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Wyoming's total energy consumption per capita is second highest in the nation. This equates to $500 million in residential energy expenditures every year, or approximately 50 trillion Btu. This study investigated the levels of home energy efficiency and potential energy savings throughout Wyoming by focusing on the effectiveness of residential model energy codes and the feasibility of achieving Zero Energy for homes within the state. The residential energy code of focus was the International Energy and Conservation Code (IECC). To address the path to Zero Energy, a case study of the National Institute of Standards and Technology (NIST) Net-Zero Energy Test Facility (NZERTF) was performed.

Adopting the IECC is determined to be beneficial for Wyoming. The major challenge in adopting the IECC throughout the state is accommodating the enforcement of an energy code. The NZERTF is determined to be successful in achieving Zero Energy in a colder climate, yet its high costs limit its effectiveness as a national Zero Energy demonstration home and thus its effectiveness in Wyoming.

MODEL ENERGY CODES AND THE PATH TO ZERO ENERGY FOR WYOMING HOMES

by
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INTRODUCTION

The world's built environment is responsible for 71% of the global greenhouse emissions (Sankaran et al. 2016). In 2014, 41% of the total energy consumption and 72% of the total electricity usage in the United States (U.S.) was attributed to residential and commercial buildings alone (U.S. Energy Information Administration 2015). Appropriately, ongoing investment in energy efficiency throughout the built environment is occurring across the nation. In the residential sector, this is evident in the development of model energy codes and the advancement of building technologies.

Wyoming's total energy consumption per capita is second highest in the nation (SWEEP 2016a). This equates to $500 million in residential energy expenditures every year, or approximately 50 trillion Btu (BCAP 2016). Aside from the quantifiable impacts of low energy efficiency throughout the state, there are also notable qualitative impacts which are incurred. For example, in a recent residential energy consumption survey conducted throughout the region, nearly half of all households reported a home that was too drafty during the winter (SWEEP 2016a).

This study investigates the levels of home energy efficiency and potential energy savings throughout Wyoming by focusing on the effectiveness of residential model energy codes and the feasibility of Zero Energy homes within the state. The residential energy code of focus is the International Energy and Conservation Code (IECC), due to its widespread use throughout the nation and existing presence in the state. The true effectiveness of adopting the IECC in Wyoming is determined in conclusion. To address the path to Zero Energy for homes in the state, a case study of the National Institute of Standards and Technology (NIST) Net-Zero Energy Test Facility (NZERTF) is used. The conclusions from looking at the NZERTF are twofold: 1) its effectiveness as a Zero Energy residence is evaluated, as is, and 2) the general feasibility of building a Zero Energy home in Wyoming is investigated.

BACKGROUND

The adoption of model energy codes can prove to be arduous depending on the level of building infrastructure in place and, naturally, the willingness of a jurisdiction to adopt. These two variables distill into a number of interacting factors, majorly dependent on context. For similar reasons, the transition of the home marketplace from traditional to one flush with Zero Energy homes is challenging. Nevertheless, both model energy codes and Zero Energy homes are becoming more prevalent throughout the nation.

Residential Model Energy Codes

Residential model energy codes establish and enforce energy efficiency criteria for new and existing homes. Model energy codes in the United States, as recognized today, date back to the early 1970s (Graham 1996). From the 1980s to early 2000s, building energy codes such as the Model Energy Code (renamed IECC in 1998) were minimal, and often saw efficiency improvements of only 1% to 3% per code cycle (DOE n.d.). A much stronger dedication to energy efficiency has been made in the past decade. A large component of this surge is the American Recovery and Reinvestment Act of 2009, which invested over $150 billion in the advancement of the nation’s infrastructure, housing, and clean energy use (American Recovery and Reinvestment Act 2009). It is in these recent years that building energy codes such as the IECC have seen their greatest progress.

Many arguments can be made in favor of building energy codes, including those proposed by the United States Department of Energy (DOE) below. Energy codes (DOE 2011b):

1. Reduce wasteful energy consumption to heat, cool, ventilate and provide hot water for new buildings.
2. Protect the environment by helping decrease unnecessary emissions.
3. Progress in strictness, scope, and enforcement, all of which provide new jobs and opportunities to enhance the skills of the current workforce.
4. Protect homeowners and tenants from long-term financial burdens that can result from short-term design and construction decisions.
5. Provide a common basis upon which to educate the building design and construction community in energy efficiency.
6. Increase the use of energy efficient technologies proven through incentive programs, freeing up resources to focus on new, more efficient additional technologies.
7. Provide a cost-effective step toward mitigating problems associated with growing demand for energy and power resources.
8. Help drive the development and deployment of new building technologies and design strategies.
9. Support energy conservation and efficiency actions beyond minimum code levels.
10. Provide a common foundation for evaluating, regulating, and incentivizing building design, construction, technologies, and performance.

There are also many arguments against the development of energy codes. Foremost, energy codes such as the IECC are developed by private organizations. Inevitable conflicts occur, and will always occur, between code developers and those under the code’s mandate, i.e. builders. The IECC, for example, is strongly supported by the DOE. The DOE is undeniably a leading authority on energy efficiency, yet its role is seen by some to extend beyond the traditional technical advisory role to one that actively, “pushes energy goals…working with states to encourage adoption and enforcement” (NAHB n.d.). In the past, federal funding has been issued as an incentive to adopt the newest code. Many within the building industry argue that such funding would be more effective if directed toward assisting states in actual code implementation, including, “training code officials and aiding compliance/enforcement efforts” (NAHB n.d.). Even further, there is concern from builders regarding the product neutrality of codes. As an example, rigid foam sheathing, whether extruded polystyrene (XPS), expanded polystyrene (EPS), or polyisocyanurate, is favored by codes such as the IECC for colder climate zones due to thermal envelope provisions. This potentially encourages market advantage for foam manufacturers rather than other products (NAHB n.d.). The building industry has pushed for more builder flexibility and "energy-neutral tradeoffs," yet such attempts have been made with limited success (NAHB n.d.). Ultimately, energy codes exist as much more than energy codes, and must be evaluated within context.

The Advancement of Home Building Technology

The understanding of energy use, demands, and the overall design of homes is advancing. A majority of what makes a home efficient are its building materials and systems, which are readily accessible by consumers. A fitting example for the common consumer is light-emitting diode (LED) lighting. Five years ago, LEDs represented less than 3% of the residential lighting market (Cardwell 2013). Although LEDs promised energy efficiency, the combined effect of high costs and the mark of new technology discouraged consumers from purchase. With the progression of technology, LED prices are dropping and market penetration is steadily rising. It is projected that LEDs will reach 36% market share by 2020 and 74% by 2030 (DOE 2012b). Compared to a market with no additional penetration of LEDs, this equates to a lighting energy consumption decrease of approximately 50% nationwide, or enough electricity to power nearly 24 million homes (DOE 2012b).

Other examples of advances in building technology, and particularly pertinent to this study, are photovoltaic (PV) panels and heat pumps. PVs have experienced a similar market history as LEDs, and are becoming more commonplace on U.S. rooftops. Wyoming currently has over 12 solar companies throughout the state, with 9 being contractors/installers for homes. For 2015, 137 kW were produced by the homes in the state, an 89% increase over 2014. Furthermore, the average price of installing a residential solar system is consistently dropping. Nationwide, the average 2015 system was 6% lower than 2014 and 48% lower than the average cost in 2010 (SEIA 2016). This trend in cost reduction is paired with improved product performance. The majority of currently available PVs are in the range of 10-20% power conversion efficiency in real world conditions, yet laboratory tested efficiencies are consistently increasing with research and development (Green et al. 2016).

Similar in improving performance are heat pumps. Heat pumps, “move heat from the cool outdoors into your warm house and during the cooling season, heat pumps move heat from your cool house into the warm outdoors. Because they move heat rather than generate heat, heat pumps can provide equivalent space conditioning at as little as one quarter of the cost of operating conventional heating or cooling appliances” (DOE n.d.). There are three types of heat pump systems: air source, water source, and geothermal. Air source heat pumps, which are addressed in this study, are most common (DOE n.d.). It has been shown that air source heat pump performance can be significantly harmed by cold climates such as in Wyoming, yet products in recent years are retaining 100% efficiency at temperatures as low as 5°F (Brown et al. 2011; Johnson 2013; Stevens et al. 2013). Some manufacturers even claim 80% efficiency down to -25°F (Mitsubishi Electric 2015).

Improving performance and decreasing costs are projected for LEDs, PVs, and air source heat pumps in the coming years. Furthermore, these products can be readily purchased and installed by a homeowner for immediate energy efficiency benefits, whether building a new home or retrofitting an existing.

At the forefront of home building technology are Zero Energy homes, which combine efficient products with performance-oriented design. Zero Energy Buildings (ZEBs) produce as much energy as they consume on an annual basis. The DOE promotes ZEBs as having the following long-term advantages: “lower environmental impacts, lower operating and maintenance costs, better resiliency to power outages and natural disasters, and improved energy security" (Peterson et al. 2015, 4). Furthermore, there is the potential to improve the general state of comfort for occupants, which is affected by many of the building aspects in which ZEBs are advanced, i.e. a well-insulated thermal envelope. This is particularly important in cold climates such as Wyoming.

ZEBs represent a major market opportunity for the entire construction industry (Sankaran et al. 2015). In a recent survey conducted by the Net-Zero Energy Coalition, the number of residential buildings on the path to Zero Energy was inventoried throughout the United States and Canada. The inventory categories are as follows: Zero Energy Ready, which can supply 90% or more of the annual energy demand (or could, if/when renewable energy is added or system capacity is increased); Zero Energy, which supplies 100% or more of the annual energy demand; Net Producer, which supplies 110% or more of the annual energy demand; and the Thousand Home Challenge (retrofit), which entails deep energy reduction projects in existing homes, whether or not they include renewable energy (Sankaran et al. 2016). As of January 2016, the number of Zero Energy residential buildings in the United States was equivalent to nearly 1% of the total 2014 U.S. housing starts (Sankaran et al. 2016).

There are still challenges hindering the growth of residential Zero Energy, and specifically single-family homes (Sankaran et al. 2016). Zero Energy began primarily as an experimental goal for custom single-family homes outside of the reach of a typical American family (Sankaran et al. 2016). Consequently, there still exists consumer skepticism concerning cost, performance, and overall livability. Wyoming and the greater Rocky Mountain region, however, are especially hospitable to Zero Energy houses due to low cooling loads, the effectiveness of good insulation in reducing heating loads, and the excellent availability of solar energy (Soltaniehha et. al. 2012). Furthermore, Zero Energy houses have been successfully marketed in the region, exemplified by the masterplan *Stapleton Community* in northern Colorado, which provides homeowners with Zero Energy Ready housing options (Stapleton 2016). Furthermore, many Zero Energy home prototypes for Wyoming have been successfully developed (Gardzelewski and Denzer 2015).

