A DESIGN APPROACH TO ACHIEVING THE PASSIVE HOUSE STANDARD IN A HOME ENERGY RETROFIT

by

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Passive House is a voluntary, performance-based energy standard for buildings. Passive Houses use on average 90% less energy for space conditioning than code-designed houses; Passive House therefore offers an ambitious performance target for home energy retrofits. Retrofits built to the Passive House standard in Europe have demonstrated a high level of energy performance. In the U.S., few Passive House retrofits exist to date; for this reason, design and cost information for such retrofits is lacking. This study establishes an exemplar through designing the Passive House retrofit of an older home in Eugene, Oregon. The retrofit's cost-effectiveness was examined by comparing projected "business as usual" (BAU) life cycle costs to those associated with retrofit. While the BAU scenario resulted in the lowest cost over a 30-year life cycle, the difference is relatively small; minor adjustments to key variables make the retrofit financially viable.

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CHAPTER I

INTRODUCTION

Background

Energy Use in the Residential Sector

According to the U.S. Energy Information Administration, the residential sector is responsible for 22% of end-use energy consumption in the United States.[1] This statistic places a substantial portion of the responsibility for fossil fuel use and greenhouse gas emissions on housing. In addition to its environmental consequences, the housing stock's poor energy performance has a detrimental effect on the national economy, as high energy bills inflate monthly expenditures for cash-strapped homeowners already struggling to make ends meet. While new housing units must be designed to perform more efficiently, the greatest potential for improvement lies in the existing housing stock – particularly in homes built before 1970.[2]

Energy Retrofits

One solution to poor energy performance in an existing residential building is to perform an energy retrofit. Home energy retrofits first appeared during the energy crisis of the 1970's as a means of bringing older residential buildings up to current energy standards and often involve interventions such as replacing windows, increasing insulation, updating HVAC systems, and incorporating renewable energy sources such as photovoltaics. Though a variety of strategies may be implemented, energy retrofits are typically focused on improving the efficiency of the building envelope and HVAC system; over 70% of the energy efficiency potential in an existing residential building lies in improvements to these building systems.[3] Energy retrofits offer a means of maintaining the

[1] U.S. Energy Information Administration, 2010b

[2] Choi Granade et al., 2009

[3] Choi Granade et al., 2009

embodied value (economic, historic, or otherwise) in an existing home while improving upon its energy performance.

Recently, policymakers have come to realize the viability of energy retrofits in addressing the efficiency of the U.S. residential sector. In 2009, by way of federal investments from the American Recovery and Reinvestment Act (Recovery Act), the U.S. Department of Energy under the Obama administration budgeted $450 million to catalyze the retrofit of existing buildings.[4] The same year, the White House Council on Environmental Quality published the *Recovery Through Retrofit* Report, in which the executive branch acknowledged the economic benefits of retrofit: "Home retrofits can potentially help people earn money, as home retrofit workers, while also helping them save money, by lowering their utility bills. By encouraging nationwide weatherization of homes, workers of all skill levels will be trained, engaged, and will participate in ramping up a national home retrofit market."[5]

While policymakers realize the potential in energy retrofits, they also acknowledge that such retrofits must be affordable if homeowners are to invest in them. In the *Recovery Through Retrofit* Report, the Council on Environmental Quality states, "the upfront costs of home retrofit projects are often beyond the average homeowner's budget."[6] Fortunately, financial incentives at the federal, state, and local levels are already in place to help homeowners fund energy retrofit projects. The U.S. Department of Energy now provides tax credits to homeowners for a variety of energy efficiency measures. Additionally, state organizations, such as the Oregon Department of Energy, offer tax credits to homeowners who invest in energy upgrades.[7] At the local level, utilities such as the Eugene Water and Electric Board (EWEB) in Eugene, Oregon provide monetary incentives to homeowners for various improvements that reduce household energy use.[8]

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[4] U.S. Department of Energy, 2009

[5] United States, Middle Class Task Force, Council on Environmental Quality, 2009

[6] United States, Middle Class Task Force, Council on Environmental Quality, 2009

[7] Oregon Department of Energy, 2011

[8] Eugene Water and Electric Board, n.d.

The Passive House Standard

Though many standards for home energy performance exist, none is as stringent as Passive House. Professor Bo Adamson and Dr. Wolfgang Feist developed the Passive House concept in Germany in the 1980's and built the first Passive House prototype in 1990.[9] In 1996, Dr. Feist founded the Passive House Institute in Darmstadt, Germany.[10] Since then, over 15,000 residential, commercial, and institutional buildings have achieved the standard throughout Europe.[11] Passive House has recently gained traction in the United States, with a dozen or so buildings currently certified and countless others in various stages of certification.[12]

The Passive House standard is entirely performance-based; the performance requirements are outlined in Table 1 alongside the corresponding method of verification. The energy use requirements are verified using the Passive House Planning Package (PHPP), the Passive House Institute's energy modeling software for use in the design and verification of Passive House buildings. This software is discussed in more detail in Chapter III.

Table 1: Passive House performance requirements

Performance Requirement	**Limiting Value**	**Verification Technique**
Specific Space Heat Energy Demand	≤ 4.75 kBTU/(ft^{2}yr)	Passive House Planning Package
Specific Useful Cooling Energy Demand	≤ 4.75 kBTU/(ft^{2}yr)	Passive House Planning Package
Specific Primary Energy Demand	≤ 38.0 kBTU/(ft^{2}yr)	Passive House Planning Package
Pressurization Test Result	≤ 0.60 ACH_{50}	Blower Door Test

Due to Passive House's stringent performance requirements, a Passive House on average uses 90% less energy for heating and cooling than a code-designed house.[13]

[9] Kernagis, 2008

[10] Kernagis

[11] Wilson, 2010

[12] Information gathered during the Passive House Consultant Training Program in Washington, D.C., 2010

[13] Klingenberg, Kernagis, and James, 2009

Passive Houses achieve the stringent performance requirements listed in Table 1 through careful design and construction. First, a Passive House typically has a compact shape in order to minimize building surface area relative to volume, thereby reducing heat loss through the envelope.[14] Additionally, the building envelope must be superinsulated and thermal bridge free. Thermal bridges are continuous, uninsulated paths of material through an assembly by which heat transfers via conduction. Thermal bridges become sources of heat loss in a building envelope. Examples of thermal bridges include wood or metal studs, window frames, and plumbing penetrations. The building envelope must be thoughtfully detailed – particularly at connections – in order to keep thermal bridges to an absolute minimum.

In addition to being superinsulated, the Passive House envelope must be airtight. Air leakage, or infiltration, can be a major source of heat loss in a home. Every Passive House maintains a carefully detailed airtight layer to minimize heat loss due to infiltration. Of course, airtightness can create problems in terms of moisture and indoor air quality. For this reason, every Passive House is equipped with a heat recovery ventilator (HRV), a small device which consists of a low energy fan and a heat exchanger. During the winter, the unit runs continuously as it exhausts building air and intakes fresh air simultaneously. As the two air volumes move over the heat exchange element, the warm exhaust air exchanges its heat with the cold intake air. This incredibly efficient system continuously ventilates the building without giving up heating energy produced inside the envelope.

While typically applied to new construction, the Passive House standard can also be achieved in the retrofit of an existing building. Until recently, Passive House retrofits have been confined to Europe. In 2010, the first Passive House retrofit in the U.S. was completed in Sonoma, California.[15] Described in detail in Chapter II, the Sonoma retrofit illustrates the potential for the Passive House standard to serve as an ambitious performance benchmark for home energy retrofits in U.S. climates.

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[14] Stecher and Klingenberg, 2008

[15] Defendorf, 2010

Eugene, Oregon

Eugene, Oregon is located along Interstate 5 in the Willamette Valley approximately 110 miles south of Portland. In 2008, the city's population was estimated at 154,620.[16]

Climate

Located in the Marine West Coast climate[17] at approximately 44°N latitude, Eugene experiences dry, mild summers and wet, mild winters. Eugene's climate is heating dominated, as homes require active heating systems for occupant comfort in the winter, while passive strategies such as natural ventilation are usually adequate for summer cooling. Like most of the Pacific Northwest, Eugene experiences considerable rainfall and averages 50.9 inches of precipitation annually.[18] The vast majority of this precipitation occurs between fall and spring. Summers in Eugene are exceptionally clear and mild, keeping the cooling demand to a minimum. Table 2 includes summer and winter design data for Eugene.

Table 2: Eugene climate data

Climate Data	**Value**
Heating Degree Days	4546 HDD65°F
Winter Design Temperature	25.6°F
Cooling Degree Days	2354 CDH50°F
Summer Design Temperature	83.5°F

Source: Grondzik, Kwok, Stein, & Reynolds, 2010

Housing Stock

According to the U.S. Census Bureau, there are over 68,000 housing units in Eugene, Oregon; about 38,000 (or 56%) of these units are single family detached homes. Approximately 40%

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[16] Portland State University, Population Research Center, 2009

[17] Peel, Finlayson, and McMahon, 2007

[18] National Climatic Data Center, 2004

of the Eugene housing stock was constructed before 1970;[19] consequently, a significant portion of Eugene's housing stock has a high potential for energy efficiency improvements through retrofit. Due to relatively mild summer temperatures in the Willamette Valley, Eugene homes are rarely fitted with active cooling systems and simply rely on passive strategies such as natural ventilation. Through the application of Passive House strategies, conventional heating systems can be eliminated by relying on solar gains, internal gains, and installing an energy recovery ventilator (ERV) to recover heat and moisture from exhaust air.

Problem Statement

While the Passive House standard has a high potential for application in retrofits in the Pacific Northwest, a literature review has revealed that few Passive House retrofit projects have been completed in this region. Consequently, there is little information on the design and cost of such retrofits. This study seeks to establish an exemplar through designing a retrofit of an existing older home in Eugene, Oregon with the goal of achieving the Passive House standard. Further, this study will investigate the life cycle cost impact of retrofitting the house to the Passive House standard, assuming a 30-year life cycle, by comparing projected "business as usual" (BAU) life cycle costs to life cycle costs associated with Passive House retrofit.

Key Questions and Hypothesis

The primary issue behind this study is that very few examples of Passive House retrofits exist in the Pacific Northwest to date. As a result, little information is available on design approaches to achieving the Passive House standard through retrofit; for the same reason, cost information on Passive House retrofits is lacking. This study is focused on developing an exemplar to address the following questions:

[19] U.S. Census Bureau, 2010b

a) What is an optimum approach to achieving the Passive House standard in the retrofit of an existing older home in Eugene, Oregon?

b) When life cycle costs associated with performing a Passive House retrofit are compared to BAU life cycle costs, which scenario results in a lower cost to the homeowner over a 30-year life cycle?

The hypothesis of this study states that the Passive House retrofit scenario will result in a lower cost to the homeowner than the BAU scenario over a 30-year life cycle.

Key Definitions

A 30-year life cycle was selected because this is the typical period before which major renovations are generally required in a building; another envelope upgrade will likely be required after 30-40 years.[20] Additionally, 30 years is the typical length of a home mortgage in the United States.

This study defines the BAU scenario as the scenario in which building improvements are made to achieve and maintain minimum energy code requirements and functionality of existing building systems.

Life cycle costs include costs associated with design, construction, energy use, and maintenance over the building's life cycle and take into account monetary incentives for retrofit and the anticipated value of the building at the end of the life cycle.

[20] Laustsen, 2008

CHAPTER II

REVIEW OF EXISTING LITERATURE

Passive House in Europe

Professor Bo Adamson and Dr. Wolfgang Feist developed the Passive House concept in Germany in the late 1980's and built the first Passive House prototype in 1990.[21] In 1996, Dr. Feist founded the Passive House Institute in Darmstadt, Germany. Currently, over 15,000 residential and commercial buildings have been built to the Passive House standard throughout Europe. Passive House buildings are most prevalent in Austria, where 17% of new construction is being built to the standard.[22] In 2007, the Austrian state of Vorarlberg passed a law requiring all new state-funded construction projects to be built to the Passive House standard.[23]

CEPHEUS

CEPHEUS, or Cost Efficient Passive Houses as European Standards, is a research project sponsored by the European Union which tested the viability of the Passive House standard by evaluating the performance of 221 housing units at 14 projects built to the standard throughout Germany, Sweden, Austria, Switzerland, and France. Completed in 2001, the study demonstrates that the documented Passive House projects have an average energy savings of more than 80% over typical construction.[24]

The study also revealed a relatively close relationship between calculated performance in the Passive House Planning Package (PHPP) and actual measured performance. On average, the calculated values for specific space heating demand in the PHPP were lower than the measured values; however the difference in the values was relatively small. Further, this study was conducted

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[21] Kernagis, 2008

[22] Wilson, 2010

[23] Kernagis

[24] Feist, Peper, & Gorg 2001

during the first year of occupancy; the authors of the CEPHEUS Final Public Report estimate that performance will likely improve in subsequent years when construction material moisture has evaporated and building systems have been more finely tuned.

The construction costs of the Passive House projects in the CEPHEUS study averaged 8% more than typical projects by the same developers. Considering the operational cost savings of the Passive House projects, the average simple payback period of the initial investment was estimated at 21 years.[25]

Passive House Retrofits in Europe

In Europe, where annual new construction represents a very small percentage of the building stock, energy retrofits are of utmost importance. For instance, in Austria, the annual rate of construction of new apartment buildings is only 1% of the existing building stock[26] (similarly, the number of new housing units built in Eugene, Oregon between 2005 and 2009 account for less than 4% of the total Eugene housing stock).[27] In an environment where new construction accounts for such a small portion of the building stock, retrofits become crucial if energy performance is to be improved.

Since 2001, renovations in Austria, Germany, and Switzerland have been completed using Passive House components. These projects are sometimes referred to as "factor 10-houses," as the post-retrofit energy demand is as little as one tenth of the original demand. These projects have demonstrated a high level of performance and occupant comfort. Additionally, according to Passive House designer and researcher Martin Ploss, "detailed analyses show that most of the measures used in Passive House retrofit are economically feasible."[28]

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[25] Feist, Peper, & Gorg 2001

[26] Ploss, 2008

[27] U.S. Census Bureau, 2010b

[28] Ploss, 2008

As a means of catalyzing the retrofit of existing housing projects throughout Europe, the European Commission's Intelligent Energy Europe program established the "Passive House Retrofit Kit" to inform social housing companies of the benefits, principles, and approaches to high performance energy retrofits. The primary goal of this project was to establish a web-based resource that allows social housing companies to determine whether or not a specific housing project is suitable for retrofit. This online resource also provides Passive House retrofit examples for common building typologies for each of the countries included in the project. Further, the resource includes information on the economic feasibility of Passive House retrofits.

A Retrofit Cost Analysis in Belgium

A study carried out by researchers at Catholic University College Ghent determined the life cycle cost and payback period for four retrofit scenarios for a 1950 single family house in Belgium.[29] The four scenarios are as follows: 1) the "normative scenario," based on European Energy Performance of Buildings Directive (EPBD) requirements, 2) the "common practice" model, which is the actual state of the existing building as renovated in 2005, 3) the "low energy scenario," in which insulation levels are increased and an air handling unit with heat recovery installed, and 4) the Passive House scenario. The four scenarios were compared using the Passive House Planning Package.

The study found that the Passive House retrofit scenario would require an additional investment of 27% over the normative scenario. Additional costs for the Passive House retrofit scenario are mostly associated with wall insulation, the heat recovery ventilator, the air-to-ground heat exchanger, and triple glazed windows. The common practice model was found to have the lowest discounted payback period, which was determined to be 11.2-18.1 years, depending on energy escalation rates. The low energy scenario had the second lowest payback period, which was determined to be 11.6-20 years. The Passive House retrofit scenario had the longest payback period, which the study found to be between 18.4 and 40+ years, depending on energy escalation rates. The

[29] Versele, Vanmaele, Bresch, Klein, & Wauman, 2009

study concludes, "The Passive House standard is justified economically if energy prices increase with 8 to 10% every year over the next 40 years. If prices increase with 2% or 5%, refurbishing as a low energy house is most economical."[30]

The above study illustrates that the Passive House retrofit of a 1950 home in Belgium is only economically viable in the case of high energy escalation rates. This research, however, is specific to European construction costs, methods of construction, energy prices, and climate.

EnerPHit

Achieving the Passive House standard's rigorous performance requirements in a retrofit is inherently difficult. Existing building shape, site location, and orientation are often at odds with Passive House principles. Additionally, walls, roofs, and floors have likely been framed without consideration for thermal bridging. Further, the airtightness requirement, perhaps the most difficult Passive House requirement to achieve in a retrofit, presents many challenges, as detailing a continuous, airtight layer in an existing building is exceedingly difficult.

The Passive House Institute acknowledges this difficulty and in 2010 released EnerPHit, a pilot version of a Passive House retrofit standard with less stringent requirements for existing buildings. According to the Passive House Institute, a retrofit may be certified as a "Quality-Approved Energy Retrofit with Passive House Components" if the existing building conditions create significant barriers to achieving the Passive House standard, and "modernising to Passive House level would not be practical or cost-effective."[31]

In the EnerPHit standard, the specific space heat demand requirement has been increased from 4.75 kBTU/(ft^2yr) to 7.92 kBTU/(ft^2yr). Additionally, the airtighness requirement, notoriously difficult to meet in retrofit projects, has been increased from 0.6 ACH_{50} to 1.0 ACH_{50}. Currently, EnerPHit is in its pilot phase in Europe but has yet to be implemented in the U.S.

[30] Versele, Vanmaele, Bresch, Klein, & Wauman, 2009

[31] Feist, 2010

Passive House in the U.S.

The first Passive House in the U.S. was built by German-born architect Katrin Klingenberg in Urbana, Illinois in 2003.[32] In 2008, Klingenberg and collaborator Mike Kernagis cofounded the Passive House Institute U.S. (PHIUS). Since then, a dozen or so buildings in the U.S. have achieved the standard, with countless others in various stages of certification. Projects have achieved certification in regions throughout the U.S.; Passive Houses have been built in northern states with high heating demands, such as Minnesota,[33] and recently a Passive House was completed in the cooling-dominated state of Louisiana.[34] Last year, the first Passive House in the Pacific Northwest was completed in Salem, Oregon by Bilyeu Homes. Like all Passive Houses, the Salem house achieves a high level of comfort without the use of a conventional heating system.

The Smith House

The Smith House was built in 2003 in Urbana, Illinois and was the first Passive House in the United States. Subsequent monitoring of the Smith House provides evidence of the validity of the Passive House concept in North American climates. In accordance with Passive House principles, the Smith House is almost cubic in shape. In the following excerpt from "Design and Performance of the Smith House, A Passive House," authors Stecher and Klingenberg (Klingenberg also designed the Smith House) describe the reasoning behind the cubic form: "The Passive House approach dictates minimizing losses before maximizing gains, and as such the shape of the building typically ends up being close to cubical. This is because the cube has the most usable interior volume for its envelope area, with the exception of the sphere."[35]

The foundation of the Smith House consists of a slab on grade with a concrete block frost wall. The slab has 14" of expanded polystyrene (EPS) insulation beneath it, while the outside face of

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[32] Stecher and Klingenberg, 2008

[33] *Passive House Institute U.S.*, 2011

[34] Clearfield, 2011

[35] Stecher and Klingenberg, 2008

the frost wall has 6" of EPS. The exterior walls are composed of 12" wooden I-joists, typically used to frame floor assemblies, in lieu of a double stud wall assembly, thereby reducing construction time. A fiberglass blown in blanket insulation system (BIBS) was installed in the wall cavity; 4" of EPS were installed outboard of the structural wall sheathing. The roof of the Smith House is composed of 16" wooden I-joists with a fiberglass BIBS.

The windows of the Smith House are triple glazed casements with thermally broken spacers and insulated frames. Solar Heat Gain Coefficient (SHGC) values for the glazing were selected based on window orientation. The west windows have a low SHGC to decrease the likelihood of summer overheating, while the east windows are shaded by vegetation, making a low SHGC unnecessary. The south windows have a high SHGC to maximize solar gains during the winter.

To ensure that the house complied with Passive House's stringent airtightness requirement, there are no mechanical, electrical, or plumbing penetrations in the exterior walls or roof. Electric outlets and switches on exterior walls are surface mounted. In lieu of a plumbing vent penetration in the roof, an air admittance valve was used to properly ventilate the plumbing system without compromising the airtight layer. The building services enter the house through the concrete slab.

The Smith House, like all Passive Houses, does not have a conventional heating system and is equipped with a heat recovery ventilator (HRV), a device which continuously ventilates the home with fresh air while simultaneously recovering heat energy from exhaust air and reusing it to heat the home. Additionally, an integrated electric heating element is used to supplement the HRV; this 3400 Btu/h element adequately meets the Smith House's supplemental heating needs. Finally, a ground heat exchanger is used to pre-heat the incoming fresh air. This 100 foot pipe, commonly referred to as an "earth tube," uses the ground's heat to raise the temperature of the incoming fresh air and prevents frost from forming on the HRV. In addition to its role in heating the home, the earth tube provides benefits in the summer by pre-cooling incoming fresh air; in mild climates such as the Pacific Northwest, a properly sized earth tube may meet a home's entire cooling requirement.[36]

[36] Stecher and Klingenberg, 2008

During the twelve month period between February 2005 and February 2006, the Smith House's electricity consumption for heating was 3.4 kBtu/ft^2; this figure is significantly less than Passive House's specific heating demand requirement of 4.75 kBtu/ft^2. By further comparison, a code-designed house of identical shape, window area, and orientation would consume 35.5 kBtu/ft^2 of electricity for heating during a one-year period.[37] The Smith House's energy consumption represents a savings of 90% over an identical code-designed house.

The Smith House performs extraordinarily well without compromising occupant comfort. A study conducted over a six day period in February of 2006 demonstrates that while the outdoor temperature fluctuated considerably, the indoor temperature remained relatively constant and within the range of occupant comfort. While the Smith House has demonstrated a high level of energy performance and occupant comfort, little is known regarding its cost-effectiveness. As Stecher and Klingenberg note: "There have not yet been enough homes built in the U.S. to the Passive House Standard in order to provide an adequate comparison with regard to cost."[38]

Passive House in Salem, Oregon

The first Passive House in the Pacific Northwest was completed in Salem, Oregon in 2010 by Bilyeu Homes. An average home in this climate consumes approximately 2483 kWh/month. The owners are reporting that the home's monthly energy use during the first ten months of occupancy is on average 450 kWh; this represents a savings of 82% over average consumption. The success of this project illustrates the viability of the Passive House concept in the Pacific Northwest.

First Passive House Retrofit in the U.S.

The first Passive House retrofit in the U.S. was completed in Sonoma, California in 2010. The existing two bedroom, two bath, 2400 square foot home was built in the 1960's. The post

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[37] Stecher and Klingenberg, 2008

[38] 2008

retrofit R-values for the envelope components are as follows: R-31 exterior walls, R-12 – R-20 floors, and R-78 roof. Due to its status as an industry frontrunner, the Sonoma retrofit has been selected as a prototype for the Department of Energy's Build America Program. [39]

While a wealth of knowledge will likely be gleaned from the Sonoma retrofit's design, construction, and performance, the climate of Sonoma is very mild and the heating demand is minimal – nearby San Francisco has a mere 3016 heating degree days.[40] By comparison, Eugene, Oregon has 4546 heating degree days; by further comparison, Minneapolis, Minnesota has 7981 heating degree days.[41] Significantly more aggressive approaches to retrofit will likely be required to achieve higher R-values in regions with greater heating demands. Further, the Sonoma house is a rather unique single storey ranch structure consisting of two volumes separated by a narrow breezeway.[42] Strategies utilized for this housing type are not necessarily broadly applicable to retrofit projects of varying housing typologies in other U.S. climate zones.

