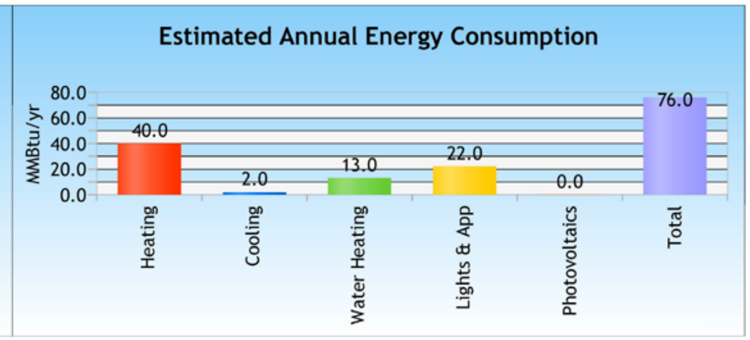
HERS PERFORMANCE



ENERGY RATING CERTIFICATE

BUILDING KNOWLEDGE





Address	5941 Otter View Trail	Annual Estimates*		Building Knowledge, Inc.	
	White Bear Lake, MN 55110	Electric(kWh): 5349		PO Box 1376	
House Type	Single-family detached	Natural gas(Therms): 582		Certified Rater	Patrick O'Malley
Cond. Area	1654 sq. ft.	C02 emissions(Tons): 7		Rater ID	9377462
Rating No.		Annual Savings**: $1492		Registry ID	103374497
Issue Date	October 23, 2014			Rating Date	10/22/14
Certification	Verified				

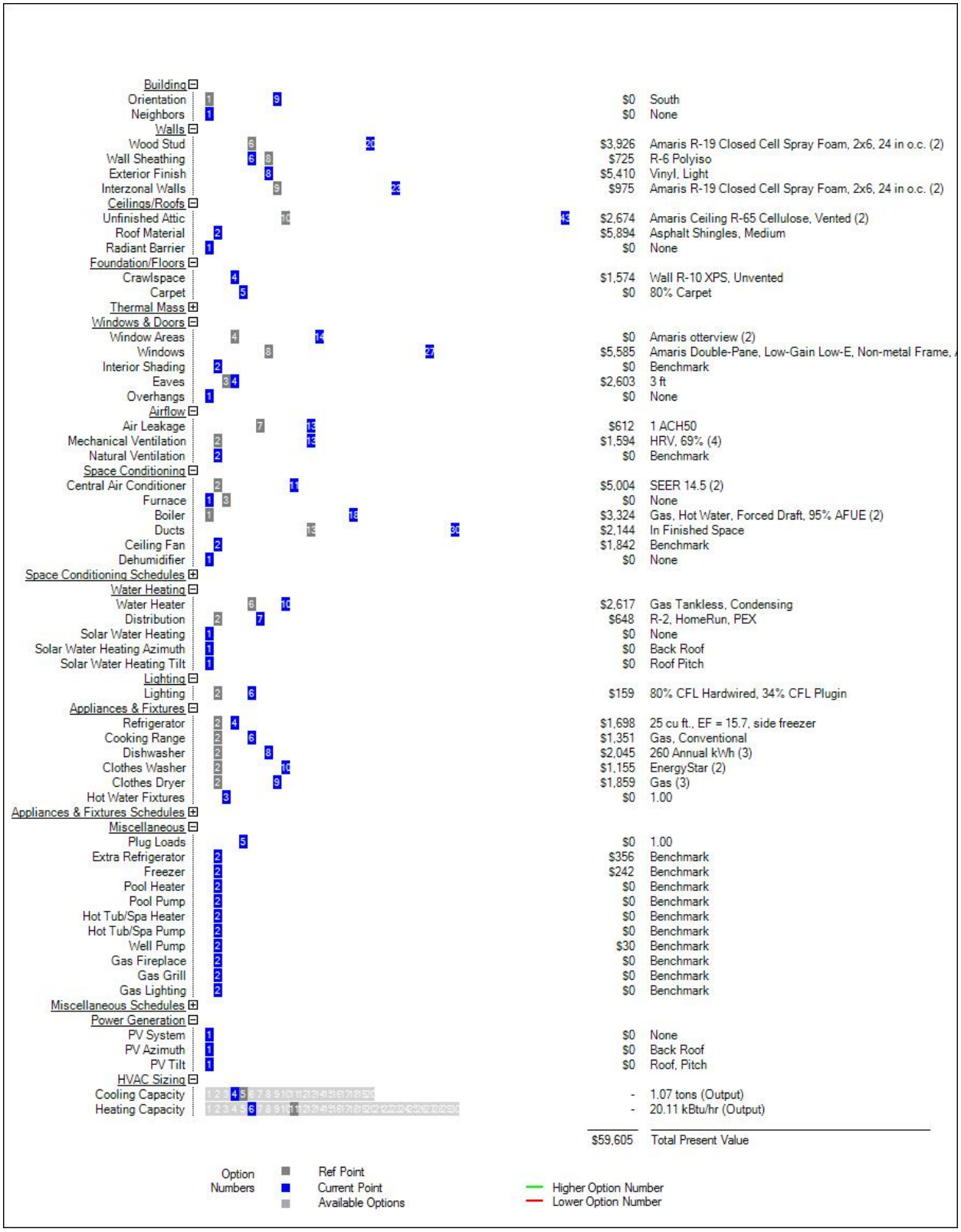
* Based on standard operating conditions

** Based on a HERS 130 Index Home

REM/Rate - Residential Energy Analysis and Rating Software v14.5.1

The Home Energy Rating Standard Disclosure for this home is available from the rating provider.

Appendix J: Amaris Custom Homes—White Bear Township, Minnesota, Project BEopt Inputs



Appendix K: Amaris Custom Homes—Mound, Minnesota, Project HERS Reports

Home Energy Rating Certificate

BUILDING KNOWLEDGE

7137 Pleasantview Drive
Mounds View, MN 55112

5 Stars Plus
Confirmed
HERS Index: 41

Registry ID	**129439466**
Rating Number	
Certified Energy Rater	Patrick O'Malley
Rating Date	11/13/14
Rating Ordered For	

General Information

Conditioned Area	3537 sq. ft.	House Type	Single-family detached
Conditioned Volume	32970 cubic ft.	Foundation	Conditioned basement
Bedrooms	4		

Mechanical Systems Features

Integrated Htg/DHW:	Natural gas, Htg eff 0.95 CAafue. DHW eff 0.80 CAef.
Cooling:	Air conditioner, Electric, 14.5 SEER.
Duct Leakage to Outside	5.00 CFM25.
Ventilation System	Balanced: ERV, 80 cfm, 84.0 watts.
Programmable Thermostat	Heat=Yes; Cool=Yes

Building Shell Features

Ceiling Flat	R-49.0	Slab	R-10.0 Edge, R-10.0 Under
Sealed Attic	NA	Exposed Floor	NA
Vaulted Ceiling	NA	Window Type	U-Value: 0.280, SHGC: 0.290
Above Grade Walls	R-25.0	Infiltration Rate	Htg: 871 Clg: 871 CFM50
Foundation Walls	R-29.5	Method	Blower door test

Lights and Appliance Features

Percent Interior Lighting	100.00	Range/Oven Fuel	Natural gas
Percent Garage Lighting	100.00	Clothes Dryer Fuel	Natural gas
Refrigerator (kWh/yr)	952.00	Clothes Dryer EF	2.75
Dishwasher Energy Factor	0.79	Ceiling Fan (cfm/Watt)	0.00

Estimated Annual Energy Cost

Use	MMBtu	Cost	Percent
Heating	55.3	$506	30%
Cooling	3.3	$88	5%
Hot Water	15.9	$143	8%
Lights/Appliances	31.1	$730	43%
Photovoltaics	-0.0	$-0	-0%
Service Charges		$240	14%
Total	**105.6**	**$1707**	**100%**

Criteria

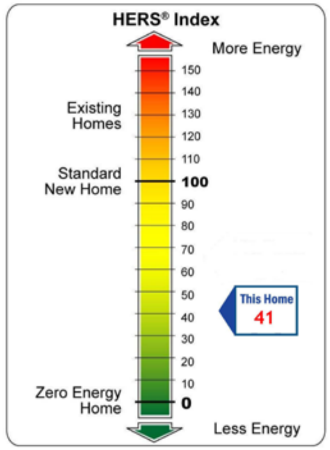
This home meets or exceeds the minimum criteria for the following:
EPA ENERGY STAR Version 2 Home
EPA ENERGY STAR Version 2.5 Home
2006 International Energy Conservation Code
2009 International Energy Conservation Code
2012 International Energy Conservation Code

Building Knowledge, Inc.
PO Box 1376
Burnsville, MN 55337
952-944-5605
www.buildingknowledge.com

REM/Rate - Residential Energy Analysis and Rating Software v14.5.1

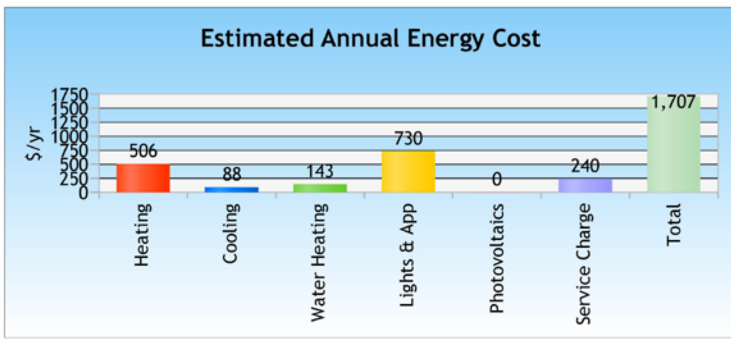
This information does not constitute any warranty of energy cost or savings.
The Home Energy Rating Standard Disclosure for this home is available from the rating provider.