CHAPTER 1: MODEL ENERGY CODES FOR WYOMING HOMES

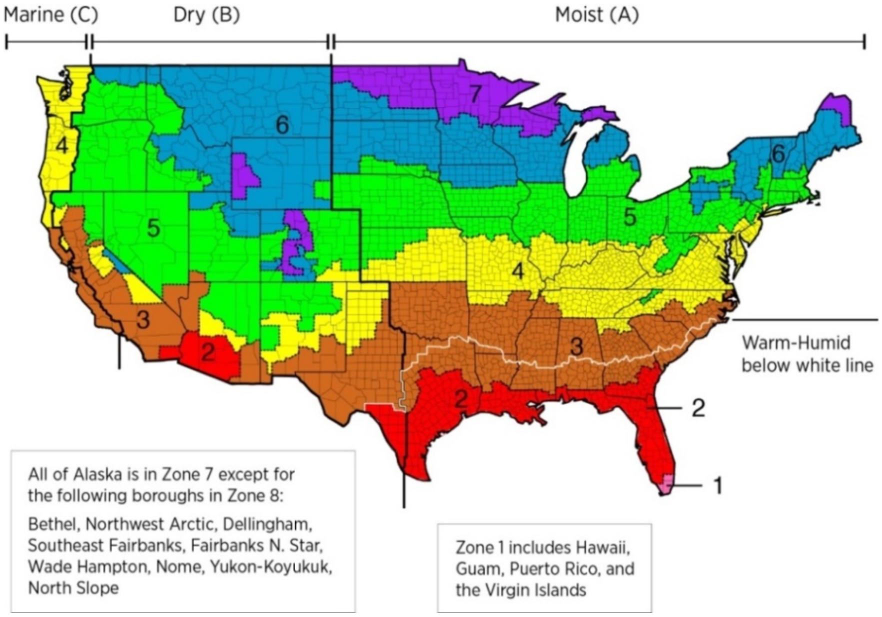
Wyoming does not enforce a statewide residential energy code. Rather, it is a "home rule" state, deeming code adoption voluntary by each local jurisdiction (SWEEP 2016b). The only energy provisions which exist at the state level are contained in Appendix Chapter 53 of the 1991 Uniform Building Code, which references the 1989 Model Energy Code (BCAP 2016). Modern building technologies unarguably exceed these energy provisions in terms of efficiency. This warrants an evaluation of implementing current model energy codes for the state. Of the model energy codes enforced throughout the nation, the IECC is most common. Furthermore, it is currently active throughout Wyoming. Therefore, the IECC is the model energy code of focus in this study.

International Energy Conservation Code (IECC)

First introduced in 1998 and updated every three years, the IECC focuses on energy efficiency through cost savings, consumption reduction, and environmental conservation for commercial and residential buildings (ICC 2016). It aims to accomplish these goals through efficient thermal envelope design, mechanical systems, lighting systems, and the implementation of new construction materials and methods (Energy Star 2016). In addition to residential and commercial buildings, the IECC now encompasses building sites, systems, and equipment, including pools, exterior lighting, equipment buildings, and on-site renewables (Mozingo 2016).

The IECC is published by the non-profit International Code Council (ICC), which also produces various other building codes within the compatible International Code "family," including the International Residential Code (IRC), International Fire Code (IFC), International Building Code (IBC), and International Plumbing, Mechanical, Fuel Gas (PMG) codes (ICC 2016). The various codes within the International Code family are designed to work cooperatively rather than competitively. Therefore, although the IECC is the dedicated energy code, other codes such as the IRC contain energy provisions referenced from the IECC. Relevant to this study is the IECC Residential, which includes, "detached one and two family dwellings and multiple single-family dwellings (townhouses) as well as Group R-2, R-3 and R-4 buildings three stories or less in height above grade plane" (Mozingo 2016). This study looks specifically at new, detached single-family dwellings.

Essential to the IECC is climate zone distinction. For each region of the U.S., IECC requirements adjust according to the unique historical climate characteristics of the area (Figure 1). The separation of climate zones influences how the IECC is developed.



All of Alaska is in Zone 7 except for the following boroughs in Zone 8:

Bethel, Northwest Arctic, Dellingham, Southeast Fairbanks, Fairbanks N. Star, Wade Hampton, Nome, Yukon-Koyukuk, North Slope

Zone 1 includes Hawaii, Guam, Puerto Rico, and the Virgin Islands

Figure 1. IECC Climate Zones (DOE 2012a).

IECC Development

IECC development begins at the national level through, “national industry consensus processes with input from industry representatives, trade organizations, government officials, and the general public” (Williams 2014). Throughout the development process, the DOE not only supports the IECC, but is required by statute to publicly release a determination of whether updated/revised codes will result in increased energy savings (Williams 2014). Consequently, during the development of the IECC the DOE evaluates energy and cost savings with easily reproduced methodologies, and discloses code proposals and associated information to stakeholders for feedback (Williams 2014). Collectively, this information is used to inform jurisdictions’ decision to adopt updated codes.

With each iteration, the IECC undergoes numerous proposals and amendments. This restructuring, however, is not always quantifiable in terms of energy consumption and costs. As an example, the update process from IECC 2012 to IECC 2015 is examined. Similar to all code updates, many proposals were made for IECC 2015, yet the number of proposed changes does not correlate to a measurable improvement in energy efficiency:

> Of the 76 code change proposals approved for inclusion in the 2015 IECC: 6 were considered beneficial, 62 were considered neutral, 5 were considered negligible, 2 were considered detrimental, and 1 was considered to have an unquantifiable impact…A significant majority of approved residential proposals have no direct impact on residential energy efficiency. Most such proposals involve clarifications to the code, improvements in the code’s usability and/or consistency with itself or other ICC codes, corrections to inadvertent errors in the code text or wording, addition of options or minor extensions to existing options that increase flexibility for users, updates to references, or requirements for additional documentation in compliance submittals by builders (Mendon et. al 2015a, iii).

IECC Adoption

Once an IECC version is fully developed, it moves to state and local governments to be adopted, and often in an “amended” form. In Wyoming, proposed changes to the state energy code are submitted to the Wyoming Department of Fire Prevention and Electrical Safety (DFPES). Upon review of such proposals, the DFPES then submits recommendations to the state Building Codes Council, which determines approval. Adoption within local jurisdictions is then required for the code revisions to be enforced (DOE 2015).

Throughout the nation many states and local jurisdictions have adopted the IECC, or at least have adopted efficiency measures equal to or greater than the IECC (Figure 2).

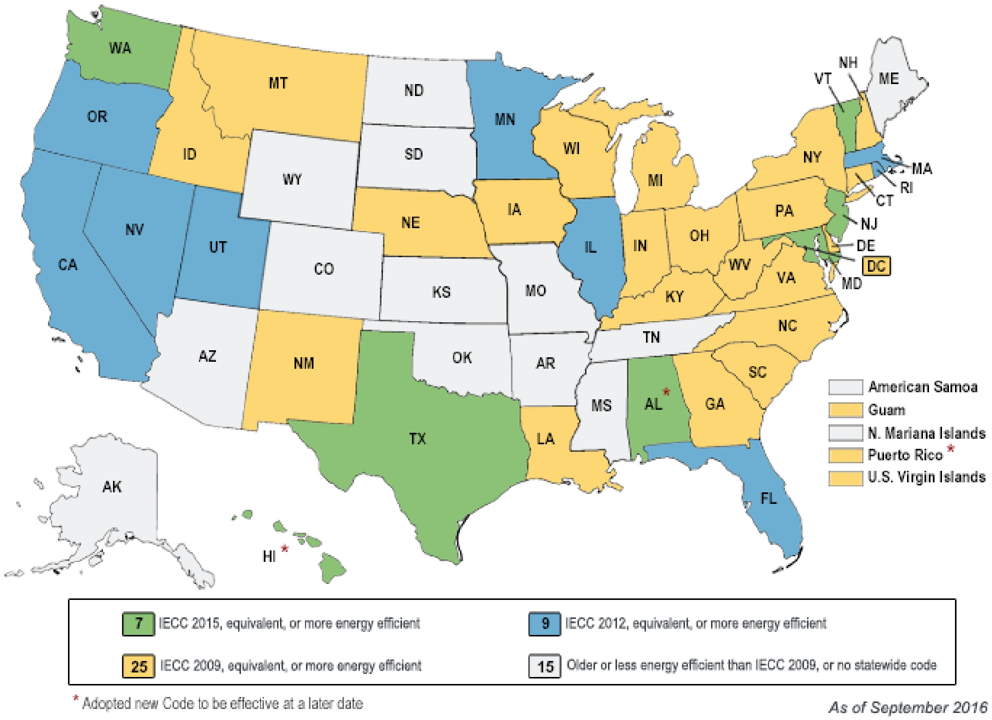


Figure 2. U.S. IECC Adoption Status (DOE 2016).

There are no immediately apparent adoption trends throughout the nation, such as consistency throughout a climate zone. IECC adoption is as much of a political decision as it is an energy efficiency choice. Therefore, each state must be evaluated independently when investigating the motives behind adoption.

IECC Compliance

Once adopted, it is the responsibility of local governments and educated code officials to enforce compliance on behalf of architects, engineers, builders, etc. (Williams 2014). However, “even when a code is adopted by a state or municipality, code provisions often remain unenforced” (Holladay 2016b). Compliance with the IECC is vital in seeing the energy and cost savings as intended, and the process has evolved throughout the code’s lifetime. With each iteration, the IECC looks to reaffirm three fundamental intents (Mozingo 2016):

1. Regulate the design and construction of buildings for the effective use and conservation of energy over its lifetime.
2. Provide flexibility to permit the use of innovative approaches and techniques to achieve this objective.
3. The IECC is not meant to abridge safety, health or environmental requirements contained in other applicable codes or ordinances.

Executing these intents varies from state to state, as well as from jurisdiction to jurisdiction. Common procedures include: reviewing building plans and specifications; evaluating specifications of products, materials, and equipment; reviewing energy assessments and certifications; reviewing energy calculations; and on-site inspection preceding occupancy (DOE 2014).

For architects, engineers, builders, etc., meeting compliance can be achieved through a variety of methods. Currently, the IECC allows the following compliance paths:

1. Prescriptive
2. U-factor alternative/Total UA alternative
3. Simulated Performance
4. Energy Rating Index (ERI)

In addition to these compliance options, mandatory IECC requirements must always be met, which include whole house pressure tests, lighting requirements, and a programmable thermostat (Mozingo 2016).

The prescriptive compliance path requires the building thermal envelope to meet minimum requirements established by the IECC based on climate zone. For compliance, the following must be documented: path declaration; fulfillment of thermal envelope requirements; and a description of how mandatory items will be met, including air barrier and insulation requirements, system control requirements, and lighting equipment requirements (Mozingo 2016). The IECC is structured in that the thermal envelope requirements hold the greatest influence over energy consumption and cost effects. For homes in colder climate zones such as Wyoming, this is particularly true. The most dramatic changes in thermal envelope requirements in the past decade occurred in the transition from IECC 2009 to 2012 (Table 1).

Table 1. IECC Thermal Envelope Prescriptive Requirements in Wyoming (DOE 2006, 2011b; Schwarz and Byers 2015).

