Energy Reports 5 (2019) 489–500

Contents lists available at ScienceDirect

Energy Reports

journal homepage: www.elsevier.com/locate/egyr

Research paper

Assessing housing retrofits in historic districts in Havre Montana

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ARTICLE INFO

Article history:
Received 13 May 2018
Received in revised form 15 March 2019
Accepted 28 March 2019
Available online 7 May 2019

Keywords:
Energy efficiency
Residential buildings
Energy codes
Historical buildings

ABSTRACT

This paper explores the impact of retrofitting single-family residential buildings in historic districts with energy efficiency measures that are compliant with the 2012 version of the International Energy Conservation Code (IECC). This study focuses on Sears's kit homes that were built in the early 1900s in the historic district of Havre, Montana. By conducting whole building energy simulations, this study assesses the impact of implementing each measure in terms of energy savings, reduction in carbon emissions and resultant paybacks. In addition the selected measures were grouped together into various groups and assessed. Combining all measures provided 81% energy savings and a simple payback period of 4–8 years and a time until Net Present Value (NPV) of 9.5 - > 30 years over the corresponding base-case. In addition to demonstrating strong economic justifications, the implementation of efficiency measures is highly recommended for the benefit of preserving historic districts and in turn contributing to the reduction in energy consumption as well as carbon emissions of historic residential building stock in the United States.

1. Introduction

1.1. Significance of historic buildings and importance of reducing energy consumption in such buildings

Residential buildings in historic districts often reflect the tangible past and unique heritage in the communities and neighborhoods within which they are located. In addition, the neighborhoods in which these buildings are located contribute significantly to the State and national experience. Hence, such buildings have an intrinsic value to our current communities and for future generations and have to be preserved. However, economic contingencies often act against the preservation of such buildings. More often than not the demolition of such buildings is considered giving way to buildings that are more energy efficient, hence both economically and sustainably justified.

The historic built environment of the United States provides crucial tangible representations of the nation's diverse and dynamic past. Through these artifacts, Americans connect to their heritages and gain a sense of identity through place (National Register Bulletin, 1995). Historic districts of residences are particularly important in conveying a strong sense of history and of identity; through the intimate icons of home and neighborhood, many Americans feel linked to past families and lives. Preserving such buildings both retains the connection of contemporary peoples to history and ensures that future generations will feel the empathetic ties to history and community.

Economic considerations often constrain sensitive preservation of these historic residences. Foremost is the issue of historic homes' energy efficiency. According to the Residential Energy Consumption survey (RECS), when considering annual whole building energy consumption, residential buildings constructed before the 1950s and 60s are about 30 to 40 percent less efficient than buildings built after 2000 (U.S. Energy Information Administration, 2013). As a major component of the current housing stock, older residences also contribute to energy consumption and carbon emissions. The National Association of Home Builders (NAHB) reports that in 2011 almost 41% of the owner-occupied housing in the United States was built prior to 1969 and can be considered historic (Miller, 2014). For some, these economic and environmental concerns justify replacing historic houses with new structures.

Clearly, Frey et al. (2012) the energy performance of such homes and their contributions to carbon emissions are significant and must be reduced (Moran et al., 2014). But rather than demolition, historic homes can be rehabilitated to retain their historic characteristics while conserving energy. Appropriate rehabilitation provides other benefits as well; it creates new jobs and businesses, increases tourism, saves tax dollars with effective reuse of

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https://doi.org/10.1016/j.egyr.2019.03.008

Nomenclature

ACH	Air Changes per Hour (h^{-1})
ACH_{50}	Air Changes per Hour at pressure of 50 Pa (h^{-1})
AFUE	Annual Fuel Utilization Efficiency
DHW	Domestic Hot Water
DOE	Department of Energy
EEM	Energy Efficiency Measure
EF	Energy Factor
eGRID	Emissions & Generation Resource Integrated Database
EPA	Environmental Protection Agency
$HDD_{65\ °F}$	Heating Degree Day
IECC	Energy Conservation Code
LCC	Life-cycle-cost
LPD	Lighting Power Density
MDPHHS	Montana Department of Public Health and Human Services
NAHB	National Association of Home Builders
NPS	National Park Service
NPV	Net Present Value
PNNL	Pacific Northwest National Lab
o.c.	On-center
RECS	Residential Energy Consumption Survey
R-value	h. ft^2 °F/Btu (m^2 K/W)
SHGC	Solar Heat Gain Coefficient
SHPO	State Historic Preservation Office
TMY	Typical Meteorological Year
TPS	Technical Preservation Services
U-value	Btu/h. ft^2 °F (W/m^2 K)

existing public and utility infrastructure, and increases property values. More importantly, preserving historic houses with appropriate energy conservation technologies keeps a strong sense of place and community (State Historic Preservation Office, 2013).

Historic preservationists have long known that conserving historic buildings reduces resource and material consumption and thus is the definition of "sustainable" (Park, 1998). Rehabbing for energy conservation may involve emphasizing the inherent energy efficiencies of historic buildings and enhancing them with new technologies to maximize performance. The Secretary of the Interior's guidelines for sustainably rehabilitating historic buildings recognizes the long-term environmental benefits of such rehabilitations (Grimmer et al., 2011). These guidelines show that bringing buildings into compliance with current energy codes while maintaining the buildings' historic characteristics is a realistic goal. If property owners respect their houses' historic value and preserve their original character, successful rehabilitations can balance energy efficiency and historic preservation.

1.2. Sustainable historic preservation guidelines in the United States

The National Park Service's Technical Preservation Services (TPS) is responsible for establishing the principles and appropriate strategies for preserving historic buildings. It has laid out four approaches: preservation, rehabilitation, restoration, and reconstruction. The choice of treatment depends on a variety of factors, including the property's historical significance, physical condition, proposed use, and intended interpretation. However, as pointed out by Dupont et al., the guidance is written for a wide audience and is at best generic (Dupont et al., 0000). Rehabilitation is the most common treatment; the best way to preserve historic buildings is to use them. Recognizing that this requires changes to historic buildings, the TPS established a set of standards and guidelines for "adaptive reuse". The Secretary of the Interior's Standards for Rehabilitation laid out the broad principles within which to make decisions that allowed updates and modern amenities while protecting historic design and building fabric. Accompanying guidelines assisted decision making by showing what constituted acceptable rehabilitation solutions of which several versions were published (Technical Preservation Services, 0000; Weeks and Grimmer, 1995; Morton et al., 1997). Though this document included recommendations for energy conservation, the issue gained momentum through the 1980s and 1990s as rapid climate change forced widespread attention on "sustainability". Thus, in 2011, the TPS released its latest set of guidelines that directly addresses sustainability in historic buildings within the rehabilitation standards (Grimmer et al., 2011). The document provides the basis for this study's examination of the economic feasibility of energy conservation efforts in historic residences, the most common and widespread historic resource, within a Montana historic district.

1.3. Current historic preservation practices in Montana

Like most States, Montana has rich and diverse historic properties, perhaps over 54,000 historic buildings, structures, and districts. The National Register of Historic Places officially lists only about 1100 of these (State Historic Preservation Office, 2013). Although Montana's State Historic Preservation Office (SHPO) has had considerable success in preserving the State's important heritage places, many of these properties are at risk due to commercial and resource development, urban sprawl, neglect, mismanagement, changing population needs, lack of understanding, and limited financial resources for preservation (State Historic Preservation Office, 2013). Addressing energy conservation issues in Montana's endangered buildings will assist in their preservation and reinforce a model of sustainable rehabilitation for other States.

As a case study for the financial feasibility of historically-sensitive energy conservation, this research focuses on a residence within a historic district in Havre, Montana (Fig. 1). Located on the "high line", the historic Great Northern Railway route near the Canadian border, Havre is the largest regional city of roughly 10,000 people. It sits in an agricultural landscape of grazing and wheat production and experiences the extremes of summer heat and winter cold associated with the semi-arid Northern Plains. Though a transportation hub and portal to Canada, the town lies over 100 miles from the closest Montana city, Great Falls. Havre has a dense cluster of people relatively isolated from the rest of the State's population. This scenario is typical for Montana. By examining historic buildings and sustainability here, this study shows that the need for affordable housing and energy-efficient historic rehabilitation exists not only in densely populated metropolitan cities but also in moderately-sized cities like Havre and rural States like Montana.