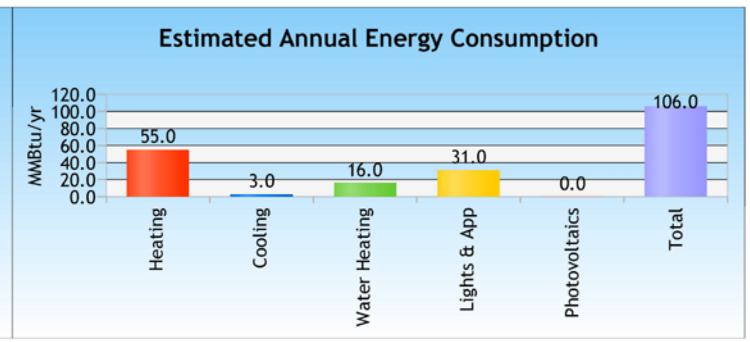
HERS PERFORMANCE



ENERGY RATING CERTIFICATE

BUILDING KNOWLEDGE





Address	7137 Pleasantview Drive	Annual Estimates*	Building Knowledge, Inc.	
	Mounds View, MN 55112	Electric(kWh): 8542	PO Box 1376	
House Type	Single-family detached	Natural gas(Therms): 764	Certified Rater	Patrick O'Malley
Cond. Area	3537 sq. ft.	C02 emissions(Tons): 11	Rater ID	9377462
Rating No.		Annual Savings**: $2400	Registry ID	129439466
Issue Date	June 01, 2015		Rating Date	11/13/14
Certification	Verified			

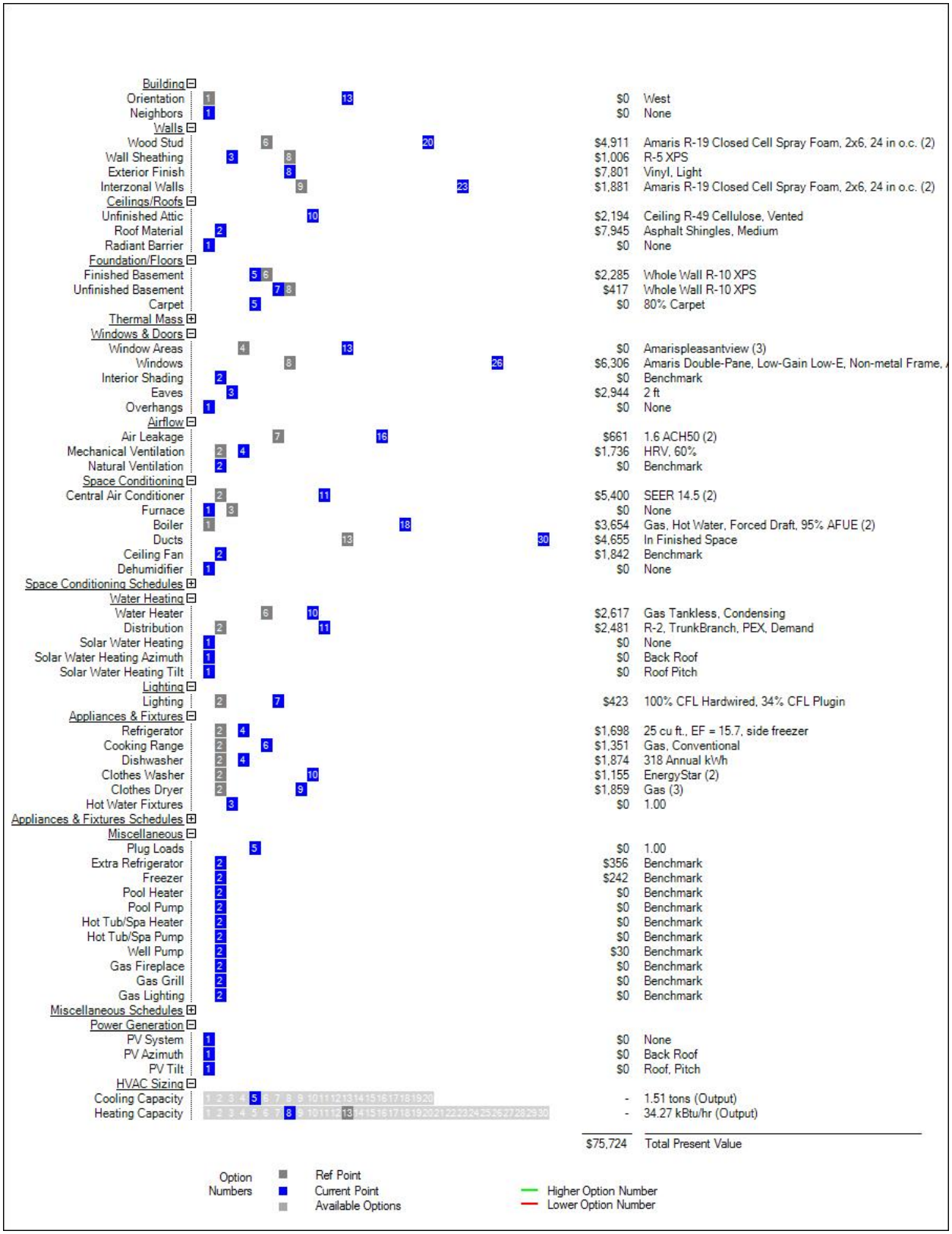
* Based on standard operating conditions

** Based on a HERS 130 Index Home

REM/Rate - Residential Energy Analysis and Rating Software v14.5.1

The Home Energy Rating Standard Disclosure for this home is available from the rating provider.

Appendix L: Amaris Custom Homes—Mound, Minnesota, Project BEopt Inputs



Appendix M: Amaris Custom Homes—Stillwater, Minnesota, Project HERS Reports

Home Energy Rating Certificate

BUILDING KNOWLEDGE

115 Willow Street
Stillwater, MN 55082

5 Stars Plus
Confirmed
HERS Index: 44
Efficient Home Comparison: 56% Better

Registry ID	156941112
Rating Number	
Certified Energy Rater	Patrick O'Malley
Rating Date	1/27/15
Rating Ordered For	Kari Branjord

General Information

Conditioned Area	2927 sq. ft.	House Type	Single-family detached
Conditioned Volume	27908 cubic ft.	Foundation	Conditioned basement
Bedrooms	4		

Mechanical Systems Features

Heating:	Fuel-fired air distribution, Natural gas, 95.5 AFUE.
Cooling:	Air conditioner, Electric, 15.0 SEER.
Water Heating:	Conventional, Natural gas, 0.74 EF, 50.0 Gal.
Duct Leakage to Outside	5.00 CFM25.
Ventilation System	Balanced: HRV, 75 cfm, 100.0 watts.
Programmable Thermostat	Heat=Yes; Cool=Yes

Building Shell Features

Ceiling Flat	R-65.5	Slab	R-10.0 Edge, R-10.0 Under
Sealed Attic	NA	Exposed Floor	R-72.0
Vaulted Ceiling	NA	Window Type	U-Value: 0.300, SHGC: 0.250
Above Grade Walls	R-24.5	Infiltration Rate	Htg: 868 Clg: 868 CFM50
Foundation Walls	R-10.0	Method	Blower door test

Lights and Appliance Features

Percent Interior Lighting	90.00	Range/Oven Fuel	Natural gas
Percent Garage Lighting	100.00	Clothes Dryer Fuel	Natural gas
Refrigerator (kWh/yr)	521.00	Clothes Dryer EF	2.67
Dishwasher Energy Factor	0.00	Ceiling Fan (cfm/Watt)	0.00

Estimated Annual Energy Cost

Use	MMBtu	Cost	Percent
Heating	68.6	$631	36%
Cooling	3.1	$82	5%
Hot Water	17.0	$153	9%
Lights/Appliances	26.6	$624	36%
Photovoltaics	-0.0	$-0	-0%
Service Charges		$240	14%
Total	**115.3**	**$1731**	**100%**

Criteria

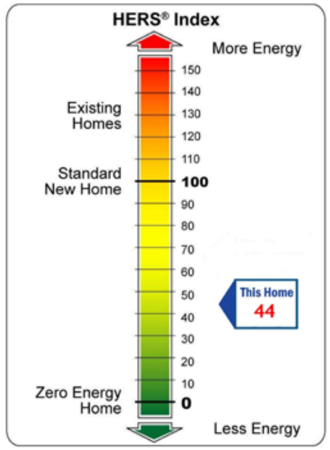
This home meets or exceeds the minimum criteria for the following:
EPA ENERGY STAR Version 3 Home
2006 International Energy Conservation Code
2009 International Energy Conservation Code