Climate Zone	Year	Window U-Factor	Window SHGC	Ceiling R-Value	Wood Framed Wall R-Value	Mass Wall R-Value	Floor R-Value	Basement Wall R-Value	Slab R-Value and Depth (ft.)	Crawl Space Wall R-Value	Air Leakage (ACH50)
5	2006	0.35	NR	38	19 or 13+5	13	30	10/13	10, 2	10/13	-
	2009	0.35	NR	38	20 or 13+5	13/17	30	10/13	10, 2	10/13	7
	2012	0.32	NR	49	20 or 13+5	13/17	30	15/19	10, 2	15/19	3
	2015	0.32	NR	49	20 or 13+5	13/17	30	15/19	10, 2	15/19	3
6	2006	0.35	NR	49	19 or 13+5	15	30	10/13	10, 4	10/13	-
	2009	0.35	NR	49	20 or 13+5	15/20	30	15/19	10, 4	10/13	7
	2012	0.32	NR	49	20+5 or 13+10	15/20	30	15/19	10, 4	15/19	3
	2015	0.32	NR	49	20+5 or 13+10	15/20	30	15/19	10, 4	15/19	3
7	2006	0.35	NR	49	21	19	30	10/13	10, 4	10/13	-
	2009	0.35	NR	49	21	19/21	38	15/19	10, 4	10/13	7
	2012	0.32	NR	49	20+5 or 13+10	19/21	38	15/19	10, 4	15/19	3
	2015	0.32	NR	49	20+5 or 13+10	19/21	38	15/19	10, 4	15/19	3

R-values (ft^2-FBtu/h) are minimums, U-values (Btu/hft^2-F) are maximums
"X+Y" means R-X cavity + R-Y continuous
X/Y means R-X continuous or R-Y cavity

For builders, there are a number of resulting construction implications with increasingly rigorous thermal envelope requirements. For example, to meet the increasing wall R-values in Wyoming, "most builders will find that the easiest compliance option will be to include R-5 or better foam insulation on the exterior of a 2 x 6 wall, or R-10 or better foam insulation on the exterior of a 2 x 4 wall. To meet R-5, builders will need at least 1.5 inch of EPS, 1 inch of XPS, or ¾ inch of polyisocyanurate. To meet R-10, builders will need at least 3 inches of EPS, 2 inches of XPS, or

1 ½ inches of polyiso" (Holladay 2011). Code accommodating measures such as these quickly add to construction costs. On a national level in climate zones 5, 6, and 7, the thermal envelope requirements of IECC 2012 contributed nearly 50% of the total construction cost increases compared to 2009 (Mendon et al. 2013).

IECC compliance can also be met through a UA trade-off, or U-factor alternative, which allows documenting assembly U-factors equal to or less than the equivalent prescriptive R-values specified. Therefore, a home is in compliance with the IECC if the total thermal envelope UA, or sum of U-factors multiplied by assembly areas, is equal to or less than specified by the code. In this method, unlike the prescriptive, thermal bridging effects of the home's framing materials must also be taken into account (Mozingo 2016). To ensure compliance with this method, the assistance of code compliance software such as REScheck, which simplifies and expedites the process, is recommended.

The simulated performance path for compliance requires a proposed residence, "be shown to have an annual energy cost that is less than or equal to the annual energy cost of a standard reference design" (Mozingo 2016). This performance-based approach is completed through various software tools, such as REM/*Rate* and EnergyGauge, and the analysis results are documented for approval. A list of currently accredited tools is available online (BEST 2016). Within the performance report, the following must be submitted (Mozingo 2016):

1. Residence location.
2. Inspection checklist identifying building component properties. This checklist must show the estimated annual energy cost of both proposed design and code reference design.
3. Name of individual completing the report.
4. Name and version of compliance software.

There is also the option of the ERI compliance path, which is new to IECC 2015. Compliance in this manner requires a proposed design to show an ERI score equal to or less than that prescribed by code. “The ERI score is defined as a numerical score where 100 is equivalent to IECC 2006 and 0 is equivalent to a Zero Energy home. Each integer value on the scale represents a one percent change in the total energy use of the rated design” (RESNET 2016). Therefore, builders have the ability to meet compliance through a variety of performance options, yet must still fulfill mandatory 2009 IECC code requirements such as, “hot water piping provisions... minimum insulation, and window envelope performance requirements” (RESNET 2016). Each state or jurisdiction has the power to determine how the ERI method is enforced. RESNET’s Home Energy Rating System (HERS) is the most common due to its national recognition and use in calculating the energy performance of a home. HERS scores are generally equivalent to ERI scores (Mendon 2014). To date, “over 1.5 million have been rated in the U.S. under the RESNET standards and in 2013, half of all new homes were rated and issued a HERS Index Score” (RESNET 2016). Factors which affect the HERS rating of a home include: efficient mechanical equipment, higher R-values in the thermal envelope than required by the 2009 IECC, house orientation, infiltration below 3ACH50, duct leakage to the outside, duct locations, whole house fans, compact fluorescent lamps (CFL) or LED lighting above 75% efficacy, and high efficiency appliances (Mozingo 2016). Another factor which greatly affects the HERS rating is on-site energy generation, i.e. PVs. A 4 kW PV array has the potential to lower a home’s HERS rating 20 points or more (Dillon 2015). As the IECC is energy conservation oriented, production has not been properly addressed within the code.

The improvement of the IECC is commonly displayed using the ERI for convenience. By looking at the ERI, a consistent reduction of energy consumption over the past decade is promoted by the IECC (Figure 3).

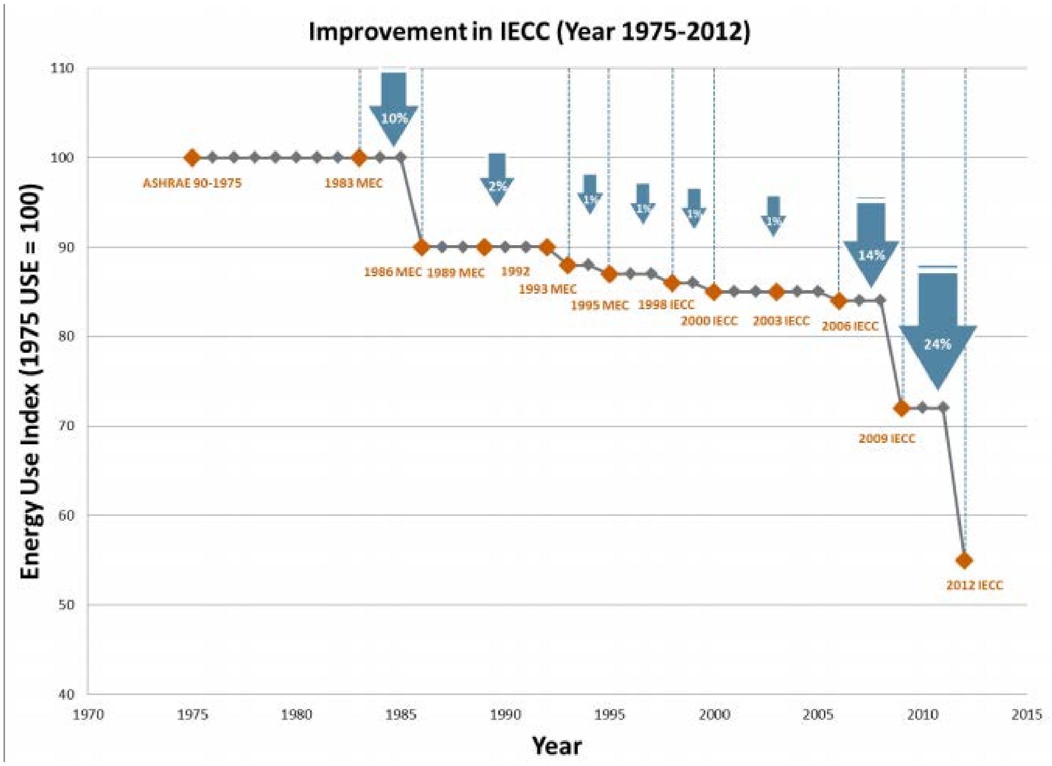


Figure 3. IECC Residential Improvement (Livingston et al. 2014).

When looking at the maximum HERS scores for IECC compliance in Wyoming's climate zones, a similar improvement is promoted (Table 2).

Table 2. ERI Compliance Maximum HERS Scores (RESNET 2016).

Climate Zone	IECC 2009	IECC 2012	IECC 2015
5	82	80	55
6	83	79	54
7	85	78	53

As shown in Figure 3, the transition from IECC 2009 to IECC 2012 is determined to be the most beneficial for average national energy conservation and cost savings. This is due to the significant changes in thermal envelope provisions. For Wyoming's climate zones, maximum HERS scores for compliance indicate the shift from IECC 2012 to IECC 2015 is determined to be most beneficial. This is inconsistent with the code amendments as previously described, and is in part due to the averaging of efficiency improvements over climate zones, arbitrary code mandates to reflect a decreasing trend in energy consumption, and conservative defense against the flexibility of ERI compliance.

Within the Rocky Mountain region, IECC compliance is traditionally met by the prescriptive path (Schwarz and Byers 2015). Therefore, in this study the prescriptive compliance path is the method of focus. More than tradition, however, attempting to evaluate code effects based upon other compliance methods is difficult to accurately recreate. For example, the flexible nature of compliance on behalf of builders if selecting the simulated or ERI path is difficult to quantify.

IECC Adoption in Wyoming

To determine the current state of building energy codes in Wyoming's 123 jurisdictions, a survey was conducted throughout the state. Each county seat's building department was contacted directly or online (Table 3). Although not a comprehensive list of jurisdictions, this survey exhibits the general representation of energy codes throughout the state and its more populated areas. Many jurisdictions have adopted the IRC, which references the IECC, yet commonly amend to exclude energy provisions. Further, many jurisdictions amend the IECC itself, typically in the form of less strict prescriptive values.

For the jurisdictions without an adopted energy code, there is not always an explicit reason given. Foremost, Wyoming is largely rural, and like many rural areas throughout the nation, there are some jurisdictions that have no building codes whatsoever (Holladay 2011). Also influential is the lack of incentive at the local jurisdiction level. For many jurisdictions, local planning and building regulations are long-standing, and there are no complaints.

Table 3. IECC Adoption in Wyoming.

County/ Seat	Energy Code
Albany/Laramie	x/IECC 2012 (amended)
Big Horn/Basin	x/x
Campbell/Gillette	x/IECC 2012 (reference only, amended)
Carbon/Rawlins	x/IECC 2015 (reference only, amended)
Converse/Douglas	x/IECC 2012 (reference only, amended)
Crook/Sundance	x/x
Fremont/Lander	x/IECC 2006 (reference only)
Goshen/Torrington	x/IECC 2006
Hot Springs/Thermopolis	x/IECC 2012 (reference only)
Johnson/Buffalo	x/IECC 2012 (reference only)
Laramie/Cheyenne	x/IECC 2015 (amended)
Lincoln/Kemmerer	x/x
Natrona/Casper	x/IECC 2015 (reference only, amended)
Niobrara/Lusk	x/x
Park/Cody	x/IECC 2015 (reference only, amended)
Platte/Wheatland	x/x
Sheridan/Sheridan	x/IECC 2012 (amended)
Sublette/Pinedale	x/x
Sweetwater/Rock Springs	x/IECC 2015 (reference only, amended)
Teton/Jackson	IECC 2012 (amended)/IECC 2012 (amended)
Uinta/Evanston	x/IECC 2012 (reference only)
Washakie/Worland	x/IECC 2012 (reference only)
Weston/Newcastle	x/IECC 2015 (reference only)

Figure 4. Map of Wyoming (Mapsof.net 2016).