1.4. Need for this study

While the standards and guidelines for historic preservation maintained by the TPS provide a comprehensive set of recommendations that can be implemented to restore and improve the energy efficiency of historic buildings, these standards are neither technical nor prescriptive. In addition, the standards do not address the impact of implementing these measures on reductions

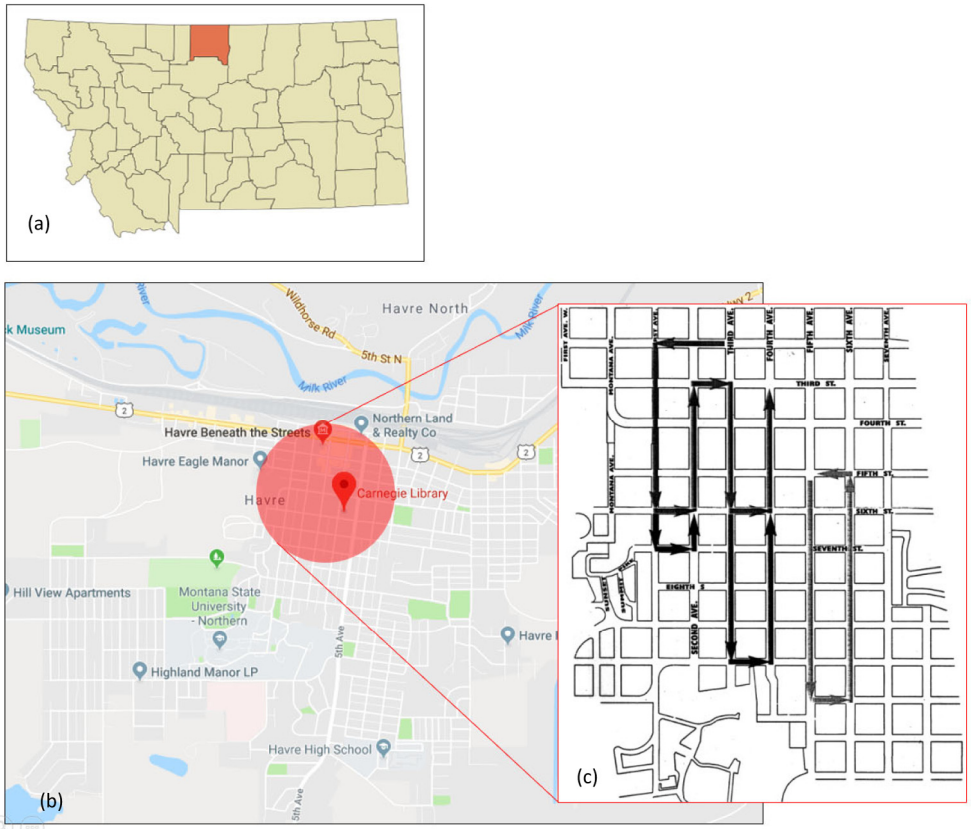


Fig. 1. Havre, Montana a. Location of Havre in Montana (marked in red) (Location of Havre Montana, 0000), b. Map of Havre (Map of Havre, 0000), c. Historic district of Havre (Havre Historic Preservation Commission, 0000) . (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

in energy consumption and associated paybacks as well as the reduction in carbon emissions.

This paper goes a step further and provides a quantitative assessment of historic residential buildings, which discusses and assesses the impact of installing recommended energy efficiency measures in terms of reduction in energy consumption, resultant paybacks, and reductions in carbon emissions. The paper assess the implementation of individual measures as well as combining these measures to comply with the current energy code in the State of Montana. In providing this assessment this paper presents a case for justifying the retention of the historic built environment using energy efficient rehabilitation.

This paper has been developed from an unpublished student project at the School of Architecture, Montana State University (Cabrera, 2016).

2. Goals & objectives

From the above discussion on preservation of historic residential buildings it was determined that energy efficiency in homes in historic districts can be obtained with minimal compromise to the historic fabric. Hence, the goal of this study is to determine the best practices for selection and installation of energy efficiency retrofits that preserve the fabric of historic buildings in Montana while at the same time meeting the building energy code in Montana. For that purpose, this study evaluates:

- Methods that are available for retrofitting historic residential buildings for energy efficiency
- Selected packages of one or more energy efficient strategies
- Calculating corresponding reductions in carbon emissions
- Calculating corresponding life-cycle-cost (LCC) analysis

3. Methodology

3.1. Procedure of assessment

In order to conduct the analysis, the study considered compliance with the residential building energy code for the State of Montana, which currently is the 2012 IECC with amendments. To perform this analysis a base-case simulation model of the residential building was created. This base-case simulation model reflected the current condition of the historic homes with no retrofits. Next, the analysis considered a number of measures and assessed each one for their individual impact on energy efficiency, carbon emission reduction, and payback periods. These measures were first simulated individually. The measures were then combined into different groups, which included a case that was compliant with the 2012 IECC (Horton, 2014).

As noted by TPS, treatments common to new construction had to be evaluated carefully before implementing them in historic buildings in order to avoid inappropriate alteration of important architectural features and irreparable damage to historic building materials (State Historic Preservation Office, 2013). It is also noted that the façade of a historic residential building is usually a feature in which the owner will desire minimal changes, allowing for the retention of both aesthetic and thus historic value of the exterior of the residence (State Historic Preservation Office, 2013). However, this also presents a challenge of selection and installation of appropriate energy retrofit measures. As pointed out by the TPS, in order to proceed with the retrofitting of historic buildings, several common energy conservation measures can be considered. These include: reduction of infiltration, improving the efficiency of heating and cooling systems, installation of efficient

lighting fixtures and appliances, installation of insulation, and the addition of shading devices.

From studies examined during the literature review, it was noted that refurbishment strategies such as insulation, air tightness, ventilation, and heating and cooling strategies were interdependent and hence had to be evaluated in terms of their impact on whole building energy consumption. Therefore, a whole building simulation DOE-2.1e was used to assess the selected measures.

DOE-2.1e is an hourly, fixed-schematic, whole-building energy simulation program that predicts hourly energy usage given the hourly weather information. DOE-2.1e has been widely used for evaluating the energy performance of buildings, and offers a great capability for simulating a wide range of design features, and has been extensively validated (Sullivan and Winkelmann, 1998). The program implements one subprogram for translation of inputs (the BDL Processor) and four simulation subprograms (i.e., LOADS, SYSTEMS, PLANT and ECONOMICS) that are executed sequentially. The simulation options available to evaluate heat transfer include: (i) the response factor method,[1] and (ii) the ASHRAE weighting factor method, which is an alternative approach for calculating overall heat transfer within each thermal zone. Further information regarding this program can be found in Winkelmann et al. (1993). The analysis used the Typical Meteorological Year (TMY3) weather data for Havre Montana (Wilcox and Marion, 2008).

3.2. Case-study house

The building prototype chosen for the simulation model used in the evaluation of efficiency measures, is representative of early 20th-century residences that make up historic districts across the nation. In 1989, the National Register listed the Havre Residential Historic District that encompassed 37 blocks of mostly early 20th-century houses on the town's south side. Constructed between 1895 and 1940, these structures illustrate Havre's urban growth from a small town dependent on trade with a nearby federal military fort (Fort Assiniboine) to becoming an important Great Northern Railway division point, railroad yard, roundhouse, and shop complex. Though remote, Havre, its people, and its domestic architecture mirrored developments in the rest of the United States during this period.

As a contributing element of Havre's historic district, the case-study house represents common early 20th-century architecture and provides a general model for energy analysis in historic buildings. Most likely constructed between 1913 and 1919, this two-story, hipped roof American Foursquare residence sheltered Havre's middle-class families in approximately 1248 ft^2 (115.9 m^2) and three bedrooms. Though builders never erected this type in the same numbers as Craftsman bungalows, it is well-represented in early 20th-century historic districts; Havre's district included at least 24 other Foursquares. The house appears remarkably similar to the house listed in the Sears Roebuck's catalogue of houses, the Fullerton, and may indeed have been ordered from Sears, especially considering Havre's close connection to the Great Northern Railway. Building contractors often copied popular structures, therefore, the case study house may be a product of local enterprise. Between 1913 and 1917, the Home Builders Investment Company hired numerous Havre contractors to erect many of the over 100 houses built during this period. Whether or not a Sears house, this structure's participation in a national architectural movement allows researchers to extrapolate its energy conservation to other historic buildings.