Achieving the Passive House standard added a premium to the cost of the Sonoma retrofit, which was completed for 10-15% above the cost of a typical single family home retrofit in the area. Rick Milburn, the builder and Certified Passive House Consultant who managed the construction of the Sonoma retrofit, estimates that construction costs will decrease as more homeowners pursue Passive House certification.[43]

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[39] Defendorf, 2010

[40] Grondzik, Kwok, Stein, and Reynolds, 2010

[41] Grondzik, Kwok, Stein, and Reynolds

[42] Defendorf, 2010

[43] Defendorf

CHAPTER III

METHODOLOGY

Overview of Methodology

The first phase of this research is the literature review discussed in Chapter II which established the need for the study due to the current lack of Passive House retrofit design and cost information. Details of the literature review are presented in Chapter II; in this chapter, the literature review is discussed only in the context of its role in the research methodology. The methodology is presented in a diagram in Figure 1 and described below.

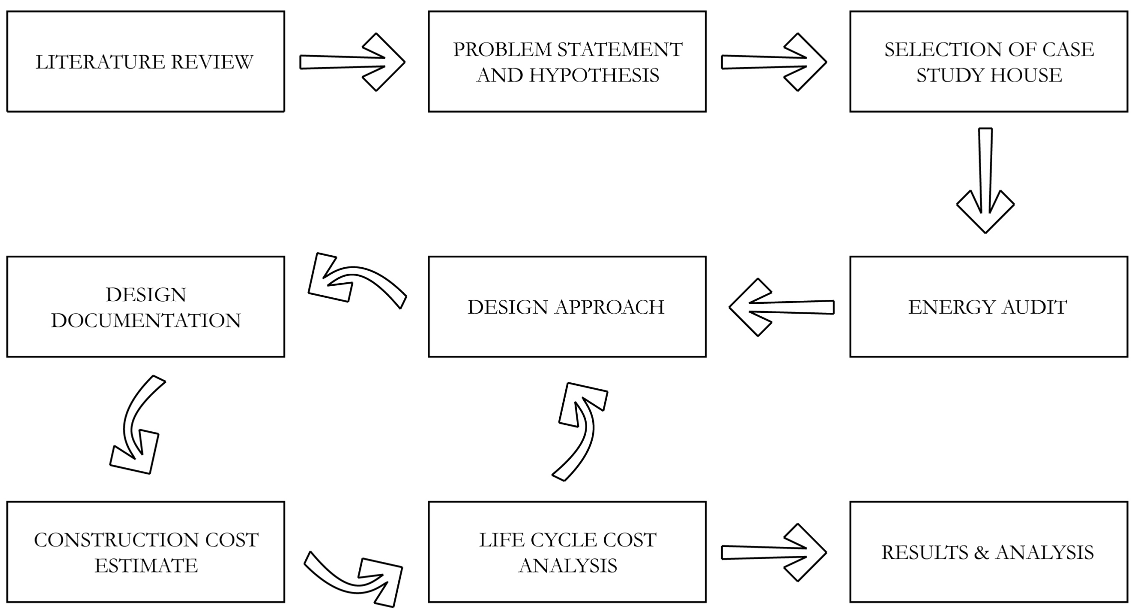

Figure 1: Diagram of research methodology

The second phase of the research is the selection of a house suitable for the study based on its age and formal characteristics. The selected house is herein referred to as 'the case study house.' In the third phase of the study, an energy audit of the case study house was conducted to determine its current level of energy performance. In the fourth phase of the study, the case study house was measured and photographed in order to produce an accurate set of as-built drawings. The fifth phase of the study is the design approach, in which the retrofit was designed primarily using energy modeling software. The sixth phase of the study is design documentation, in which the design approach established in the fifth phase of the study was documented using computer-aided drafting and design (CADD) software. The seventh phase of the study is the construction cost estimate; the eighth and final phase is the life cycle cost analysis.

The researcher acknowledges the cyclical nature of the design process; while the research generally progressed according to the outlined methodology, earlier phases were revisited as new information came to light. For instance, cost information uncovered in the latter phases of the project caused the researcher to revisit the design and documentation phases.

Selection of the Case Study House

In order to document a small number of pre-1970 single family homes in Eugene, twenty such homes were photographed and a brief catalogue was created. This catalogue established the presence of older homes in Eugene with characteristics suitable to the application of Passive House retrofit strategies. Specifically, homes with compact, nearly cubic shapes were photographed; these homes have formal characteristics already conforming to Passive House principles. The majority of the catalogued homes were built significantly earlier than 1970; most were likely built in the early 20th century. Photographs of the homes are included in Appendix A.

The catalogue of photographs described above established the presence of existing older homes in Eugene with formal characteristics already conforming to the principles of Passive House design. Once the presence of such homes was established, a representative house was chosen for further study. The selected house is herein referred to as 'the case study house' and was chosen because its age and formal characteristics are similar to those of the catalogued homes described above and pictured in Appendix A. Additionally, the researcher is acquainted with the owner, who granted the researcher access to the home to perform the study. The case study house is pictured in Figure 2 and described in detail in the next section.

Figure 2: The case study house

Characteristics of the Case Study House

The case study house is a three bedroom, one and a half bath home with approximately 1550 square feet of living area on the first and second floors. The house has an unconditioned attic which is accessible by an access door in the ceiling of the second floor hallway. The west half of the house has an unconditioned basement; the east half is above a crawlspace. A small addition, which includes the half bath and a breakfast nook, was built at a later date.

The house's construction type is typical of Eugene single family homes from its era; the walls, suspended floors, and roof are wood framed. True 2x4 lumber was used for the studs and rafters, while the floor joists are 2x8's. The interior wall and ceiling finish is plaster on wood lath. The exterior walls are clad in wood shiplap siding attached directly to the 2x4 studs. The roof is composed of asphalt shingles and tar paper over a layer of plywood.

The case study house has a gas cooking range and furnace; the remainder of the home's energy is supplied by electric power. Like the vast majority of homes in Eugene, the case study house is not fitted with a cooling system. The house was thoroughly measured and photographed in order to generate an accurate set of as-built drawings; these drawings were produced using computer-aided drafting and design (CADD) software and are included in Appendix B.

Energy Audit

An energy audit of the case study house was completed in order to examine its potential for energy efficiency improvements. The audit was scheduled in consultation with the owner, who granted the researcher access to the house to perform the audit.

Energy Bills 2009 Calendar Year

In order to determine current annual energy expenditures for the case study house, energy bills were compiled and reviewed. Natural gas service is provided by NW Natural, a private natural gas company based in Portland, OR. Electric power is supplied by the Eugene Water and Electric Board (EWEB), a local public utility company. Electricity and natural gas bills for the 2009 calendar year were obtained from the owner. At the time of the energy audit, 2009 was the latest full calendar year for which energy bills were available.

The case study house's monthly energy usage and expenditures for the 2009 calendar year were compiled in a spreadsheet for analysis. Annual energy expenditures for the case study house were compared to Oregon average annual household energy expenditures. Results are presented in Chapter IV.

Survey of Existing Envelope

A visual inspection of the case study house's existing envelope was performed to examine the potential for efficiency improvements. Existing wall, roof, and floor assemblies were surveyed. Based on information collected during the survey, R-values of the existing assemblies were calculated and compared to the minimum R-values required by the 2010 Oregon Energy Efficiency Specialty Code. Results are presented in Chapter IV.

Thermographic Inspection

As a means of uncovering inefficiencies in the building envelope, a thermographic inspection of the case study house was performed using an infrared camera. A FLIR Systems ThermaCAM™ B2 infrared camera was borrowed from the University of Oregon Agents of Change laboratory and used in the test. The inspection took place on a day in early September just before sunrise. The home's furnace was switched on one hour prior to the inspection in order to maximize the difference between the indoor and outdoor temperatures; the FLIR manual recommends a temperature differential of at least 10°F.[44] At the time of the test, the outdoor ambient air temperature was 55°F and the indoor ambient air temperature was 66°F, a difference of 11°F. The interior and exterior surface temperatures of the walls were also measured using a laser thermometer; the interior and exterior surface temperatures measured 62.5°F and 52.5°F, respectively.

Infrared images produced during the inspection were analyzed for low surface temperatures, usually evidence of heat loss due to thermal bridges or infiltration. Results, including infrared images produced during the inspection, are presented in Chapter IV.

Blower Door Test

A blower door test of the case study house was conducted to determine the current rate of infiltration. In preparation for the test, all intentional openings in the building envelope were sealed. In addition to closing all exterior doors and windows, the following openings were sealed with polyethylene sheeting and tape: HVAC supply diffusers and return air grille, bathroom exhaust fans, and fireplace. All interior doors were left open, with the exception of the closet doors. Because the basement is not conditioned and is assumed to be outside the thermal envelope, the basement door remained closed during the test. A Minneapolis Blower Door Model 3 kit was borrowed from the University of Oregon Agents of Change laboratory and installed in the front door of the house prior to the test. A photograph of the installed blower door unit is presented in Figure 3.

[44] FLIR Systems, 2004

Figure 3: Blower door unit installed prior to test

The blower door fan was switched on and the airflow through the unit was measured using the air flow meter included in the Minneapolis Blower Door kit. While the fan was running, the researcher and an assistant inspected the envelope for areas of infiltration. Results of the blower door test, including a calculation of the case study house's air change rate, are presented in Chapter IV.

Survey & As-Built Drawings

The house was thoroughly measured and photographed in order to generate an accurate set of as-built drawings; these drawings were produced using computer-aided drafting and design (CADD) software. The as-built drawings are included in Appendix B.

Design Approach

Various sources were consulted throughout the design of the retrofit. The Passive House Consultant Training Program, in which the author was enrolled in the summer of 2010, offered suggestions for design approaches to retrofit; casual meetings with local professionals involved in retrofit projects provided additional ideas. Two books served as key references during the design phase: *The Super Insulated Retrofit Book: A Homeowner's Guide to Energy-Efficient Renovation* and *Details for Passive Houses: A Catalogue of Ecologically Rated Constructions*.[45, 46]

The as-built drawings were printed and trace paper overlays were used to sketch possible design approaches; various approaches and iterations were explored before a general design approach was selected. Next, a design development drawing set was produced using CADD software; this drawing set documented the general design approach and served as a reference for envelope areas, floor areas, and building assemblies during the initial input of building parameters into the Passive House Planning Package (PHPP). The PHPP is a Microsoft Excel-based energy modeling software for use in the design and verification of Passive House buildings.

Once the general design approach parameters were input, minor adjustments were made until the software illustrated compliance with the Passive House standard. Possible thermal bridges were investigated using THERM, a two-dimensional building heat-transfer modeling software developed by the Lawrence Berkeley National Laboratory.

Design Documentation

The final design from the previous phase of the study was documented in a bid set consisting of relevant drawings and specifications; this bid set is included in Appendix C. Drawings were produced using CADD software. The bid set was used as the basis for determining the construction cost in the next phase of the study.

Construction Cost Estimate

This study defines the construction cost as the total material, labor, and equipment costs associated with completing the retrofit, plus a percentage for contractor overhead and profit.

[45] Marshall and Argue, 1981

[46] IBO, Austrian Institute for Building Biology and Building Ecology (Ed.), 2008

Using the bid set as a reference, the cost of the retrofit was estimated using RS Means CostWorks, an online construction cost database which adjusts costs for local material and labor conditions. The costs were compiled in a spreadsheet and sent to a local contractor for verification. The local contractor suggested assuming 15% for overhead and profit; this percentage was used in lieu of assumptions made by the costing software. Federal, state, and utility incentives for retrofit were determined and deducted from the estimated construction cost. The construction cost spreadsheet is included in Appendix D.

Life Cycle Cost Analysis

Life cycle costs for two scenarios – the "business as usual" (BAU) scenario and the Passive House retrofit scenario – were compared in order to determine that scenario which results in the lowest cost to the homeowner over a 30-year period. The BAU scenario is defined as the scenario in which building improvements are made to achieve and maintain minimum energy code requirements and functionality of existing building systems. All life cycle costs in each scenario were discounted to a net present value using a discount rate of 4%; this percentage is based on current home equity loan interest rates from a local credit union.[47] A 30-year life cycle was selected because this is the typical period before which major renovations are generally required in a building; another envelope upgrade will likely be required after 30-40 years.[48] Additionally, 30 years is the typical length of a home mortgage in the United States.

Due to the atypical occupancy of the case study house (the owner is the sole occupant of the house; by contrast, the average occupancy of an owner-occupied unit in Eugene is 2.45), average annual household energy expenditures from the U.S. Energy Information Administration (EIA) were used to estimate current annual energy costs in lieu of data from the actual energy bills.[49] The percentage of energy savings in the retrofit scenario was determined by comparing the EIA average annual household

[47] Northwest Community Credit Union, 2003

[48] Laustsen, 2008

[49] U.S. Census Bureau, 2010b

energy use to the annual energy use calculated by the PHPP.

Energy escalation rates used in the study are based on EIA energy price projections for electricity and natural gas. Three EIA energy price scenarios were investigated: the Reference Case, the Low Oil Price Case, and the High Oil Price Case. However, since the EIA has vastly underestimated the rising price of oil in recent years, as noted by Williams-Derry[50], the researcher acknowledges that escalations rates published by the EIA are conservative. Further, the Reference Case predicts that the real price of electricity will actually decrease by 2035. For this reason, the High Oil Price Case, which predicts that the real price of energy will rise at a moderate rate of 0.3% per year for electricity and 0.4% per year for natural gas,[51] was selected as the scenario on which the study will be focused.

Maintenance and replacement costs were estimated using RS Means Costworks; replacement intervals were based on information from the National Association of Homebuilders.[52] The resale value of the home at the end of the life cycle was determined using an appreciation rate of 1.5% and a current appraised value of $400,000. A study in Seattle illustrates that the resale value for a certified green home is on average 8.5% higher than that of an average home;[53] this percentage was used to estimate the added value of the house in the retrofit scenario over the BAU scenario at the end of the life cycle.

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[50] 2011

[51] U.S. Energy Information Administration, 2010a

[52] Seiders et al., 2007

[53] GreenWorks Realty, n.d.

CHAPTER IV

RESULTS & ANALYSIS

Energy Audit Results

Energy Bills 2009 Calendar Year

According to data from the U.S. Energy Information Administration (EIA), Oregon average annual household expenditures for electricity and natural gas are $1,045.92 [54] and $887.90,[55] respectively. The case study house's energy bills for the 2009 calendar year were compiled, analyzed, and compared to the above averages in order to establish the relative energy performance of the case study house. 2009 energy expenditures for the case study house totaled $979.60 and are presented in Figure 4. Electricity accounted for $443.32 of the 2009 energy expenditures, while natural gas accounted for $531.47.

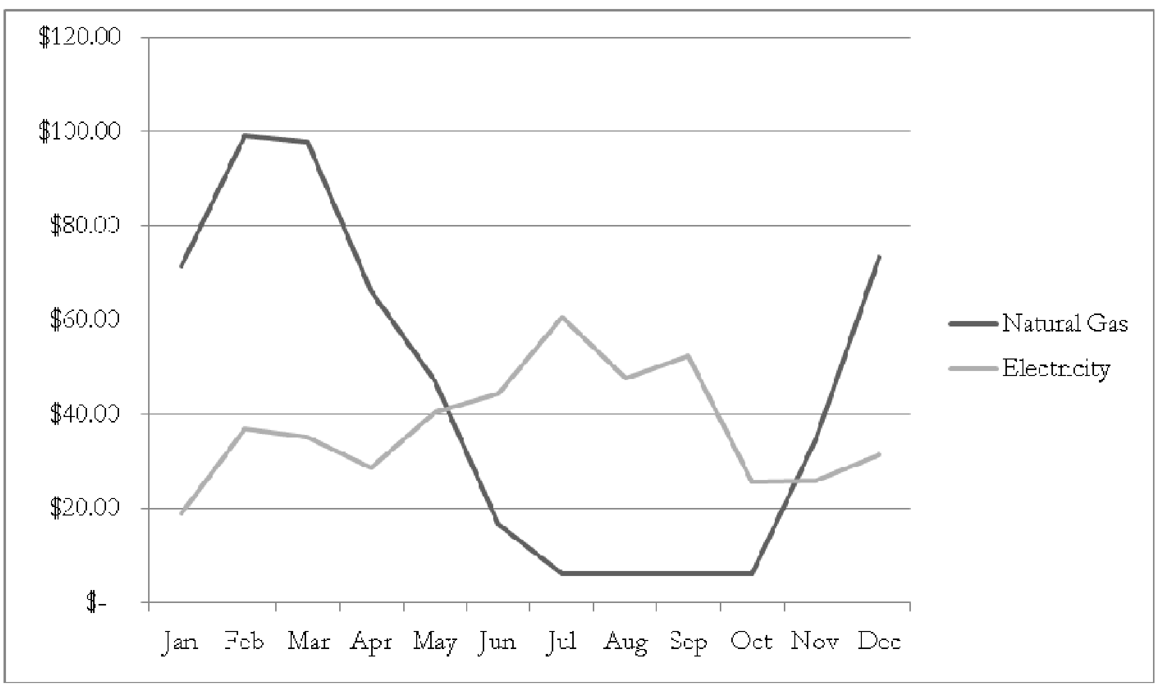

Figure 4: Case study house energy expenditures, 2009 calendar year

[54] U.S. Energy Information Administration, 2010d

[55] U.S. Energy Information Administration, 2010c

Relative to Oregon average annual household energy expenditures, one might assume that the case study house is performing rather well. However, it must be taken into account that the sole occupant of the house is the owner; by contrast, the average household size of an owner-occupied unit in Eugene is 2.45 occupants.[56] Additionally, the owner claims to be very energy conscious, using the appliances, lighting, and heat sparingly. Certainly, this careful attention to energy use could contribute to relatively low energy expenditures. Further, the owner's frequent travel causes the house to be unoccupied for substantial periods of time during which plug loads, lighting loads, and heating loads are almost non-existent. It is likely that the energy expenditures would be considerably higher in the case of a more typical occupancy situation. Finally, as illustrated by the results of the latter phases of the energy audit described in the next few sections, the case study house has significant potential for energy efficiency improvements.

Survey of Existing Envelope

The survey of the existing envelope revealed that energy upgrades have been performed to the case study house during its lifetime. While the house is over a hundred years old, the envelope has been modernized over the years so that the R-values of the existing assemblies are likely considerably higher than the R-values of the assemblies as originally constructed.

This visual inspection of the envelope revealed that the majority of the original wood single glazed windows have since been replaced with vinyl double glazed windows, with the exception of the basement windows and one window in the master bedroom. The remaining wood window in the master bedroom has a 1/8" gap between its two leaves and is likely a significant source of infiltration.

Additionally, it was noted that blown in cellulose insulation was installed in the exterior 2x4 wall cavity; this information was determined by a visual inspection of the exterior wall cavity via the attic. This inspection also revealed that the blown in cellulose has settled below the level of the attic

[56] U.S. Census Bureau, 2010b

floor, creating a small gap in the home's thermal envelope. The window and exterior wall upgrades were performed sometime prior to the current owner's purchase of the home in 2005.

In a visual inspection of the unfinished attic, approximately ten inches of fiberglass batt insulation on the attic floor were measured. Though the insulation appears to be in good condition, a small gap occurs along the exterior edge of the attic. Additionally, the depth of the insulation varies – it appears that areas of the insulation have been compressed to a thickness of less than ten inches. Research illustrates that the compression of fiberglass batt insulation has a negative impact on its performance.[57] Upon an inspection of the crawlspace, fiberglass batt insulation was noted between the existing 2x8 first floor joists. This insulation has begun to sag and is likely not performing as it was when first installed.

Based on the survey described above, R-values for each of the existing assemblies were calculated using the Passive House Planning Package "R-Values" sheet and its assumptions for the R-values of standard materials. The calculated R-value for each assembly is listed in Table 3 alongside the corresponding R-value required by the 2010 Oregon Energy Efficiency Specialty Code.[58]

Table 3: R-values of existing assemblies compared to minimum code-required R-values

Envelope Assembly	**R-Value, Case Study House**	**R-Value, Min. Code-Required**
Wall	R-14	R-21
Roof	R-33	R-38
Floor	R-28	R-30

As evident in Table 3, each of the existing envelope assemblies is not energy code compliant, illustrating a significant potential for efficiency improvements. In particular, the existing exterior walls show substantial efficiency potential, as a 50% increase in R-value would be necessary to meet current energy code requirements.

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[57] Graves and Yarbrough, 1990

[58] International Code Council, Inc., 2010

Thermographic Inspection

Select infrared images produced during the thermographic inspection are pictured below. These images reveal low surface temperatures at roof framing members where significant heat loss occurs due to thermal bridging. Additionally, low surface temperatures may be noted adjacent to doors, windows, and in corners where heat loss occurs due to thermal bridging, infiltration, or both.

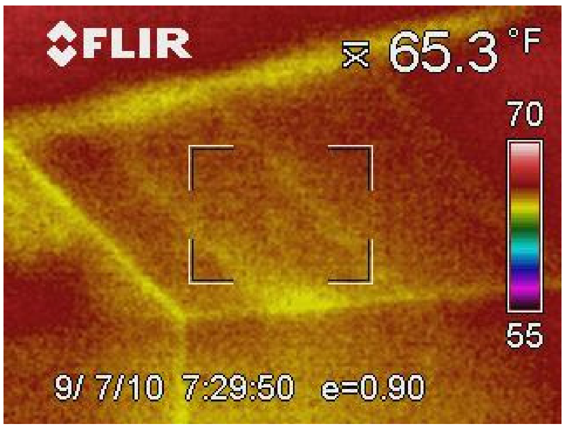

Figure 5: Thermal bridges at wood rafters

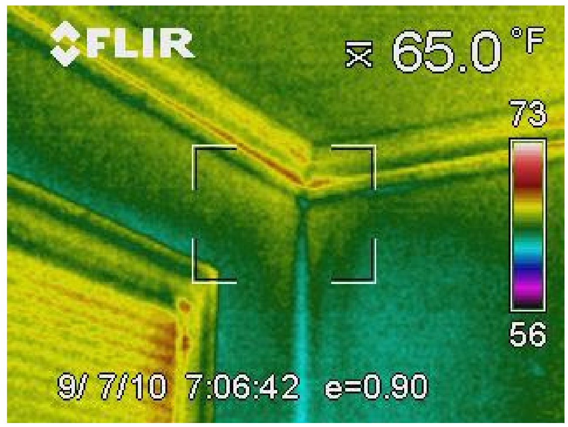

Figure 6: Heat loss at wall corner

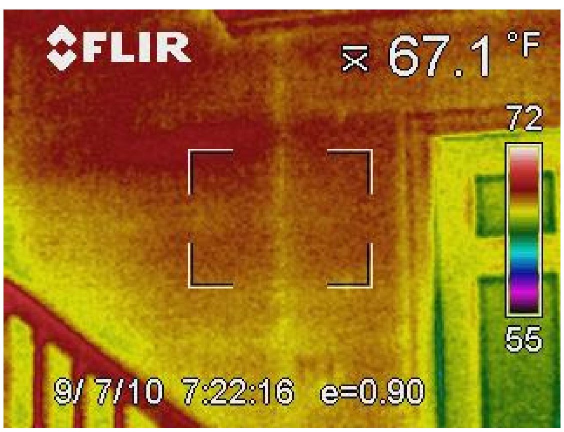

Figure 7: Thermal bridge at metal pipe

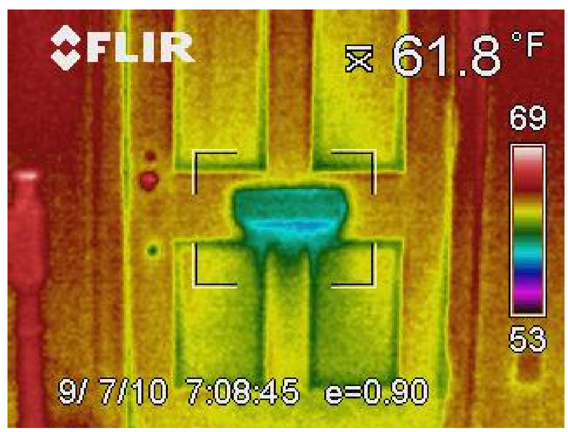

Figure 8: Heat loss at front door

The inspection also revealed the front door to be a significant source of heat loss. As evident in Figure 8, its surface temperature is considerably lower than the surface temperature of the adjacent wall; further, its mail slot is a major source of infiltration. Overall, the thermographic inspection revealed that the case study house has a high potential for efficiency improvements through retrofit strategies that reduce thermal bridging and infiltration.