Another reason for limited energy code enforcement is the limitation of personnel, as it is common in Wyoming for building departments to be operated by a small number of people. Code adoption would require the addition of code officials and/or the training of existing personnel to accommodate code enforcement. Such difficulties exist nationwide, and, "unfortunately, in most jurisdictions, most provisions of U.S. energy codes have never been enforced. For the IECC to be meaningful, thousands of local building code officials will need extensive training, and the budgets of thousands of local building departments will need to be substantially increased" (Holladay 2011).

IECC Effectiveness in Wyoming

To assess the effectiveness of the IECC throughout the state, a prototype single-family home provided by the DOE is utilized to simulate energy consumption and savings. This energy simulation model is used for national IECC energy use reduction and cost saving determinations. The DOE has previously determined that at the state level, Wyoming homes perform on an average level equivalent to the 2003 IECC or less (DOE 2015). For purposes of code comparison, this study assumes that new homes in Wyoming jurisdictions which have not adopted a form of the IECC perform on a level equivalent to IECC 2006.

Utilizing DOE provided parameters, the prototype single-family home used is described in general below. Complete simulation parameters are published (Mendon et al. 2015b). IECC year dependent variables, such as the building envelope, change according to code year.

- **Conditioned floor area:** 2,400 ft.^{2} (dependent on foundation system, Figure 5 shows slab-on-grade)
- **Cooling system:** central electric air conditioning (SEER 13)
    - Cooling setpoint = 75°F
- **Domestic hot water (DHW) (thermal efficiency):** electric resistance (0.917), natural gas (0.67)
- **Door area:** 42 ft.^{2}
- **Footprint and height:** 30 ft. x 40 ft., two-story, 8.5 ft. high ceilings

- **Foundation system:** slab-on-grade, heated basement, unheated basement, crawlspace
- **Glazing distribution (window-to-wall ratio):**
  - North – 13.1%
  - South – 13.1%
  - East – 17.5%
  - West – 17.5%
- **Gross exterior wall area:** 2,380 ft.^{2}
- **Heating system options (AFUE 78% / HSPF 7.7):** electric resistance, natural gas furnace, air source heat pump
  - Heating setpoint = 72°F
- **Internal mass:** 8 lb/ft^2
- **Location:** Jackson, WY (Climate Zone 7)
- **Miscellaneous electric loads (MELs):** 7,709 kWh
- **Occupancy:** 3
- **Orientation:** Due south (see Figure 5)
- **Roof slope:** 4/12
- **Ventilation:** 60 CFM Outdoor Air, Continuous

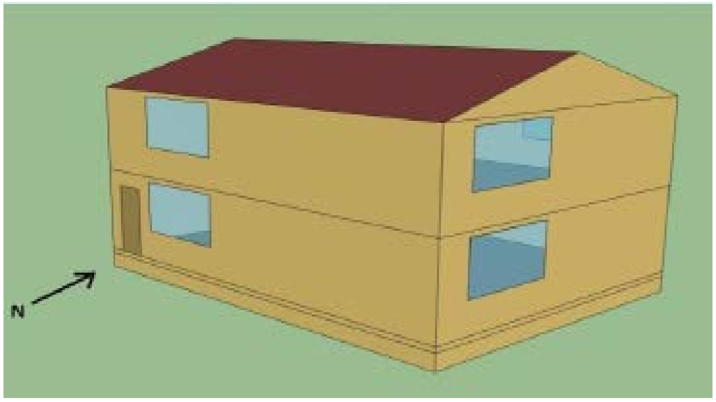


Figure 5. DOE IECC Prototype (Mendon et al. 2015b).

To account for the variability of foundation and heating systems for this prototype home, energy and cost estimation data are aggregated and weighted based upon Wyoming's housing characteristics (Table 4). For new Wyoming homes, natural gas heating and heated basements are most common.

Table 4. New Wyoming Construction Shares (Mendon et al. 2016).

Heating System	Natural Gas	78%
	Heat Pump	19%
	Electric Resistance	3%
Foundation Type	Slab-on-Grade	27%
	Heated Basement	37%
	Unheated Basement	11%
	Crawlspace	26%

Energy simulations for the prototype model were performed through *EnergyPlus* software, and results are exhibited in Table 5.

Table 5. IECC Prototype Average Annual Consumption.

Jackson, WY	Heating System	Heating (kWh)	Cooling (kWh)	Lighting (kWh)	MELs (kWh)	System Fans (kWh)	DHW (kWh)	Total (kWh)	EUI (kWh/ft^2)
IECC 2006	Electric Resistance	27673	614	2025	7709	1305	5022	44348	18
	Natural Gas Furnace	34531	655	2025	7709	1289	7499	53707	22
	Air Source Heat Pump	15997	606	2025	7709	2587	5022	33947	14
IECC 2015	Electric Resistance	16726	637	1448	7709	884	5021	32426	14
	Natural Gas Furnace	20552	689	1448	7709	892	7492	38783	16
	Air Source Heat Pump	10066	639	1448	7709	1694	5021	26577	11

Financial analyses to determine energy and cost savings were completed with the methodology used by the DOE for its IECC determinations. To account for fuel price fluctuations, all fuel prices are adjusted to 2015 DOE data. As shown in Table 6, the shift from IECC 2009 to IECC 2012 is indeed the most dramatic in terms of construction costs. Yet, as shown in Tables 7 and 8, the energy savings from IECC 2012 results in a payback period similar to IECC 2009. This extends to IECC 2015, which results in a payback period of approximately 6 years compared to an IECC 2006 home. There were 1681 housing starts in Wyoming in 2015 (NAHB 2016). If IECC 2015 were adopted statewide, annual energy savings of approximately $1 million could be garnered within the first year through newly built homes.

Table 6. IECC Total Construction Cost Increase ($) in Wyoming (DOE 2012c, Mendon et al. 2016).

Climate Zone	IECC 2009	IECC 2012	IECC 2015
5	832	2294	2319
6	907	3385	3461
7	625	3103	3179
Compared to IECC 2006			

Table 7. IECC Potential Annual Energy Savings ($) in Wyoming (DOE 2012c, Mendon et al. 2016).

Climate Zone	IECC 2009	IECC 2012	IECC 2015
5	123	426	488
6	129	458	493
7	144	540	507
Compared to IECC 2006			

Table 8. IECC Simple Payback Period (Years) in Wyoming (DOE 2012c, Mendon et al. 2016).

Climate Zone	IECC 2009	IECC 2012	IECC 2015
5	6.2	4.9	4.8
6	6.3	6.5	7.0
7	4.2	5.4	6.3
Compared to IECC 2006			

Although simplified, the DOE prototype provides the approximate potential of the IECC in Wyoming, and is a reasonable starting point in evaluating model energy code effects in the state. Nevertheless, the prototype model used for IECC determinations could be improved to more accurately reflect Wyoming home energy use. The DOE prototype model has been used for national IECC determinations since 2006. The only parameters that are altered with each determination are those which provide direct code comparison through simulation. This leads to energy simulations disconnected from reality, particularly for a new home. With this, there is no organized system of home energy data for Wyoming. Therefore, the most recent Residential Energy Consumption Survey (RECS), compiled in 2009, is shown for comparison. Although RECS data is aggregated over a wide region, and is limited to the selected survey homes, it is a realistic starting point to estimate typical home energy use in Wyoming.

RECS 2009 reported an average annual consumption of approximately 31,000 kWh per household for a home within the region of similar size to the IECC prototype, and an average Energy Use Intensity (EUI) of 13 (Table 9). Depending on the heating system, this suggests nearly decade-old homes in a region largely unoccupied by energy codes are competitive in terms of efficiency with IECC 2015. The average home size correlating to these values is approximately 2,130 ft^2, and the associated heating system operates at an efficiency of 0.80 (EIA 2009).

Table 9. RECS West Region 2009 Average Energy Consumption (EIA 2009).

West	Heating (kWh)	Cooling (kWh)	Room Electricity (kWh)	DHW (kWh)	Total (kWh)	EUI (kWh/ft^2)
RECS 2009	14508	821	9936	5891	31155	13
Average ft^2 *= 2130*						

Two energy consumption factors not adjusted for the IECC prototype model are system efficiencies and MELs. In reality, products with higher efficiencies than those assumed by IECC determinations would likely be installed if building a new home. Furthermore, although MELs are difficult to accurately simulate, IECC determinations potentially overestimate user energy habits. The prototype model was therefore modified.

Foremost, based upon the new Wyoming construction shares (Table 4), electric resistance space heating is precluded due to its low popularity. The natural gas furnace efficiency was also modified to reflect the Energy Star requirement for northern climates (Energy Star 2016), and the air source heat pump efficiency was modified based upon recent product tests and manufacturer claims (Brown et al. 2011; Johnson 2013; Mitsubishi Electric 2015; Stevens et al. 2013). A heat pump water heater, based upon currently available products, was also incorporated for use in conjunction with heat pump space heating. There is no standard methodology for estimating

MELs. The unpredictable nature of human habits poses a great challenge for comprehensive whole building energy simulations:

> We have a general knowledge of the types of devices that people have in their homes and how that mix has changed over time, but there is a dearth of empirical data on people's usage patterns of those devices. Detailed field studies to generate statistically meaningful results would be labor intensive and cost prohibitive…Several studies have looked at multiple homes for relatively short durations and found that the energy use between similar homes can vary wildly based on different occupants (Sparn et al. 2016).

MELs were therefore calibrated to reflect an average of Zero Energy home case studies (Sparn et al. 2016; DOE 2011a), NIST occupancy research (Omar and Bashby 2013), RESNET methodology (RESNET 2015), and Passive House Institute US methodology (PHIUS) (Wright and Klingenberg 2015). These values range from 3,870 kWh/year (PHIUS) to 4,837 kWh/year (RESNET), assuming all electric appliances. For this study, MELs are assumed as 4,500 kWh/year. More research in accurately representing MELs for future IECC determinations is recommended.

Below is a summary of the prototype home parameters adjusted to produce the average annual consumption data in Table 10:

- **DHW (coefficient of performance):** heat pump water heater (3.00) for use with heat pump space heating
- **Heating system options (AFUE 0.90 / HSPF 10):** electric resistance (precluded), natural gas furnace, air source heat pump
- **MELs:** 4,500 kWh

Modifying the DOE prototype produces a significant decrease in energy consumption, and ultimately reflects more accurately the potential efficiency of newly built homes. By keeping IECC year dependent variables constant through simulations, direct comparisons of code effects are still possible.

Table 10. Modified IECC Prototype Average Annual Consumption.

Jackson, WY	Heating System	Heating (kWh)	Cooling (kWh)	Lighting (kWh)	MELs (kWh)	System Fans (kWh)	DHW (kWh)	Total (kWh)	EUI (kWh/ft^2)
IECC 2006	Natural Gas Furnace	30748	655	2025	4500	1289	7499	46715	19
	Air Source Heat Pump	9224	606	2025	4500	2587	1674	20617	9
IECC 2015	Natural Gas Furnace	18585	689	1448	4500	892	7492	33606	14
	Air Source Heat Pump	5575	639	1448	4500	1694	1674	15530	6

IECC to Zero Energy in Wyoming

With the updated DOE prototype, solar energy was investigated to evaluate the potential of an IECC home to reach Zero Energy through PVs. Estimations are unique to SunPower SPR-320E-WHT-U PVs (SunPower 2010), and a system cost of 3.09 $/W (Chung et al. 2015). For natural gas heating, DOE Source Energy Conversion Factors are utilized (Peterson 2015). Source energy, “accounts for the energy consumed on-site in addition to the energy consumed during generation and transmission in supplying the energy to a site” (Ueno and Straube 2010). This differs from site energy, which is the metered energy consumption of a building. DOE Source Energy Conversion factors allow for a house to “trade” consumption of a fuel like natural gas for PV production at a converted equivalent, to account for the inefficiencies of imported electricity. The conversion factors for natural gas to PV production are 1.09 : 3.15. This means a home can be Zero Energy by using natural gas and producing about 1/3 of that energy with PV. Propane and wood, which are common heat sources in rural areas of the Rocky Mountain West, have similar values to natural gas. Of course, the additional energy costs for these alternative fuels must be considered.