The analysis of the case-study house utilized specifications for envelope, space conditions and mechanical systems as provided by Building America performance analysis procedures for existing buildings (Hendron and Engebrecht, 2010), Sears catalogue for stick homes (Sears, Roebuck and Co, 2006) and a report on baseline characteristics of the residential sector for Idaho, Montana and Oregon (Baylon and Borrelli, 2001). The layout of the house is presented in Fig. 2 and a simulation model of the house is provided in Fig. 3. The detailed specifications and corresponding references are provided in Table 1.

3.3. Validation of the base-case model

Since measured data was not available for the case-study house, electric and natural gas consumption obtained from the simulation model was compared to energy consumption of similar homes obtained from several sources, including: Residential Energy Consumption Survey (RECS) for 1980 and residential simulation models developed by the Pacific Northwest National Lab (PNNL) that are compliant with the 2012 IECC (Baylon and Borrelli, 2001; Mendon et al., 2013). The year 1980 was selected because it precedes the year in which Montana adopted its first energy code (i.e., 1985), which represents the 1983 version of the Model Energy Code (Web: Building Codes Assistance Project, 2018). Prior to 1985, buildings were not required to comply with any energy code, and therefore the inputs in the base-case energy model are indicative of this fact.

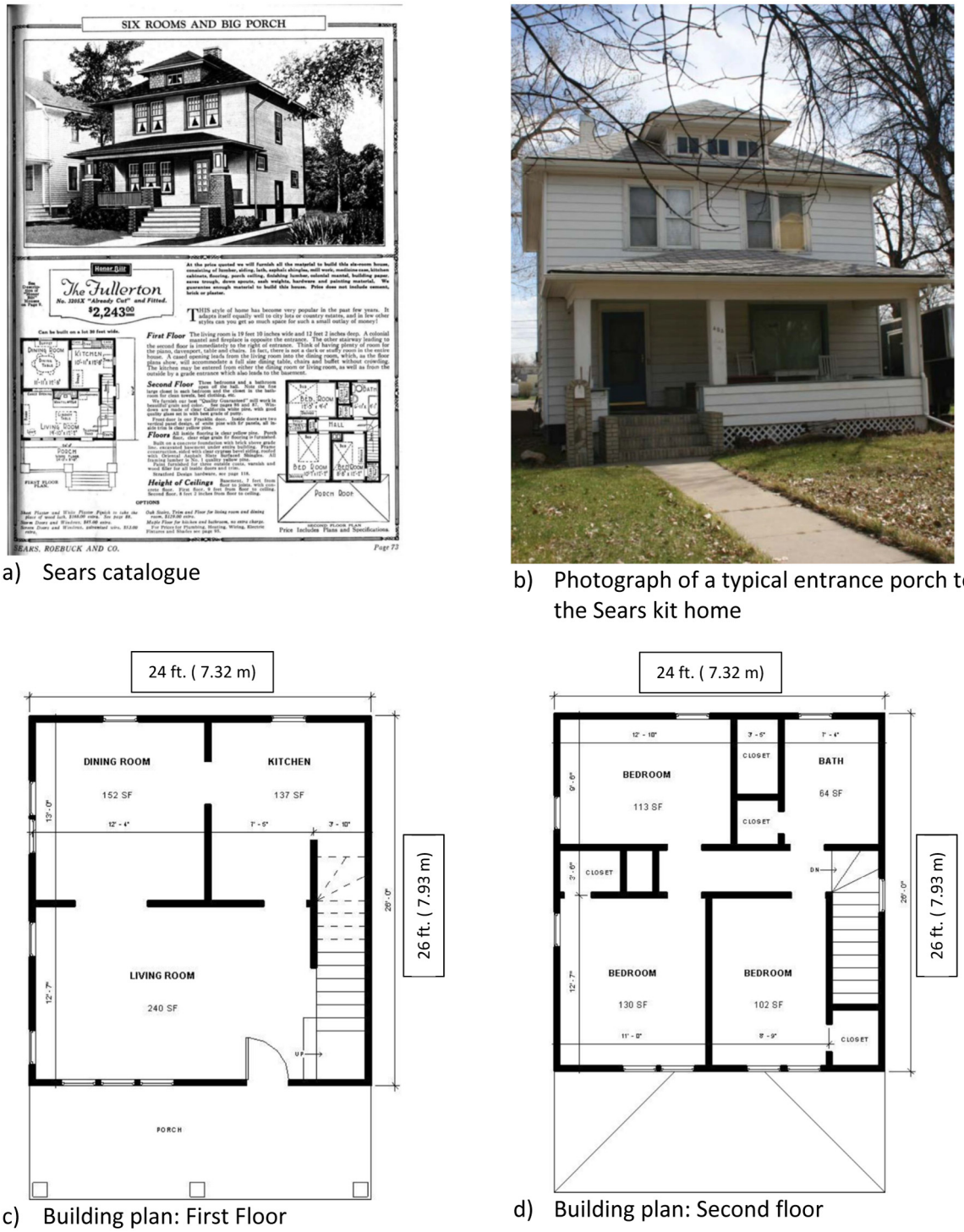
According to the RECS data from 1980 for residential buildings across the United States, the average natural gas consumption was 125 MMBtu (131.9 GJ). For houses built in the mountain region of western United States, the average natural gas consumption was 115 MMBtu (121.3 GJ). For houses built in climate zones with greater than 7000 $HDD_{65\,^\circ F}$ (3920 $HDD_{18.3\,^\circ C}$), average natural gas consumption per household was estimated to be at 148 MMBtu (156.2 GJ).[2] Similarly, for houses built before 1939, natural gas energy consumption per household was observed to be 143 MMBtu (150.9 GJ). Finally, for house sizes between 1000–1400 ft^2 (92.9–130.1 m^2), natural gas consumption per household was observed to be 115 MMBtu (121.3 GJ).

Based on the PNNL 2012 IECC compliant simulation model for a 2400 ft^2 (223 m^2) house in Helena, Montana, normalized to the conditioned area, the natural gas consumption was determined to be 33.0 kBtu/ft^2 (0.37 GJ/m^2). The normalized natural gas consumption of the 2012 IECC compliant simulation model with an area of 1248 ft^2 (115.9 m^2) used in this study was reported to be 35.9 kBtu/ft^2 (0.41 GJ/m^2).

The natural gas consumption of the base-case building used in this study is 354.2 MMBtu (GJ) which is higher than the numbers reported from the 1980 RECS report. This is because the RECS reports provide an estimate of the entire building stock making it difficult to pinpoint the energy consumption of a 1243 ft^2 house built in early 1900s, in cold and dry climate of Havre. On the other hand, the comparison of the results from the 2012 IECC compliant model with that of PNNL proved to be very similar indicating that the simulation model used in this study was appropriate.

[1] Response factors are used to determine the transient flow of heat through the exterior walls and roofs as they react to fluctuating climatic conditions. If desired by the user, the BDL processor can calculate Custom Weighting Factors to build user-defined libraries of materials and walls.

[2] It should be noted that Havre, Montana has 8844 $HDD_{65\,^\circ F}$. (4953 $HDD_{18.3\,^\circ C}$).



a) Sears catalogue

b) Photograph of a typical entrance porch to the Sears kit home

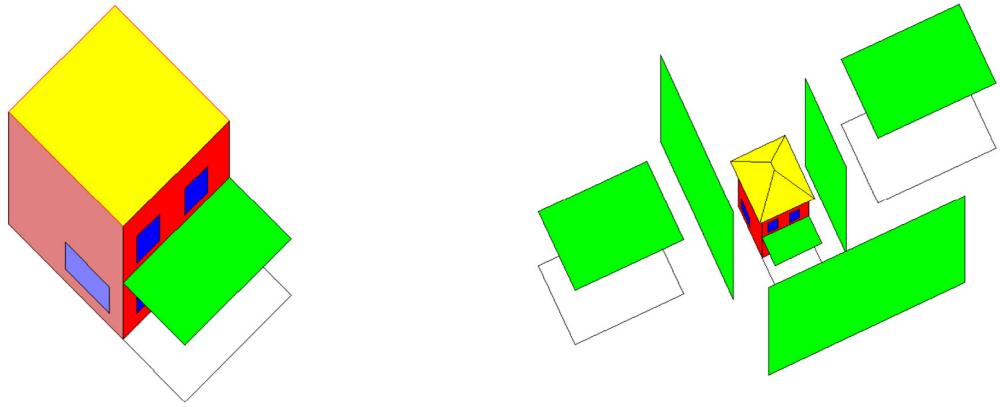
c) Building plan: First Floor

d) Building plan: Second floor

Fig. 2. The 'Fullerton' model from the Sears catalogue used as a prototype to develop the base-case simulation model.