Blower Door Test

The Pennsylvania Housing Research Center defines a leaky house as having an air change rate greater than 10 ACH_{50}.[59] By comparison, a house must demonstrate an air change rate of ≤ 0.6 ACH_{50} to achieve the Passive House standard. These values are given as a frame of reference for the results of the blower door test presented below.

At the standard pressure differential of 50Pascal, the measured airflow through the blower door fan was approximately 7,200cfm. The air changes per hour at 50Pascal (ACH_{50}) was determined using the following formula:

$$ACH_{50} = (CFM_{50} \text{ x } 60)/\text{Net Volume} = (7{,}200\text{cfm x } 60)/12{,}657\text{ft}^3 = 34.1$$

The blower door test confirmed the homeowner's claim that the house is considerably drafty. The fact that the case study house does not have exterior plywood sheathing may account for such a high rate of air leakage. Though most of the original wood single glazed windows have been replaced, one window in the master bedroom is original; this window has a significant gap between its two leaves through which a considerable amount of infiltration was noted during the test. The blower door test demonstrates that the house is very leaky and likely loses a significant amount of heat due to infiltration.

Overall, the energy audit demonstrates that the house has a high potential for retrofit strategies that address the condition and level of insulation, significant thermal bridges, and high rate of infiltration.

Proposed Retrofit Design

Design Approach

The proposed retrofit design is documented in the bid set (see Appendix C) and described below. An exterior approach for the retrofit was pursued over an interior approach. A review of

[59] Van der Meer, 2001

existing literature suggests approaching the retrofit from the exterior; additionally, the Passive House Consultant Training Program advocated use of the exterior approach when feasible. An exterior approach nullifies the tedious detailing required at wall to floor connections in the case of an interior approach. Detailing an airtight, thermal bridge free envelope is much more manageable in an exterior approach; exterior sheathing and insulation can run continuous around the entirety of the walls and roof. Further, interior approaches are incredibly invasive, both in terms of demolition of interior finishes and disruption of occupants. Finally, it was determined that due to the age and condition of the existing cladding that an exterior approach would be most appropriate, as the siding and roofing would benefit from replacement in the near future.

In the proposed retrofit, the existing wood siding is removed, along with the blown in cellulose insulation. The wall cavities are filled with a fiberglass blown in blanket insulation system (BIBS). New oriented strand board (OSB) sheathing is installed on the outboard side of the existing 2x4 studs, creating the airtight layer required by Passive House. Four inches of polyisocyanurate rigid insulation, a rainscreen, and fiber cement siding are installed outboard of the new sheathing.

In the retrofit of the attic and roof assembly, the fiberglass batt insulation on the attic floor is removed; the attic becomes part of the thermal envelope. The existing roof sheathing is removed and replaced with OSB, creating the airtight layer. New 9.5" TJI joists are installed on top of the new OSB. A fiberglass blown in blanket insulation system (BIBS) is installed between the existing 2x4 rafters and between the new TJI joists. A second layer of OSB is installed on top of the new TJI joists; roof felt and asphalt shingles are installed on top of the second layer of OSB.

In the proposed retrofit, the stair between the basement and first floor is demolished and the stair opening is framed closed in order to thermally isolate the basement from the rest of the house; the basement is considered to be outside of the thermal envelope and is only accessible from an existing exterior door. The existing batt insulation between the first floor joists is removed and replaced with a fiberglass blown in blanket insulation system (BIBS). Four inches of foil-faced polyisocyanurate rigid insulation are installed below the first floor joists; seams are carefully taped to create the airtight layer. An exterior wall section of the proposed retrofit is presented in Figure 9.

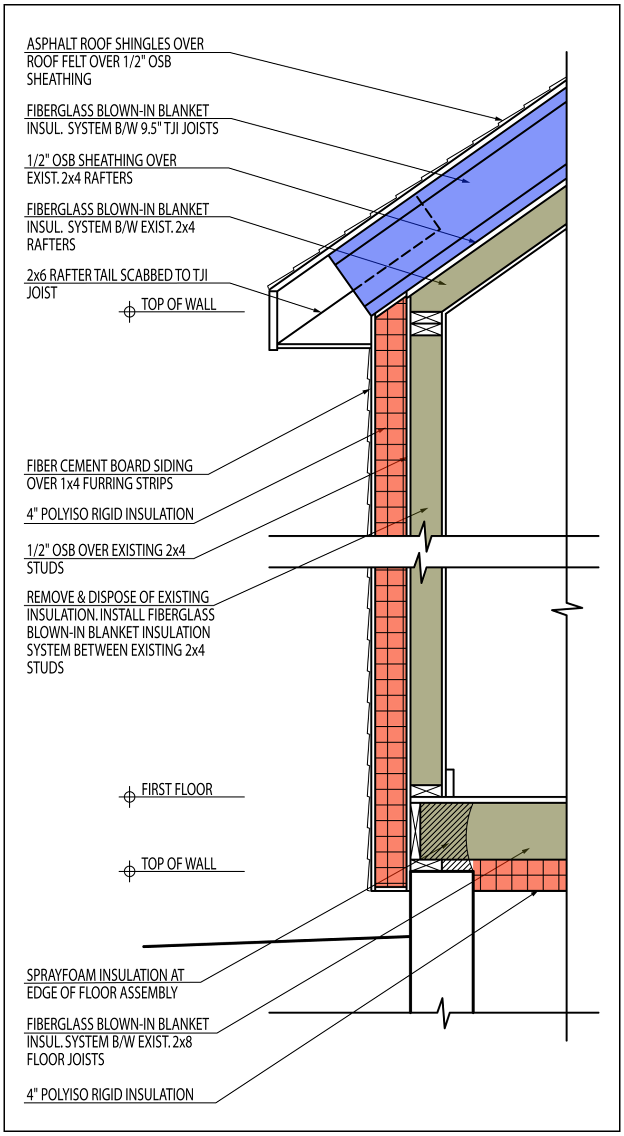

Figure 9: Wall section of proposed retrofit

Airtight Layer

The Passive House airtight layer must be established during design and its integrity must be maintained during construction. In the proposed retrofit of the case study house, the airtight layer is composed of the oriented strand board (OSB) sheathing on the exterior walls and roof. Beneath the first floor system, the airtight layer is created by a layer of foil-faced polyisocyanurate rigid insulation.

Additionally, a small amount of spray foam insulation is applied at the edge of the floor assembly to maintain the airtight layer. A sectional diagram of the airtight layer is presented in Figure 10.

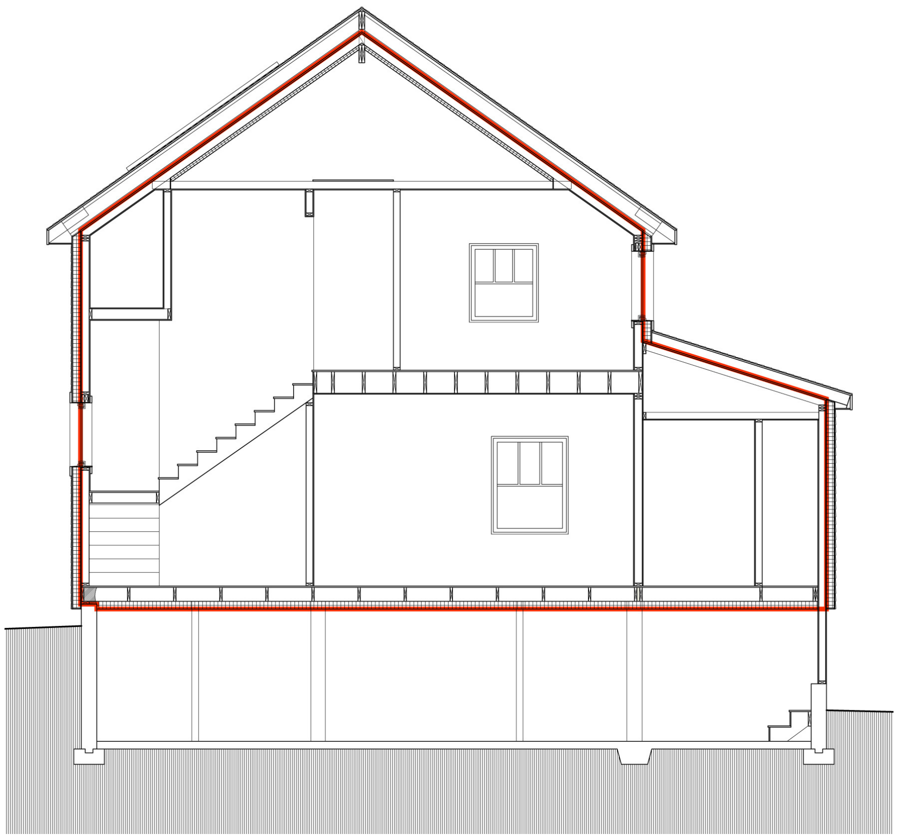

Figure 10: Sectional diagram of airtight layer

Thermal Bridges

In an effort to maintain occupant thermal comfort, Passive House stipulates that the difference in temperature between any interior surface and the indoor air must be no greater than 4°F.[60] As the interior design temperature for a Passive House is 68°F, no surface temperature may drop below 64°F. Thermal bridges must be minimized if this requirement is to be achieved. The proposed retrofit's exterior approach resulted in minimizing thermal bridges due to framing, as the wall and floor assemblies are covered in a layer of rigid insulation. However, thermal bridges may occur at areas such as the connection between the exterior wall and first floor assembly.

[60] Information gathered during the Passive House Consultant Training Program in Washington, D.C., 2010

Due to the high potential for thermal bridging at this area, the connection detail was modeled in THERM to determine whether additional interventions, such as insulating the face of the foundation wall, were necessary. Screenshots taken during the THERM simulation are presented in Figures 11 and 12.

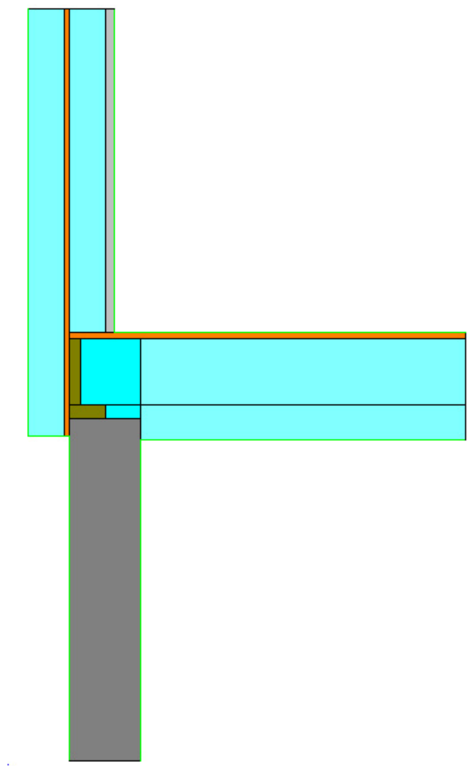

Figure 11: Section detail of wall to floor connection as modeled in THERM

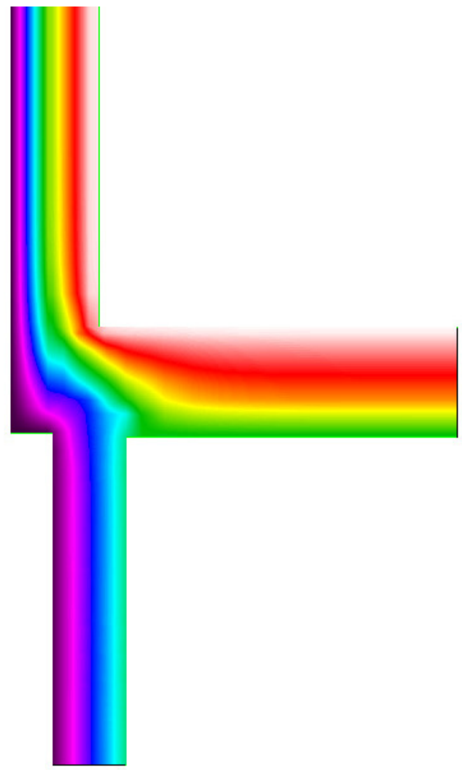

Figure 12: Results of THERM simulation illustrating temperature gradient within the assembly

From a careful study of the results of the THERM simulation, it was determined that the surface temperature of the interior corner of the assembly – the area with the most potential for heat loss due to thermal bridging – does not drop below 64°F. As a result, no additional intervention is needed at this connection.

Mechanical System

In the proposed retrofit, the heat recovery ventilator (HRV) is installed in the attic; HRV manufacturers recommend installation within the thermal envelope for optimal performance. Additionally, the open attic space allows for the easy installation of HRV ductwork serving the second floor. An existing vertical chase provides HRV supply and return ducts a means of reaching the first floor living spaces. Ductwork on the first floor is housed in a new bulkhead above the existing kitchen cabinets. On the first floor, HRV supply diffusers are located in the dining room, breakfast room, and living room, while HRV exhausts are located in the bathroom and kitchen. On the second floor, supply diffusers are located in the bedrooms, while an exhaust is located in the bathroom. This technique of supplying fresh air to the living spaces and exhausting stale air from the bathrooms and kitchen is advocated by the Passive House Institute.

When the retrofit was modeled in the Passive House Planning Package (PHPP), it was determined that the heating demand could not be met by the fresh air alone; in other words, supplemental heating would be required. For this reason, the proposed retrofit design includes a ductless mini-split heat pump that provides supplemental heating as needed during the winter. For more information regarding the design of the mechanical system, see the mechanical drawings included in the bid set (Appendix C).

Aesthetics

As the focus of this research is the design approach and economics of Passive House retrofits, the aesthetics of the case study house were not largely considered. However, the researcher acknowledges that in the retrofit of the case study house, as in the retrofit of any house, the visual and experiential qualities of architecture are of utmost importance. In order to limit the number of variables and preserve the study's focus on design approach and economics, a few simple aesthetic guidelines were established by the researcher, in consultation with the owner, early in the study.

Firstly, the owner noted her appreciation of the fact that each room in the house has windows on two sides; this quality was maintained throughout the design of the retrofit. Secondly, since the owner is quite satisfied with the functionality of the existing house, the layout of the house would only change as necessary to achieve the Passive House standard, as in the case of the demolition of the basement stairs and the addition of the shower and laundry closet in the first floor bath – modifications which arose from the decision to exclude the basement from the thermal envelope. Thirdly, while this study is certainly outside the realm of historic preservation, the existing character of the home would be maintained to the extent possible.

Passive House Planning Package: Design and Verification

The first iteration of the retrofit design differed slightly from the design approach described above. When the parameters from the first iteration were input into the Passive House Planning Package (PHPP), the software determined that the design did not comply with all of the performance requirements of the Passive House standard. Specifically, the annual heating demand and the primary energy demand requirements had not been met. Therefore, minor revisions were made until the PHPP confirmed that the design complied with these requirements. While the first design iteration utilized blown in cellulose insulation in the wall, roof, and floor cavities, a fiberglass blown in blanket (BIBS) system was substituted in the final design approach due to its higher R-value. Further, in order to meet the primary energy demand requirement, a solar hot water system was included in the final design approach, reducing electricity usage for domestic hot water.

The PHPP's verification sheet provides values for the energy demands of the proposed design and illustrates whether or not the design complies with the Passive House standard. When Passive House certification is pursued, a copy of this sheet is sent to the Passive House Institute U.S., along with other required documents. Energy demands from the PHPP verification sheet for the proposed retrofit design are included in Figure 13.

Energy Demands with Reference to the Treated Floor Area					
Treated Floor Area:	1552	ft^2			
	Applied:	Monthly Method	PH Certificate:		Fulfilled?
Specific Space Heat Demand:	4.69	kBTU/(ft^2yr)	4.75 kBTU/(ft^2yr)		Yes
Pressurization Test Result:		ACH_{50}	0.6 ACH_{50}		
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	35.4	kBTU/(ft^2yr)	38.0 kBTU/(ft^2yr)		Yes
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	21.2	kBTU/(ft^2yr)			
Specific Primary Energy Demand Energy Conservation by Solar Electricity:		kBTU/(ft^2yr)			
Heating Load:	2.85	BTU/(ft^2hr)			
Frequency of Overheating:	0	%	over	77.0 °F	
Specific Useful Cooling Energy Demand:		kBTU/(ft^2yr)	4.75 kBTU/(ft^2yr)		
Cooling Load:	1.80	BTU/(ft^2hr)			

Figure 13: Passive House Planning Package verification sheet

The software illustrates compliance with the Passive House standard's energy demand requirements; however, as noted in Chapter I, the airtightness requirement can only be met through conducting a blower door test at the end of construction. Since this project is a feasibility study and has not been constructed, verification of this requirement is not possible. However, careful attention was given to the airtight layer during the design phase as previously described. Provided that the airtight layer was constructed as specified by the bid set and that its integrity was maintained during construction, this requirement would likely be met; further, the Sonoma project described in the literature review offers a precedent in which the airtightness requirement was achieved in a retrofit.[61]

The post-retrofit R-values for the assemblies were calculated using the PHPP's R-values sheet and its assumptions for the R-values of common building materials. The pre and post-retrofit R-values for the assemblies are presented in Table 4.

Table 4: Pre and post-retrofit R-values of assemblies

Envelope Assembly	**R-Value, Pre-Retrofit**	**R-Value, Post-Retrofit**
Wall	R-14	R-42
Roof	R-33	R-60
Floor	R-28	R-54

[61] Defendorf, 2010

Energy Performance

The energy consumption of an average single family home in Eugene was estimated as a basis for comparison to the consumption of the retrofit design as calculated by the PHPP. According to data from the U.S. Energy Information Administration, single family homes in climates with 4000-5999 heating degree days (Eugene has 4546 HDD) consume on average 101.7 million BTU of energy per year.[62] If the average size of an existing home in the U.S. is 1800 square feet (the author's best estimate based on data from the U.S. Census Bureau),[63] then the average energy consumption of a single family home in Eugene is estimated as follows:

$$101.7 \text{ million BTU/yr} \div 1800 \text{ square feet} = 56.5 \text{ kBTU/(ft}^2\text{yr)}$$

By comparison, the PHPP calculated the end-use electricity consumption of the retrofit design to be 13.8 kBTU/(ft^{2}yr). This represents a 76% savings in energy use over the average consumption as estimated above.

<u>Construction Cost Estimate</u>

The estimated construction cost for the retrofit was $80,410.62. This amount seems reasonable when compared to Alex Wilson's estimate that a deep energy retrofit of an average sized home costs $50,000-$75,000.[64] An amount of $21,437.01, considered not to be directly associated with achieving the Passive House standard, was deducted from the construction cost before the life cycle costing phase. This deducted amount includes costs associated with new siding, sheathing, roofing, and insulation necessary to meet current energy code requirements, as well as construction costs specific to the case study house. Additionally, eligible federal, state, and utility credits for energy improvements were determined; these credits totaled $6,250. Finally, resale values for the

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[62] U.S. Energy Information Administration, 2008

[63] U.S. Census Bureau, 2010a

[64] Wilson, 2009

existing equipment, including the existing gas furnace, were estimated and deducted from the total construction cost; the resale value of the existing equipment totaled $1,300. The portion of the construction cost associated with achieving the Passive House standard was determined as follows:

$80,410.62 - $21,437.01 - $6,250 - $1,300 = $51,423.61

This adjusted amount, herein referred to as "the Passive House premium," accounts for 64% of the total construction cost. A summary of the construction cost estimate is presented in Table 5. The complete construction cost spreadsheet is included in Appendix D.

Table 5: Summary of construction cost estimate

Item	**Cost**
Material, Labor, & Equipment	$69,922.28
15% Contractor O&P	$10,488.34
Total Construction Cost	**$80,410.62**
Costs Not Associated with Achieving the Passive House Standard	- $21,437.01
Initial Credits	-$7,550.00
"The Passive House Premium"	**$51,423.61**

Life Cycle Cost Analysis

EIA Reference Case

Real dollar escalation rates predicted by the Energy Information Administration (EIA) Reference Case for the end use residential price of electricity and natural gas are -0.2% and 0.5%, respectively.[65] When life cycle costs for the retrofit and BAU scenarios were estimated and discounted to a net present value, the BAU scenario resulted in the lowest cost to the homeowner over a 30-year life cycle. A summary of results are presented in Table 6; the complete life cycle cost spreadsheet for the EIA Reference Case is included in Appendix E.

[65] U.S. Energy Information Administration, 2010a

Table 6: Present worth life cycle costs, EIA Reference Case

Life Cycle Costs	BAU	Passive House Retrofit
Initial Costs	-	$51,423.61
Replacement Costs	$3,816.53	$2,988.04
Energy Costs	$35,938.41	$6,289.85
Deduct Additional Resale Value	-	-$16,385.51
Total	$39,754.94	$44,315.99

EIA Low Oil Price Case

Real dollar escalation rates predicted by the Energy Information Administration (EIA) Low Oil Price Case for the end use residential price of electricity and natural gas are 0% and 0.1%, respectively.[66] When life cycle costs for the retrofit and BAU scenarios were estimated and discounted to a net present value, the BAU scenario resulted in the lowest cost to the homeowner over a 30-year life cycle. A summary of results are presented in Table 7; the complete life cycle cost spreadsheet for the EIA Low Oil Price Case is included in Appendix E.

Table 7: Present worth life cycle costs, EIA Low Oil Price Case

Life Cycle Costs	BAU	Passive House Retrofit
Initial Costs	-	$51,423.61
Replacement Costs	$3,816.53	$2,988.04
Energy Costs	$35,596.11	$6,324.26
Deduct Additional Resale Value	-	-$16,385.51
Total	$39,412.64	$44,350.40

EIA High Oil Price Case

Real dollar escalation rates predicted by the Energy Information Administration (EIA) High Oil Price Case for the end use residential price of electricity and natural gas are 0.3% and 0.4%,

[66] U.S. Energy Information Administration, 2009

respectively.[67] When life cycle costs for the retrofit and BAU scenarios were estimated and discounted to a net present value, the BAU scenario resulted in the lowest cost to the homeowner over a 30-year life cycle. A summary of results are presented in Table 8; the complete life cycle cost spreadsheet for the EIA High Oil Price Case is included in Appendix E.