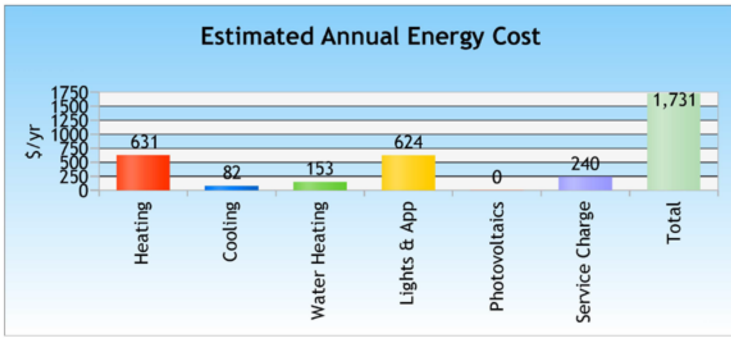
Building Knowledge, Inc.
PO Box 1376
Burnsville MN 55337
952-944-5605
www.buildingknowledge.com

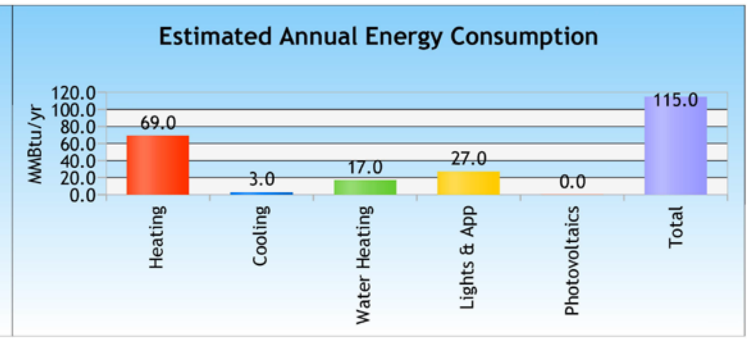
REM/Rate - Residential Energy Analysis and Rating Software v14.5.1

The Home Energy Rating Standard Disclosure for this home is available from the rating provider.

HERS PERFORMANCE ENERGY RATING CERTIFICATE







Address	115 Willow Street Stillwater, MN 55082	Annual Estimates* Electric(kWh): 7491	Building Knowledge, Inc. PO Box 1376	
House Type	Single-family detached	Natural gas(Therms): 897	Certified Rater	Patrick O'Malley
Cond. Area	2927 sq. ft.	C02 emissions(Tons): 11	Rater ID	9377462
Rating No.		Annual Savings**: $2306	Registry ID	156941112
Issue Date	February 03, 2015		Rating Date	1/27/15
Certification	Verified			

* Based on standard operating conditions

** Based on a HERS 130 Index Home

REM/Rate - Residential Energy Analysis and Rating Software v14.5.1

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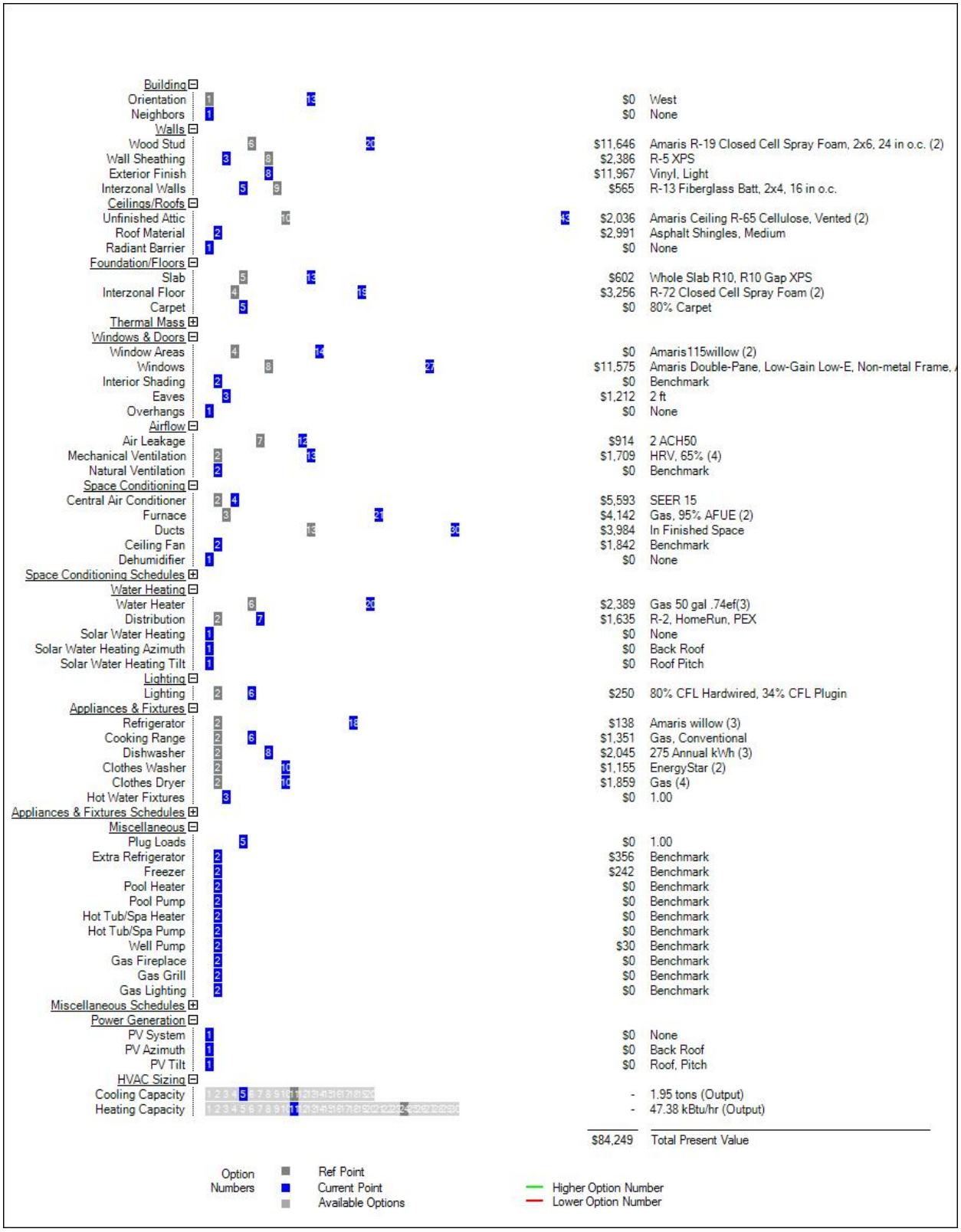
The Home Energy Rating Standard Disclosure for this home is available from the rating provider.

Appendix N: Amaris Custom Homes—Stillwater, Minnesota, Project BEopt Inputs



Appendix O: Cobblestone Homes—Midland, Michigan, Project HERS Reports and ZERH Certification

Home Energy Rating Certificate

2936 E IRON WOODS PASS
MIDLAND, MI 48642

5 Stars Plus
Confirmed

Registry ID: **051416150**
Rating Number: **EEHM1051338**
Certified Energy Rater: CHARLES E. CRIBLEY
Rating Date: 5/29/2014
Rating Ordered For: NEW HOMEOWNER

Uniform Energy Rating System — **Energy Efficient**

1 Star	1 Star Plus	2 Stars	2 Stars Plus	3 Stars	3 Stars Plus	4 Stars	4 Stars Plus	5 Stars	5 Stars Plus
500-401	400-301	300-251	250-201	200-151	150-101	100-91	90-86	85-71	70 or Less

HERS Index: 44

General Information

Conditioned Area: 4008 sq. ft
Conditioned Volume: 36947 cubic ft
Bedrooms: 4
HouseType: Single-family detached
Foundation: Conditioned basement

Mechanical Systems Features

Heating: Fuel-fired air distribution, Natural gas, 96.0 AFUE.
Cooling: Air conditioner, Electric, 13.0 SEER.
Water Heating: Conventional, Natural gas, 0.63 EF, 60.0 Gal.
Duct Leakage to Outside: 0.00 CFM25.
Ventilation System: Balanced: ERV, 120 cfm, 60.0 watts.
Programmable Thermostat: Heating: Yes Cooling: Yes

Building Shell Features

Ceiling Flat: R-49.1
Sealed Attic: NA
Vaulted Ceiling: NA
Above Grade Walls: R-20.6
Foundation Walls: R-11.5
Slab: R-0.0 Edge, R-5.0 Under
Exposed Floor: NA
Window Type: U-Value: 0.280, SHGC: 0.280
Infiltration Rate: Htg: 786 Clg: 786 CFM50
Method: Blower door test

Lights and Appliance Features

Percent Interior Lighting: 90.00
Percent Garage Lighting: 100.00
Refrigerator (kWh/yr): 459.00
Dishwasher Energy Factor: 0.74
Range/Oven Fuel: Natural gas
Clothes Dryer Fuel: Natural gas
Clothes Dryer EF: 3.01
Ceiling Fan (cfm/Watt): 121.00

Estimated Annual Energy Cost
Confirmed

Use	MMBtu	Cost	Percent
Heating	44.0	$412	26%
Cooling	2.3	$75	5%
Hot Water	21.1	$192	12%
Lights/Appliances	32.1	$880	55%
Photovoltaics	-6.0	$-194	-12%
Service Charges		$240	15%
Total	**93.5**	**$1604**	**100%**

This home meets or exceeds the minimum criteria for all of the following:
EPA ENERGY STAR Version 3 Home
2003 International Energy Conservation Code
2004 International Energy Conservation Code
2006 International Energy Conservation Code
2009 International Energy Conservation Code

EEH MIDWEST INC
PO BOX 503248
INDIANAPOLIS IN 46250

317-915-9204
www.eehmidwest.com

NATIONAL MORTGAGE INDUSTRY HERS ACCREDITATION REGISTRY No. 1998-017

The Home Energy Rating Standard Disclosure for this home is available from the rating provider.