3.4. Energy retrofit measures

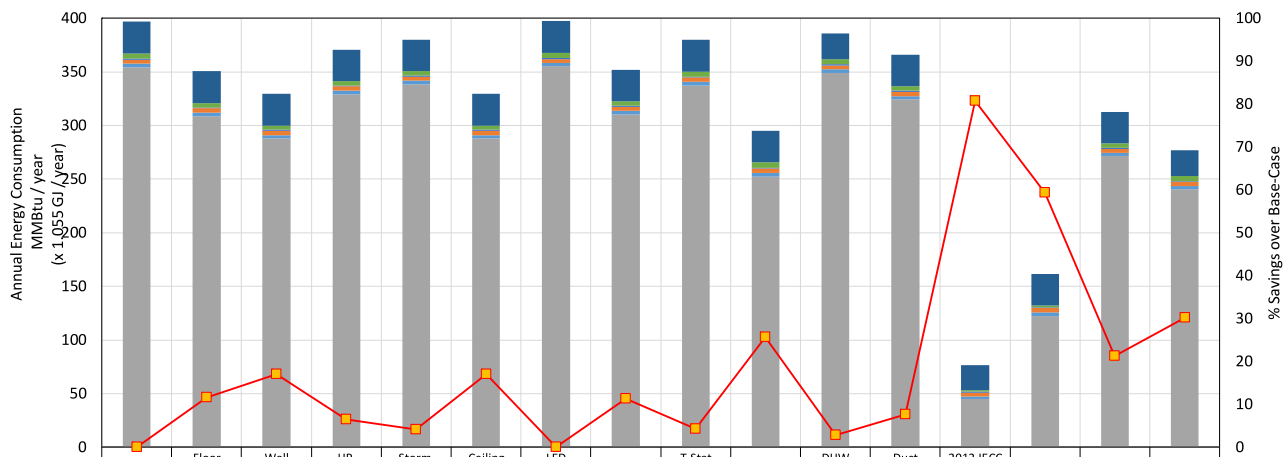
The energy retrofit measures considered for this analysis were compiled from various sources, including: Illustrated Guidelines on Sustainability for Rehabilitating Historic Buildings (Grimmer et al., 2011), Weatherization Manual compiled by the Montana Department of Public Health and Human Services (MDPHHS) (MDPHHS, 2016), and the 2012 IECC (CC, 2012). The relevant measures selected from these sources are presented in Table 2. Corresponding changes in the simulation model are described in Table 3. In addition to simulating individual measures and the code compliant measure, three packages were created based on the savings above the base-case scenario. The measures selected for these packages are presented in Table 3. Table 3 documents the inputs that have been made in the simulation model to evaluate the energy efficiency measures (EEMs), with each row documenting inputs to the individual simulation runs. The top row indicates the different inputs in the simulation model and the first column documents the different cases including the base-case as well as the energy efficiency measure being evaluated. The second row presents the inputs in the base-case simulation run. The subsequent rows document the changes made in



a) Simulation model of the 'Fullerton' model house

b) Simulation model of the 'Fullerton 'model house with surrounding trees and shading

Fig. 3. The base-case simulation model used for analysis.



	BC	Floor R-value	Wall R-value	HP Window	Storm Window	Ceiling R-value	LED Lighting	Infiltration	T.Stat Setback	AFUE	DHW EF	Duct Leakage	2012 IECC Compliant	Package 1	Package 2	Package 3
TOTAL (E+G)	396.8	350.5	329.4	370.8	380.1	329.4	397.3	352.0	379.7	295.0	385.7	366.1	76.6	161.6	312.6	276.7
DHW (G)	29.5	29.5	29.5	29.5	29.5	29.5	29.5	29.5	29.5	29.5	23.6	29.5	23.6	29.5	29.5	23.6
Vent Fans (E)	5.0	4.3	4.0	4.0	4.3	4.0	5.0	4.3	4.7	5.0	5.0	4.4	1.0	1.5	4.1	4.7
Pumps & Misc (E)	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Misc. Equipment (E)	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
Lights (E)	3.4	3.4	3.4	3.4	3.4	3.4	2.5	3.4	3.4	3.4	3.4	3.4	2.5	3.4	2.5	3.4
Space Heat (G)	354.2	308.6	287.8	329.2	338.2	287.8	355.6	310.1	337.4	252.4	349.0	324.1	44.8	122.5	271.8	240.3
% Savings	0	12	17	7	4	17	0	11	4	26	3	8	81	59	21	30

Fig. 4. Energy consumption results of the individual test cases and 2012 IECC compliant case (MMBtu/year, X 1.055 GJ/year).

the base-case model to simulate the corresponding energy efficiency measures. The changes made to the inputs in each run are highlighted.

3.5. Payback period analysis

A range of component costs were considered for this analysis including installation and first costs. These costs are provided in Table 4. The costs were established from the National Residential Efficiency Measure Database that was developed by the National Renewable Energy Laboratory (NREL, 2012) and by report by Faithful + Gould (Faithful + Gould, 2012). The database provides material and implementation costs for different retrofit measures. For residential consumption, the cost of electricity for was estimated to be \$0.10/kWh (\$29.04/GJ) and the cost of natural gas was estimated to be \$.99/Therm (\$9.39/GJ). Fuel prices for Montana were taken from report evaluating cost effectiveness for residential provisions of the 2015 IECC for Montana (Mendon et al., 2016).

Two metrics were used to evaluate the cost effectiveness of the measures: Simple payback period and life-cycle-cost (LCC) assessment. In the simple payback period[3] assessment only the costs and benefits directly related to the implementation of the energy-saving measure are considered. However, many long term factors such as escalation in fuel prices, tax effects and measure replacements are ignored in a simple payback analysis. On the other hand, the LCC analysis balances upfront costs with longer term consumer savings and includes factors such as taxes, discount rates, inflation rates and mortgage rates. In this paper, the results of the LCC analysis are reported in terms of 'Net Present Value (NPV)'[4] and 'Time until NPV'.[5] The parameters for the LCC analysis implemented in this study has been adopted from

[3] Simple payback period can be defined as the time it takes to recover the initial investment on energy savings.

[4] Net Present Value (NPV) of a project reduces the cash flows though out its life to an equivalent single present value adjusting cash flows in different years to a common year for comparison using a discount rate that accounts for the changing value of money over time. A larger positive NPVs indicate a greater feasibility for the implemented efficiency measure.

[5] Since calculating the NPV involves an acceptable rate of return for the investment, a zero NPV at a particular period of time means that the investment has returned a minimum rate of return on investment.

Table 1
Specifications for the base-case house.