Table 8: Present worth life cycle costs, EIA High Oil Price Case

Life Cycle Costs	**BAU**	**Passive House Retrofit**
Initial Costs	-	$51,423.61
Replacement Costs	$3,816.53	$2,988.04
Energy Costs	$36,982.83	$6,570.42
Deduct Additional Resale Value	-	-$16,385.51
Total	$40,799.36	$44,596.55

In all three energy price cases, the BAU scenario results in the lowest cost to the homeowner over a 30-year life cycle. As evident in the tables above, the three energy price cases produce very similar results. The differences in life cycle costs between the BAU and retrofit scenarios in the three energy price cases are as follows: $3,797.19 in the High Oil Price Case, $4,561.05 in the Reference Case, and $4,937.76 in the Low Oil Price Case. For the reasons discussed in Chapter III, the life cycle cost analysis results for the EIA High Oil Price Case will be used as the basis for discussion in the next chapter.

[67] U.S. Energy Information Administration, 2009

CHAPTER V

DISCUSSION

While the BAU scenario results in the lowest cost to the homeowner over a 30-year life cycle, the difference in cost between the two scenarios is relatively small – less than 9%. There are a number of variables which influence the life cycle cost analysis; adjustments to any one of these variables could potentially reverse the outcome of the study. In the researcher's manipulation of the life cycle costing spreadsheet, the variables which have the greatest impact on the outcome of the analysis are initial construction costs, credits, current energy expenditures, escalation rates, and the percentage of energy savings in the retrofit scenario. As a means of further investigating the feasibility of Passive House retrofits in the U.S., the author suggests research in the following topics.

Cold Climates

Relative to much of the United States, Eugene's climate is considerably mild. The annual energy costs to heat an early 20th century home in Eugene are likely significantly less than the costs to heat a similar home in Bozeman, Montana, for example, which has over twice the number of heating degree days. According to the U.S. Energy Information Administration, households in climates with more than 7000 heating degree days spend an average of 25% more on energy bills than households in climates with fewer than 4000 heating degree days.[68] Higher energy expenditures correlate to a higher potential for cost savings through retrofit. Based on the small difference in life cycle costs between the two scenarios in this study, it is highly likely that a Passive House retrofit similar in scope to the case study retrofit, if performed in a colder climate, would prove to be financially viable over a 30-year period.

68 U.S. Energy Information Administration, 2008

Housing Typology

This study is specific to one housing type which is prevalent in Eugene as illustrated by the photographs in Appendix A. A variety of single family housing types exist in Eugene; certainly, a wide variety of types exist throughout the United States. Since typology is closely tied to building form, and building form to retrofit approach, more research will be needed to develop recommendations for retrofits based on housing type. Such research may lead to the development of a system through which individual homes can be quickly evaluated to determine their retrofit potential and, if suitable for retrofit, suggest the efficiency measures to be taken.

Energy Escalation Rates

Energy escalation rates – the percentage by which energy prices increase annually – are predicted by, among other public and private entities, the U.S. Energy Information Administration (EIA). Unfortunately – as escalation rates are incredibly difficult to predict – the EIA often misjudges the rising price of oil. As recently as 2004, the EIA predicted that oil would maintain its price of around $30 per barrel for the next few decades. Even in its High Oil Price case, the EIA predicted that the price of oil would stay below $45 per barrel through 2025.[69]

Having now experienced oil prices well over $100 per barrel, it is clear how unreliable energy price predictions can be. Energy price predictions, however, greatly influence financial decisions regarding energy efficiency improvements. The outcome of the life cycle cost analysis completed in this study, for instance, is largely determined by energy escalation rates. Increasing the escalation rates by relatively small increments have a major impact on the results of the study. For instance, an escalation rate of 1% for electricity and 1.5% for natural gas would place the life cycle costs for the two scenarios within $1 of each other.

[69] Williams-Derry, 2011

Nonprofit Scenarios

The initial costs and credits associated with the retrofit have an enormous influence on the outcome of the life cycle cost analysis. In the construction cost estimate, overhead and profit accounted for an additional 15% of the total material, labor, and equipment cost. If the contractor was a nonprofit entity and overhead and profit were deducted from the initial construction costs, the net present value of the life cycle costs in the retrofit scenario would be lower than that of the BAU scenario by almost $4,000. Based on this finding, non-profits such as Habitat for Humanity may find Passive House retrofits to be economically viable.

Credits and Incentives for Retrofit

Currently, 12% of the construction costs specific to achieving the Passive House Standard are funded by federal, state, and utility credits. If an additional 7% of these costs were funded by credits, the total life cycle costs for the two scenarios would be identical. Credits and incentives specific to achieving the Passive House standard could provide the additional funding necessary to make the retrofit financially viable over a 30-year life cycle.

Appraised Value

By some estimates, homeowners in the U.S. move on average every five to seven years. Few American homeowners, therefore, will occupy a single home for the entirety of a 30-year mortgage. Regardless of whether or not a 30-year payback for a Passive House retrofit is achieved, homeowners will not likely be persuaded to opt for a Passive House retrofit based on economic factors alone since most will sell their home before the payback is reached. As stated in the Recovery Through Retrofit Report: "Homeowners face high upfront costs and many are concerned that they will be prevented from recouping the value of their investment if they choose to sell their home."[70]

[70] United States, Middle Class Task Force, Council on Environmental Quality, 2009

For this reason, banks must come to realize the added value in a Passive House over a typical code-designed house. If this added value is acknowledged by lending sources, homeowners would have the potential to recoup their initial investment in the retrofit through a higher resale value at the end of ownership. A house which saves 70% on energy use over a typical code-designed house has a significantly higher economic value to a homeowner due to lower operating costs and higher quality of construction; this added value should be recognized by banks during the appraisal process.

Passive House Retrofit Standard

EnerPHit, the Passive House Institute's standard for retrofits, is currently in its pilot phase in Europe. If implemented in the U.S., the less stringent standard could result in a considerable cost reduction for Passive House retrofits. However, due to the fact that the EnerPHit standard allows for a higher specific space heating demand, the energy savings would likely not be as substantial. For this reason, further research is needed to determine the cost-effectiveness of retrofits designed to the EnerPHit standard.

Additional Scenarios

In the life cycle costing phase of this study, two scenarios were examined: the business as usual (BAU) scenario, in which the case study house is upgraded to current energy code requirements, and the Passive House retrofit scenario, in which the case study house is retrofitted to perform to the Passive House standard. A third scenario might be considered, in which the case study house is not upgraded at all. The disparity in energy performance between the case study house as it exists today and a Passive House might be significantly greater than that of the two scenarios examined. Further, the case study house has been upgraded throughout its lifetime so that its performance is likely considerably better than that of a typical hundred-year-old home. It would be beneficial to examine a home which has never been upgraded; the disparity in performance between such a home and a Passive House would likely be vast.

Life Cycle Assessment

This study has examined the life cycle costs associated with achieving the Passive House standard in a home energy retrofit. The existing Passive House body of knowledge would benefit from a life cycle assessment of a Passive House retrofit. Clearly, a Passive House retrofit results in a considerable reduction in energy use; on the other hand, there is a significant amount of embodied energy in the construction materials used to complete the retrofit. A careful study of the balance between a Passive House retrofit's embodied energy and the anticipated energy savings over the building's life cycle would provide keen insight into the retrofit's true environmental consequences.

CHAPTER VI

CONCLUSION

While the hypothesis of this study was disproven, the difference in life cycle costs of the two scenarios is small enough that minor adjustments to key variables, as discussed in the previous chapter, result in the retrofit being cost-effective over a 30-year period.

The Economics of Retrofit

The unpredictable nature of energy prices – and the national economy as a whole – offers a compelling argument for improving the efficiency of our nation's existing housing stock. As evident in this study, Passive House retrofits provide a means of greatly improving the energy performance of existing older homes. Due to extremely low energy bills, owners of Passive Houses and other high performance homes will be far more likely to weather periods of high energy prices and economic uncertainty than owners of old, leaky homes.

To some homeowners, the financial questions behind Passive House retrofits are secondary to the environmental questions. In casual conversation with the owner of a Passive House retrofit project now underway in Oregon, the owner noted that the economics of the project were secondary to the larger issues of carbon emissions and climate change. While the author tends to agree, the widespread implementation of Passive House retrofits will require that such retrofits are affordable; currently, homeowners are paying a premium for Passive House. Fortunately, as more homeowners opt for Passive House retrofits, this premium will likely become smaller. Further, as banks begin to acknowledge the added economic value in Passive Houses, financially-minded homeowners will begin to invest in them. In any case, one thing is for sure: Passive House offers an ambitious performance standard for home energy retrofits that measurably addresses the efficiency of the existing housing stock and can be achieved using existing construction techniques and technologies.