Table 11 displays the range of PVs needed to offset the various prototype home energy consumptions, dependent on systems installed, and the associated costs of a solar system of that size. The PV model selected (SunPower SPR-320E-WHT-U) has an efficiency of approximately 20%, which is on the upper end of market available products. Based upon energy simulation data, each PV produces approximately 444 kWh per year for the prototype home in Jackson. Building a new home according to the thermal envelope requirements of the IECC and incorporating high efficiency systems would still incur a considerable expense in achieving Zero Energy through PVs alone.

Table 11. IECC to Zero Energy in Wyoming.

Jackson, WY	IECC 2015 - IECC 2006	
	Energy Consumption (kWh)	PVs Needed
Heating	5,575 - 10,639	13 - 24
Cooling	~ 600	2
System Fans	884 - 2,587	2 -6
DHW	1,674 - 2,595	4 - 6
Lighting	1,448 - 2,025	4 - 5
MELs	4,500	11
Total to Zero Energy	14,681 - 22,946	34 - 52
Cost of PV System ($)	33,619 - 51,418	

Alternatively, assuming a new home built outside of energy code enforcement consumes as much as an IECC 2006 home, an equivalent IECC 2015 “efficiency” could be achieved by installing as little as 12 PV panels. Upgrading lighting to match IECC 2015 would eliminate an additional PV panel for a total of 11 PVs. Payback periods for PV systems of this size are currently similar to the average simple payback period associated with adopting the IECC (Bhandari et al. 2015).

Further IECC Prototype Development

Further design refinements to the prototype home, outside of system efficiencies and MELs, are recommended for future IECC exploration in the state. In particular, evaluation of the external glazing is recommended to address passive solar effects. In addition to arbitrary window-to-wall ratios, material properties such as solar heat gain coefficients (SHGC) remain constant as the IECC currently prescribes only U-values for Wyoming’s climate zones.

Although IECC determinations are intended to exhibit the effects of code changes, generic glazing distribution and window properties limit the true efficiency potential of a code home in Wyoming. Ultimately, simulating a newly built code home in Wyoming requires a more comprehensive design approach than the standard DOE methodology. By doing so, it is hypothesized that the gap between the IECC and Zero Energy will narrow.

CHAPTER 2: ZERO ENERGY HOMES IN WYOMING[1]

The lack of Zero Energy homes in Wyoming is largely a result of consumer unawareness and/or skepticism regarding the cost, effectiveness, and overall livability of a Zero Energy home. To address this, and ultimately determine if Zero Energy homes are accessible by an average Wyoming consumer, the NIST House is investigated and then translated to Wyoming.

NIST House

The NIST House – properly called the Net-Zero Energy Residential Test Facility, or NZERTF – was constructed in Gaithersburg, Maryland, in 2012-2013 with the goal of market transformation.

Figure 6. NIST House (NIST 2016).

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[1] CHAPTER 2: ZERO ENERGY HOMES IN WYOMING is being published as, “The NIST House: Technical and Aesthetic Applicability in the Rocky Mountain West,” by Schneider, M., Gardzelewski, J., and A. Denzer. *2017 AEI National Conference*.

It was intended to demonstrate that a house could “look and feel” like a typical American home while achieving Zero Energy (Kneifel 2014, 1). The NIST House has performed well within this objective. With energy savings of up to 60% compared to IECC 2012, it generates about 5% more energy than it consumes while meeting all the needs of a typical family of four. As for all buildings, however, its performance is site-specific. This raises questions about its value as a national demonstration project and applicability to other areas of the nation, such as Wyoming.

The NIST House was designed by Building Science Corporation (BSC), led by Betsy Petit, FAIA. An explicit aim of the NIST House project was to conform to norms of the U.S. housing market. As said by Petit, “the style and size of the house was to be a typical residence that might be built in the local suburban area for a family of four” (Petit et al. 2015, 13). The final design includes a detached garage, conditioned basement, and an interior livable space measuring 2,700 ft^2.

The NIST House features a relatively compact form, and a building envelope which can be characterized as “superinsulated” and “supertight.” Its walls are constructed with advanced framing techniques to reduce thermal bridging and insulated to R-44, while the ceiling is insulated to R-75. These measures are, “nearly two times than called for by the prescriptive 2012 IECC” (Petit et al. 2015, 24). Airtightness was most recently measured to be 0.63 air changes per hour at 50 pascals pressure (0.63ACH50). NIST mechanical engineer Mark Davis says, “the most important difference between this home and a Maryland code-compliant home is the improvement in the thermal envelope – the insulation and air barrier” (Bello 2014). All windows are triple-glazed with a U-factor of 0.2 Btu/hft^2-F. Window-to-wall percentages were determined by orientation to manage heat losses and unwanted solar gains. The NIST House incorporates high-efficiency mechanical systems, including an air source heat pump and a dedicated heat recovery ventilator (HRV). The design also features a south-facing 10.2 kW (32 panel) roof-mounted PV system, as well as a small solar thermal heating system for DHW. Full specifications and details have been published and are summarized in Table 12 (Petit et al. 2015; Kneifel 2014).

Table 12. Summary of NIST House Construction.

Building Category	Specifications	Details
Windows	U-Factor	0.2
	SHGC	0.25
	VT	0.4
Framing and Insulation	Framing	2 in x 6 in - 24 in OC
	Exterior Wall	R-20+24*
	Basement Wall	R-22*
	Basement Floor	R-10*
	Roof	R-45+30*
Building Envelope Airtightness	Air Change Rate	0.63ACH50
	Effective Leakage Area	15.3 in^2
		14.0 in^2
Lighting	% of Efficient Lighting	100% efficient built-in fixtures
HVAC	Heating/Cooling	Air source heat pump (SEER 15.8/HSPF 9.05)
	Outdoor Air**	Separate HRV system (80 ft^3/min)
Domestic Hot Water	Water Heater	50 gallon heat pump water heater (COP 2.33)
	Solar Thermal	2 panel, 80 gallon solar thermal storage tank
Solar PV System	System Size	10.2 kW (South facing, Tilt: 18.4°)

R-values (ft ^{2} -FBtu/h), U-values (Btu/hft ^{2} -F)
Minimum outdoor air requirements are based on ASHRAE62.2-2010

Since its completion, the NIST House has achieved Zero Energy. During the first year of demonstration total consumption was 13,086 kWh and total production by its PV array was 13,577 kWh (Bello 2014). Annual performance for 2015 also showed an energy surplus (Figure 7).

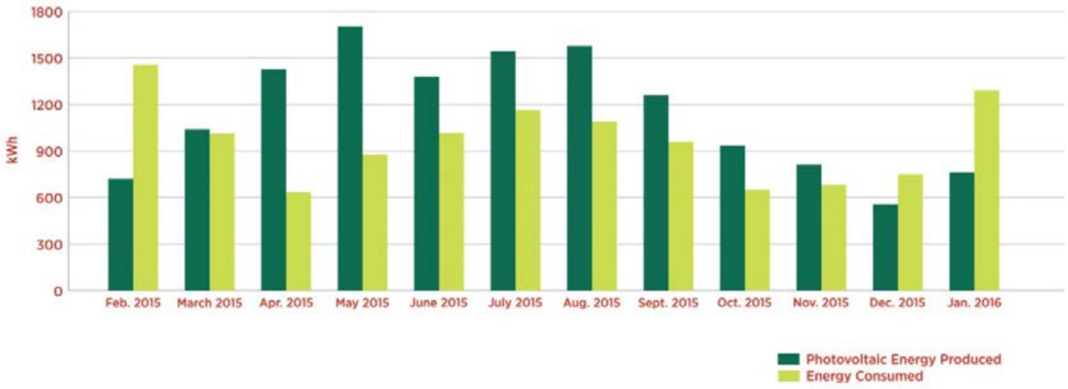


Figure 7. Monthly NIST House Performance for 2015 (NIST 2016).

NIST House Modeling Procedure

For a baseline energy comparison, the NIST House was modeled in DesignBuilder, a software tool which uses the DOE endorsed simulation engine EnergyPlus (Figure 8).

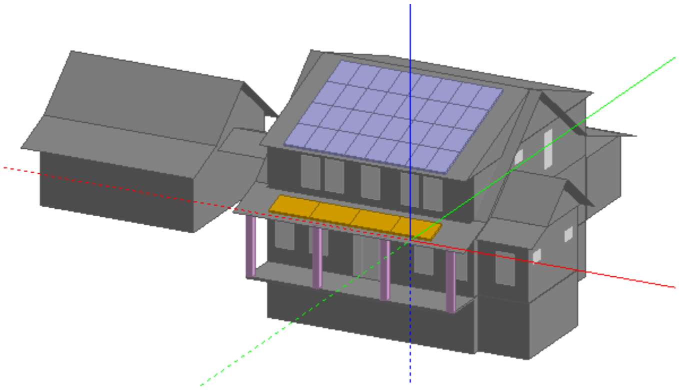


Figure 8. Study Energy Simulation Model.

All assumptions, model dimensions, and DesignBuilder simulation parameters are calibrated to demonstration phase simulations conducted by NIST, concurrent simulations, and specifications of the NIST House as-built (Kneifel 2012; Kneifel et al. 2015; Petit et al. 2015). The only exception to this is the occupancy configuration, which includes lighting, water, and MEL schedules. Due to their great variability, this study implemented a different occupancy configuration than that of NIST simulations (Kneifel 2012; Kneifel et al. 2015), and thus a different configuration than the NIST House during demonstration. Best practice templates were selected from DesignBuilder according to the thermal zones of the home. As seen in Figure 9, the study model produces similar results as NIST simulations and measured NIST House data.

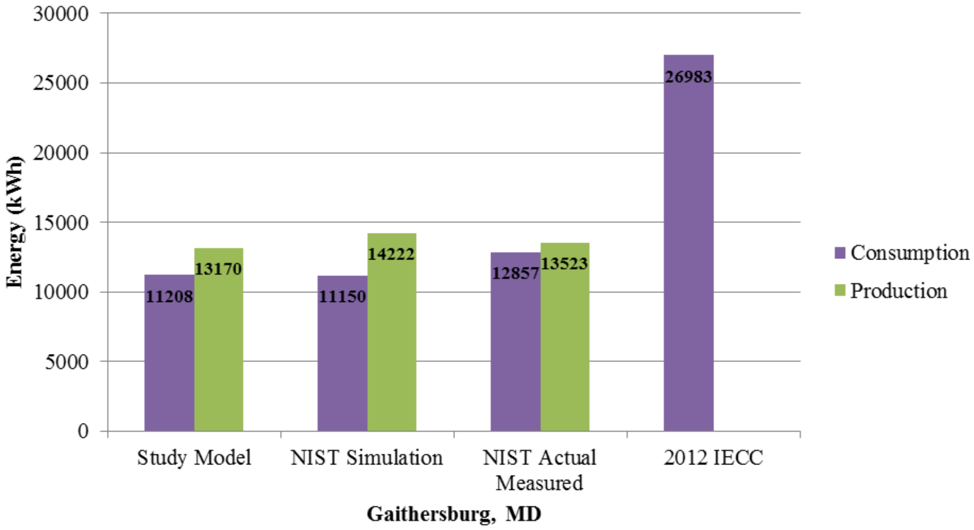


Figure 9. NIST House Annual Performance.