REM/Rate - Residential Energy Analysis and Rating Software v14.4.1
This information does not constitute any warranty of energy cost or savings.

Component Consumption

Property
NEW HOMEOWNER
2936 E IRON WOODS PASS
MIDLAND, MI 48642

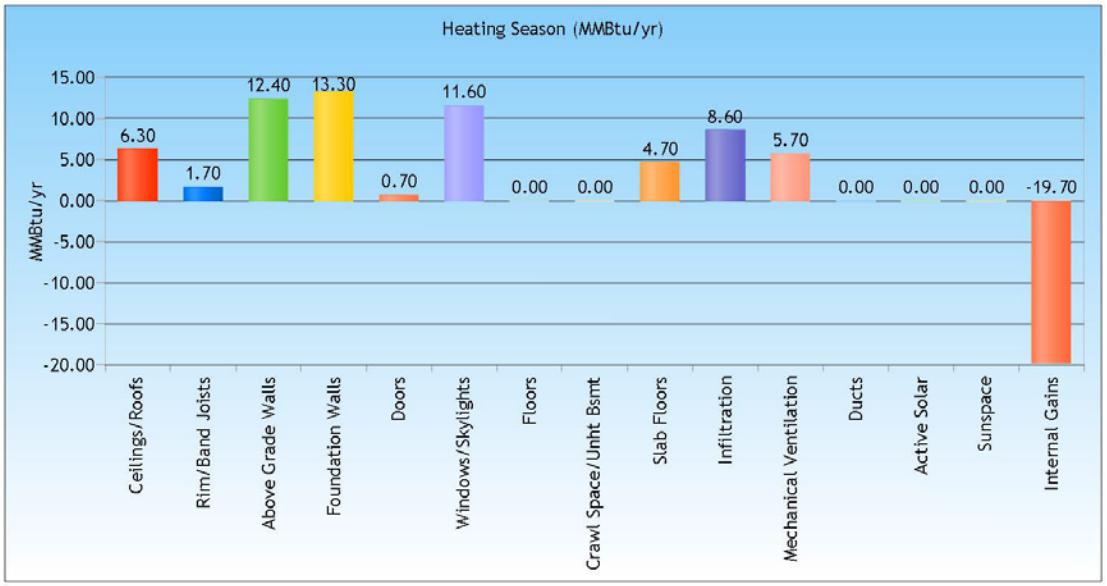
Organization
ENERSAFE
989-488-9409
CHARLES E. CRIBLEY

HERS
Confirmed
5/29/2014
ID:1362145

Weather:Flint, MI
CEC250V14.4.1
CEC250V14.4.1.blg

Builder
COBBLESTONE HOMES LLC

Heating Season	MMBtu/yr
Ceilings/Roofs	6.3
Rim/Band Joists	1.7
Above Grade Walls	12.4
Foundation Walls	13.3
Doors	0.7
Windows/Skylights	11.6
Floors	0.0
Crawl Space/Unht Bsmt	0.0
Slab Floors	4.7
Infiltration	8.6
Mechanical Ventilation	5.7
Ducts	0.0
Active Solar	0.0
Sunspace	0.0
Internal Gains	-19.7
Total	45.2



Component Consumption

Property
NEW HOMEOWNER
2936 E IRON WOODS PASS
MIDLAND, MI 48642

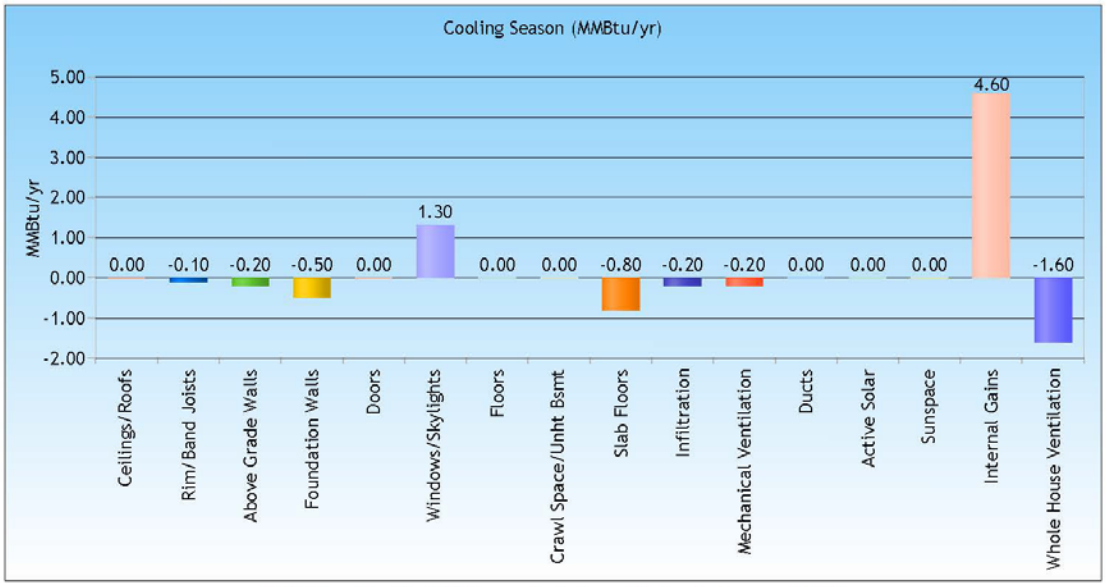
Organization
ENERSAFE
989-488-9409
CHARLES E. CRIBLEY

HERS
Confirmed
5/29/2014
ID:1362145

Weather:Flint, MI
CEC250V14.4.1
CEC250V14.4.1.blg

Builder
COBBLESTONE HOMES LLC

Cooling Season	MMBtu/yr
Ceilings/Roofs	-0.0
Rim/Band Joists	-0.1
Above Grade Walls	-0.2
Foundation Walls	-0.5
Doors	-0.0
Windows/Skylights	1.3
Floors	0.0
Crawl Space/Unht Bsmt	0.0
Slab Floors	-0.8
Infiltration	-0.2
Mechanical Ventilation	-0.2
Ducts	0.0
Active Solar	0.0
Sunspace	0.0
Internal Gains	4.6
Whole House Ventilation	-1.6
Total	2.4



U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

DOE ZERO ENERGY READY HOME™

U.S. DOE ZERO ENERGY READY HOME 2014 WINNER Housing Innovation Awards

Cobblestone Homes

2014 Model Home
Midland, MI

BUILDER PROFILE

Cobblestone Homes, Saginaw, MI
Melissa Wahl, 989-692-0140
Melissa@cobblestonelifestyle.com
www.cobblestonelifestyle.com
Rater: Enersafe, Charles Cribley
chuck@cobblestonelifestyle.com

FEATURED HOME/DEVELOPMENT:

Project Data:

- Name: 2014 Model Home
- Location: Midland, MI
- Layout: 4 bedrooms, 3.5 baths, 2 floors
- Conditioned Space: 2,745 ft² with basement
- Climate Zone: IECC 5A, cold
- Completion: May 2014
- Category: Custom

Modeled Performance Data:

- HERS Index: without PV 49, with PV 44
- Projected Annual Utility Costs: without PV $1,900, with PV $1,706
- Projected Annual Energy Cost Savings (compared to a home built to the 2009 IECC): without PV $440, with PV $634
- Annual PV production revenue: $194
- Builder's Added Cost Over 2009 IECC: without PV $6,000, with PV $18,000
- Annual Energy Savings: without PV 8,491 kWh, 799 therms natural gas, with PV 6,730 kWh

Having a homebuyer base dominated by scientists and engineers from one of the world's largest chemical companies has prompted Cobblestone Homes to stay on the cutting edge of building science. "Our homebuyers really do their research," laughs Melissa Wahl who, together with her husband Mark, founded Cobblestone Homes in Saginaw, Michigan, in 2003.

To stay ahead of their homebuyers, Cobblestone is constantly researching new home building technologies. Every year or so the company builds a prototype house to test new products and methods. In 2014, Cobblestone chose the U.S. Department of Energy's Zero Energy Ready Home criteria for its prototype home.

The DOE Zero Energy Ready Home program requires builders to meet a suite of energy, health, and durability requirements including ENERGY STAR Certified Homes Version 3.0, the U.S. Environmental Protection Agency's Indoor airPLUS and WaterSense requirements, additional DOE Zero Energy Ready Home efficiency requirements, and "renewable-ready" measures that ensure the home is ready for solar photovoltaic and water heating when the homeowner is ready to install them.