APPENDIX A

PHOTOGRAPHS OF SELECT EUGENE HOUSES













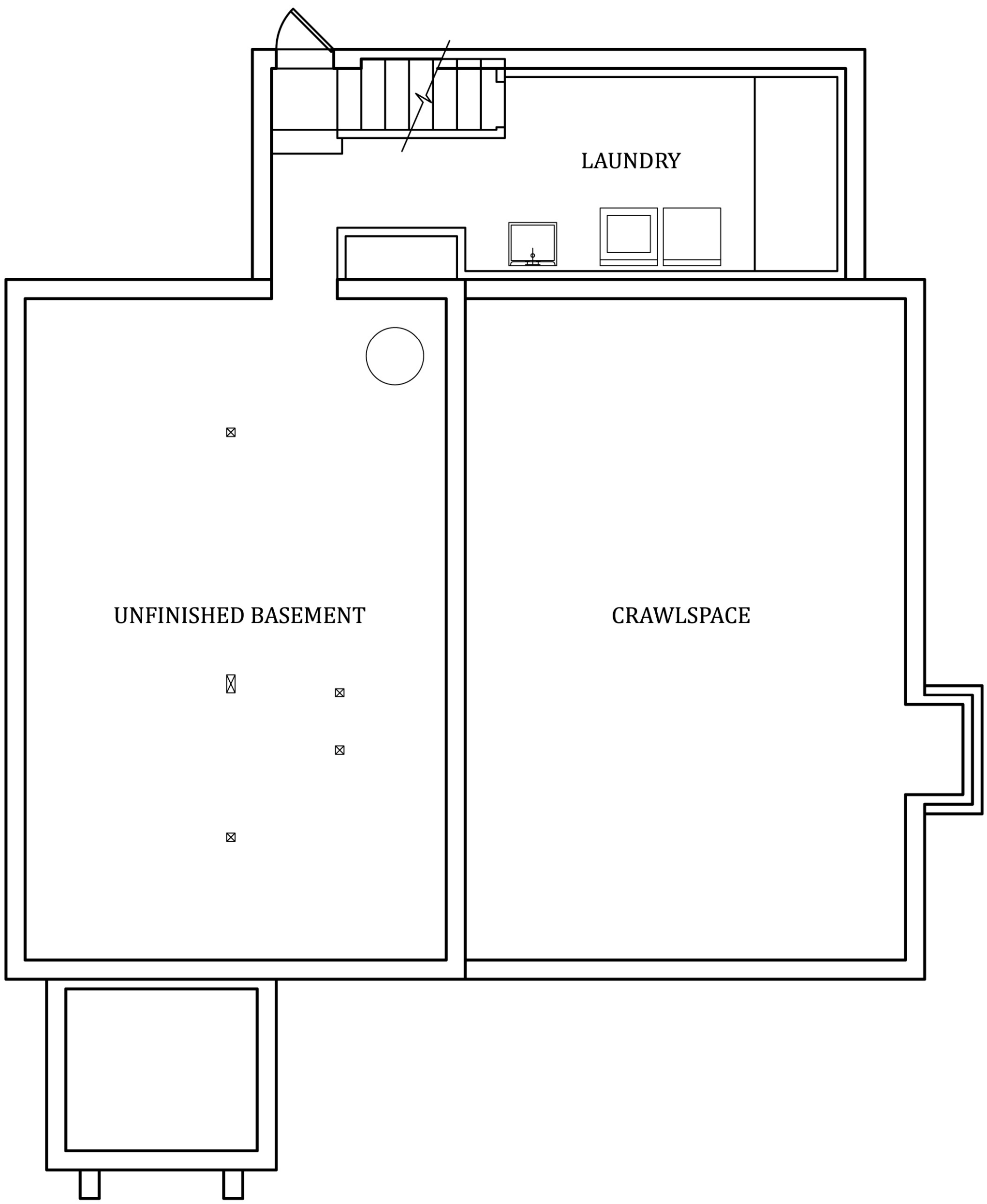




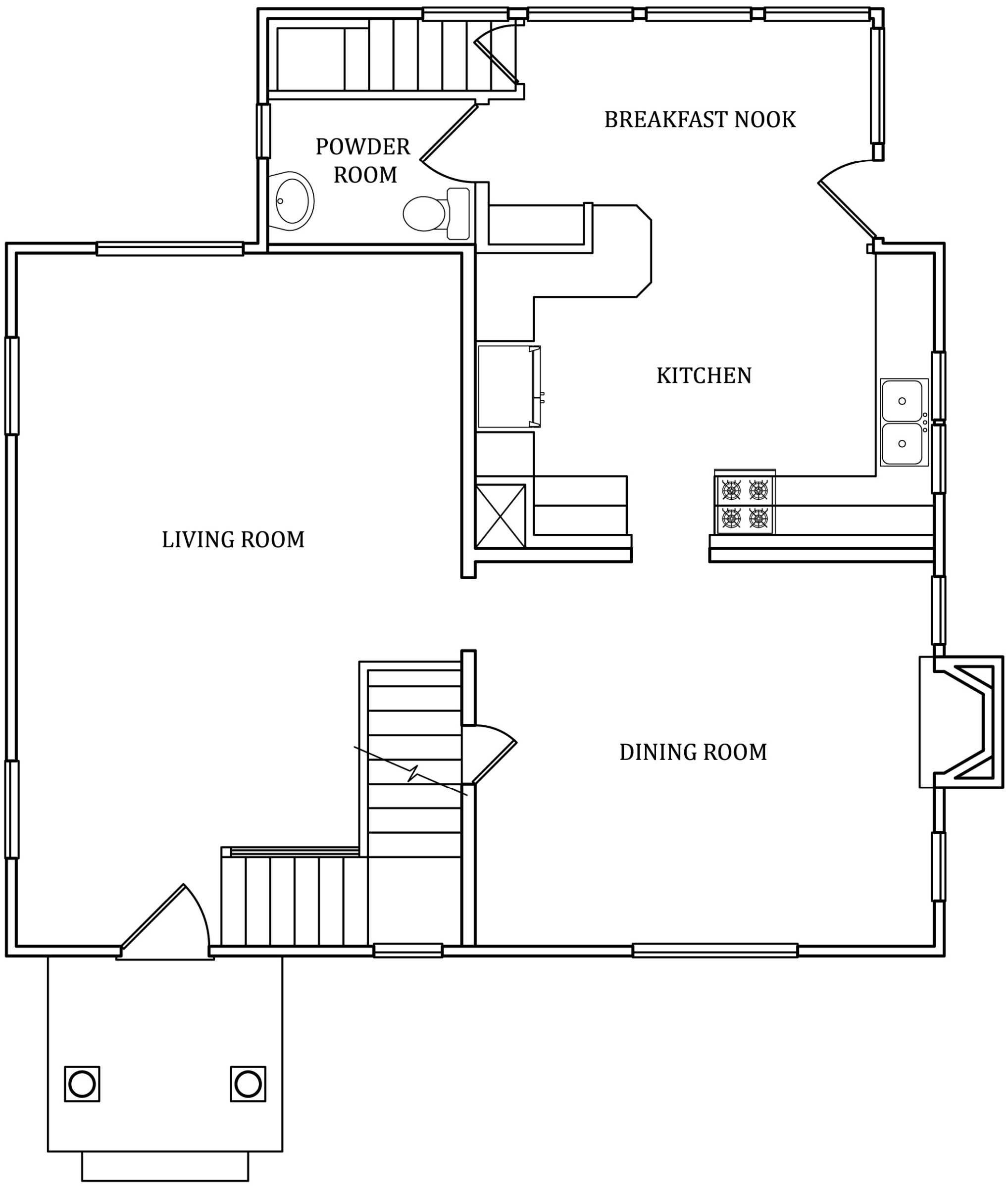



APPENDIX B

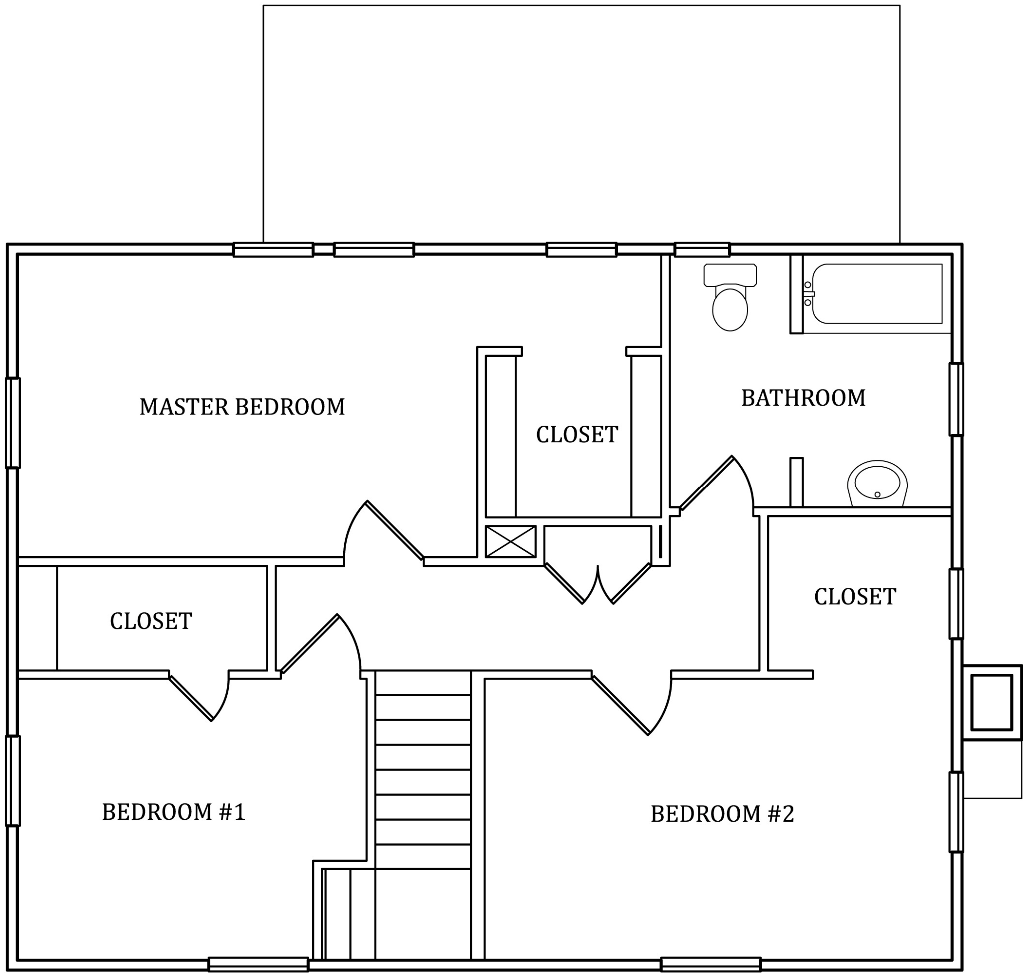
AS-BUILT DRAWINGS



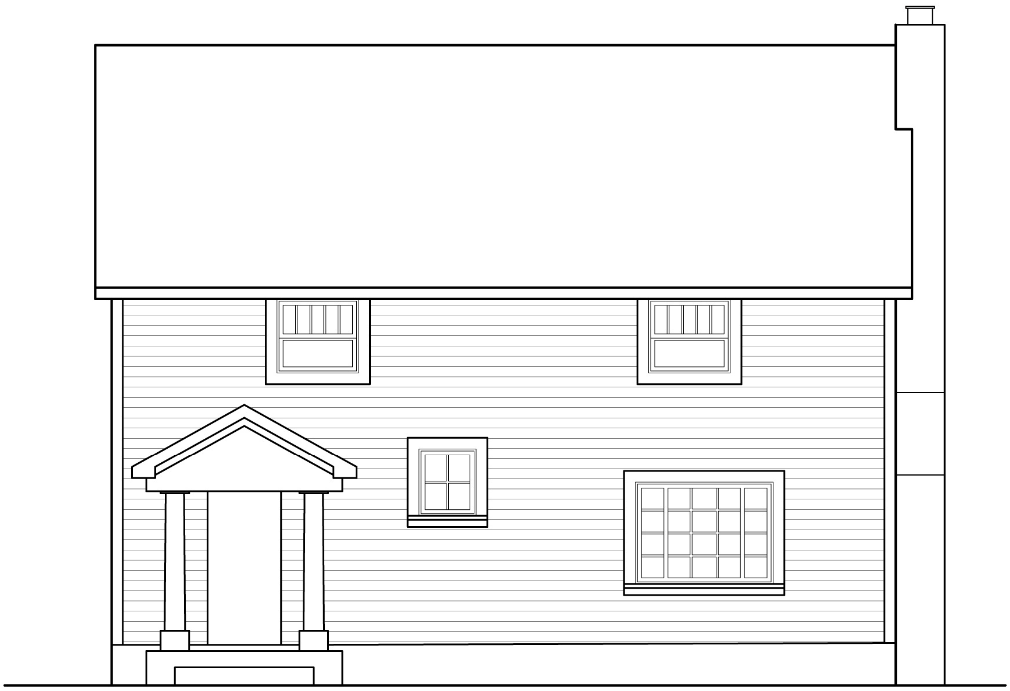
Foundation/Basement Plan



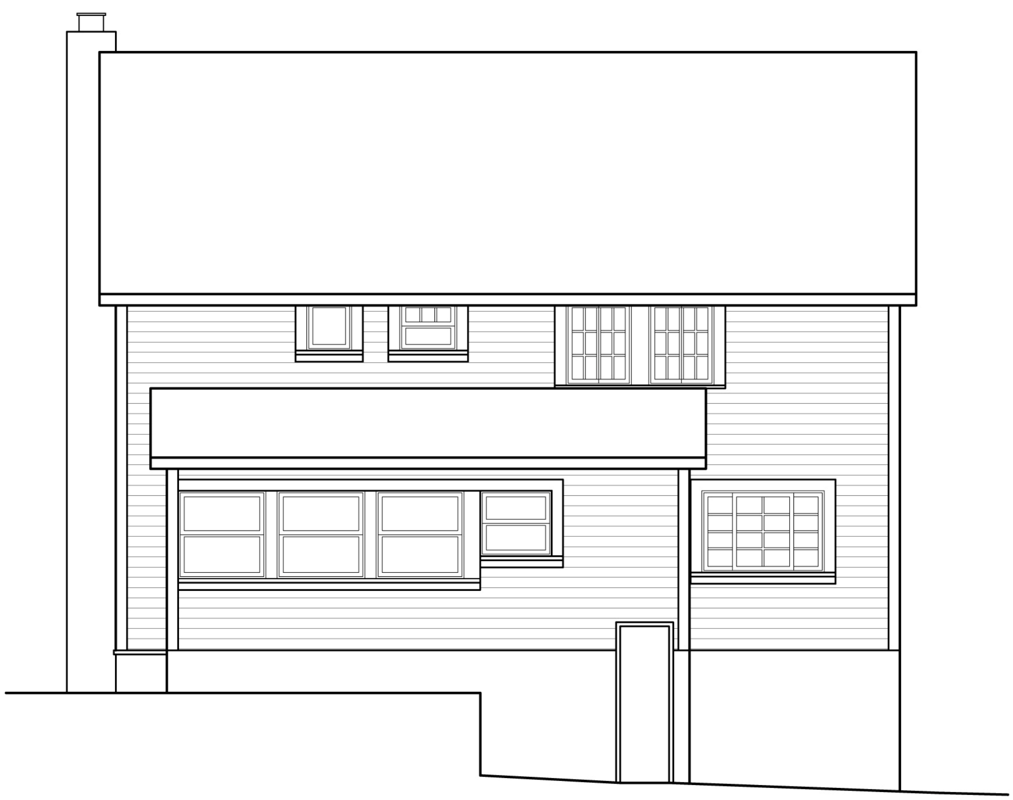
First Floor Plan



Second Floor Plan



South Elevation



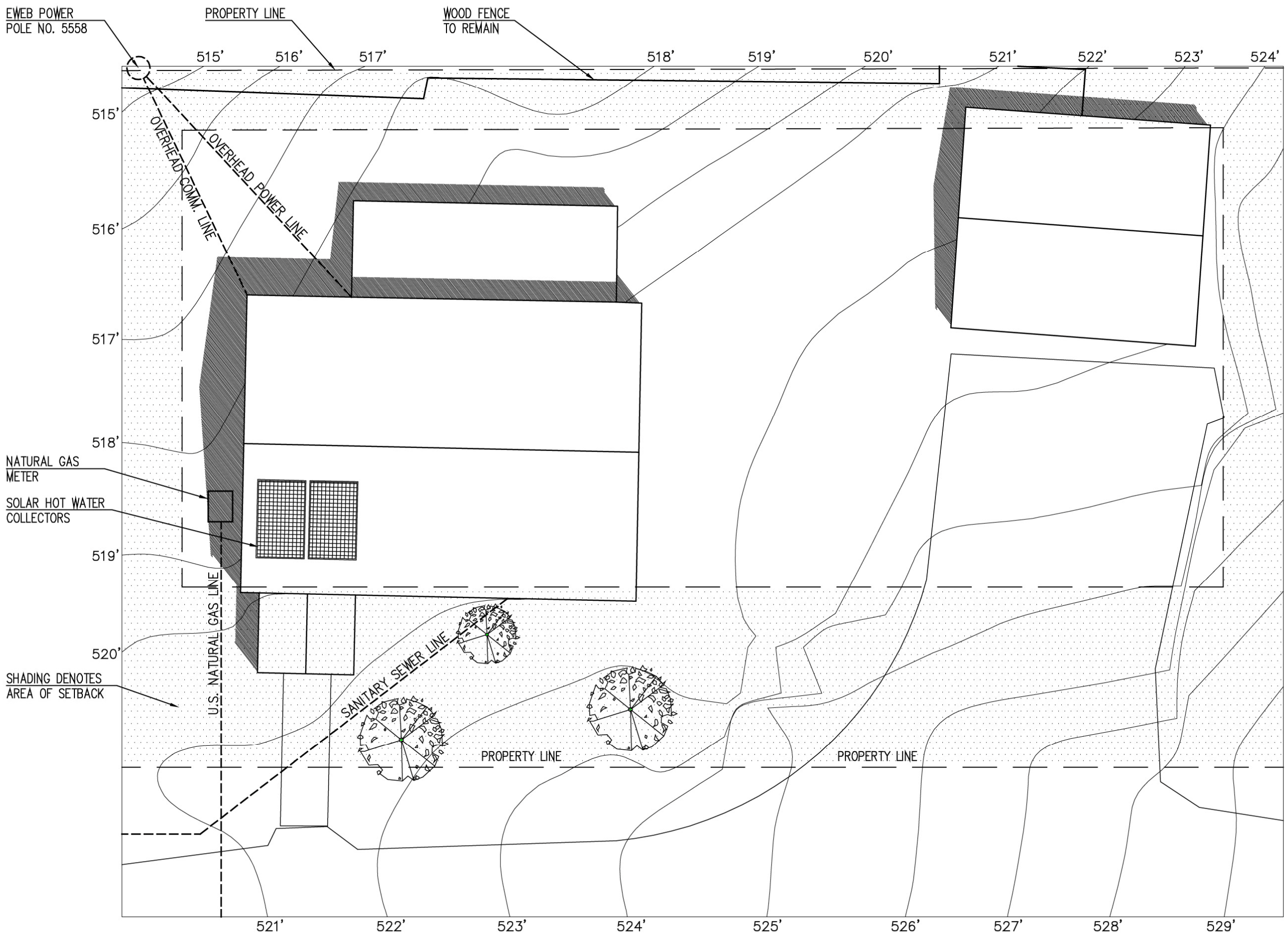
North Elevation

East Elevation

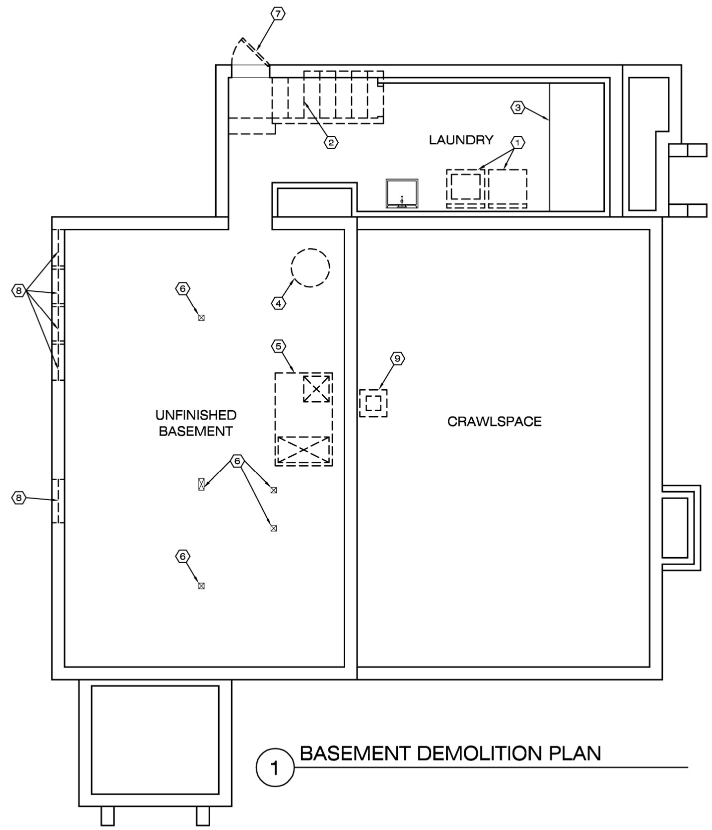
West Elevation

APPENDIX C

BID SET

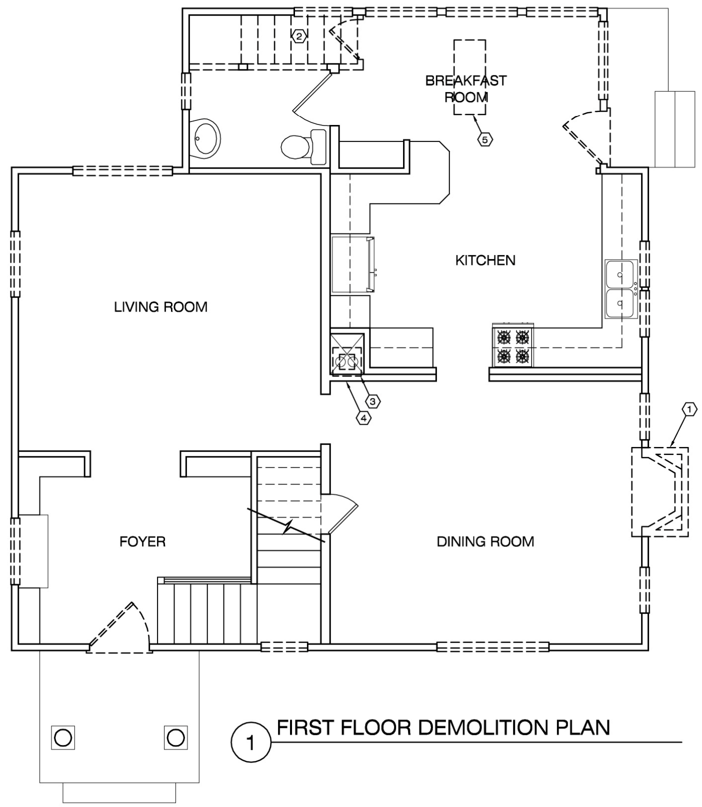

EWEB POWER POLE NO. 5558
PROPERTY LINE
WOOD FENCE TO REMAIN
515'
516'
517'
518'
519'
520'
521'
522'
523'
524'
525'
526'
527'
528'
529'
OVERHEAD COMM. LINE
OVERHEAD POWER LINE
NATURAL GAS METER
SOLAR HOT WATER COLLECTORS
U.S. NATURAL GAS LINE
SANITARY SEWER LINE
SHADING DENOTES AREA OF SETBACK
PROPERTY LINE
PROPERTY LINE

1 SITE PLAN



1 BASEMENT DEMOLITION PLAN

DOOR LEGEND	WALL LEGEND	GENERAL NOTES	KEY NOTES
EXISTING DOOR TO REMAIN EXISTING DOOR TO BE DEMOLISHED	EXISTING WALL TO REMAIN EXISTING WALL TO BE DEMOLISHED	-	(1) EXISTING WASHER & DRYER TO BE REMOVED AND SALVAGED FOR RESALE BY OWNER. (2) EXISTING WOOD STAIR TO BE DEMOLISHED. (3) EXISTING COUNTERTOP TO REMAIN. (4) EXISTING ELEC. HOT WATER HEATER TO BE REMOVED AND SALVAGED FOR RESALE BY OWNER. (5) EXISTING GAS FURNACE TO BE REMOVED & SALVAGED FOR RESALE BY OWNER. DEMOLISH ASSOCIATED DUCTWORK & DIFFUSERS/GRILLES.. (6) EXISTING WOOD POST TO REMAIN. (7) EXISTING DOOR, FRAME, & TRIM TO BE DEMOLISHED. (8) EXISTING WINDOW TO BE DEMOLISHED. (9) EXISTING BRICK CHIMNEY TO BE DEMOLISHED.



1 FIRST FLOOR DEMOLITION PLAN

DOOR LEGEND

EXISTING DOOR TO REMAIN

EXISTING DOOR TO BE DEMOLISHED

WALL LEGEND

EXISTING WALL TO REMAIN

EXISTING WALL TO BE DEMOLISHED

WINDOW LEGEND

EXISTING WINDOW TO BE DEMOLISHED

GENERAL NOTES

EXISTING WINDOWS, FRAMES, & TRIM TO BE DEMOLISHED.

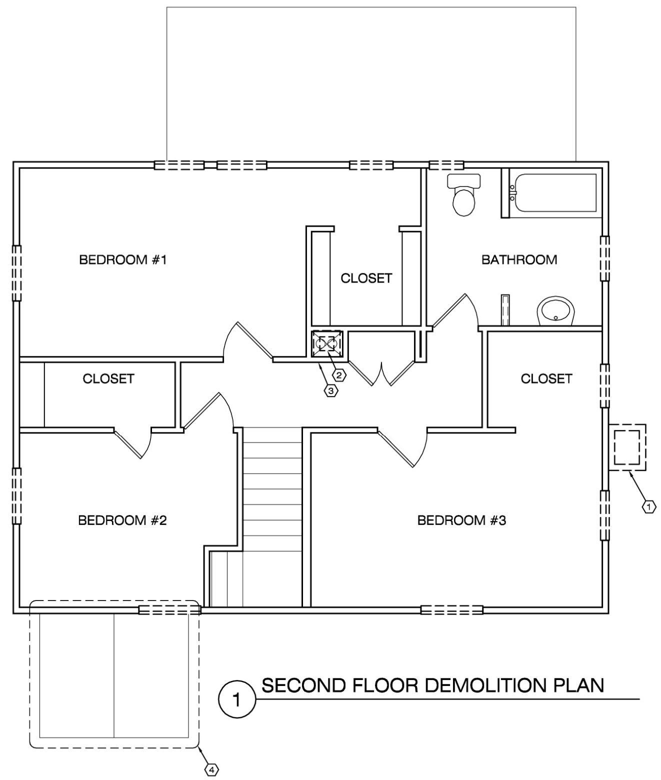
EXISTING EXTERIOR DOORS, FRAMES, & TRIM TO BE DEMOLISHED.

EXISTING EXTERIOR WOOD SIDING AND TRIM TO BE DEMOLISHED.

EXISTING GUTTERS & DOWNSPOUTS TO BE DEMOLISHED.

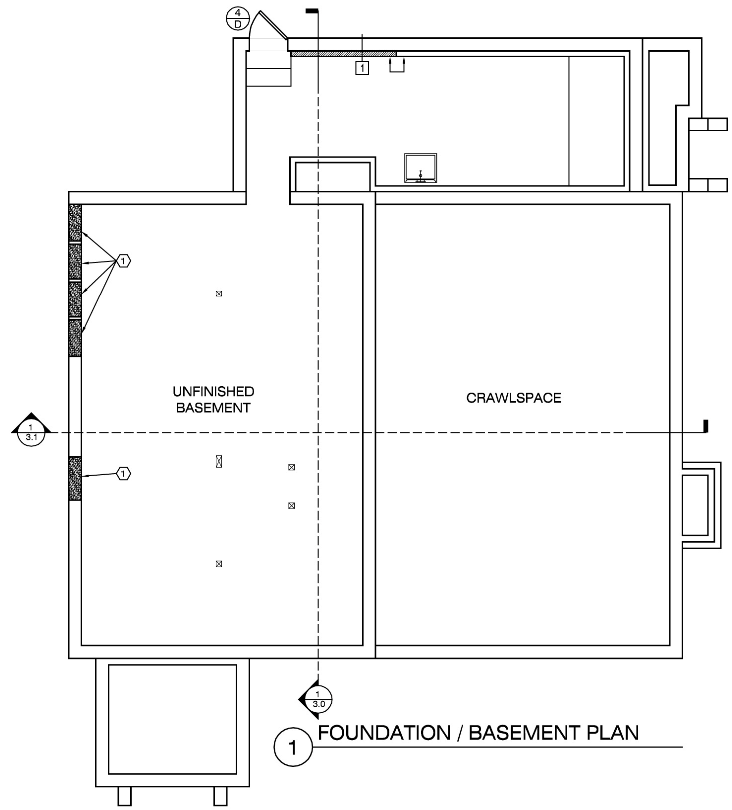
KEY NOTES

1. EXISTING BRICK FIREPLACE & CHIMNEY TO BE DEMOLISHED.
2. EXISTING WOOD STAIR BELOW TO BE DEMOLISHED.
3. EXISTING BRICK CHIMNEY TO BE DEMOLISHED. MAINTAIN EXISTING VERTICAL CHASE FOR NEW HRV SUPPLY & RETURN DUCTS.
4. EXISTING FRAME WALL TO BE DEMOLISHED AS NEEDED TO PROVIDE ACCESS TO EXISTING BRICK CHIMNEY.
5. DEMOLISH EXISTING SKYLIGHT.



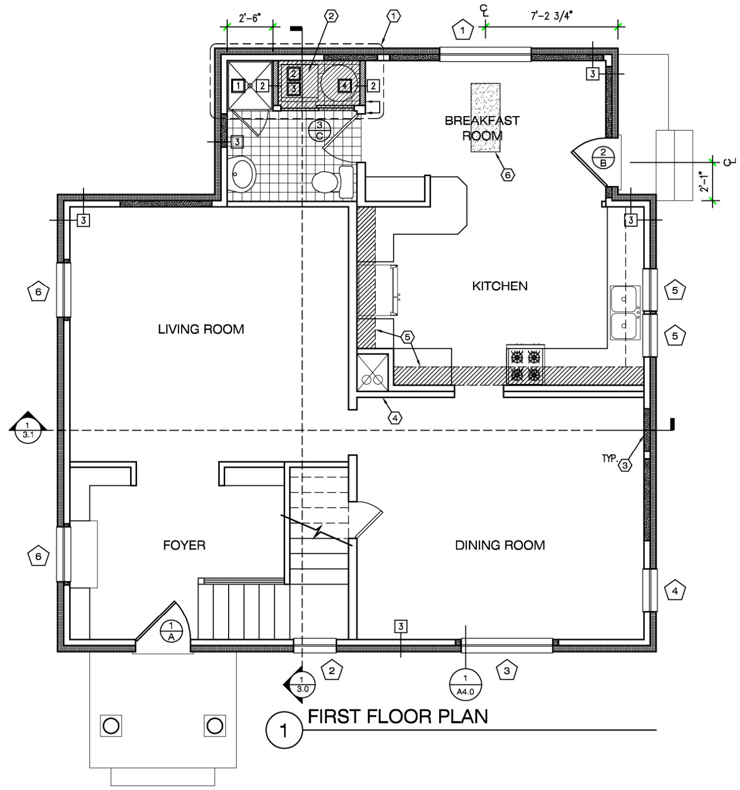
1 SECOND FLOOR DEMOLITION PLAN

DOOR LEGEND	WALL LEGEND	GENERAL NOTES	KEY NOTES
EXISTING DOOR TO REMAIN EXISTING DOOR TO BE DEMOLISHED	EXISTING WALL TO REMAIN EXISTING WALL TO BE DEMOLISHED **WINDOW LEGEND** EXISTING WINDOW TO BE DEMOLISHED	EXISTING WINDOWS, FRAMES, & TRIM TO BE DEMOLISHED. EXISTING EXISTING EXTERIOR WOOD SIDING AND TRIM TO BE DEMOLISHED. EXISTING GUTTERS & DOWNSPOUTS TO BE DEMOLISHED.	(1) EXISTING BRICK CHIMNEY TO BE DEMOLISHED. (2) EXISTING BRICK CHIMNEY TO BE DEMOLISHED. MAINTAIN EXISTING VERTICAL CHASE FOR NEW HRV SUPPLY & RETURN DUCTS. (3) EXISTING FRAME WALL TO BE DEMOLISHED AS NEEDED TO PROVIDE ACCESS TO EXISTING BRICK CHIMNEY. (4) DEMOLISH EXISTING ROOF AT FRONT STOOP AS NEEDED TO ALLOW CONTINUOUS INSTALL OF RIGID INSULATION



1 FOUNDATION / BASEMENT PLAN

DOOR LEGEND	WALL LEGEND	GENERAL NOTES	KEY NOTES
EXISTING DOOR TO REMAIN NEW DOOR	EXISTING WALL TO REMAIN NEW WALL TYPE 1: FURR OUT NEW 2x4 WALL AT EXISTING BASEMENT WALL. SEE DTL. 1 SHEET A4.1.	–	(1) HATCHED AREA DENOTES NEW INFILL FRAMING AT EXISTING OPENING.



1 FIRST FLOOR PLAN

EQUIPMENT KEY SEE MEP SHEETS FOR MORE INFO.

	DESCRIPTION	MANUF.	MODEL
1	SHOWER	–	–
2	WASHER	–	–
3	CONDENSING DRYER	–	–
4	COMBO ELECTRIC WATER HEATER/ SOLAR STORAGE TANK	–	–

DOOR LEGEND

EXISTING DOOR TO REMAIN

NEW DOOR

GENERAL NOTES

NEW WINDOWS AND DOORS TO BE INSTALLED IN EXISTING ROUGH OPENINGS UNLESS OTHERWISE NOTED.

PATCH EXISTING FLOOR & FINISH AT DEMOLISHED DIFFUSER LOCATIONS.

WALL LEGEND

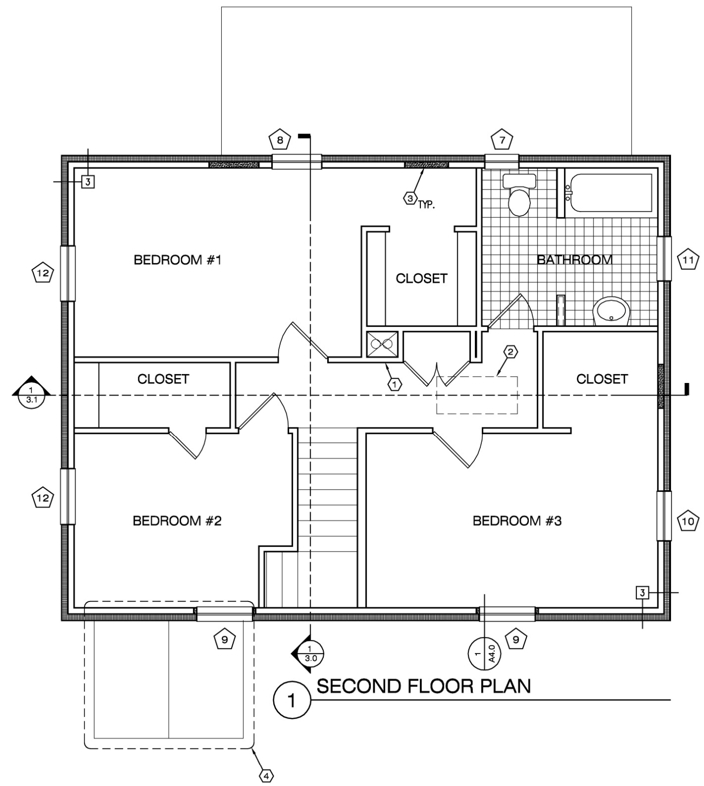
EXISTING WALL TO REMAIN

2 — NEW WALL TYPE 2: 2x4 INTERIOR WALL. SEE DTL. 2 SHEET A4.1.

3 — NEW WALL TYPE 3: NEW POLYISO RIGID INSULATION OVER EXISTING 2x4 WALL. SEE DTL. 3 SHEET A4.1.

KEY NOTES

1. FRAME OVER EXISTING STAIR OPENING AT THIS AREA. SEE SHEET A2.0 FOR MORE INFORMATION.
2. INSTALL NEW FLOOR FINISHES AT HATCHED AREA TO MATCH EXISTING.
3. HATCHED AREA DENOTES NEW INFILL FRAMING AT EXISTING OPENING, TYP. PROVIDE NEW FINISHES TO MATCH EXISTING.
4. PATCH & REPAIR EXISTING FRAME WALL & FINISHES AS NEEDED.
5. HATCHED AREA DENOTES NEW GWB BULKHEADS ABOVE EXISTING CABINETS TO HOUSE HRV DUCTWORK.
5. HATCHED AREA DENOTES NEW INFILL FRAMING AT EXISTING SKYLIGHT OPENING. PROVIDE NEW FINISHES TO MATCH EXISTING.



1 SECOND FLOOR PLAN

DOOR LEGEND

EXISTING DOOR TO REMAIN

NEW DOOR

WALL LEGEND

EXISTING WALL TO REMAIN

NEW WALL TYPE 3: NEW POLYISO RIGID INSULATION OVER EXISTING 2x4 WALL. SEE DTL. 3 SHEET A4.1.