The effects of the different occupancy configuration of the baseline model are shown in Figure 10, which highlights the contributions of building systems (HRV, HVAC), domestic hot water (DHW, solar thermal), and room electricity (lighting, MELs, appliances) on total energy consumption.

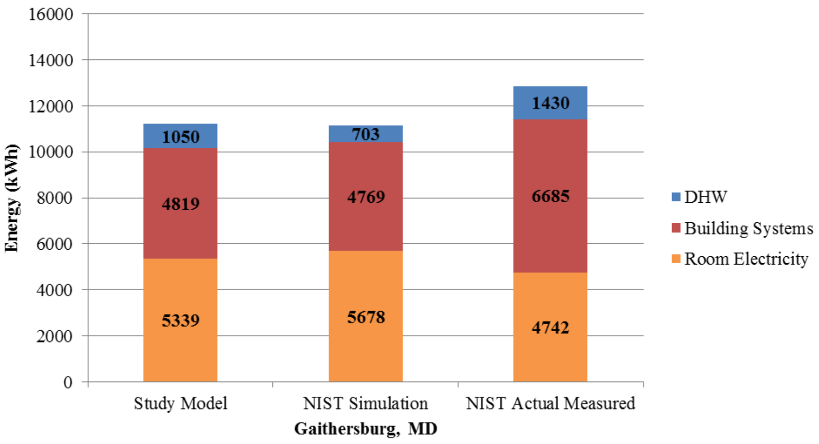


Figure 10. NIST House Annual Energy Consumption Breakdown.

Application of NIST House to Wyoming

With the NIST House modeled accurately, it was then simulated in three locations in Wyoming: Casper, WY; Jackson, WY; and Laramie, WY. These three locations not only represent varying climates throughout the state (Table 13), but also represent jurisdictions which have adopted, or at least reference, IECC 2012.

Table 13. Climate Characteristics of Maryland and Wyoming.

Location	Climate Zone	HDD65	CDD50
Gaithersburg, MD	4A	4666	3677
Casper, WY	6B	7256	2236
Jackson, WY	7B	9374	979
Laramie, WY	6B	7578	1611

Simulation results shown in Figure 11 demonstrate that the NIST House would achieve Zero Energy performance in Wyoming as-built.

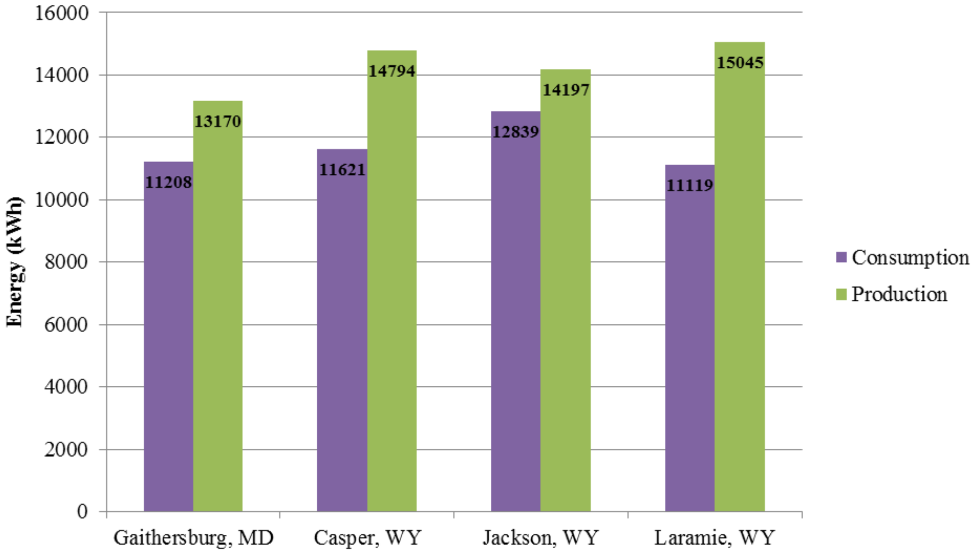


Figure 11. Modeled Annual Performance of NIST House.

The variance in consumption reflects the effects of climate on heating and cooling loads (Figure 12), and the variance in production reflects the different received solar radiation of each location.

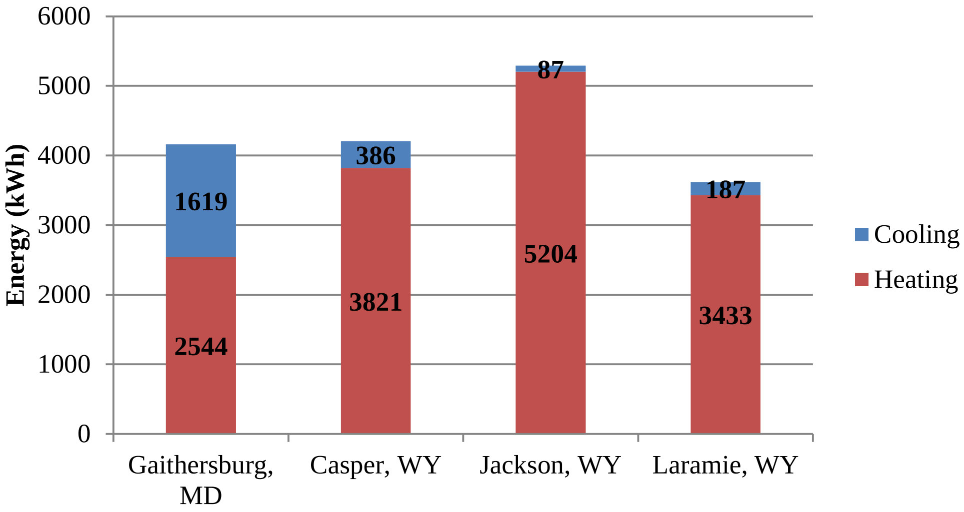


Figure 12. Modeled Annual Heating and Cooling of NIST House.

Dehumidification is needed during the summer in Maryland and contributes to the annual cooling load. In Wyoming, dehumidification is not necessary due to low humidity year round. Cooling in Wyoming is also arguably unnecessary if natural ventilation is introduced considering the low annual cooling load.

The energy simulation model also verified that the NIST House was not designed to take advantage of passive solar heating, as seen in Table 14. These values represent the net solar gain (total solar gain – glazing losses) on the south façade during the heating season. The negative solar gain effects are exacerbated by the fact that the lower windows on the south façade glazing are shaded by the front porch.

Table 14. Passive Solar Heating on South Façade of NIST House.

Location	Heating Season	Net Solar Gain (kWh)
Gaithersburg, MD	October-April	-41
Casper, WY	October-May	-78
Jackson, WY	September-May	-536
Laramie, WY	September-May	114

RM-NIST House

Despite the fact that the NIST House, as-is, would perform well in the climate of the Wyoming, the effects of design refinements are explored. The redesigned house is called Rocky Mountain NIST, or RM-NIST. The following subject areas are explored: insulation types and values; window types; DHW heating methods; and conventional heating methods and energy conversion factors. For purposes of comparison, these characteristics were kept constant: architectural design, including size; and construction type (2x6 advanced framing, basement, etc.).

Similar to the IECC, the envelope of the NIST House is one of the greater influences on its performance and cost. The advanced frame construction of the NIST House is kept constant as it translates well to the climate of Wyoming, 2 x 6 construction is common in the region, and it reduces the amount of lumber required (Holladay 2010).

First modeled were the effects of using the “Pretty Good House” (PGH) standards for cold climates developed by the Building Science Corporation, i.e. R-5 windows (SHGC=0.25, VT=0.40), R-10 basement slab, R-20 below grade walls, R-40 above grade walls, and a R-60 roof (Maines 2012).

Table 15. Insulation Cost-Effectiveness of NIST House.

Jackson, WY		**Insulation**	**R-Value**	**Material Cost ($/ft^2)**	**Annual Consumption (kWh)**
NIST	Slab	2" XPS	10	0.94	12839
	Below Grade Walls	2" Polyiso / 2" XPS	23	2.48	
	Above Grade Walls	4" Polyiso / 6" Cellulose	44	3.74	
	Roof	5" Polyiso / 11 7/8" Cellulose	75	5.15	
PGH	Slab	2" XPS	10	0.94	13392
	Below Grade Walls	4" XPS	20	1.88	
	Above Grade Walls	4" XPS / 6" Cellulose	40	2.54	
	Roof	6" XPS / 8" Cellulose	60	3.70	
Total Difference		*3"*	*22*	*3.25*	*553*
RM-NIST	Slab	2" XPS	10	0.94	13450
	Below Grade Walls	4" XPS	20	1.88	
	Above Grade Walls	3" XPS / 6" Cellulose	35	2.07	
	Roof	6" XPS / 11 7/8" Cellulose	72	4.12	
Total Difference		*0"*	*15*	*3.30*	*611*

Then the effects of using XPS in place of polyisocyanurate, the rigid foam sheathing found throughout the NIST House, were modeled. Polyiso generally exhibits worse thermal performance when temperatures drop (BSC 2013). Alternatively, XPS generally performs better when temperatures drop, making it more suitable for cold climates (Holladay 2013). Further, its regional cost is approximately 50% of polyiso and is readily available in Wyoming. Adhering to minimum R-value code requirements (Holladay 2015, 2016a), XPS can be substituted for polyiso in the roof and walls of the NIST House to reduce material costs without sacrificing significant energy performance (Table 15). Of note are the results from the "Pretty Good House" standards. Decreasing from the NIST baseline values of 10-23-44-75 to 10-20-40-60 caused a 4.3% increase in total energy consumption for Jackson, WY (553 kWh, about 1.25 PV panels).

The NIST House did not take advantage of passive solar heating, which is currently a subject of debate and discussion. Since the 1940s it has been well-established that passive solar design can lead to significant savings in mechanical heating (Denzer 2013). However, recent improvements in superinsulation and airtight construction have led some to forsake this method (Lstiburek 2014). This position, however, assumes poor shading control and a low tolerance for temperatures outside a narrow-band comfort zone.

Table 16. Alternate Window Specifications for RM-NIST.

Type	U-Value	SHGC	VT
Pella Triple-Pane SunDefense Low-E w/Argon	0.20	0.25	0.40
Pella Double-Pane SunDefense Low-E w/Argon	0.24	0.27	0.65
Pella Triple-Pane NaturalSun Low-E w/Argon	0.20	0.62	0.73
Pella Double-Pane NaturalSun Low-E w/Argon	0.26	0.68	0.79

For RM-NIST, the effects of passive solar heating by modeling a variety of cost-friendly and code compliant windows readily available in the region were explored (Table 16). The results are presented in Figure 13. The benefit of Triple-Pane over Double-Pane is marginal as the total window area is rather small. This conforms to the recommendations of a Canadian study of costs of Zero Energy houses: “pick a ‘good’ window (from an energy perspective) although not necessarily the best unit” (Proskiw 2010).