Characteristics	Information sources for base-case	Specifications to match base-case	Specifications to match 2012 IECC w/ amendments
Building			
Area	Construction drawings	Total: 1248 ft^2 (115.9 m^2) Footprint: 624 ft^2 (58.0 m^2)	
Aspect ratio		1:1	
Floor-to-floor height		9 ft (2.7 m)	
Orientation		Front facing south	
Construction			
Wall construction	Construction drawings & Hendron and Engebrecht (2010)	2″ × 6″ wood studs w/ 16″ o.c. (23% framing factor) (5 cm × 15.2 cm wood studs w/ 40.6 cm o.c.)	
Roof / Ceiling construction		2 × 6 wood truss / studs w/ 16 in. o.c. (13% framing factor) (5 cm × 15.2 cm wood studs w/ 40.6 cm o.c.)	
Floor construction		2 × 6 wood studs w/ 16 in. o.c. (11% framing factor) (5 cm × 15.2 cm wood studs w/ 40.6 cm o.c.)	
Crawlspace construction		Concrete wall X feet above ground, Y feet below ground	
Crawlspace wall insulation	Hendron and Engebrecht (2010)	R-0 (0 m^2 K/W)	
Wall insulation		R-0[7] (0 m^2 K/W)	R-21 (3.69 m^2 K/W)
Roof insulation		R-0 (0 m^2 K/W)	R-49 (8.62 m^2 K/W)
Floor insulation		R-0 (0 m^2 K/W)	R-30 (5.28 m^2 K/W)
Glazing area	Construction drawings	20% window-to-wall area ratio	
Glazing U-factor	Petersen et al. (2015)	1.11[7] (6.31 W / m^2 K)	0.32 (0.46)[2] (1.82 W / m^2 K) (2.62)
Glazing SHGC		0.86	0.57 (0.54)[2]
Interior shades	CC (2012)	SHGC multiplier For heating season (November–April): 0.7 For cooling season (May–October): 0.85	
Space conditions			
Thermostat setpoint	Hendron and Engebrecht (2010)	No cooling Heating: 70 °F (21.1 °C)	
		No setback	Setback of 5 °F (2.8 °C)
Internal heat gain (Lighting + Equipment + Occupants)	Mendon et al. (2013)	64,530 Btu/day (18.9 kWh/day)	58,765 Btu/day[1] (17.2 kWh/day)
Infiltration conditioned space	CC (2012)	8 ACH_{50}	4 ACH_{50}[3,4]
Ventilation rates Attic & Crawl space[5]	CC (2012)	1 ft^2 of leakage area per 300 ft^2 of ceiling inspected (1 m^2 of leakage area per 31 m^2 of ceiling inspected)	
Mechanical systems			
Heating system	Hendron and Engebrecht (2010)	Natural gas	
Type		Forced air, natural draft furnace	Forced air, induced draft furnace
Efficiency		0.56 AFUE	0.78 AFUE
Ignition		Standing pilot light	Electronic ignition
Duct leakage[6]		Supply & Return 15%	Supply & Return 4%
Mechanical ventilation		None	Installed & operated according to specifications in the 2012 IRC
DHW heater		Natural gas	
Size		40 Gallons (0.15 m^3)	
Efficiency		EF: 0.45	EF: 0.59
DHW temperature setpoint		120 °F (48.9 °C)	

Notes:
1. The reduced internal heat gains is calculated by changing out the incandescent lighting assumed in the base-case with high efficacy lamp fixtures. The method implemented to calculate the resultant energy consumed has been adopted from the HERS Standards (Baylon and Borrelli, 2001).
2. Specifications for storm windows are provided in parenthesis (Culp and Widder, 2015).
3. The Montana code amends the requirement to R-21 (3.69 m^2 K/W) cavity with no continuous insulation.
4. The Montana code amends the 3 ACH_{50} requirement in the 2012 IECC to 4 ACH_{50}.
5. Ventilation for crawlspaces in the simulation model is switched off during winter months (November through April).
6. Duct leakage not explicitly modeled in the simulation model. Corresponding multipliers are utilized in the simulation model to account for duct leakage and duct R-value. Multipliers are referenced from HERS Standards (RESNET, 2013).
7. R-values in IP units are reported in terms of h ft^2 °F/Btu, U-values in IP units are reported in terms of Btu / h ft^2 °F.

methodology developed by the Department of Energy (DOE). The parameters are summarized in Table 5 (Mendon et al., 2016). Both metrics are described in greater detail in Taylor and Mendon (2015).

3.6. Carbon emissions analysis

Carbon emission and corresponding reductions were calculated using the Green House Gas Equivalencies Calculator that is developed and maintained by the United States Environmental Protection Agency (EPA) (U.S. Environmental Protection Agency, 2016). Resultant annual carbon emissions (tons per year) from electricity and natural gas use are calculated from established databases and methodologies. The EPA's comprehensive source of data on environment characteristics for most electric power generated in the United States, Emissions & Generation Resource

Table 2
Compilation of individual energy efficiency measures (MDPHHS, 2016).

Building category	Measure
Windows	○ Installing interior or exterior storm windows or panels that are compatible with existing historic windows ○ Installing compatible and energy-efficient replacement windows that match the appearance, size, design, proportion and profile of the existing historic windows and that are also durable, repairable and recyclable, when existing windows are too deteriorated to repair ○ Retrofitting historic windows with high-performance glazing or clear film, only if the historic character can be maintained ○ Installing clear, low-emissivity (low-e) glass or film without noticeable color in historically-clear windows to reduce solar heat gain ○ Repairing or reopening historically-operable interior transoms, to improve air flow and cross ventilation ○ Removable film on windows (if the film is transparent), solar screens, or window louvers, in a manner that does not harm or obscure historic windows or trim ○ Storm windows or doors, and wood screen doors in a manner that does not harm or obscure historic windows or trim
Insulation	○ Insulating unfinished spaces such as attics, basements and crawlspaces ○ Using appropriate type of insulation in unfinished spaces and ensuring the space is adequately ventilated ○ Ensuring that air infiltration is reduced before adding wall insulation ○ Installing appropriate wall insulation, only after lower impact treatments have been carried out prior ○ Insulation, such as non-toxic fiberglass and foil wrapped, in walls, floors, ceilings, attics, and foundations in a manner that does not harm or damage historic fabric ○ Blown-in wall insulation where no holes are drilled through exterior siding, or where holes have no permanent visible alteration to the structure
Infiltration	○ Weather-stripping and caulking historic windows, when appropriate, to make them weather tight ○ Air sealing of the building shell, including caulking, weather-stripping, and other air infiltration control measures on windows and doors, and installing thresholds in a manner that does not harm or obscure historic windows or trim
Mechanical systems	○ Upgrading existing HVAC systems to increase efficiency and performance within normal replacement cycles ○ Installing an energy-efficient system that takes into account whole building performance and retains the historic character of the building and site when a new HVAC system is necessary ○ Supplementing the efficiency of HVAC systems with less energy-intensive measures, such as programmable thermostats, attic and ceiling fans, louvers and vents, where appropriate ○ Retaining or installing high efficiency, ductless air conditioners when appropriate, which may be a more sensitive approach than installing a new, ducted, central air-conditioning system that may damage historic building material ○ Repair or replacement of water heaters ○ Install insulation on water heater tanks and water heating pipes ○ Conduct other efficiency improvements on heating and cooling systems, including replacing pilot lights with electronic ignition devices, and installing vent dampers ○ Modify duct and pipe systems so heating and cooling systems operate efficiently and effectively, including adding return ducts, replace diffusers and registers, replace air filters, install thermostatic radiator controls on steam and hot water heating systems. ○ Install programmable thermostats, outdoor reset controls, UL listed energy management systems or building automation systems and other HVAC control systems
Lighting systems	○ Electrical work, including improving lamp efficiency ○ Incorporate other lighting technologies such as dimmable ballasts, daylighting controls, and occupant controlled dimming

Integrated Database (eGRID), and their Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1900–2011 are typical sources (U.S. Environmental Protection Agency, 2012, 2013).

4. Results

Energy consumption of the base-case residential building, various individual energy efficiency strategies and packages are presented in Fig. 4. In addition, the figure presents the percent savings of total energy consumption over the base-case energy consumption for the various strategies.

4.1. Energy performance of base-case, individual energy efficiency measures and 2012 IECC compliant model

As expected, the energy consumption of the base-case building was dominated by space heating, which amounted to 89% percent of the total annual energy consumption. Hence, when considering the energy performance of individual measures, strategies that could reduce energy consumption from space heating were found to be most effective. For example, it was observed that improving the AFUE provided energy savings of 26%. Measures such as improving wall R-value and ceiling R-value provided energy savings of 17%. Improving the floor insulation and infiltration resulted in energy savings of 12% and 11% respectively. Implementing measures such as installation of a programmable thermostat provided savings of 4% and improving duct tightness provided a saving of 8% over the corresponding energy consumption of the base-case model.