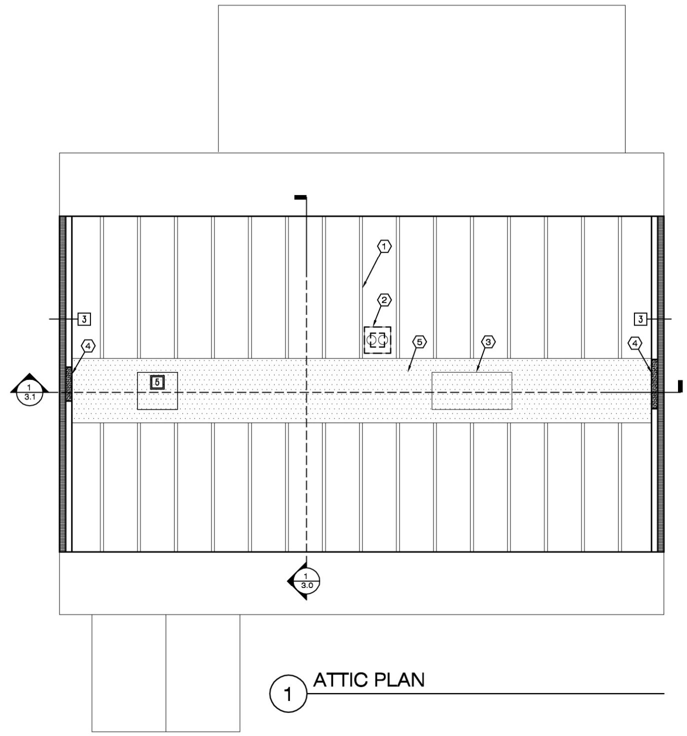
GENERAL NOTES

NEW WINDOWS TO BE INSTALLED IN EXISTING ROUGH OPENINGS UNLESS OTHERWISE NOTED.

PATCH EXISTING FLOOR & FINISH AT DEMOLISHED DIFFUSER LOCATIONS.

KEY NOTES

1. PATCH & REPAIR EXISTING FRAME WALL & FINISHES AS NEEDED.
2. EXISTING ATTIC ACCESS ABOVE TO REMAIN.
3. HATCHED AREA DENOTES NEW INFILL FRAMING AT EXISTING OPENING, TYP. PROVIDE NEW FINISHES TO MATCH EXISTING.
4. FRAME NEW ROOF AT FRONT STOOP AS NEEDED TO PROVIDE CONTINUOUS INSTALL OF RIGID INSULATION. SEE DETAIL 2 SHEET A4.0 FOR MORE INFO.



1 ATTIC PLAN

EQUIPMENT KEY

	DESCRIPTION	MANUF.	MODEL	NOTES
5	HRV	–	–	

GENERAL NOTES

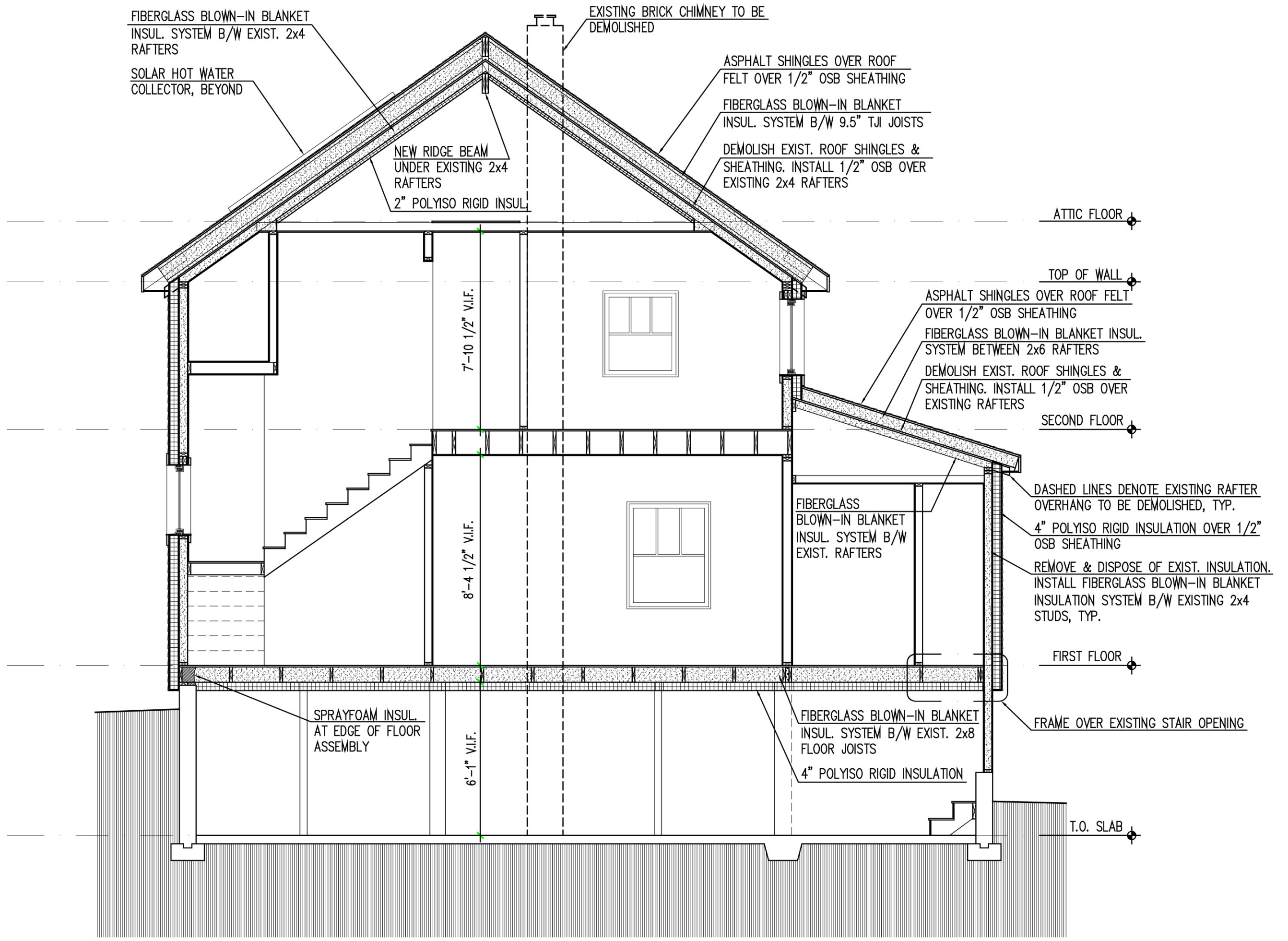
–

WALL LEGEND

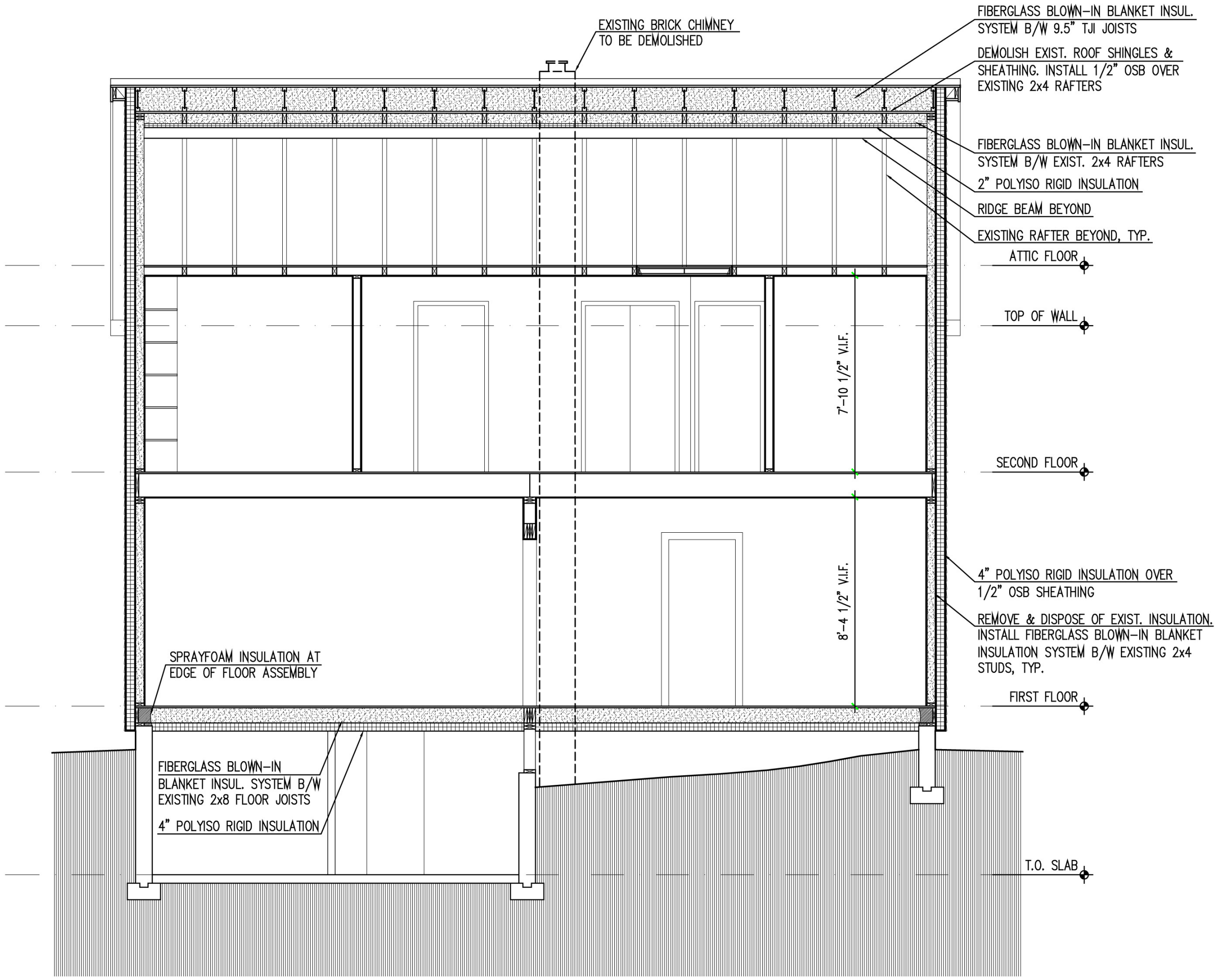
- EXISTING WALL TO REMAIN
- 3 — NEW WALL TYPE 3: NEW POLYISO RIGID INSULATION OVER EXISTING 2x4 WALL. SEE DTL. 3 SHEET A4.1.

KEY NOTES

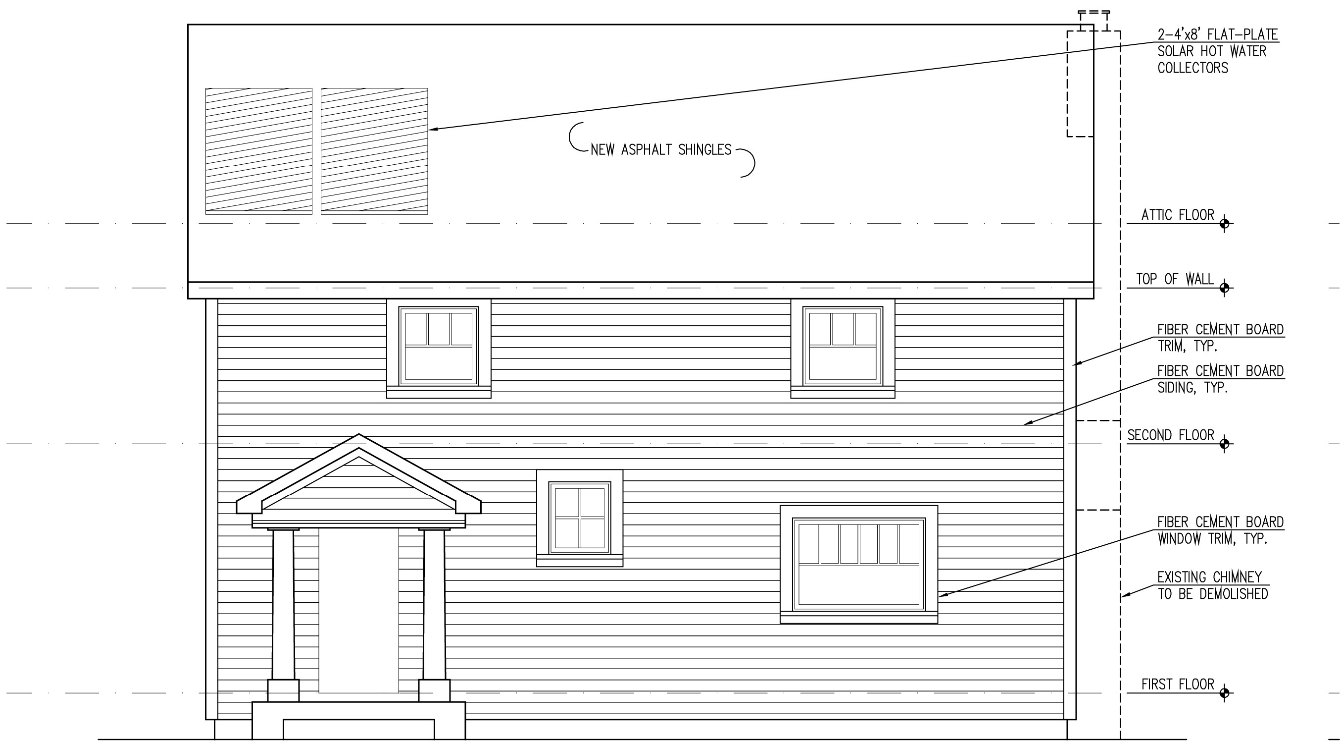
1. EXISTING 2x4 CEILING JOIST BELOW, TYP.
2. EXISTING BRICK CHIMNEY TO BE DEMOLISHED. MAINTAIN EXISTING VERTICAL CHASE FOR NEW HRV SUPPLY & RETURN DUCTS.
3. EXISTING ATTIC ACCESS TO REMAIN.
4. DEMOLISH EXISTING WINDOW, FRAME, & TRIM AT THIS LOCATION. INSTALL NEW 2x4 INFILL FRAMING.
5. NEW 3/4" PLYWOOD FLOOR AT HATCHED AREA.