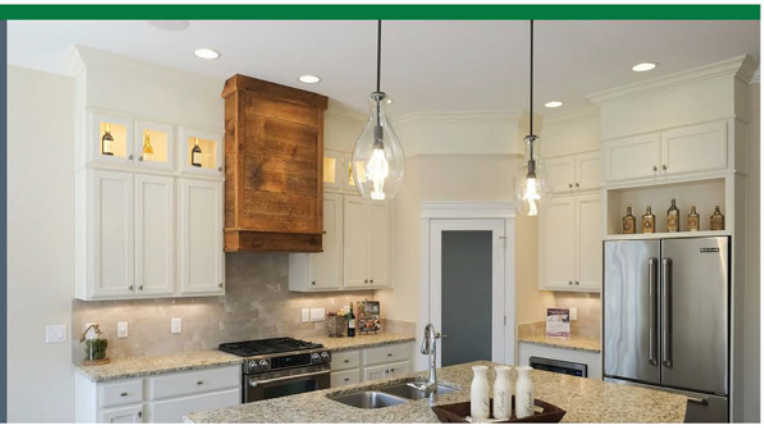
"We started out with ENERGY STAR in 2004 and that is now the minimum for every house we do. We've done an American Lung Association Healthy House and incorporated those guidelines. We did a DOE Builders Challenge Home and made it a true zero energy home with a -4 Home Energy Rating System (HERS) score," said Melissa. Cobblestone's first DOE Zero Energy Ready Home scored a HERS 49 without PV panels. "We will build more DOE Zero Energy Ready Homes. ENERGY STAR is no longer an option for us, it's assumed. I hope we will get to that point with DOE Zero Energy Ready Home," said Melissa.

ZERO ENERGY READY HOME U.S. DEPARTMENT OF ENERGY

The U.S. Department of Energy invites home builders across the country to meet the extraordinary levels of excellence and quality specified in DOE's Zero Energy Ready Home program (formerly known as Challenge Home). Every DOE Zero Energy Ready Home starts with ENERGY STAR Certified Homes Version 3.0 for an energy-efficient home built on a solid foundation of building science research. Advanced technologies are designed in to give you superior construction, durability, and comfort; healthy indoor air; high-performance HVAC, lighting, and appliances; and solar-ready components for low or no utility bills in a quality home that will last for generations to come.

DOE ZERO ENERGY READY HOME Cobblestone Homes

Cobblestone Homes' first DOE Zero Energy Ready Home features 100% energy-efficient LED or compact fluorescent-based lighting. The plumbing fixtures all meet the EPA WaterSense water-conserving criteria. The home's refrigerator, dishwasher, and ceiling fans are all ENERGY STAR-rated products.



What makes a home a DOE ZERO ENERGY READY HOME?

1 **BASELINE**
ENERGY STAR Certified Homes Version 3.0

2 **ENVELOPE**
meets or exceeds 2012 IECC levels

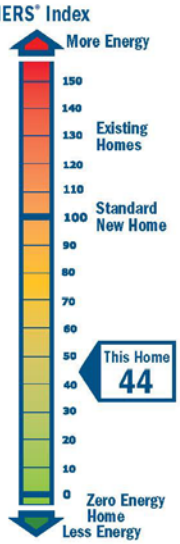
3 **DUCT SYSTEM**
located within the home's thermal boundary

4 **WATER EFFICIENCY**
meets or exceeds the EPA WaterSense Section 3.3 specs

5 **LIGHTING AND APPLIANCES**
ENERGY STAR qualified

6 **INDOOR AIR QUALITY**
meets or exceeds the EPA Indoor airPLUS Verification Checklist

7 **RENEWABLE READY**
meets EPA Renewable Energy-Ready Home.



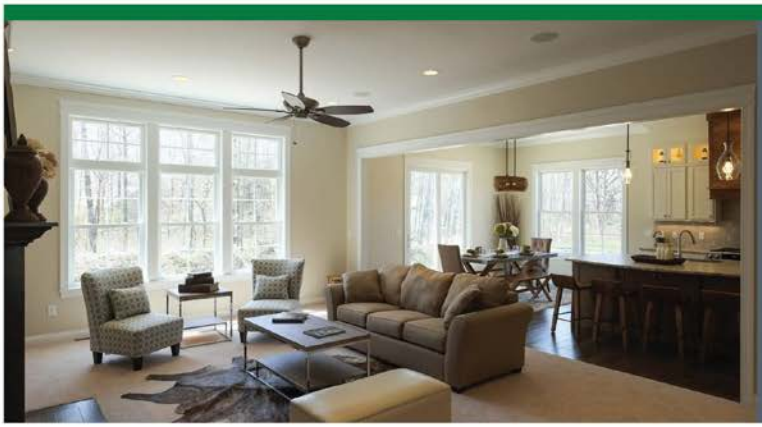
The family-run business of 15 full-time staff and over 125 dedicated subs builds about 50 to 60 homes a year. Cobblestone's first DOE Zero Energy Ready Home is a 2,745-ft², 4-bedroom, 3.5-bath home with a full basement. The home is located in Midland, Michigan, headquarters of DOW Chemical, which provided solar photovoltaic roofing shingles for the home and is conducting a year's worth of energy monitoring. The home is being used as a demonstration home while monitoring is going on, with displays of energy-efficient technologies set up in the garage.

Cobblestone has partnered with DOW and other building science researchers on previous homes. Cobblestone attempts to collect data every three years on each house they have built. They take the unusual step of offering a contest to their homeowners. Homeowners are asked to submit 12 months of energy bills. Cobblestone analyzes the bills and the homeowner who beats their estimated usage by the most wins $3,000 or a trip to Disneyland. "This contest allows us to verify after-occupancy performance," said Melissa.

More than 5,000 people toured Cobblestone's previous DOE Builders Challenge home. Over 400 people have already toured the DOE Zero Energy Ready Home between May and July 2014, including prospective homeowners, members of the media, realtors, college students in construction programs, other builders, vendors, boy scout troops, and interested members of the community.

Visitors to the home will notice the home's numerous double-pane, argon-filled, PVC-framed windows. They probably won't notice the windows' low-emissivity coatings, which minimize the amount of heat transferring through the glass. They are sure to notice the eye-catching modern folk art lighting fixtures. They may not know that they use 100% high-efficiency light sources, either LED or compact fluorescent lamps. And they may not suspect that each of the home's four ceiling fans are ENERGY STAR rated, as are the refrigerator and dishwasher.

Another barely visible but highly notable feature is the 1.4 kWs of photovoltaic (PV) roof tiles. The PV tiles are made of a flexible material that has the same dimensions and thickness as asphalt shingles. Rather than sit-on-top panels, the tiles are integrated with the shingles as part of the roofing layer. The home's roof structure and orientation on the lot were designed to allow room for up to 891 ft² of PV tiles and/or of solar thermal water heating panels should a solar water heating system be desired in the future.



The home's walls are filled with 2.5 inches of closed-cell spray foam, which provides exceptional insulating, air sealing, and sound-proofing qualities. Under the home's vinyl siding, an additional inch of rigid foam insulation is installed over the home's OSB exterior wall sheathing. The rigid foam has a vertically grooved surface to direct any rainwater that gets behind the siding down and out of the wall.

The plumbing fixtures in the kitchen and bathrooms are all compliant with the EPA WaterSense program's strict criteria for water efficiency. A button on the bathroom wall triggers a recirculation pump to ensure you won't wait more than 30 seconds for hot water at the tap.

The home's 96% efficient gas furnace and 2.5-ton 13 SEER air conditioner with variable-speed ECM motor are located in the basement. The furnace and water heater are sealed combustion, direct-vent appliances for safe, efficient operation.

Some of the most impressive energy-efficiency features of the home are the ones visitors never see. Beneath the 9-foot poured concrete foundation walls, the footings were covered with a painted-on water seal product to form a capillary break. The concrete walls were water-proofed on the exterior and then covered with a 1-in. vertically grooved moisture-resistant extruded polystyrene rigid foam, which serves as both a drainage board and insulation layer. The interior of the basement walls was insulated with the same 1-in. foam board to provide a total basement wall R-value of R-11.5. This board aids in directing water down to the perimeter drain tiles located both inside and outside of the foundation so that water can be directed away from the structure.

Cobblestone Homes would typically install 2 inches of rigid foam on the outside of the foundation wall and no foam on the inside in new construction, but they chose to put 1 inch on either side in the model home to show visiting remodelers the interior installation option. Cobblestone selected a foam product that does not require a "thermal break" ignition barrier. Most foam insulations must be covered with an ignition barrier like drywall because they can burn or melt when exposed to flame.

If visitors could peek into the above-grade walls, they would see that the 2x4 16 inch on center stud-framed exterior walls have 1 inch of XPS rigid foam installed over the OSB exterior wall sheathing. All of the seams in the foam are sealed with tape to form a water-tight barrier so house wrap is not needed, which saves the builder time and money. Cobblestone uses a felt paper house wrap and plastic mesh rain screen only on those portions of the exterior walls where brick and stone will be installed. The wall cavities are then insulated from the inside with 2.5+ inches of closed-cell polyurethane spray foam. The spray foam provides insulation, air sealing, and strength to the walls, which Cobblestone feels can help the home resist high winds. The wall framing is nailed and glued together with two beads of construction adhesive or caulk at every wood-to-wood joint.

HOME CERTIFICATIONS

DOE Zero Energy Ready Home Program

ENERGY STAR Certified Homes Version 3.0

EPA Indoor airPLUS

EPA WaterSense

ENERGY STAR

Building America U.S. Department of Energy

Every DOE Zero Energy Ready Home combines a building science baseline specified by ENERGY STAR Certified Homes with advanced technologies and practices from DOE's Building America research program.