Improvements in lighting were not effective as an individual measure. No savings were observed on implementing high efficiency lighting fixtures. It should be noted that in the base-case building, lighting and appliances loads accounted for only 2% of the total energy consumption. However, when combined with other measures, this sub-category forms an increasingly larger portion of the total energy consumption (i.e., 8%). Therefore, implementing high efficiency lighting can contribute to the reduction in energy consumption. Implementing energy efficient windows did not have a significant impact on the reduction in energy consumption. Measures such as improved window characteristics provided minimal savings of 7% and installation of storm windows reduced the energy consumption by 4%. This is because the windows covered only a small area (i.e., 20%) of the exterior walls.

When combining the measures together into a simulation model representing a 2012 IECC compliant residential building, 81% savings were achieved over the corresponding energy consumption of the base-case model. When considering various efficiency packages: Package 1, 2 and 3 provided savings of 59%, 21% and 30%, respectively.

4.2. Assessment of simple payback periods and time until zero NPV

A different picture emerges when conducting a simple payback and LLC analysis of the individual efficiency measures, the three packages, and the 2012 IECC compliant case. The availability of inexpensive natural gas coupled with modest energy savings

Table 3
Specifications for individual energy efficiency measures.

Base-case / EEM Cases	Floor R-value h.°F ft²/ Btu (m²K/W)	Wall R-value h.°F ft²/ Btu (m²K/W)	Window U-value Btu/h. °F ft² (W/m²K)	Window SHGC	Ceiling R-value h.°F ft²/ Btu (m²K/W)	Internal Heat Gains Btu/day (GJ/day)	Infiltration ACH_{50}	Thermostat Setback	AFUE	DHW EF	Distribution System Efficiency
Base-case	**R-0 (0)**	**R-0 (0)**	**1.11 (6.31)**	**0.86**	**R-0 (0)**	**64,530 (0.07)**	**15**	**None**	**56%**	**0.45**	**0.8**
Envelope											
Floor R-value	**R-19 (3.34)**	**R-0 (0)**	**1.11 (6.31)**	**0.86**	**R-0 (0)**	**64,530 (0.07)**	**15**	**None**	**56%**	**0.45**	**0.8**
Wall R-value	**R-0 (0)**	**R-21 (3.69)**	**1.11 (6.31)**	**0.86**	**R-0 (0)**	**64,530 (0.07)**	**15**	**None**	**56%**	**0.45**	**0.8**
HP Window	**R-0 (0)**	**R-0 (0)**	**0.32 (1.82)**	**0.57**	**R-0 (0)**	**64,530 (0.07)**	**15**	**None**	**56%**	**0.45**	**0.8**
Storm Window	**R-0 (0)**	**R-0 (0)**	**0.46 (2.62)**	**0.54**	**R-0 (0)**	**64,530 (0.07)**	**15**	**None**	**56%**	**0.45**	**0.8**
Roof R-value	**R-0 (0)**	**R-0 (0)**	**1.11 (6.31)**	**0.86**	**R-49 (8.62)**	**64,530 (0.07)**	**15**	**None**	**56%**	**0.45**	**0.8**
Space Conditions											
Reduced LPD	**R-0 (0)**	**R-0 (0)**	**1.11 (6.31)**	**0.86**	**R-0 (0)**	**58,765 (0.06)**	**15**	**None**	**56%**	**0.45**	**0.8**
Infiltration	**R-0 (0)**	**R-0 (0)**	**1.11 (6.31)**	**0.86**	**R-0 (0)**	**64,530 (0.07)**	**4**	**None**	**56%**	**0.45**	**0.8**
T. Setback	**R-0 (0)**	**R-0 (0)**	**1.11 (6.31)**	**0.86**	**R-0 (0)**	**64,530 (0.07)**	**15**	**5 (2.8)**	**56%**	**0.45**	**0.8**
Mechanical											
AFUE	**R-0 (0)**	**R-0 (0)**	**1.11 (6.31)**	**0.86**	**R-0 (0)**	**64,530 (0.07)**	**15**	**None**	**78%**	**0.45**	**0.8**
DHW EF	**R-0 (0)**	**R-0 (0)**	**1.11 (6.31)**	**0.86**	**R-0 (0)**	**64,530 (0.07)**	**15**	**None**	**56%**	**0.59**	**0.8**
Duct Leakage	**R-0 (0)**	**R-0 (0)**	**1.11 (6.31)**	**0.86**	**R-0 (0)**	**64,530 (0.07)**	**15**	**None**	**56%**	**0.45**	**0.88**
Packages											
Package 1	**R-19 (3.34)**	**R-21 (3.69)**	**1.11 (6.31)**	**0.86**	**R-49 (8.62)**	**64,530 (0.07)**	**4**	**None**	**56%**	**0.45**	**0.8**
Package 2	**R-0 (0)**	**R-0 (0)**	**1.11 (6.31)**	**0.86**	**R-0 (0)**	**58,765 (0.06)**	**4**	**5 (2.8)**	**56%**	**0.45**	**0.88**
Package 3	**R-0 (0)**	**R-0 (0)**	**1.11 (6.31)**	**0.86**	**R-0 (0)**	**64,530 (0.07)**	**15**	**5 (2.8)**	**78%**	**0.59**	**0.88**
Code-compliant	**R-19 (3.34)**	**R-21 (3.69)**	**0.32 (1.82)**	**0.57**	**R-49 (8.62)**	**58,765 (0.06)**	**4**	**5 (2.8)**	**78%**	**0.59**	**0.88**

Notes:
1. HP: High performance.
2. LPD: Lighting Power Density.
3. T: Thermostat.
4. AFUE: Annual Fuel Utilization Efficiency.
5. DHW EF: Domestic Hot Water Energy Factor.

for different measures and low usage rates of energy efficient systems (i.e., lighting) can be attributed to long payback periods exhibited by certain efficiency measures as presented in Table 6.

When considering simple payback periods, measures that improved the specifications of the building envelope such as the installation of floor, wall and roof insulation, paybacks ranged between 1–10 years. On the other hand, improvement to windows provided simple payback periods between 7–26 years. LCC analysis revealed that efficiency measures such as improved floor R-value and ceiling R-values were more viable in terms of shorter time to repay the loans and interests associated with the installation of these measures (i.e, time until zero NPV between 1.5–6.5 years). On the other hand the installation of improved windows resulted in a repayment period of greater than 30 years. This is because of the small window-to-wall area ratio and high first costs associated with the installation of these windows.

When considering space conditions: measures such as improved lighting efficiency provided simple payback period of 5–11 years; reducing infiltration provided simple payback periods of 3–10 years; and installation of programmable thermostat provided a simple payback period of 0–2 years. LCC analysis resulted in repayment period of greater than 30 years for installation of LED lighting systems. The measure for improved lighting efficiency is not seen as viable because of the short hours of operation input as schedules in the simulation model resulting in very small reduction in resultant electricity consumption. In addition, the implementation of energy efficient LED lights also resulted in a slight increase in heating energy consumption, negatively impacting the overall energy reduction obtained from implementing this measure. For the measure of reduced infiltration, the LCC revealed a large range of values for time until zero NPV depending on the cost of measure. Measures such as caulking and weather stripping can be considered as low cost

Table 4
Cost estimates (per unit) for energy efficiency measures[1].

Component	Minimum cost		Maximum cost	Unit	Service life[9]
Envelope components					
Floor insulation, R-30 fiberglass batt	0.82 (8.91)	–	1.50 (16.30)	$/ft^2 of floor area over crawlspace ($/m^2)	30 years
Wall insulation[3], R-19 cellulose, 2 × 6	2.00 (21.74)	–	4.20 (45.65)	$/ft^2 of wall area ($/m^2)	30 years
Double-pane, high-gain low-E, nonmetal frame, air fill	22.00 (239.13)	–	43.00 (467.39)	$/ft^2 of window area ($/m^2)	30 years
Single-pane, clear, non-metal frame, clear storm	7.20 (78.26)	–	14.00 (152.17)	$/ft^2 of window area ($/m^2)	30 years
Ceiling insulation, R-49 fiberglass	1.60 (17.39)	–	3.40 (36.96)	$/ft^2 of floor area under attic ($/m^2)	30 years
Space conditions					
LED lighting	2.90	–	6.40	Per lamp	10 years
Reducing infiltration[4,5], 4 ACH_{50}	1.00 (10.87)	–	3.80 (41.30)	$/ft^2 of floor area ($/m^2)	30 years
Mechanical					
Duct tightness[6], 7.5% leakage, R-8 insulation	1.40 (15.22)	–	3.20 (34.78)	$/per ft^2 of duct surface area ($/m^2)	N.A
Gas furnace[7], 98% AFUE	17.00 (4.98)	–	34.00 (9.96)	$/kBtu/h of heating capacity ($/kW)	15 years
Programmable thermostat	63.00		320.00	$/per unit	15 years
DHW heater[8], EF = 0.67	450.00	–	940.00	$/per unit	15 years