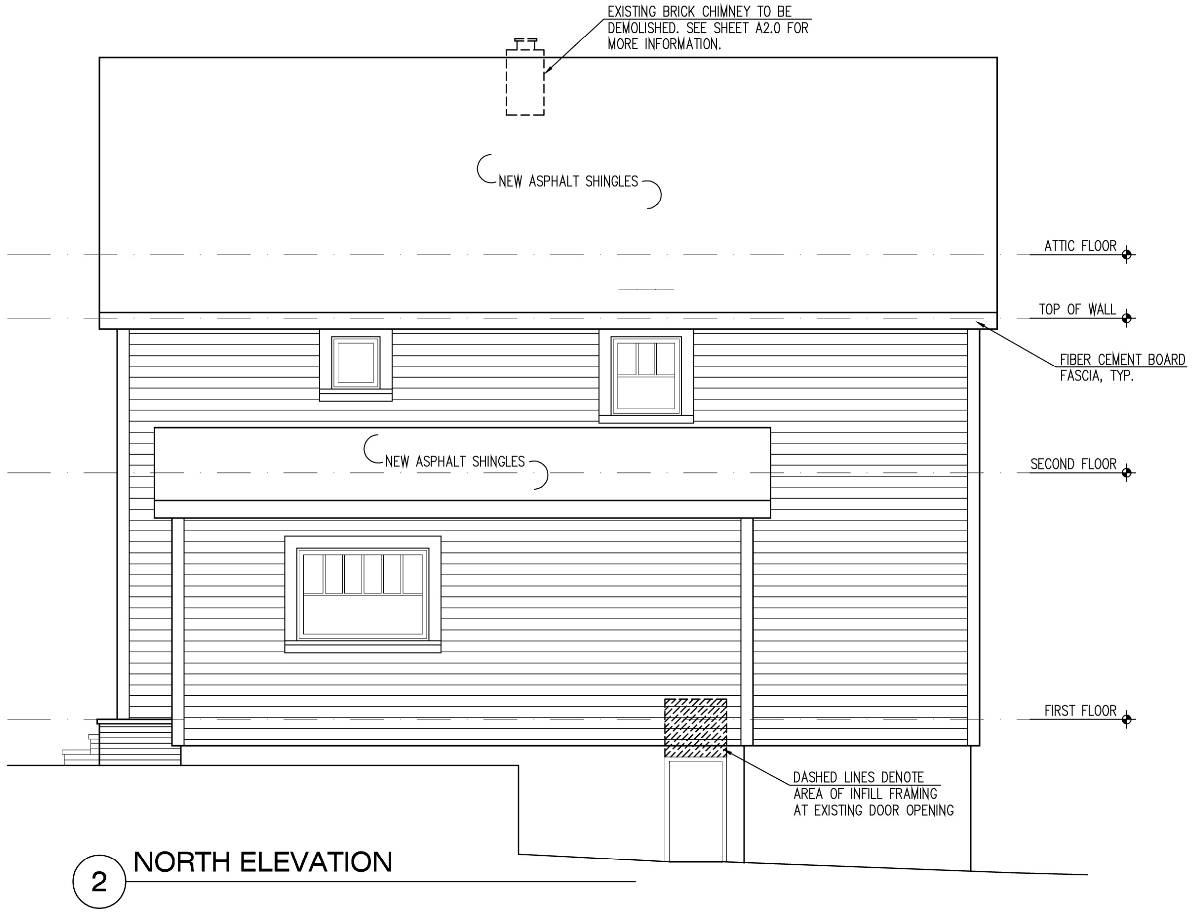
1 NORTH-SOUTH SECTION

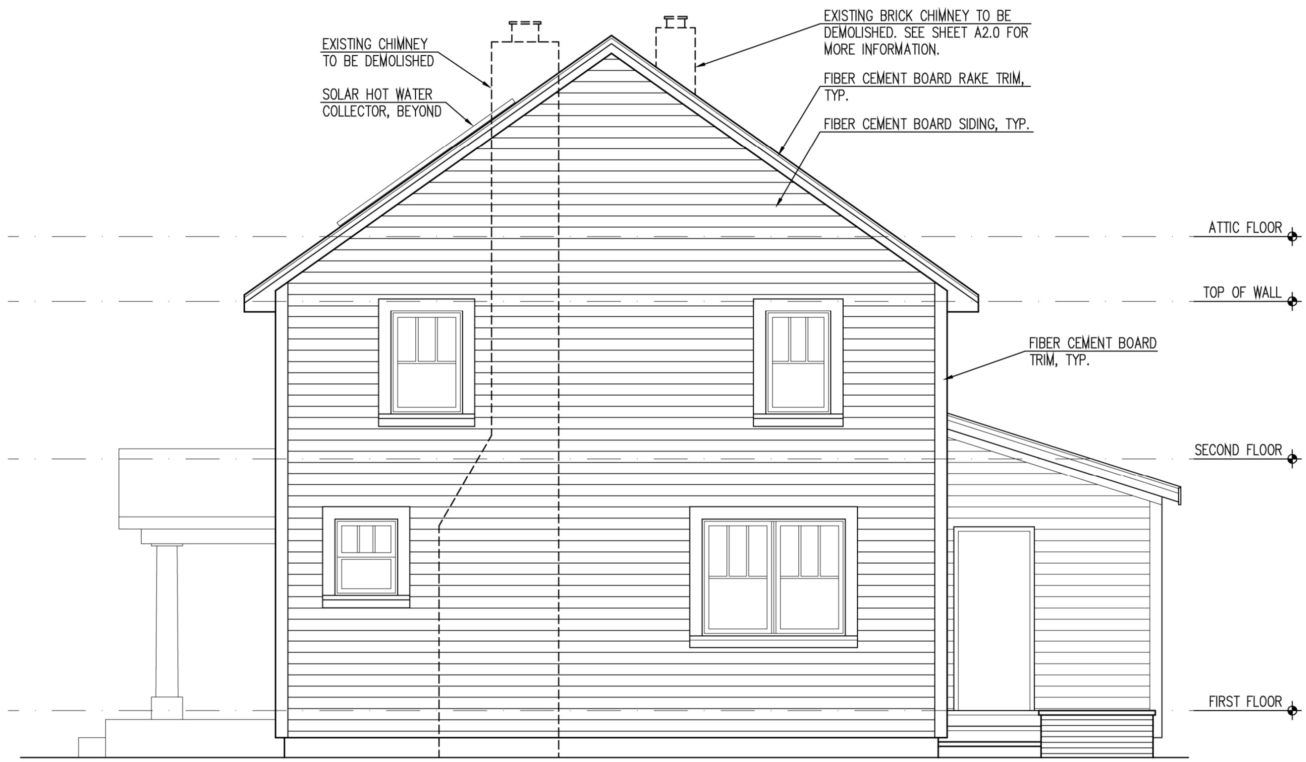


1 EAST-WEST SECTION

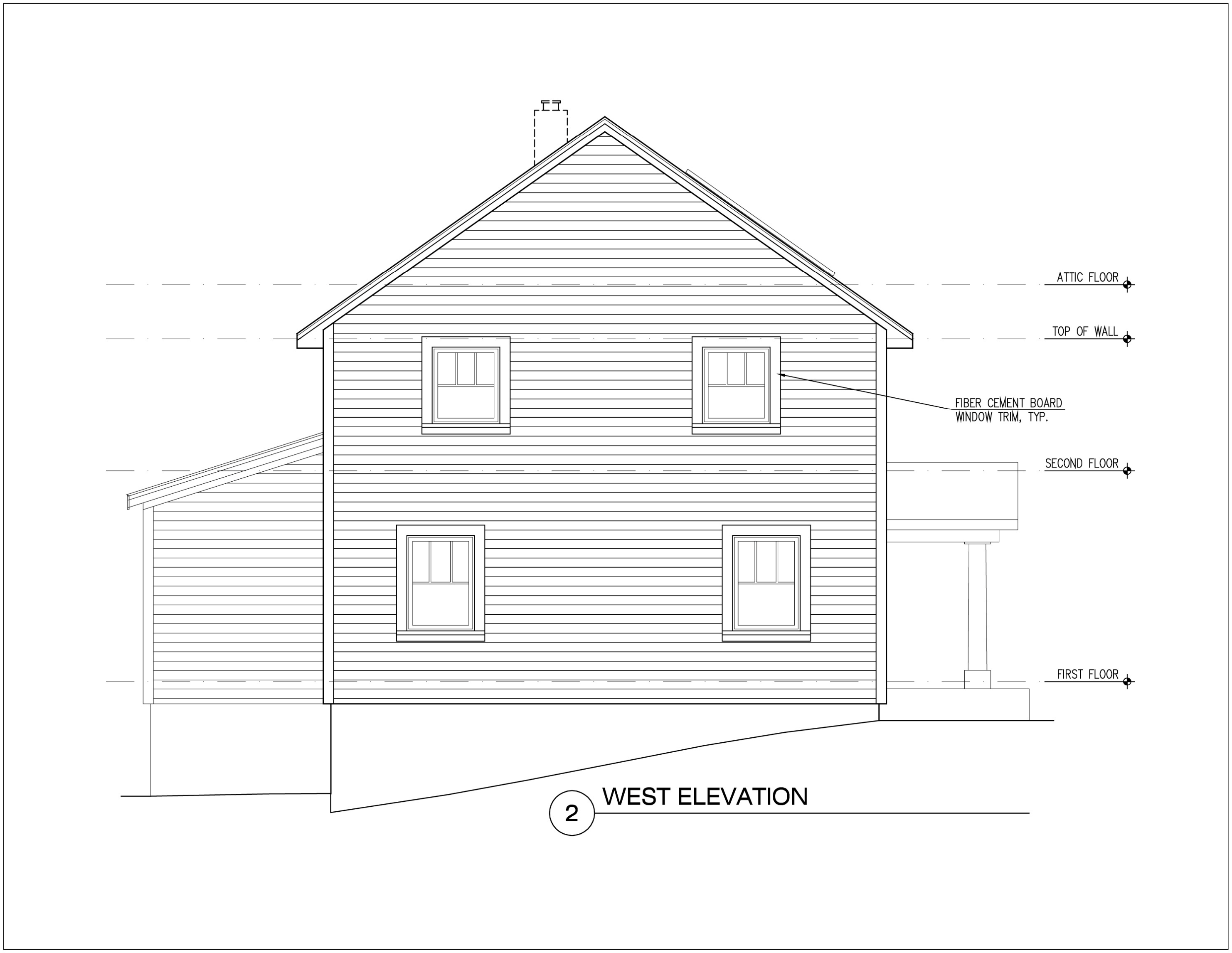


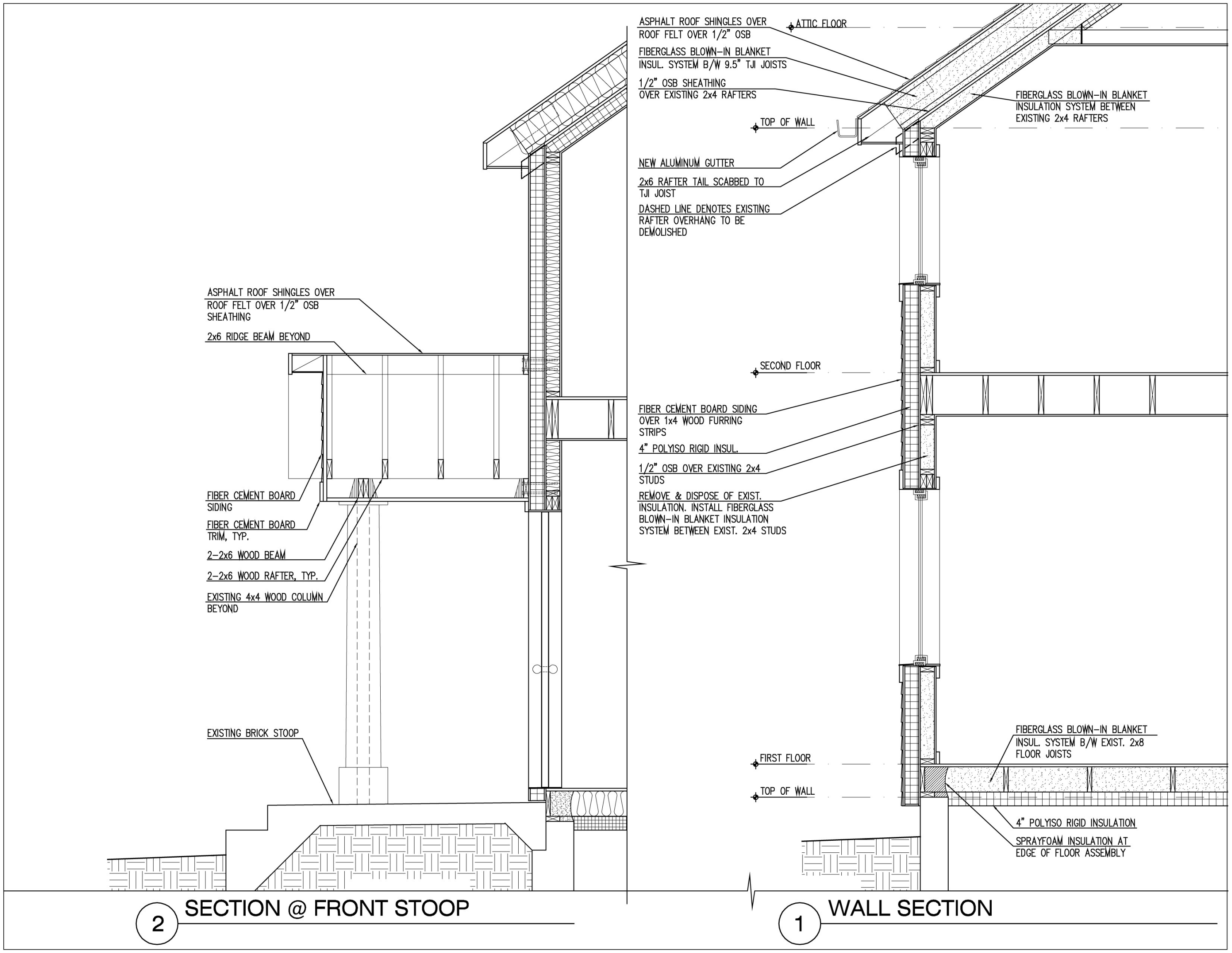
1 SOUTH ELEVATION

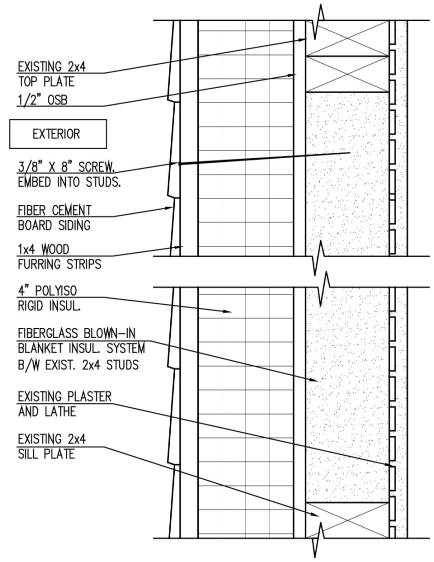

EXISTING BRICK CHIMNEY TO BE DEMOLISHED. SEE SHEET A2.0 FOR MORE INFORMATION.
NEW ASPHALT SHINGLES
ATTIC FLOOR
TOP OF WALL
FIBER CEMENT BOARD FASCIA, TYP.
NEW ASPHALT SHINGLES
SECOND FLOOR
FIRST FLOOR
DASHED LINES DENOTE AREA OF INFILL FRAMING AT EXISTING DOOR OPENING
2
NORTH ELEVATION



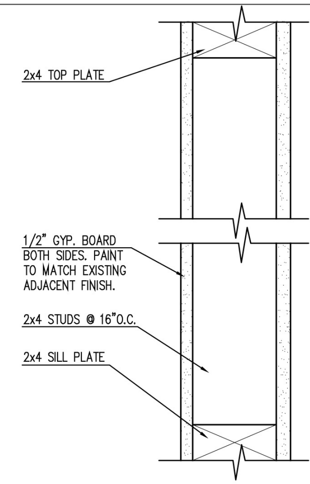
1 EAST ELEVATION


ATTIC FLOOR
TOP OF WALL
FIBER CEMENT BOARD
WINDOW TRIM, TYP.
SECOND FLOOR
FIRST FLOOR
2
WEST ELEVATION

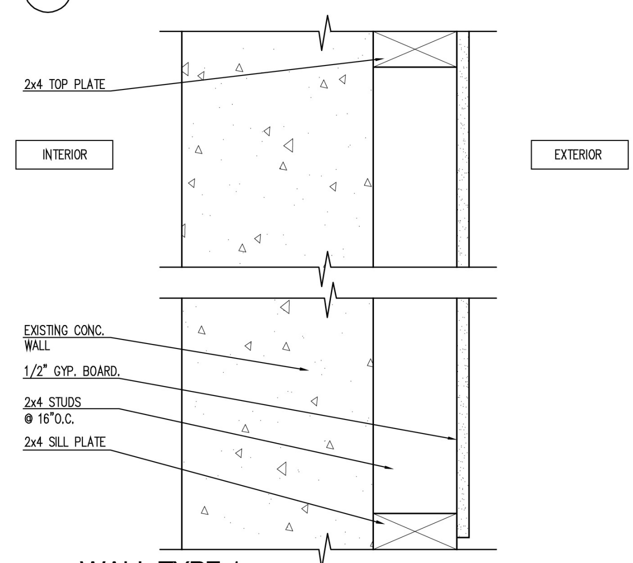

ASPHALT ROOF SHINGLES OVER ROOF FELT OVER 1/2" OSB
ATTIC FLOOR
FIBERGLASS BLOWN-IN BLANKET INSUL. SYSTEM B/W 9.5" TJI JOISTS
1/2" OSB SHEATHING OVER EXISTING 2x4 RAFTERS
FIBERGLASS BLOWN-IN BLANKET INSULATION SYSTEM BETWEEN EXISTING 2x4 RAFTERS
TOP OF WALL
NEW ALUMINUM GUTTER
2x6 RAFTER TAIL SCABBED TO TJI JOIST
DASHED LINE DENOTES EXISTING RAFTER OVERHANG TO BE DEMOLISHED
ASPHALT ROOF SHINGLES OVER ROOF FELT OVER 1/2" OSB SHEATHING
2x6 RIDGE BEAM BEYOND
SECOND FLOOR
FIBER CEMENT BOARD SIDING OVER 1x4 WOOD FURRING STRIPS
4" POLYISO RIGID INSUL.
1/2" OSB OVER EXISTING 2x4 STUDS
REMOVE & DISPOSE OF EXIST. INSULATION. INSTALL FIBERGLASS BLOWN-IN BLANKET INSULATION SYSTEM BETWEEN EXIST. 2x4 STUDS
FIBER CEMENT BOARD SIDING
FIBER CEMENT BOARD TRIM, TYP.
2-2x6 WOOD BEAM
2-2x6 WOOD RAFTER, TYP.
EXISTING 4x4 WOOD COLUMN BEYOND
EXISTING BRICK STOOP
FIBERGLASS BLOWN-IN BLANKET INSUL. SYSTEM B/W EXIST. 2x8 FLOOR JOISTS
FIRST FLOOR
TOP OF WALL
4" POLYISO RIGID INSULATION
SPRAYFOAM INSULATION AT EDGE OF FLOOR ASSEMBLY
2 SECTION @ FRONT STOOP
1 WALL SECTION



3 WALL TYPE 3



2 WALL TYPE 2



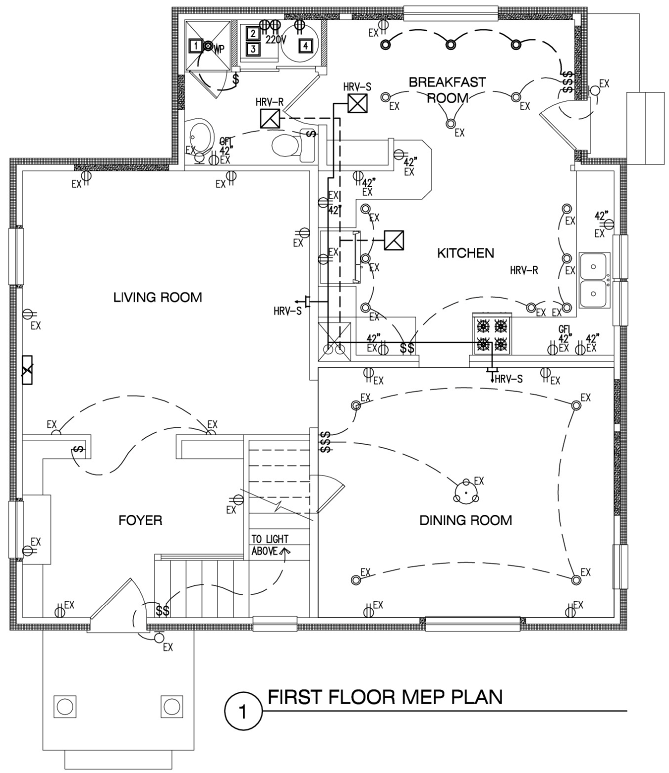
1 WALL TYPE 1

WINDOW SCHEDULE

WINDOW TYPE	WINDOW MANUFACTURER	MODEL NUMBER	WINDOW TYPE	FRAME TYPE	DIMENSIONS	
					Width	Height
TYPE 1	–	–	AWNING	FIBERGLASS	5'–0"	3'–6"
TYPE 2	–	–	FIXED	FIBERGLASS	2'–4"	2'–9"
TYPE 3	–	–	AWNING	FIBERGLASS	5'–0"	3'–6"
TYPE 4	–	–	CASEMENT	FIBERGLASS	2'–4"	2'–10"
TYPE 5	–	–	CASEMENT	FIBERGLASS	2'–8"	4'–4"
TYPE 6	–	–	CASEMENT	FIBERGLASS	3'–0"	4'–3"
TYPE 7	–	–	CASEMENT	FIBERGLASS	1'–10"	2'–0"
TYPE 8	–	–	CASEMENT	FIBERGLASS	2'–8"	3'–0"
TYPE 9	–	–	CASEMENT	FIBERGLASS	3'–0"	3'–0"
TYPE 10	–	–	CASEMENT	FIBERGLASS	2'–8"	3'–10"
TYPE 11	–	–	CASEMENT	FIBERGLASS	2'–5"	3'–10"
TYPE 12	–	–	CASEMENT	FIBERGLASS	3'–0"	3'–5"

DOOR SCHEDULE

WINDOW TYPE	DOOR MANUFACTURER	MODEL NUMBER	DOOR TYPE	FRAME TYPE	DIMENSIONS	
					Width	Height
TYPE 1	–	–	FIBERGLASS ENTRY	WOOD	3'–0"	6'–8"
TYPE 2	–	–	FIBERGLASS ENTRY	WOOD	3'–0"	6'–8"
TYPE 3	–	–	BYPASS CLOSET DOOR	WOOD	4'–0"	6'–8"
TYPE 4	–	–	BASEMENT ENTRY	WOOD	2'–0"	4'–0"



1 FIRST FLOOR MEP PLAN

EQUIPMENT KEY

	DESCRIPTION	MANUF.	MODEL
1	SHOWER	–	–
2	WASHER	–	–
3	CONDENSING DRYER	–	–
4	COMBO ELECTRIC WATER HEATER/ SOLAR STORAGE TANK	–	–

MEP LEGEND

HRV-S	HRV SUPPLY DIFFUSER, CEILING MOUNTED
HRV-R	HRV EXHAUST GRILLE, CEILING MOUNTED
HRV-S	HRV SUPPLY DIFFUSER, WALL MOUNTED
	HRV SUPPLY DUCT
	HRV RETURN DUCT
	DUCTLESS MINI SPLIT HEAT PUMP
	ELECTRICAL OUTLET
220V	220V ELECTRICAL OUTLET
$	LIGHT SWITCH
	ELECTRICAL WIRING
	6" RECESSED LIGHT FIXTURE
WP	6" WATERPROOF RECESSED LIGHT FIXTURE
EX	EXISTING ELECTRICAL OUTLET
$	EXISTING LIGHT SWITCH
	EXISTING ELECTRICAL WIRING
EX	EXISTING CHANDELIER
EX	EXISTING WALL-MOUNTED LIGHT FIXTURE
EX	EXISTING RECESSED LIGHT FIXTURE

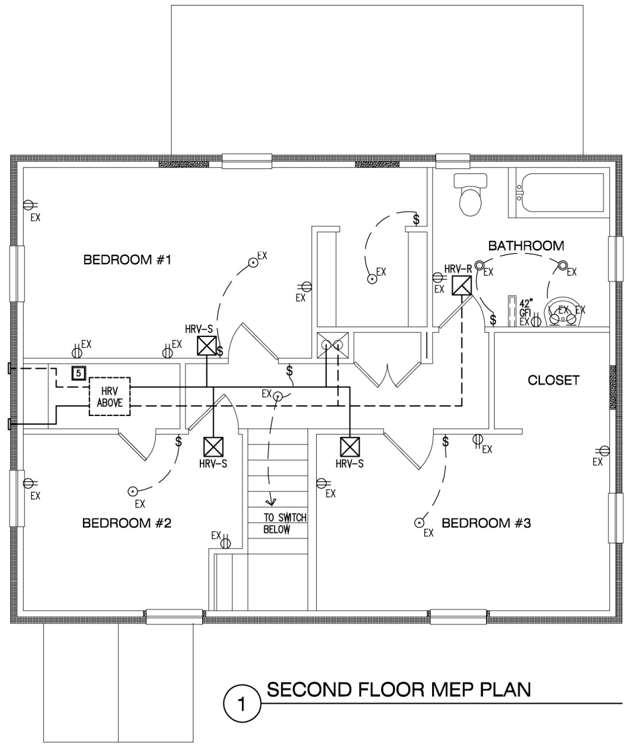
KEY NOTES

1 –

GENERAL NOTES

INSTALL AIR ADMITTANCE VALVE IN LIEU OF OPEN PIPE PLUMBING VENTILATION

REPLACE EXISTING INCANDESCENT LAMPS WITH COMPACT FLUORESCENT LAMPS



1 SECOND FLOOR MEP PLAN

EQUIPMENT KEY

	DESCRIPTION	MANUF.	MODEL
5	HRV	–	–

MEP LEGEND

HRV-S	HRV SUPPLY DIFFUSER, CEILING MOUNTED
HRV-R	HRV EXHAUST GRILLE, CEILING MOUNTED
HRV-S	HRV SUPPLY DIFFUSER, WALL MOUNTED
——	HRV SUPPLY DUCT
– – –	HRV RETURN DUCT
EX	EXISTING ELECTRICAL OUTLET
$	EXISTING LIGHT SWITCH
	EXISTING ELECTRICAL WIRING
EX	EXISTING CEILING MOUNTED LIGHT FIXTURE
EX	EXISTING WALL-MOUNTED LIGHT FIXTURE
EX	EXISTING RECESSED LIGHT FIXTURE

KEY NOTES

1 –

GENERAL NOTES

REPLACE EXISTING INCANDESCENT LAMPS WITH COMPACT FLUORESCENT LAMPS

APPENDIX D

CONSTRUCTION COST SPREADSHEET

UNIT COST ESTIMATE DERIVED FROM RS MEANS COSTWORKS:											
Quantity	Description	Labor Hours	Unit	Unit Cost Material	Unit Cost Labor	Unit Cost Equip.	Unit Cost Total	Total Cost Material	Total Cost Labor	Total Cost Equip.	Total Cost (Excludes O&P)
2	Demolish plaster & lathe as needed to provide access to interior brick chimney	0.4	Ea.	$ -	$ 9.19	$ -	$ 9.19	$ -	$ 18.38	$ -	$ 18.38
2	Demolish 2x4 framing as needed to provide access to interior brick chimney	1.143	Ea.	$ -	$ 26.19	$ -	$ 26.19	$ -	$ 52.38	$ -	$ 52.38
50	Demolish existing interior brick chimney	0.145	C.F.	$ -	$ 3.49	$ -	$ 3.49	$ -	$ 174.50	$ -	$ 174.50
105	Demolish existing brick chimney on east wall of house	0.145	C.F.	$ -	$ 3.49	$ -	$ 3.49	$ -	$ 366.45	$ -	$ 366.45
90	Demolish existing wood fascia	0.016	L.F.	$ -	$ 0.33	$ -	$ 0.33	$ -	$ 29.70	$ -	$ 29.70
50	Demolish existing rafter overhang	0.018	S.F.	$ -	$ 0.38	$ -	$ 0.38	$ -	$ 19.00	$ -	$ 19.00
1040	Demolish existing roof sheathing	0.011	S.F.	$ -	$ 0.24	$ -	$ 0.24	$ -	$ 249.60	$ -	$ 249.60
10	Demolish wood stair to basement	0.615	Riser	$ -	$ 12.79	$ -	$ 12.79	$ -	$ 127.90	$ -	$ 127.90
100	Demolish existing wood frame wall at stair to basement	0.013	S.F.	$ -	$ 0.28	$ -	$ 0.28	$ -	$ 28.00	$ -	$ 28.00
50	Demolish existing soffit	0.013	S.F.	$ -	$ 0.26	$ -	$ 0.26	$ -	$ 13.00	$ -	$ 13.00
16	2 - 2" x 6" wood beams to reframe existing roof at front stoop	0.026	L.F.	$ 0.80	$ 0.72	$ -	$ 1.52	$ 12.80	$ 11.52	$ -	$ 24.32
75	Bulkhead above kitchen cabs	0.018	L.F.	$ 0.27	$ 0.50	$ -	$ 0.77	$ 20.25	$ 37.50	$ -	$ 57.75
15	Infill framing at demolished skylight location	0.013	L.F.	$ 0.27	$ 0.36	$ -	$ 0.63	$ 4.05	$ 5.40	$ -	$ 9.45

18	2" x 8" joist framing over existing stair opening	0.015	L.F.	$ 0.60	$ 0.41	$ -	$ 1.01	$ 10.80	$ 7.38	$ -	$ 18.18
5	Frame walls at first floor bathroom / laundry	0.16	L.F.	$ 2.64	$ 4.50	$ -	$ 7.14	$ 13.20	$ 22.50	$ -	$ 35.70
100	2" x 6" rafters over existing rafters (shed roof)	0.016	L.F.	$ 0.41	$ 0.45	$ -	$ 0.86	$ 41.00	$ 45.00	$ -	$ 86.00
42	2" x 6" rafters to reframe existing roof at front stoop	0.016	L.F.	$ 0.41	$ 0.45	$ -	$ 0.86	$ 17.22	$ 18.90	$ -	$ 36.12
75	2" x 6" rafters sistered to TJI joists to create roof overhang	0.02	L.F.	$ 0.41	$ 0.56	$ -	$ 0.97	$ 30.75	$ 42.00	$ -	$ 72.75
9	2" x 6" ledger to support new floor joists at stair opening	0.027	L.F.	$ 0.41	$ 0.75	$ -	$ 1.16	$ 3.69	$ 6.75	$ -	$ 10.44
150	2" x 4" infill wall framing at demolished window locations	0.015	L.F.	$ 0.27	$ 0.41	$ -	$ 0.68	$ 40.50	$ 61.50	$ -	$ 102.00
2100	1" x 2" wood furring strips for rainscreen	0.015	L.F.	$ 0.27	$ 0.41	$ -	$ 0.68	$ 567.00	$ 861.00	$ -	$ 1,428.00
24	Subfloors, plywood, CDX, 3/4" thick at existing stair opening	0.013	SF Flr.	$ 0.62	$ 0.36	$ -	$ 0.98	$ 14.88	$ 8.64	$ -	$ 23.52
110	Subfloors, plywood, CDX, 3/4" thick in attic	0.013	SF Flr.	$ 0.62	$ 0.36	$ -	$ 0.98	$ 68.20	$ 39.60	$ -	$ 107.80
2000	Sheathing, oriented strand board, 1/2" thick over existing 2" x 4" studs	0.012	S.F.	$ 0.24	$ 0.34	$ -	$ 0.58	$ 480.00	$ 680.00	$ -	$ 1,160.00
1020	Sheathing, OSB, on roof, 1/2" thick (inner layer), installed over existing 2" x 4" rafters	0.011	S.F.	$ 0.24	$ 0.31	$ -	$ 0.55	$ 244.80	$ 316.20	$ -	$ 561.00
1140	Sheathing, OSB, on roof, 1/2" thick (outer layer)	0.011	S.F.	$ 0.24	$ 0.31	$ -	$ 0.55	$ 273.60	$ 353.40	$ -	$ 627.00
185	Sheathing, OSB, on roof, 1/2" thick (inner layer), installed over existing 2" x 4" rafters at shed	0.011	S.F.	$ 0.24	$ 0.31	$ -	$ 0.55	$ 44.40	$ 57.35	$ -	$ 101.75
215	Sheathing, OSB, on roof, 1/2" thick (outer layer) at shed roof	0.011	S.F.	$ 0.24	$ 0.31	$ -	$ 0.55	$ 51.60	$ 66.65	$ -	$ 118.25