A foam sill seal stops moisture transmission between the foundation wall and the bottom plate. Cobblestone also employs an airtight drywall approach, applying a bead of construction adhesive under the drywall at all studs.

Because Cobblestone installed the HVAC equipment and ducts in the basement, they chose a vented attic where insulation is installed on the ceiling plane. Cobblestone designs their attics with a raised-heel truss so that there is more height at the eaves to pile more insulation over the tops of the walls. First, closed-cell polyurethane foam is sprayed into the eaves to air seal and insulate the space above the outer-wall top plates from the ceiling deck to the attic ventilation baffles. Then 15 to 16 inches of blown cellulose is piled onto the flat portion of the attic deck for an attic R-value of R-49.

The spray-foamed walls, top plate, and sill plate and additional air sealing of any holes through the ceiling provide for a very airtight building shell. Blower door testing showed the home had 1.65 air changes per hour at 50 Pascals of pressure difference, far below the 7 ACH 50 limit for whole-house air leakage set by the 2009 International Energy Conservation Code (IECC). To ensure that the home has fresh, healthy indoor air, an energy recovery ventilator (ERV) was installed in the basement. The ERV has ducts to bring fresh air in from outside and to exhaust stale air to the outside. The air streams cross in a heat exchanger that allows the warmer air path to transfer heat to the cooler path. The incoming air is routed to the HVAC system's central air handler for distribution through the home.

Melissa points to air sealing as an area that challenged Cobblestone's crews to improve their technique over the years. HVAC was another area where Cobblestone pushed for improvement. "Our HVAC contractor really fought us on heating and cooling equipment sizing. They said 'we've never put in a furnace that small.' We had to put in their contract that we would pay them to change out the furnace if there were any comfort issues. Now they are firm believers in what we are doing but it's taken 7 years."

Cobblestone enjoys the challenge of continuous improvement, which is one reason they were eager to try a DOE Zero Energy Ready Home. "We are always looking for something to push us," said Melissa. Cobblestone's comprehensive system of quality checks helps to ensure that new practices will be implemented successfully. Cobblestone goes beyond the thermal by-pass checklists. The project management team inspects daily with more formal inspections done at framing, insulation, drywall, rough in, finish mechanicals, and at the end of construction on fit and finish materials. "We meet twice a week to discuss schedule and improvement opportunities for process, production, and material usage," said Melissa.

During the construction process, homeowners participate in various home construction tours – two of which are strictly to educate the homebuyer on Cobblestone's building practices and on the care and maintenance of high-performance homes. "These formal tours give our homeowners a true understanding of their new home's exceptional construction quality," said Melissa. "They often share this experience with friends and colleagues. The majority of our business comes from these referrals!"

Photos courtesy of Cobblestone Homes.

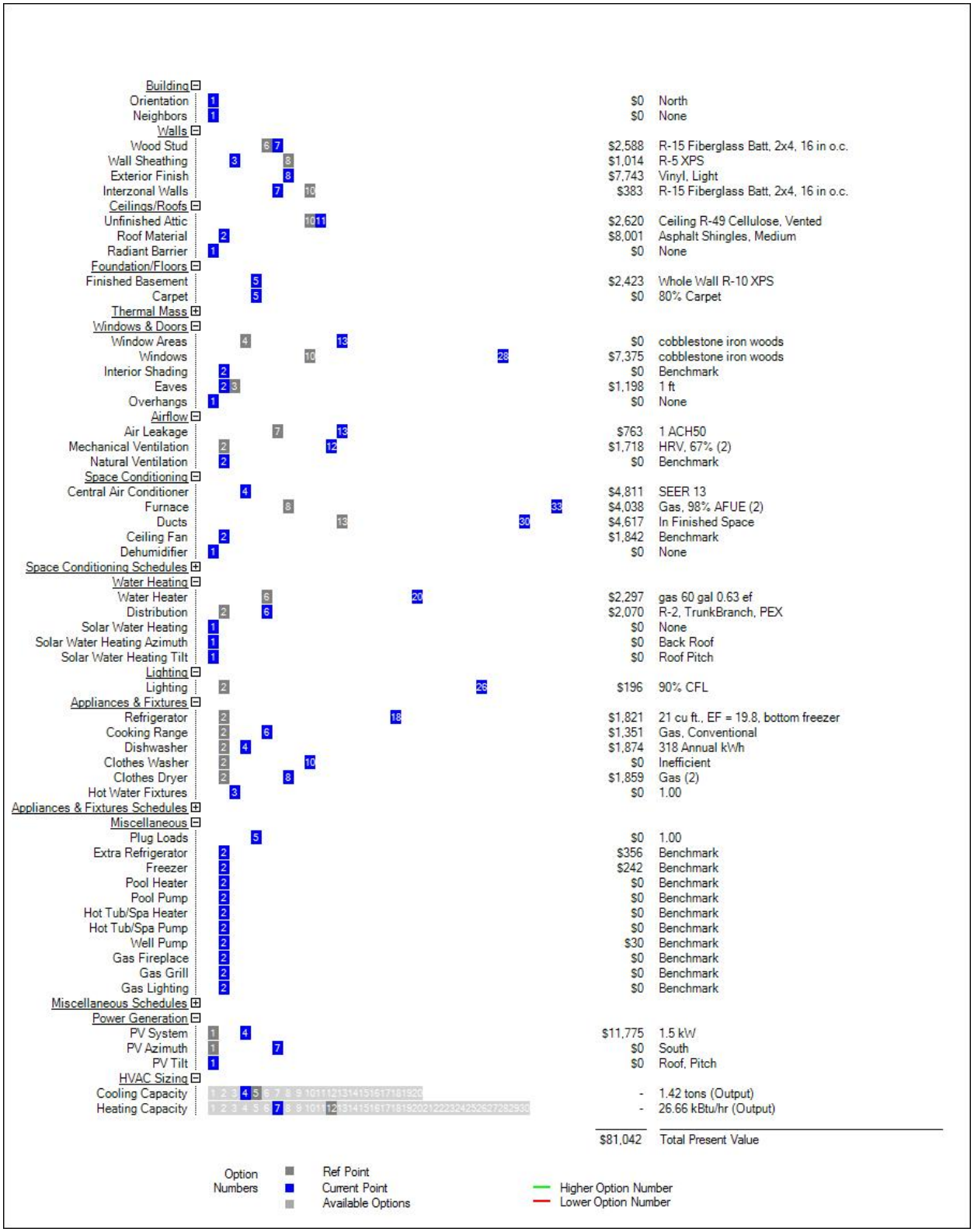
KEY FEATURES

- **DOE Zero Energy Ready Home Path:** Performance
- **Walls:** 2x4 16-inch o.c. framing, 2.5 inches (R-12) closed-cell spray-foam cavity insulation; 1-in. taped, grooved XPS rigid foam over OSB sheathing
- **Roof:** Vented attic, raised heel trusses with closed-cell spray foam over top plate from ceiling deck to baffles, 15-in. blown cellulose
- **Foundation:** Poured concrete basement walls insulated on inside and outside with taped, grooved XPS rigid foam; waterproofing on exterior under rigid foam and separating footing from walls. 1-in. XPS rigid foam under the basement slab
- **Windows:** Double-pane, argon-filled, low-e, PVC-framed. U=0.28, SHGC=0.28
- **Air Sealing:** 1.65 ACH 50
- **Ventilation:** ERV connected to central HVAC
- **HVAC:** 96% effic, sealed combustion gas furnace and 2.5-ton 13 SEER AC with ducts in conditioned basement
- **Hot Water:** 60-gal tank water heater in basement, 0.63 EF, recirc loop, PEX piping
- **Lighting:** 100% LED and CFL
- **Appliances:** ENERGY STAR-rated dishwasher, refrigerator, four ceiling fans
- **Solar:** 1.44-kW roof-integrated PV shingles; conduit installed and roof designed with optimal orientation for solar thermal panels and additional PV panels
- **Water Conservation:** EPA WaterSense showerheads, faucets, toilets

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

For more information on the **DOE Zero Energy Ready Home** program go to http://energy.gov/eere/buildings/zero-energy-ready-home
PNNL-SA-105444 September 2014

Appendix P: Cobblestone Homes—Midland, Michigan, Project BEopt Inputs



Appendix Q: Morrissey Builders—Lake Elmo, Minnesota, Project Preliminary HERS Reports

Home Energy Rating Certificate

Property
Tom and Mary Florence Brink
4719 Olson Lake Trail North
Lake Elmoe, MN 55042

HERS
Rating Type: Projected Rating
Rating Date: 10/12/2014
Registry ID:

Certified Energy Rater: Rick Cobbs
Rating Number:

Projected Rating: Based on Plans - Field Confirmation Required.