To determine the benefits of passive solar gains during the heating season, windows with a higher SHGC were simulated on the south façade. With this substitution, the original heating load is reduced by approximately 20%. Further gains could be achieved by altering the NIST House design, i.e. the depth of the front porch.

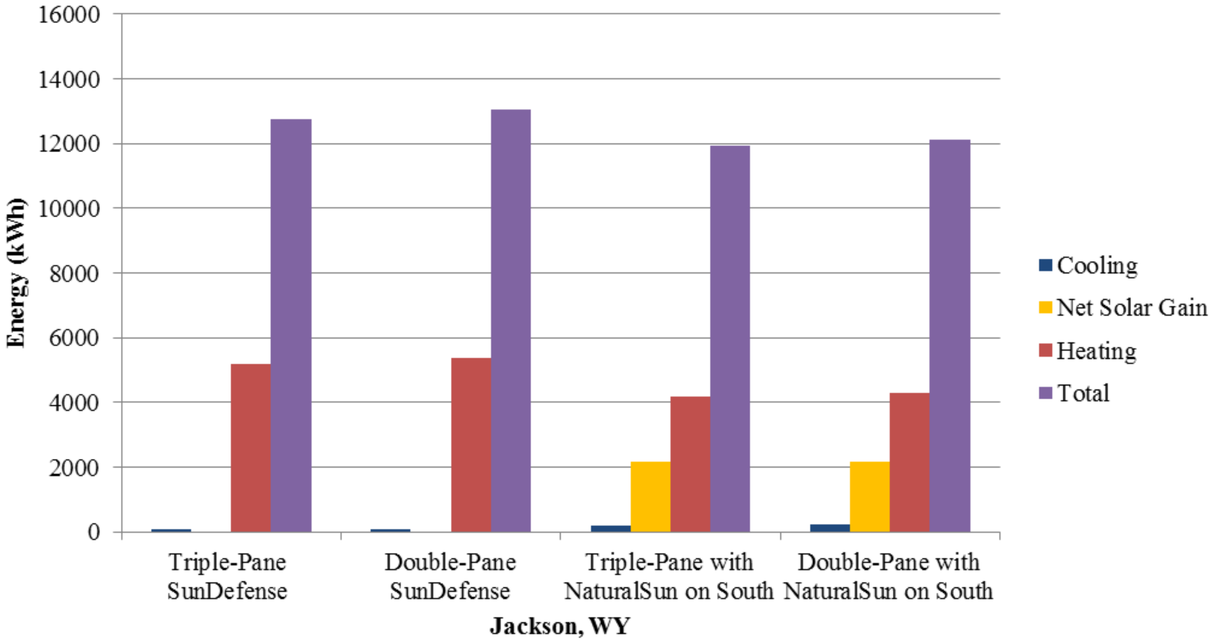


Figure 13. Effect of Window Type on RM-NIST Annual Consumption.

The solar thermal system is also eliminated from RM-NIST. Solar thermal systems are known to be an irrational choice based on cost, due to the falling costs of PV and heat pump water heaters in recent years (Holladay 2012). To reaffirm this for RM-NIST, the effects of different hot water systems were simulated. As shown in Figure 14, the effects of different hot water systems on annual energy consumption are minimal.

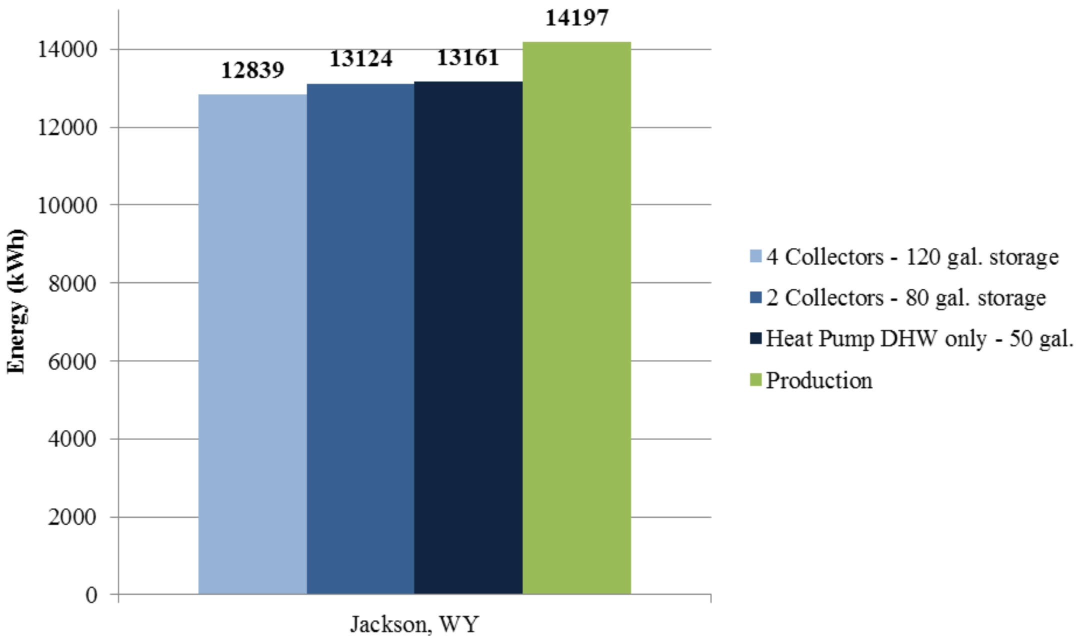


Figure 14. Effect of Hot Water System on RM-NIST Annual Consumption.

The DHW needs of RM-NIST can be satisfied by 3 additional PV panels. The cost savings of eliminating the solar thermal system is approximately $10,000 based on NIST-provided construction cost data. Furthermore, the storage tank, as well as the operation and maintenance of an additional system are eliminated.

Table 17 and Figure 15 give the final RM-NIST performance and the required number of PV panels for Zero Energy in the Wyoming locations studied.

Table 17. RM-NIST Energy Balance.

Location	Annual Energy Use (kWh)	PV Panels Needed
Casper, WY	11502	25
Jackson, WY	12733	29
Laramie, WY	10876	24

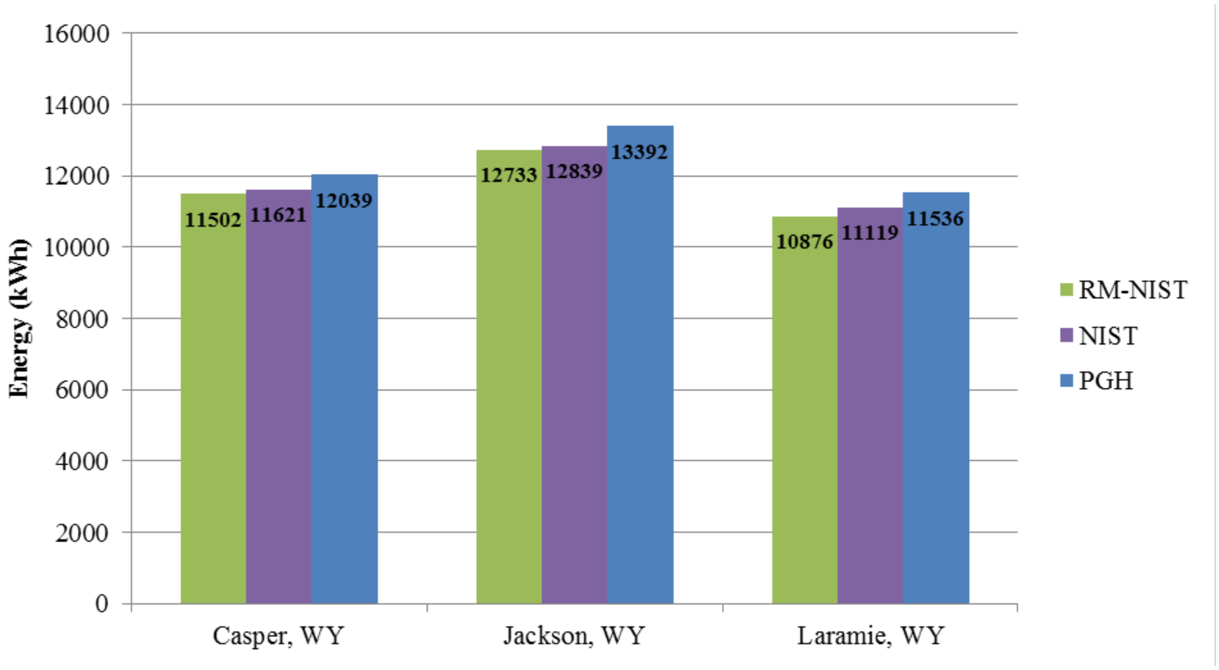
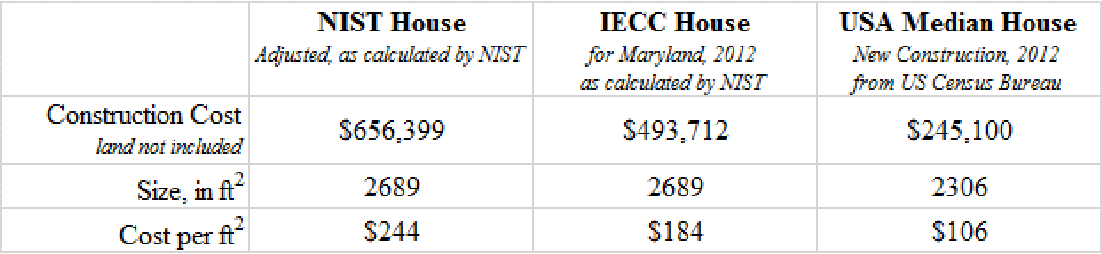


Figure 15. NIST House Annual Consumption Comparison.

Costs

The NIST House was built for $808,499, not including land. The high cost of NIST House was due in part to its function as a laboratory rather than a house. It included redundant HVAC systems, geothermal loops, and a fire suppression system. When these extra features are stripped away, project researchers calculated the cost would reduce by $152,100 to $656,399 (Kneifel 2014). This is about 2.7 times as expensive as the U.S. average for the same year of construction (Table 18). The high construction cost of the NIST House is difficult to explain or to justify.

Table 18. NIST House Costs, in Context.