Notes:
1. Pricing reflects material, installation, and construction costs.
2. Based on cost of R-20 batt insulation, R-5 exterior insulation and 2″ × 6″ framing on 24 in. o.c. (i.e., extruded polystyrene sheathing).
3. Not inclusive of envelope testing.
4. Assumes improvement from 2006 IECC specifications, which are assumed by the base-case in this analysis.
5. Not inclusive of duct testing.
6. Size of furnace assumed to be 75,000 Btu/h.
7. Based on 40-gallon tank water heater.
8. Based on R-3 insulation requirements of hot water pipes as specified in 2012 IECC, estimates for a 1200 ft^2 dwelling unit.
9. Service life for building materials such as insulation, windows and infiltration reduction methods was assumed to be the same as that of the evaluation period considered by this study (i.e., 30 years). On the other hand, service life for LED lamp replacements, heating equipment and water heaters was estimated from standard practice.

Table 5
Economic parameters used in analysis (Mendon et al., 2016).

Parameter	Value
Mortgage interest rate (fixed rate)	5.0%
Loan fees	0.6% of the mortgage amount
Loan term	30 years
Down payment	10% of home value
Nominal discount rate	5.0%
Inflation rate	1.60%
Marginal federal income tax	15%
Marginal state income tax	6.90%
Property tax	1.10%

and can be extremely viable. On the other hand, measures such as installation of air barriers and house wraps require higher investment. Implementing thermostat setbacks proved to be very effective with values for time until zero NPV indicating short repayment periods between 1 and 3.5 years.

Measures involving improved mechanical systems such as installation of an improved efficiency furnace provided a simple payback period of 1–2 years depending of the type of furnace installed. Installation of efficient water heater provided a simple payback period in the range of 6–7 years. Reducing duct leakage provided a simple payback period in the range of 0–1 years. When considering results from the LCC analysis, implementation of efficient furnace resulted in time until zero NPV between 1.5 and 2.5 years, while installation of efficient DHW resulted in repayment period of greater than 30 years. Measures for improved AFUE and DHW considered replacement costs of equipment every 15 years. The long payback period for the installation of DHW heaters is due to the relatively low consumption of hot water and the cheap cost of natural gas. The LCC analysis also indicated the viability of reducing duct leakage with time until zero NPV between 1 and 1.5 years.

When considering payback periods for the 2012 IECC compliant house, the simple payback periods were in the range of 4–8 years, while the time until zero NPV was in the range of 9.5 to greater than 30 years. Implementing Package 1, which included improved building envelope insulation (i.e., floor, ceiling and wall R-value) and methods to reduce infiltration, provided a simple payback period between 2 to 6 years and time until zero NPV between 4.5 and 30 years. Implementing Package 2, which included implementation of improved lighting systems, reduced infiltration and thermostat setback, provided a simple payback period between 2 to 6 years and time until zero NPV between 3.5 and 30 years. Finally, implementing Package 3, which included the implementation of thermostat setback and improved mechanical systems, provided a simple payback period between 1 to 2 years and time until zero NPV between 2.5 and 4.5 years.

4.3. Assessment of reductions in carbon emission

When considering reductions in carbon emissions due to the implementation of individual efficiency measures, reductions in the range of 0–5 tons per year of carbon were observed from implementing individual measures, with measures for improved building envelope and efficient AFUE providing maximum reductions in CO2 emissions because of the substantial impact these measures make on resultant energy (electricity + natural gas) consumption.

When measures were combined to form 2012 IECC compliant case, annual reductions in carbon emissions was 18 tons per year. Implementation of Package 1 resulted in carbon emissions of 13 tons per year, implementation of Package 2 resulted in carbon

Table 6
Payback analysis of the individual test cases and 2012 IECC compliant case[a].

Efficiency measure	CO2 emissions reduction	Energy costs			Upgrade costs			Simple payback			NPV at end of 30 years			Time until zero NPV		
		Electricity	Natural gas	Annual energy savings												
	(Tons/year)	($)	($)	($)	($)			(Years)			($)			(Years)		
Improved floor R-value	3	22	451	473	512	–	936	1	–	2	4,626	–	3,763	1.5	–	3.5
Improved wall R-value	4	32	657	689	3,154	–	6,622	5	–	10	1,833	–	−5,299	13.5	–	>30
High performance windows	2	30	248	277	3,696	–	7,224	13	–	26	−4,227	–	−11,411	>30	–	>30
Storm windows	1	23	158	181	1,210		2,352	7	–	13	−313	–	−2,638	>30	–	>30
Improved ceiling R-value	4	32	657	689	998	–	2,122	1	–	3	6,223	–	3,934	2.5	–	6.5
Reduced LPD	0	28	−14	14	73	–	160	5	–	11	−123	–	− 440	>30	–	>30
Reduced infiltration	2	21	437	458	1,248	–	4,742	3	–	10	2,477	–	−5,940	5.5	–	>30
Thermostat setback	1	8	166	175	63	–	320	0	–	2	1,900	–	1,124	1	–	3.5
Improved AFUE	5	0	1008	1008	688	–	1,500	1	–	2	10,044	–	7,592	1.5	–	2.5
Improved DHW energy factor	1	0	110	110	617	–	787	6	–	7	−541	–	−1,054	>30	–	>30
Reduced duct leakage	2	17	298	315	125	–	225	0	–	1	3,517	–	3,313	1	–	1.5
2012 IECC compliant	**18**	**155**	**3121**	**3277**	**12,383**	–	**26,990**	**4**	–	**8**	**12,561**	–	**−18,543**	**9.5**	–	>30
Package 1	**13**	**111**	2294	2405	**5,912**		**14,422**	**2**		**6**	**16,761**	–	**− 569**	**4.5**	–	>30
Package 2	**5**	**57**	816	872	**1,508**		**5,447**	**2**		**6**	**7,181**	–	**−1,233**	**3.5**	–	>30
Package 3	**6**	**8**	1186	1194	**1,493**		**2,832**	**1**		**2**	**9,969**	–	**6,025**	**2.5**	–	**4.5**

[a]The two columns for Simple Payback, NPV at the end of 30 years and Time until zero NPV take into consideration a range of upgrade costs established from the literature review.

emissions of 5 tons per year, and implementation of Package 3 resulted in carbon emissions of 6 tons per year. Results of reductions in carbon emissions are presented in Table 6.

5. Conclusions & recommendations

With growth in urban populations in cities such as Havre in Montana, impact on existing infrastructure is substantial. To alleviate this strain on the existing infrastructure the rehabilitation of historic building stock is eminent. In order to do so numerous constraints that are specific to such buildings have to be considered. The NPS has provided guidelines for sustainable rehabilitation. However, the measures provided in these guidelines have not been quantitatively validated for cold dry climates of Montana. This paper provides a quantitative assessment of these measures and paybacks associated with the implementation of these measures.

With an LCC analysis providing results between 9.5 and > 30 years for return on investment, the IECC compliant test case is not economically justifiable. However, combined implementation of measures resulting in a 2012 IECC compliance makes significant impact on both energy consumption and existing energy infrastructure contributing to the significant reduction in energy consumption (i.e., savings of 81%) as well as annual carbon emissions (i.e., reduction of 18 tons per year) of residential building stock in the United States. This in turn can be used to justify the preservation and rehabilitation of historic districts in the United States.

As an alternative to the IECC compliant case, the implementation of packages focusing on envelope, space conditions, and mechanical conditions are highly recommended to improve energy efficiency at affordable material and installation costs. In addition, implementation of certain individual energy efficiency measures for building such as improved floor and ceiling R-values, and improved AFUE also provide justifiable paybacks in the range of 2.5 to 6.5 years. With energy savings over the base-case ranging from 12%–26% and carbon emission reductions between 2–5 tons per year, the implementation of these measures provide a viable cost effective alternates to demonstrate energy savings for historic housing retrofits.