HERS Index: 9

General Information

Conditioned Area	2930 sq. ft.	House Type	Single-family detached
Conditioned Volume	34503 cubic ft.	Foundation	Conditioned basement
Bedrooms	3		

Mechanical Systems Features

Air-source heat pump:	Electric, Htg: 10.0 HSPF. Clg: 19.3 SEER.
Water Heating:	Heat pump, Electric, 2.75 EF, 50.0 Gal.
Duct Leakage to Outside	0.00 CFM25.
Ventilation System	Balanced: HRV, 80 cfm, 98.0 watts.
Programmable Thermostat	Heat=Yes; Cool=Yes

Building Shell Features

Ceiling Flat	NA	Slab	R-41.0 Edge, R-30.0 Under
Sealed Attic	NA	Exposed Floor	NA
Vaulted Ceiling	R-75.2	Window Type	U-Value: 0.180, SHGC: 0.330
Above Grade Walls	R-40.8	Infiltration Rate	Htg: 1.00 Clg: 1.00 ACH50
Foundation Walls	R-32.1	Method	Blower door test

Lights and Appliance Features

Percent Interior Lighting	100.00	Range/Oven Fuel	Natural gas
Percent Garage Lighting	100.00	Clothes Dryer Fuel	Electric
Refrigerator (kWh/yr)	900	Clothes Dryer EF	3.01
Dishwasher Energy Factor	0.77	Ceiling Fan (cfm/Watt)	0.00

Estimated Annual Energy Cost

Use	MMBtu	Cost	Percent
Heating	20.9	$522	108%
Cooling	6.7	$70	14%
Hot Water	3.9	$123	25%
Lights/Appliances	26.7	$718	148%
Photovoltaics	-37.1	$-1087	-225%
Service Charges		$138	29%
Total	**21.1**	**$484**	**100%**

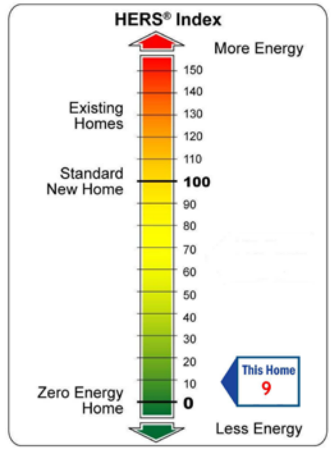
Criteria

This home meets or exceeds the minimum criteria for the following:

Building Knowledge
PO Box 1376
Burnsville, MN 55337
952-944-5605
www.buildingknowledge.com

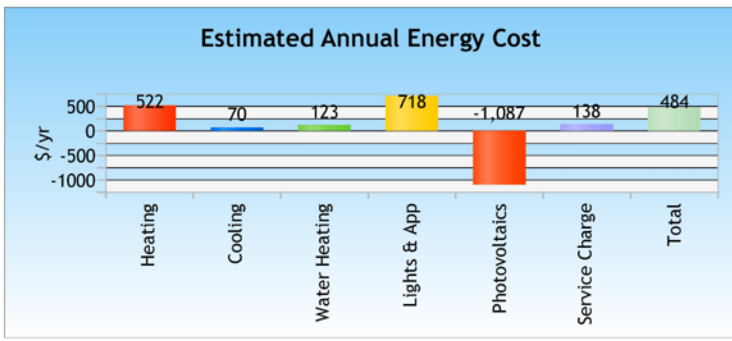
REM/Rate - Residential Energy Analysis and Rating Software v14.6.1

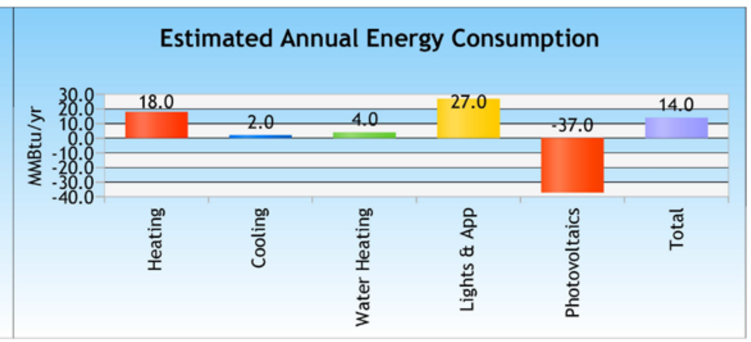
HERS PERFORMANCE



ENERGY RATING CERTIFICATE

Projected Rating: Based on Plans - Field Confirmation Required.





Address	4719 Olson Lake Trail North Lake Elmoe, MN 55042
House Type	Single-family detached
Cond. Area	2930 sq. ft.
Rating No.	
Issue Date	August 07, 2015
Certification	Verified

Annual Estimates*
Electric(kWh): 3199
Natural gas(Therms): 31
C02 emissions(Tons): 2
Annual Savings**: $4837

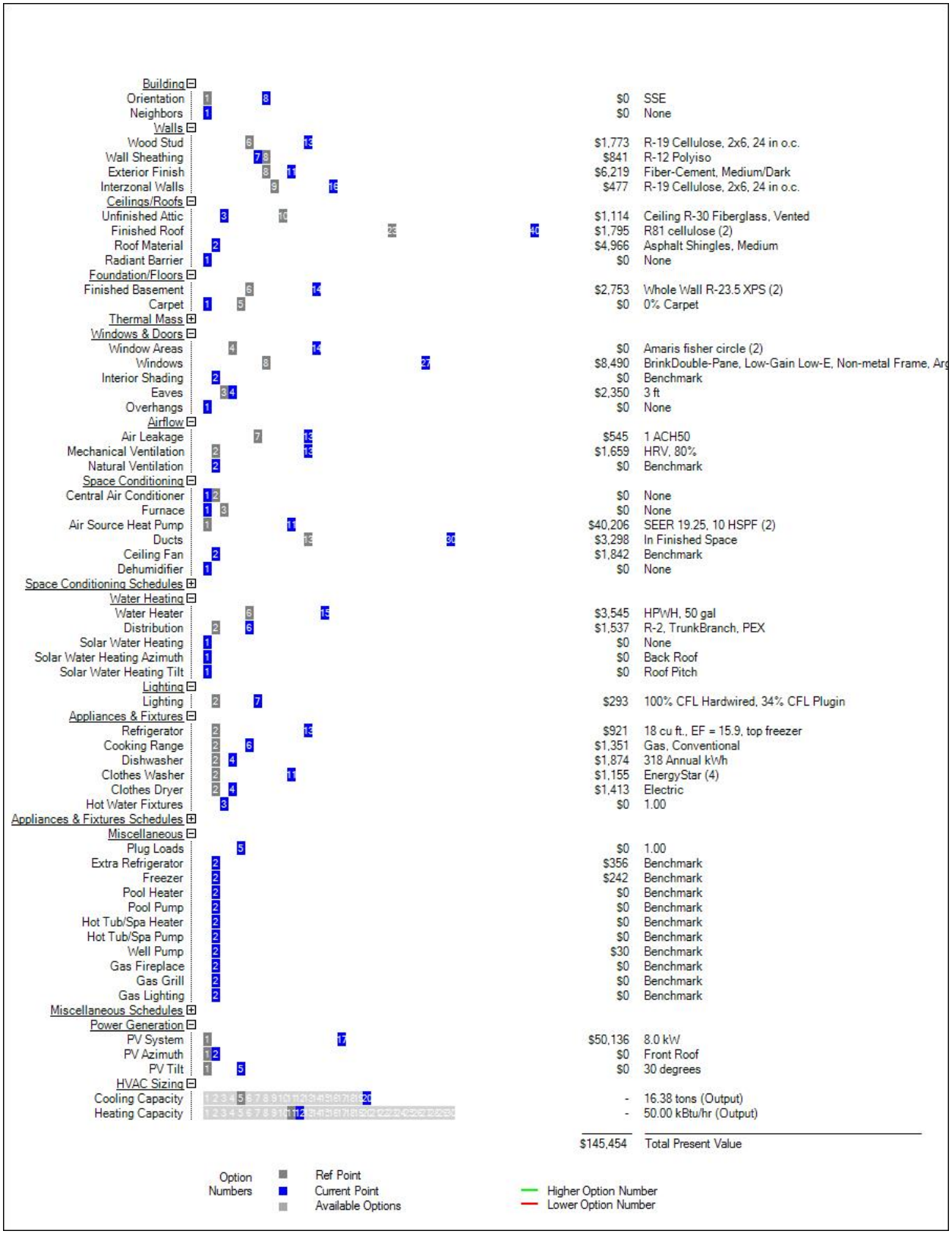
Building Knowledge PO Box 1376	
Certified Rater	Rick Cobbs
Rater ID	6167570
Registry ID	
Rating Date	10/12/2014

* Based on standard operating conditions
** Based on a HERS 130 Index Home

REM/Rate - Residential Energy Analysis and Rating Software v14.6.1

This information does not constitute any warranty of energy cost or savings. © 1985-2015 Noresco, Boulder, Colorado.
The Home Energy Rating Standard Disclosure for this home is available from the rating provider.

Appendix R: Morrissey Builders—Lake Elmo, Minnesota, Project BEopt Inputs



Appendix S: Urban Homeworks—North Minneapolis, Minnesota, Project Preliminary HERS Reports

Home Energy Rating Certificate

BUILDING KNOWLEDGE

2822 Bryant Avenue North
Minneapolis, MN 55411

5 Stars Plus
Projected Rating
HERS Index: 41
Efficient Home Comparison: 59% Better

Projected Rating: Based on Plans - Field Confirmation Required.