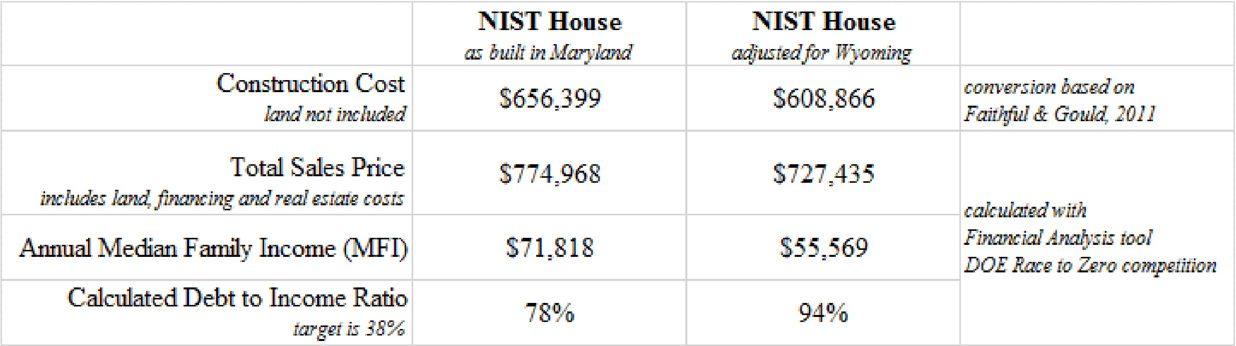


	NIST House *Adjusted, as calculated by NIST*	**IECC House** *for Maryland, 2012* *as calculated by NIST*	**USA Median House** *New Construction, 2012* *from US Census Bureau*
Construction Cost *land not included*	$656,399	$493,712	$245,100
Size, in ft^2	2689	2689	2306
Cost per ft^2	$244	$184	$106

To estimate the NIST House cost in Wyoming, a simplified method is offered by the Pacific Northwest National Laboratories (Faithful & Gould 2011). In this study, construction costs for homes in Maryland are indexed at 95.56 of the U.S. average, while Wyoming is 88.64. Given that the NIST House in Maryland costs $656,399, and using these values as conversion factors, the Wyoming cost would be adjusted to $608,866 ($226/ft^2).

To further analyze these costs, a Financial Analysis tool provided by the DOE through the *Race to Zero* competition was utilized. Table 19 shows the results of this analysis. This tool establishes a debt to income ratio of 38% as a target. With this, the NIST House is clearly unaffordable in Maryland and Wyoming. Since both of these states are indexed below the U.S. average, it is reasonable to assume the NIST House is unaffordable most everywhere in the country.

Table 19. NIST House Affordability.

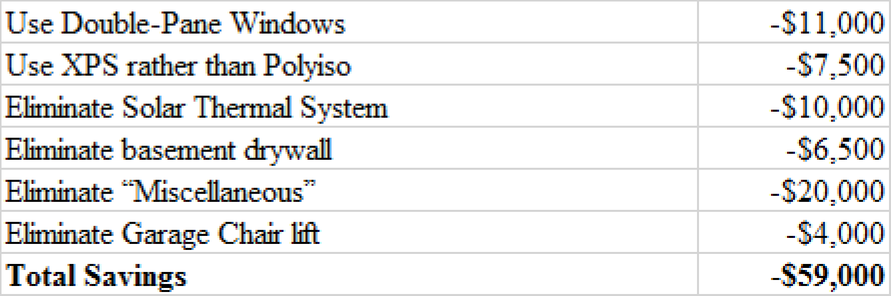


	NIST House *as built in Maryland*	**NIST House** *adjusted for Wyoming*	
Construction Cost *land not included*	$656,399	$608,866	*conversion based on Faithful & Gould, 2011*
Total Sales Price *includes land, financing and real estate costs*	$774,968	$727,435	*calculated with Financial Analysis tool DOE Race to Zero competition*
Annual Median Family Income (MFI)	$71,818	$55,569	
Calculated Debt to Income Ratio *target is 38%*	78%	94%	

By contrast, a study for office and multifamily residential buildings in the District of Columbia found construction cost premiums are 1-12% for energy efficiency and 5-19% for Zero Energy (Cortese 2013).

To address the issue of affordability, various ways of reducing the costs of RM-NIST were explored. Table 20 lists some of the potential cost savings estimated.

Table 20. RM-NIST Construction Cost Savings.



Use Double-Pane Windows	-$11,000
Use XPS rather than Polyiso	-$7,500
Eliminate Solar Thermal System	-$10,000
Eliminate basement drywall	-$6,500
Eliminate "Miscellaneous"	-$20,000
Eliminate Garage Chair lift	-$4,000
Total Savings	**-$59,000**

With regard to construction cost, there are two other major issues worthy of discussion. One is the issue of size. At 2,700 ft^2, the NIST House is quite large for a family of four. Yet, this is consistent with national trends. The average size of a newly constructed U.S. home reached a high of 2690 ft^2 in 2014, which is an increase of more than 1000 ft^2 since 1973 (Perry 2015). Prospective homebuyers who wish to be frugal with regard to energy use are likely to be interested in living more efficiently with regard to space. Building to the 'large' side of the target makes the home less affordable, and, perhaps, sends the wrong message to the marketplace.

Two is the issue of "premium" finishes. The NIST House spent more than double on interior finishes than a typical home in the U.S. on a per square foot basis (Table 21). Again it is difficult to understand why designers of a demonstration house aiming to promote Zero Energy houses would make such extravagant specifications.

Table 21. NIST House Interior Finishes Costs.

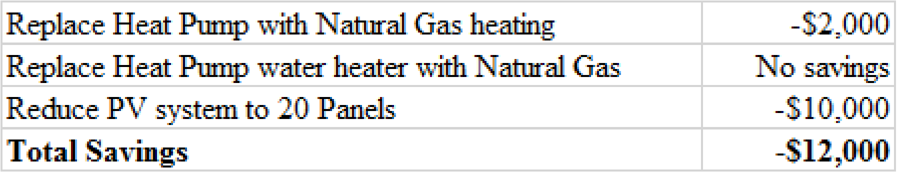
	NIST House *Adjusted, as calculated by NIST*	**IECC House** *for Maryland, 2012 as calculated by NIST*	**USA Typical House** *Based on Table 18 and Taylor (2015)*
Interior Finishes	$173,450	$166,950	$72,550
Cost per ft^2	$64.50	$62.09	$31.46

Table 22. Additional RM-NIST Savings.

Reduce size to 2200 ft^2	-$110,723
Use standard interior finishes (save $33.04/$ft^2$)	-$72,688
Savings from Table 20	-$59,000
Subtotal	-$242,411
Baseline Cost from Table 19	$608,866
New RM-NIST Construction Cost	**$366,455**

The RM-NIST House was also modeled with conventional heating sources in order to explore the effects of using the Source Energy Conversion Factors endorsed by the DOE (Peterson 2015). If the recommended design for RM-NIST in Jackson, WY, used natural gas for space heating and DHW instead of electricity, the home could achieve Zero Energy with 20 PV panels, 9 fewer than the all-electric model.

Table 23. Additional RM-NIST Savings with Conversion Factor Methodology.



Replace Heat Pump with Natural Gas heating	-$2,000
Replace Heat Pump water heater with Natural Gas	No savings
Reduce PV system to 20 Panels	-$10,000
Total Savings	**-$12,000**

Total savings combined, however, RM-NIST is still approximately 20% greater than the DOE target affordability ratio in Wyoming.

CONCLUSION

To investigate residential model energy codes and Zero Energy homes within Wyoming, two energy simulation models were utilized: 1) a prototype home provided by the DOE, with modified system efficiencies and MELs to reflect the energy use of a typical new home in Wyoming, and 2) a replica of the NIST House, with various efficiency and cost-saving refinements. The DOE prototype represents a generically designed home, intended for IECC comparison purposes. It is consequently limited in efficiency potential outside of code provisions, and possesses no performance-oriented design aspects, i.e. passive solar heating. RM-NIST represents a comprehensively designed home that reflects a high-performing suburban residence. As both, however, are single family homes (3 and 4 occupants, respectively), and comparable in size (2,400 ft^2 and 2,700 ft^2), their energy uses (Table 24) exhibit the general gap between a newly built code home and a newly built Zero Energy home in Wyoming. For comparison, each are represented here as all-electric homes.

Table 24. IECC vs. RM-NIST Annual Consumption.

Jackson, WY	**IECC 2006**	**IECC 2015**	**RM-NIST**
Cooling (kWh)	606	639	223
DHW (kWh)	1674	1674	1086
Heating (kWh)	9224	5575	4778
Room Electricity (kWh)	6525	5948	5339
System Fans (kWh)	2587	1694	1307
Total (kWh)	20617	15530	12733
EUI (kWh/ft^2)	8.6	6.5	4.7
#PVs to Zero	47	35	29

When considering EUI, RM-NIST is approximately 30% more efficient than a newly built Jackson home according to IECC 2015 requirements. Maintaining the assumption that a typical new home built in Wyoming with no code enforcement performs at a level equivalent to IECC 2006, RM-NIST is approximately 50% more efficient. Some areas of energy consumption are easier to reduce than others on the path to Zero Energy. For example, room electricity, DHW use, and thermostat set points are all dependent on user habits. Efficient building technologies, whether heating systems, lights, or PVs, are also readily available for purchase and installation for immediate benefits. Incorporating more comprehensive design aspects such as passive solar heating also have the potential to shorten the path to Zero Energy, yet must be done so early in design.

Ultimately, with the state of home building technology, ZEBs are feasible in today's home market without novel techniques. The performance of the NIST House exhibits this, and is well-designed in terms of energy efficiency and production. It could be replicated, as is, in a very cold climate such as in Wyoming, and still achieve Zero Energy throughout the year. This suggests the house is over-designed for its Maryland location, but is certainly valid as a nationwide Zero Energy demonstration project. The true challenges for widespread adoption are aesthetic and financial in nature. The NIST House properly addressed the aesthetic challenge by looking like a typical Maryland suburban home. It could be similarly adapted to Wyoming. The NIST House, however, addressed the financial challenge poorly. It is not affordable for a typical family of four in Maryland or Wyoming, even with engineering refinements and various efforts to simplify its features. Its status as a demonstration house and promotional tool are therefore limited.

The path to a more prominent Zero Energy presence in Wyoming possibly begins with adopting a model energy code such as the IECC. Energy codes indeed have a presence in the state, yet this does not necessarily mean they are always enforced. The notion of enforcing energy efficiency through legislation is daunting for many builders and jurisdictions in the state. Although difficult to fully quantify, many do not see or possibly are not fully aware of the virtues of energy codes. The ultimate question to ask is whether or not Wyoming should adopt the IECC statewide, and for those jurisdictions which already have adopted, whether or not an update to IECC 2015 is advised. The cost penalty for a jurisdiction looking to upgrade from IECC 2012 to IECC 2015 is minimal. From an energy perspective, the benefit is also minimal due to the nature of code amendments from 2012 to 2015. From a construction cost perspective, updating to IECC 2015 from versions earlier than 2012 are significant, yet potential energy savings to be gained nullify initial capital.

The conclusion for jurisdictions that have not adopted the IECC is more complex considering the steps needed to establish a properly enforced code infrastructure. As the IECC is already present throughout the state, it would benefit builders to work under the provisions of a uniform energy code if operating throughout multiple jurisdictions. Also, for most new homes, assuming an efficiency equal to IECC 2006 is likely an underestimation. Both prescriptive and mandatory code requirements are therefore reasonable. With compliance methods such as simulated performance or the ERI path in conjunction with efficient systems, devices, etc. and on-site generation, code restrictions become even more flexible. Furthermore, the IECC is open to amendments, and regional alterations to improve its applicability are common. If nothing else, the statewide enforcement of a residential energy code such as the IECC would create a more organized system of energy data to assist in further progressing the state’s efficiency, as well as create a greater sense of energy efficiency awareness. In general, Wyoming would benefit from a more concentrated residential energy effort.

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