Acknowledgments

Review and comments by Professor Jeff Haberl at Texas A&M University, Dr. Mini Malhotra Oakridge National Laboratory, and Mr. Duke Elliot University Facilities Montana State University are gratefully acknowledged.

References

Baylon, D., Borrelli, S., 2001. Market Research Report – Baseline Characteristics of the Residential Sector. Idaho, Montana, Oregon and Washington. Report Number 01-095. Ecotope Consulting Research Design, Seattle WA.

Cabrera, M.J., 2016. Energy Optimization: Mail Order Homes in a Historic District. (Unpublished thesis). School of Architecture, Montana State University, Bozeman, MT.

CC, I., 2012. International Energy Conservation Code 2012 (IECC 2012). Falls Church. VA: International Code Council.

Culp, T., Widder, S., 2015. Thermal and Optical Properties of Low-E Storm Windows and Panels. PNNL-24444. Pacific Northwest National Laboratory, Richland, WA.

Dupont, W., Rashed-Ali, R., Manteufel, T., Thompson, L., Sanciuc, H., Energy Retrofits of Older Homes in Hot and Humid Climates. APT Bulletin Journal of Preservation Technolog/ 47: 1.

Faithful + Gould. 2012. Residential Energy Efficiency Measures: Prototype Estimate and Cost Data. Faithful+Gould for Pacific Northwest National Laboratory. Available at: http://bc3.pnnl.gov/sites/default/files/Residential_Report.pdf.

Frey, P., Harris, R., Huppert, M., 2012. Saving Windows, Saving Money: Evaluating the Energy Performance of Window Retrofit and Replacement. Preservation Green Lab, Seattle, WA, Web: https://www.ncptt.nps.gov/blog/saving-windows-saving-money/ (Accessed: 12/30/2016).

Grimmer, A., Hensley, L., Petrella, A., Tepper, J.E., 2011. The Secretary of the Interiors Standards for Rehabilitation and illustrated Guidelines on Sustainability for Rehabilitating Historic Buildings. US Department of the Interior National Park Service Technical Preservation Services, Washington DC.

Havre Historic Preservation Commission, N.D. Havre Residential Historic District Walking Tour Map. Web: https://mhs.mt.gov/Portals/11/shpo/docs/havre.pdf (Accessed: 8/8/2018).

Hendron, R., Engebrecht, C., 2010. Building America House Simulation Protocols. NREL Report/Project Number: NREL/TP-550-49426. National Renewable Energy Laboratory, Golden CO.

Horton, D., 2014. Montana Residential Energy Code Handbook – A Guide to Complying with Montana's Residential Energy Code. National Center for Applied Technology (NCAT), Butte Montana.

Location of Havre Montana. N.D. Havre, Montana Wikipedia. Web: https://en.wikipedia.org/wiki/Havre,_Montana (Accessed: 8/8/2018).

Map of Havre, Montana. Google Maps. Web: https://www.google.com/maps/place/Havre,+MT+59501/@48.5424132,-109.6755558,14z/data=!4m5!3m4!1s0x53401cbe0cfc8309:0xebf50fa5ec180aa1!8m2!3d48.549999!4d-109.6840887 (Accessed: 8/8/2018).

MDPHHS, 2016. Weatherization Manual. Montana Department of Public Health and Human Services.

Mendon, V., Lucas, R., Goel, S., 2013. Cost-Effectiveness Analysis of the 2009 and 2012 IECC Residential Provisions –Technical Support Document. PNNL – 22068. Pacific Northwest Energy Laboratory, Richland, WA.

Mendon, V., Zhao, A., Taylor, E., Poehlman, M., 2016. Cost-Effectiveness Analysis of the Residential Provisions of the 2015 IECC for Montana. PNNL-24929 Rev 1. Pacific Northwest National Laboratory, Richland WA.

Miller, J., 2014. The Aging Housing Stock. Eye on Housing, National Association of Home Builders. Web: http://eyeonhousing.org/2014/01/the-aging-housing-stock/ (Accessed: 12/30/2016).

Moran, F., Blight, T., Natarajan, S., Shea, A., 2014. The use of passive house planning package to reduce energy use and co2 emissions in historic dwellings. Energy Build. 75, 216–227.

Morton, W., Hume, G., Weeks, K., et al., 1997. The Secretary of the Interiors Standards for Rehabilitation & Illustrated Guidelines for Rehabilitating Historic Buildings. US Department of the Interior National Park Service, Heritage Preservation Services, Washington DC.

National Register Bulletin 1995. How to Apply the National Register Criteria for Evaluation. U.S. Department of the Interior, Washington D.C.

NREL, 2012. National Residential Efficiency Measures Database. Development Document v30. National Renewable Energy Laboratory, Golden CO.

Park, S., 1998. Sustainable design and historic preservation. Cultural Resour. Manag.: J. Herit. Stewardship 21 (2), Web: http://tusculum.sbc.edu/toolkit/toolkit_pdfs/Park,Sharon_SustainableDesignHPpdf (Accessed: 8/8/2018).

Petersen, J., Merzouk, G., Sullivan, J., Weber, K., Cort, M., 2015. Evaluation of Interior Low-E Storm Windows in the PNNL Lab Homes. PNNL-24827. Pacific Northwest National Laboratory, Richland, WA.

RESNET, 2013. Mortgage Industry National Home Energy Rating Systems Standards. Residential Energy Services Network, Oceanside, CA.

Sears, Roebuck and Co. 2006. Sears Modern Homes, 1913. Dover Publications, Inc. Mineola, NY.

State Historic Preservation Office. 2013. Preserving Montana - The Montana Historic Preservation Plan, 2013 – 2017. State Historic Preservation Office Montana Historical Society, Helena, MT.

Sullivan, R., Winkelmann, F., 1998. Validation Studies of the DOE-2 Building Energy Simulation Program. Final Report. LBNL-42241. Environmental Energy Technology Division. Lawrence Berkeley National Lab, Berkeley CA.

Taylor, Z., Mendon, V., 2015. Methodology for Evaluating Cost-Effectiveness of Residential Energy Code Changes. PNNL-21294 Rev 1. Pacific Northwest National Laboratory, Richland WA.

Technical Preservation Services. The Secretary of the Interior's Standards: A History of the Secretary of the Interior's Standards. Web: https://www.nps.gov/tps/standards/history-of-standards.htm.

U.S. Energy Information Administration. 2013. Newer U.S. homes are 30% larger but consume about as much energy as older homes. Web: http://www.eia.gov/todayinenergy/detail.php?id=9951&src=%E2%80%B9%20Consumption%20%20%20%20%20%20Residential%20Energy%20Consumption%20Survey%20(RECS)-f2 (Accessed: 12/30/2016).

U.S. Environmental Protection Agency. US EPA. 2012. The Emissions & Generation Resource Integrated Database – Technical Support Document for eGRID with Year 2012 Data. Available at: https://www.epa.gov/sites/production/files/2015-10/documents/egrid2012_technicalsupportdocument.pdf.

U.S. Environmental Protection Agency. 2013. U.S. EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2011. Available at: https://www3.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2013-Main-Text.pdf.

U.S. Environmental Protection Agency. US EPA. 2016. Carbon Footprint Calculator. Available at: https://www3.epa.gov/carbon-footprint-calculator/.

Web: Building Codes Assistance Project. 2018. State Code Status: Montana, History. Web: https://bcapcodes.org/code-status/state/montana/ (Accessed: 8/8/2018).

Weeks, K., Grimmer, A., 1995. The Secretary of the Interior's Standards for the Treatment of Historic Properties with Guidelines for Preserving, Rehabilitating, Restoring & Reconstructing Historic Buildings. U.S. Department of the Interior National Park Service Cultural Resource Stewardship and Partnerships, Heritage Preservation Services, Washington DC.

Wilcox, S., Marion, W., 2008. User's Manual for TMY3 Data Sets. NREL/TP-581-43156. National Renewable Energy Laboratory, Golden CO.

Winkelmann, F.C., Birdsall, W.F., Buhl, K.L., Ellington, A.E., Erdem, J.J., Hirsch, B.E., Gates, S., 1993. DOE-2 Supplement, Version 2.1e. LBL-34947. Regents of the University of California, Lawrence Berkley Laboratory, Berkeley, CA.