Registry ID	
Rating Number	
Certified Energy Rater	Pat O'Malley
Rating Date	9/22/14
Rating Ordered For	

General Information

Conditioned Area	2115 sq. ft.	House Type	Single-family detached
Conditioned Volume	19661 cubic ft.	Foundation	Conditioned basement
Bedrooms	3		

Mechanical Systems Features

Heating:	Fuel-fired air distribution, Natural gas, 96.0 AFUE.
Water Heating:	Conventional, Natural gas, 0.96 EF, 34.0 Gal.
Cooling:	Air conditioner, Electric, 13.0 SEER.
Duct Leakage to Outside	3.19 CFM25.
Ventilation System	Balanced: HRV, 65 cfm, 65.0 watts.
Programmable Thermostat	Heat=Yes; Cool=Yes

Building Shell Features

Ceiling Flat	R-75.0	Slab	R-0.0 Edge, R-10.0 Under
Sealed Attic	NA	Exposed Floor	R-55.0
Vaulted Ceiling	NA	Window Type	U-Value: 0.270, SHGC: 0.180
Above Grade Walls	R-25.0	Infiltration Rate	Htg: 725 Clg: 725 CFM50
Foundation Walls	R-20.0	Method	Blower door test

Lights and Appliance Features

Percent Interior Lighting	100.00	Range/Oven Fuel	Natural gas
Percent Garage Lighting	0.00	Clothes Dryer Fuel	Electric
Refrigerator (kWh/yr)	475.00	Clothes Dryer EF	2.67
Dishwasher Energy Factor	0.00	Ceiling Fan (cfm/Watt)	0.00

Estimated Annual Energy Cost

Use	MMBtu	Cost	Percent
Heating	35.3	$331	26%
Cooling	1.9	$50	4%
Hot Water	11.7	$105	8%
Lights/Appliances	20.7	$500	40%
Photovoltaics	-0.0	$-0	-0%
Service Charges		$264	21%
Total	**69.6**	**$1250**	**100%**

Criteria

This home meets or exceeds the minimum criteria for the following:
EPA ENERGY STAR Version 3 Home
2006 International Energy Conservation Code
2009 International Energy Conservation Code

Building Knowledge, Inc.
PO Box 1376
Burnsville MN 55337
952-944-5605
www.buildingknowledge.com

REM/Rate - Residential Energy Analysis and Rating Software v14.5.1
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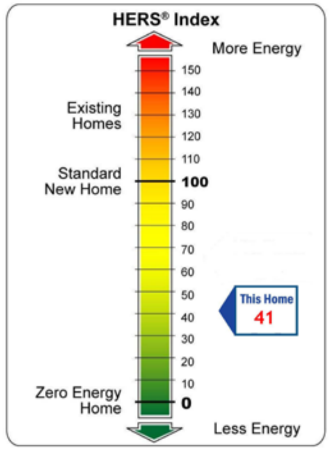
The Home Energy Rating Standard Disclosure for this home is available from the rating provider.

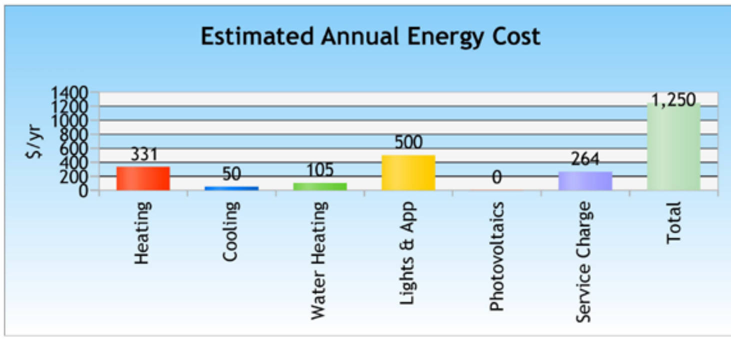
HERS PERFORMANCE

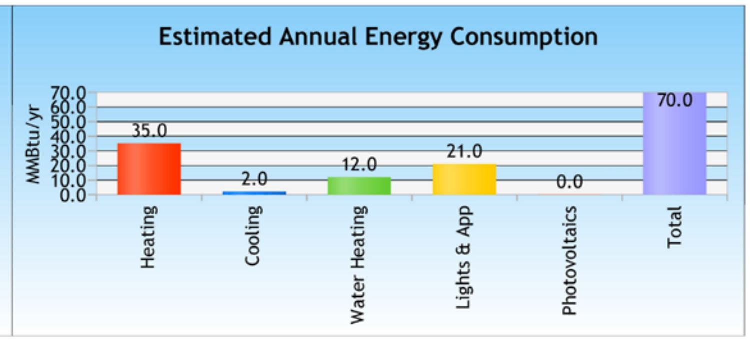


ENERGY RATING CERTIFICATE

BUILDING KNOWLEDGE

Projected Rating: Based on Plans - Field Confirmation Required.





Address	2822 Bryant Avenue North Minneapolis, MN 55411	Annual Estimates*		Building Knowledge, Inc. PO Box 1376
House Type	Single-family detached	Electric(kWh): 5950	Certified Rater	Pat O'Malley
Cond. Area	2115 sq. ft.	Natural gas(Therms): 492	Rater ID	9377462
Rating No.		C02 emissions(Tons): 7	Registry ID	
Issue Date	September 22, 2014	Annual Savings**: $1560	Rating Date	9/22/14
Certification	Verified			

* Based on standard operating conditions

** Based on a HERS 130 Index Home

REM/Rate - Residential Energy Analysis and Rating Software v14.5.1

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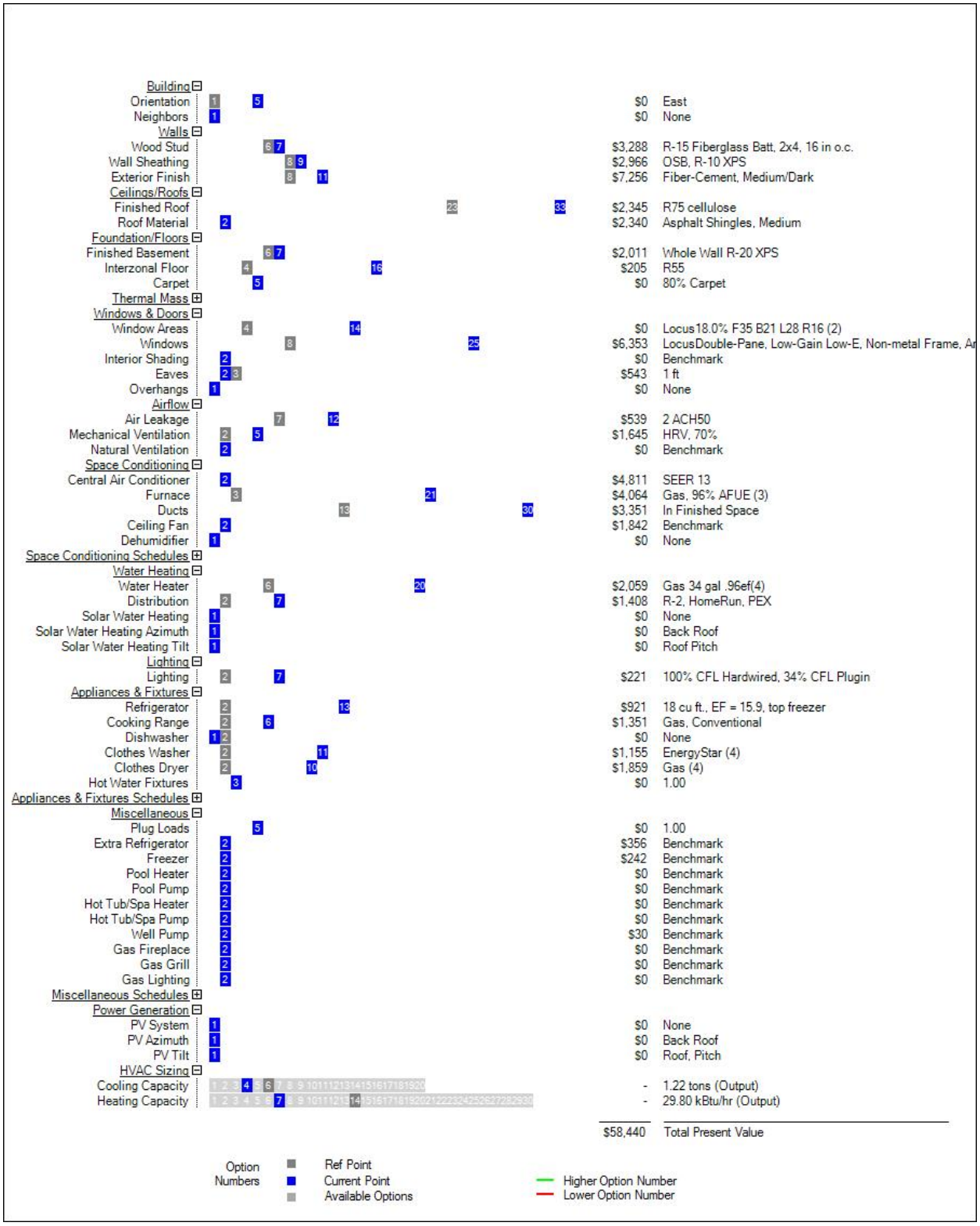
The Home Energy Rating Standard Disclosure for this home is available from the rating provider.

Appendix T: Urban Homeworks—North Minneapolis, Minnesota, Project BEopt Inputs



U.S. DEPARTMENT OF ENERGY

Energy Efficiency & Renewable Energy

For more information, visit buildingamerica.gov

DOE/GO-102017-4802 ▪ July 2017