60	Sheathing, OSB, on roof, 1/2" thick (new roof at front stoop)	0.011	S.F.	$ 0.24	$ 0.31	$ -	$ 0.55	$ 14.40	$ 18.60	$ -	$ 33.00
1020	TJI joists @ 24"o.c. installed over existing roof structure	0.013	SF Flr.	$ 1.91	$ 0.33	$ -	$ 2.24	$ 1,948.20	$ 336.60	$ -	$ 2,284.80
1	Door trim set, pine (new door at laundry closet)	0.667	Opng.	$ 18.92	$ 18.64	$ -	$ 37.56	$ 18.92	$ 18.64	$ -	$ 37.56
90	Demolish existing aluminum gutters and downspouts	0.023	L.F.	$ -	$ 0.48	$ -	$ 0.48	$ -	$ 43.20	$ -	$ 43.20
90	Demolish existing aluminum gutters and downspouts (shed roof)	0.033	L.F.	$ -	$ 0.70	$ -	$ 0.70	$ -	$ 63.00	$ -	$ 63.00
570	Remove & dispose of existing fiberglass batt insulation in attic	0.006	C.F.	$ -	$ 0.12	$ -	$ 0.12	$ -	$ 68.40	$ -	$ 68.40
690	Remove & dispose of existing blown cellulose insulation in existing wall cavities	0.003	C.F.	$ -	$ 0.06	$ -	$ 0.06	$ -	$ 41.40	$ -	$ 41.40
1040	Demolish existing ashpalt shingles	0.011	S.F.	$ -	$ 0.24	$ -	$ 0.24	$ -	$ 249.60	$ -	$ 249.60
1815	Demolish existing wood siding	0.021	S.F.	$ -	$ 0.44	$ -	$ 0.44	$ -	$ 798.60	$ -	$ 798.60
768	Polyisocyanurate rigid insulation, 2" thick, 4' x 8' sheets, installed below existing 2x4 rafters in attic	0.011	S.F.	$ 0.85	$ 0.28	$ -	$ 1.13	$ 652.80	$ 215.04	$ -	$ 867.84
840	Polyisocyanurate rigid insulation, 4" thick, 4' x 8' sheets, installed below first floor joists	0.011	S.F.	$ 2.16	$ 0.28	$ -	$ 2.44	$ 1,814.40	$ 235.20	$ -	$ 2,049.60
1980	Polyisocyanurate rigid insulation, foil faced, 4' x 8' sheets, 4" thick on exterior walls	0.011	S.F.	$ 2.16	$ 0.28	$ -	$ 2.44	$ 4,276.80	$ 554.40	$ -	$ 4,831.20
1500	Blown-in fiberglass Insulation, exterior walls, 4" thick, R15	0.007	S.F.	$ 0.23	$ 0.13	$ 0.11	$ 0.47	$ 345.00	$ 195.00	$ 165.00	$ 705.00
900	Blown-in fiberglass Insulation between existing 2" x 4" rafters, 4" thick, R15	0.007	S.F.	$ 0.23	$ 0.13	$ 0.11	$ 0.47	$ 207.00	$ 117.00	$ 99.00	$ 423.00
170	Blown-in fiberglass Insulation between existing 2" x 4" rafters, 4" thick, R15	0.007	S.F.	$ 0.23	$ 0.13	$ 0.11	$ 0.47	$ 39.10	$ 22.10	$ 18.70	$ 79.90

800	Blown-in fiberglass Insulation between existing 2" x 8" floor joists, 8" thick, R30	0.014	S.F.	$ 0.34	$ 0.26	$ 0.23	$ 0.83	$ 272.00	$ 208.00	$ 184.00	$ 664.00
960	Blown-in fiberglass Insulation between TJI rafters, 9.25" thick, R39	0.014	S.F.	$ 0.34	$ 0.26	$ 0.23	$ 0.83	$ 326.40	$ 249.60	$ 220.80	$ 796.80
84	Polyurethane spray foam insulation, 2#/CF density, 6" thick, R39 at edge of floor	0.024	S.F.	$ 2.48	$ 0.44	$ 0.70	$ 3.62	$ 208.32	$ 36.96	$ 58.80	$ 304.08
170	Blown-in fiberglass Insulation between 2" x 6" rafters, 6" thick, R23	0.008	S.F.	$ 0.23	$ 0.16	$ 0.13	$ 0.52	$ 39.10	$ 27.20	$ 22.10	$ 88.40
2000	Housewrap, exterior, spun bonded polypropylene, small roll	0.002	S.F.	$ 0.23	$ 0.05	$ -	$ 0.28	$ 460.00	$ 100.00	$ -	$ 560.00
12	Asphalt Shingles, standard strip shingles, inorganic, class A, 210-235 lb/sq (gable roof)	1.455	Sq.	$ 73.06	$ 34.44	$ -	$ 107.50	$ 876.72	$ 413.28	$ -	$ 1,290.00
3	Asphalt Shingles, standard strip shingles, inorganic, class A, 210-235 lb/sq (shed roof)	1.455	Sq.	$ 73.06	$ 34.44	$ -	$ 107.50	$ 219.18	$ 103.32	$ -	$ 322.50
1	Asphalt Shingles, standard strip shingles, inorganic, class A, 210-235 lb/sq (roof at front stoop)	1.455	Sq.	$ 73.06	$ 34.44	$ -	$ 107.50	$ 73.06	$ 34.44	$ -	$ 107.50
12	#15 roof felt (gable roof)	0.125	Sq.	$ 5.86	$ 2.97	$ -	$ 8.83	$ 70.32	$ 35.64	$ -	$ 105.96
3	#15 roof felt (shed roof)	0.125	Sq.	$ 5.86	$ 2.97	$ -	$ 8.83	$ 17.58	$ 8.91	$ -	$ 26.49
1	#15 roof felt (roof at front stoop)	0.125	Sq.	$ 5.86	$ 2.97	$ -	$ 8.83	$ 5.86	$ 2.97	$ -	$ 8.83
2000	Fiber Cement Siding, 5/16" thick x 6" wide, 4-3/4" exposure	0.039	S.F.	$ 1.26	$ 1.19	$ -	$ 2.45	$ 2,520.00	$ 2,380.00	$ -	$ 4,900.00
90	Aluminum downspouts, embossed, 2" x 3", .020" thick	0.042	L.F.	$ 1.03	$ 1.32	$ -	$ 2.35	$ 92.70	$ 118.80	$ -	$ 211.50
6	Aluminum elbows, embossed, 2" x 3"	0.08	Ea.	$ 1.30	$ 2.51	$ -	$ 3.81	$ 7.80	$ 15.06	$ -	$ 22.86
90	Aluminum gutters, stock units, plain, 5" box, .027" thick	0.067	L.F.	$ 2.73	$ 2.10	$ -	$ 4.83	$ 245.70	$ 189.00	$ -	$ 434.70

3	Demolish existing exterior doors	0.5	Ea.	$ -	$ 11.29	$ -	$ 11.29	$ -	$ 33.87	$ -	$ 33.87
1	Demolish existing interior door at existing basement stair	0.4	Ea.	$ -	$ 9.03	$ -	$ 9.03	$ -	$ 9.03	$ -	$ 9.03
4	Demolish existing wood door frames where noted in bid set	0.5	Ea.	$ -	$ 15.28	$ -	$ 15.28	$ -	$ 61.12	$ -	$ 61.12
21	Demolish existing small vinyl windows	0.5	Ea.	$ -	$ 11.29	$ -	$ 11.29	$ -	$ 237.09	$ -	$ 237.09
5	Demolish existing large vinyl windows	0.727	Ea.	$ -	$ 16.43	$ -	$ 16.43	$ -	$ 82.15	$ -	$ 82.15
7	Demolish existing wood windows	0.364	Ea.	$ -	$ 8.19	$ -	$ 8.19	$ -	$ 57.33	$ -	$ 57.33
6	Demolish existing skylight at breakfast roof	0.081	S.F.	$ -	$ 2.29	$ -	$ 2.29	$ -	$ 13.74	$ -	$ 13.74
1	Door, interior bi-passing closet, 4'-0" x 6'-8", including hardware and frame	1.333	Opng.	$ 166.97	$ 40.72	$ -	$ 207.69	$ 166.97	$ 40.72	$ -	$ 207.69
100	Demolish drywall at existing stair & bathroom as noted in bid set	0.008	S.F.	$ -	$ 0.17	$ -	$ 0.17	$ -	$ 17.00	$ -	$ 17.00
36	Gypsum lath, 1/2" thick as needed to patch existing wall adjacent to demolished chimney	0.011	S.F.	$ 0.56	$ 0.28	$ -	$ 0.84	$ 20.16	$ 10.08	$ -	$ 30.24
120	Gypsum lath, 1/2" thick as needed to patch existing wall at demolished window locations	0.011	S.F.	$ 0.56	$ 0.28	$ -	$ 0.84	$ 67.20	$ 33.60	$ -	$ 100.80
36	Gypsum Plaster, 3 coats, lath excluded, to patch existing wall adjacent to demolished chimney	0.065	S.F.	$ 0.61	$ 1.56	$ 0.22	$ 2.39	$ 21.96	$ 56.16	$ 7.92	$ 86.04
120	Gypsum Plaster, 3 coats, lath excluded, to patch existing wall at demolished window locations	0.065	S.F.	$ 0.61	$ 1.56	$ 0.22	$ 2.39	$ 73.20	$ 187.20	$ 26.40	$ 286.80
110	Gypsum wallboard, standard, taped & finished (level 4 finish), 1/2" thick, in bathroom / laundry	0.017	S.F.	$ 0.28	$ 0.46	$ -	$ 0.74	$ 30.80	$ 50.60	$ -	$ 81.40
45	Gypsum wallboard, on ceilings, taped & finished, standard, 1/2" thick, at new bulkhead above cabs	0.021	S.F.	$ 0.28	$ 0.59	$ -	$ 0.87	$ 12.60	$ 26.55	$ -	$ 39.15

6	Gypsum wallboard, on ceilings, taped & finished, standard, 1/2" thick, at demolished skylight	0.021	S.F.	$ 0.28	$ 0.59	$ -	$ 0.87	$ 1.68	$ 3.54	$ -	$ 5.22
12	Resilient Flooring, vinyl sheet goods, backed, .065" thick, in first floor bathroom & laundry	0.032	S.F.	$ 3.68	$ 0.98	$ -	$ 4.66	$ 44.16	$ 11.76	$ -	$ 55.92
1	Washing machine, stacking	2.667	Ea.	$ 1,299.00	$ 100.56	$ -	$ 1,399.56	$ 1,299.00	$ 100.56	$ -	$ 1,399.56
1	Dryer, condensing (ventless)	5.333	Ea.	$ 1,199.00	$ 149.46	$ -	$ 1,348.46	$ 1,199.00	$ 149.46	$ -	$ 1,348.46
1	Shower, stall, fiberglass, one piece with three walls, square, 32" x 32"	2.909	Ea.	$ 523.76	$ 93.42	$ -	$ 617.18	$ 523.76	$ 93.42	$ -	$ 617.18
1	Shower, stall, rough-in, supply, waste and vent for above shower	7.805	Ea.	$ 396.63	$ 250.16	$ -	$ 646.79	$ 396.63	$ 250.16	$ -	$ 646.79
150	Demolish existing ductwork	0.04	L.F.	$ -	$ 0.89	$ -	$ 0.89	$ -	$ 133.50	$ -	$ 133.50
1	Disconnect & remove existing gas furnace, salvage for resale by owner	4	Ea.	$ -	$ 120.86	$ -	$ 120.86	$ -	$ 120.86	$ -	$ 120.86
50	Wire, copper solid, 600 volt, #14, type THW	0.006	L.F.	$ 0.08	$ 0.20	$ -	$ 0.28	$ 4.00	$ 10.00	$ -	$ 14.00
2	Low voltage switching, surface switch, standard	0.2	Ea.	$ 8.10	$ 6.49	$ -	$ 14.59	$ 16.20	$ 12.98	$ -	$ 29.18
2	Low voltage switching, switchplates, plastic	0.1	Ea.	$ 3.64	$ 3.26	$ -	$ 6.90	$ 7.28	$ 6.52	$ -	$ 13.80
4	Recessed fixture, interior, prewired, 100 W, incl lamps, mounting hardware and	1	Ea.	$ 70.84	$ 32.70	$ -	$ 103.54	$ 283.36	$ 130.80	$ -	$ 414.16
COST ESTIMATES FROM PRODUCT DISTRIBUTORS & LOCAL SUBCONTRACTORS:											
1	Window package, 16 units, includes shipping							$ 11,340.88	$ 480.00		$ 11,820.88
1	Fiberglass door, includes wood frame							$ 320.00	$ 35.00		$ 355.00

1	Fiberglass door, includes wood frame							$ 340.00	$ 35.00		$ 375.00
2	Multipoint Lock Hardware										$ 300.00
1	Caulking, Sealing Airtight Layer							$ 1,000.00	$ 500.00		$ 1,500.00
1	HRV w/ preheat, includes all accessories, ductwork, and installation							$ 5,901.56	$ 3,900.00		$ 9,801.56
1	Mini split ductless heat pump, 7kBTU, one wall unit, includes install										$ 4,000.00
1	Solar DHW system, includes 2-4x8 flat plate collectors, combo storage tank/hot water heater,										$ 7,500.00
1	Air Admittance Valve for Plumbing System										$ 49.10
TOTALS:											
	Construction Cost										$ 69,922.28
	w/ 15% contractor O&P										**$ 80,410.62**
	Bathroom									deduct	$ 4,085.88
	Siding, Sheathing, Roof									deduct	$ 13,611.40
	Specific to Case Study House									deduct	$ 1,347.60
	Code Required Insulation									deduct	$ 2,392.13
	Adjusted Total										$ 58,973.61
	Less federal, state, & utility credits									credit	$ 6,250.00
	Resale of existing equipment									credit	$ 1,300.00
	"The Passive House Premium"										**$ 51,423.61**

APPENDIX E

LIFE CYCLE COST SPREADSHEETS

REFERENCE CASE

Discount Rate: 4%

Life Cycle (Years): 30

	Model 1: Business as Usual (BAU)		Model 2: Passive House Retrofit	
Initial Costs	**Estimated Cost**	**Present Worth**	**Estimated Cost**	**Present Worth**
Construction Cost			$ 69,922.28	$ 69,922.28

Total Initial Costs	**$ 69,922.28**
Include 15% Contractor O&P	**$ 80,410.62**

Deduct Costs Not Associated w/ PH Standard	Estimated Cost	Present Worth	Estimated Cost	Present Worth
Bathroom			$ 3,552.94	$ 3,552.94
Siding, Sheathing, Roof			$ 11,836.00	$ 11,836.00
Costs Specific to Case Study House			$ 1,171.83	$ 1,171.83
Code-Required Insulation			$ 2,080.11	$ 2,080.11

Total Deductions	**$ 18,640.88**
Include 15% Contractor O&P	**$ 21,437.01**
Construction Cost Less Deductions	**$ 58,973.61**

Initial Credits	Estimated Cost	Present Worth	Estimated Cost	Present Worth
Federal Tax Credits			$ 2,100.00	$ 2,100.00
State Tax Credits			$ 2,080.00	$ 2,080.00
Utility Rebates			$ 2,070.00	$ 2,070.00
Resale of Exist. Furnace			$ 800.00	$ 800.00
Resale of Exist. Washer			$ 200.00	$ 200.00
Resale of Exist. Dryer			$ 200.00	$ 200.00
Resale of Exist. Water Heater			$ 100.00	$ 100.00

Total Initial Credits	**$ 7,550.00**
Initial Costs Less Deductions & Credits	**$ 51,423.61**

Replacement Costs	Year	PW Factor	Estimated Cost	Present Worth	Estimated Cost	Present Worth
Gas Furnace	10	0.6755642	$ 2,480.00	$ 1,675.40		
Gas Furnace	25	0.3751168	$ 2,480.00	$ 930.29		
Electric Water Heater	5	0.8219271	$ 691.00	$ 567.95		
Electric Water Heater	15	0.5552645	$ 691.00	$ 383.69		
Electric Water Heater	25	0.3751168	$ 691.00	$ 259.21		
HRV	20	0.4563869			$ 1,916.00	$ 874.44
Mini Split Heat Pump	20	0.4563869			$ 4,000.00	$ 1,825.55

Solar DHW Pump/Sensor	10	0.6755642			$ 200.00	$ 135.11
Solar DHW Pump/Sensor	20	0.4563869			$ 200.00	$ 91.28
Solar DHW Pump/Sensor	30	0.3083187			$ 200.00	$ 61.66
Combo Solar Storage Tank/ Electric Water Heater	16	0.5339082			$ 2,200.00	$ 1,174.60

Total Replacement Costs (Present Worth) **$ 3,816.53** **$ 2,988.04**

Annual Costs	Escalation Rate	PWA w/ Escal.	Estimated Cost	Present Worth	Estimated Cost	Present Worth
Energy, Electric	-0.20%	16.862727	$ 1,142.00	$ 19,257.23	$ 274.08	$ 4,621.74
Energy, Natural Gas	0.50%	18.432236	$ 905.00	$ 16,681.17	$ 90.50	$ 1,668.12

Total Annual Costs (Present Worth) **$ 35,938.41** **$ 6,289.85**

End of Life Credits	Appreciation Rate	Estimated Value	Present Worth	Estimate Value	Present Worth
Resale Value	1.5%	$ 625,232.09	$ 192,770.72	$ 678,376.82	$ 209,156.24

Total End of Life Credits (Present Worth) $ 192,770.72 $ 209,156.24

End of Life Value Difference (Present Worth) **$ 16,385.51**

Total Life Cycle Costs (Present Worth) **$ 39,754.94** **$ 44,315.99**

LOW OIL PRICE CASE
Discount Rate: 4%
Life Cycle (Years): 30

	Model 1: Business as Usual (BAU)		Model 2: Passive House Retrofit	
Initial Costs	**Estimated Cost**	**Present Worth**	**Estimated Cost**	**Present Worth**
Construction Cost			$ 69,922.28	$ 69,922.28

Total Initial Costs	**$ 69,922.28**
Include 15% Contractor O&P	**$ 80,410.62**

Deduct Costs Not Associated w/ PH Standard	Estimated Cost	Present Worth	Estimated Cost	Present Worth
Bathroom			$ 3,552.94	$ 3,552.94
Siding, Sheathing, Roof			$ 11,836.00	$ 11,836.00
Costs Specific to Case Study House			$ 1,171.83	$ 1,171.83
Code-Required Insulation			$ 2,080.11	$ 2,080.11

Total Deductions	**$ 18,640.88**
Include 15% Contractor O&P	**$ 21,437.01**
Construction Cost Less Deductions	**$ 58,973.61**

Initial Credits	Estimated Cost	Present Worth	Estimated Cost	Present Worth
Federal Tax Credits			$ 2,100.00	$ 2,100.00
State Tax Credits			$ 2,080.00	$ 2,080.00
Utility Rebates			$ 2,070.00	$ 2,070.00
Resale of Exist. Furnace			$ 800.00	$ 800.00
Resale of Exist. Washer			$ 200.00	$ 200.00
Resale of Exist. Dryer			$ 200.00	$ 200.00
Resale of Exist. Water Heater			$ 100.00	$ 100.00

Total Initial Credits	**$ 7,550.00**
Initial Costs Less Deductions & Credits	**$ 51,423.61**

Replacement Costs	Year	PW Factor	Estimated Cost	Present Worth	Estimated Cost	Present Worth
Gas Furnace	10	0.6755642	$ 2,480.00	$ 1,675.40		
Gas Furnace	25	0.3751168	$ 2,480.00	$ 930.29		
Electric Water Heater	5	0.8219271	$ 691.00	$ 567.95		
Electric Water Heater	15	0.5552645	$ 691.00	$ 383.69		
Electric Water Heater	25	0.3751168	$ 691.00	$ 259.21		
HRV	20	0.4563869			$ 1,916.00	$ 874.44
Mini Split Heat Pump	20	0.4563869			$ 4,000.00	$ 1,825.55

Solar DHW Pump/Sensor	10	0.6755642			$ 200.00	$ 135.11
Solar DHW Pump/Sensor	20	0.4563869			$ 200.00	$ 91.28
Solar DHW Pump/Sensor	30	0.3083187			$ 200.00	$ 61.66
Combo Solar Storage Tank/ Electric Water Heater	16	0.5339082			$ 2,200.00	$ 1,174.60

Total Replacement Costs (Present Worth) **$ 3,816.53** **$ 2,988.04**

Annual Costs	Escalation Rate	PWA w/ Escal.	Estimated Cost	Present Worth	Estimated Cost	Present Worth
Energy, Electric	0.00%	17.292033	$ 1,142.00	$ 19,747.50	$ 274.08	$ 4,739.40
Energy, Natural Gas	0.10%	17.512274	$ 905.00	$ 15,848.61	$ 90.50	$ 1,584.86

Total Annual Costs (Present Worth) **$ 35,596.11** **$ 6,324.26**

End of Life Credits	Appreciation Rate	Estimated Value	Present Worth	Estimate Value	Present Worth
Resale Value	1.5%	$ 625,232.09	$ 192,770.72	$ 678,376.82	$ 209,156.24

Total End of Life Credits (Present Worth) $ 192,770.72 $ 209,156.24

End of Life Value Difference (Present Worth) **$ 16,385.51**

Total Life Cycle Costs (Present Worth) **$ 39,412.64** **$ 44,350.40**

HIGH OIL PRICE CASE

Discount Rate: 4%

Life Cycle (Years): 30

	Model 1: Business as Usual (BAU)		Model 2: Passive House Retrofit	
Initial Costs	**Estimated Cost**	**Present Worth**	**Estimated Cost**	**Present Worth**
Construction Cost			$ 69,922.28	$ 69,922.28

Total Initial Costs	**$**	**69,922.28**
Include 15% Contractor O&P	**$**	**80,410.62**

Deduct Costs Not Associated w/ PH Standard	**Estimated Cost**	**Present Worth**	**Estimated Cost**	**Present Worth**
Bathroom			$ 3,552.94	$ 3,552.94
Siding, Sheathing, Roof			$ 11,836.00	$ 11,836.00
Costs Specific to Case Study House			$ 1,171.83	$ 1,171.83
Code-Required Insulation			$ 2,080.11	$ 2,080.11

Total Deductions	**$**	**18,640.88**
Include 15% Contractor O&P	**$**	**21,437.01**
Construction Cost Less Deductions	**$**	**58,973.61**

Initial Credits	**Estimated Cost**	**Present Worth**	**Estimated Cost**	**Present Worth**
Federal Tax Credits			$ 2,100.00	$ 2,100.00
State Tax Credits			$ 2,080.00	$ 2,080.00
Utility Rebates			$ 2,070.00	$ 2,070.00
Resale of Exist. Furnace			$ 800.00	$ 800.00
Resale of Exist. Washer			$ 200.00	$ 200.00
Resale of Exist. Dryer			$ 200.00	$ 200.00
Resale of Exist. Water Heater			$ 100.00	$ 100.00

Total Initial Credits	**$**	**7,550.00**
Initial Costs Less Deductions & Credits	**$**	**51,423.61**

Replacement Costs	**Year**	**PW Factor**	**Estimated Cost**	**Present Worth**	**Estimated Cost**	**Present Worth**
Gas Furnace	10	0.6755642	$ 2,480.00	$ 1,675.40		
Gas Furnace	25	0.3751168	$ 2,480.00	$ 930.29		
Electric Water Heater	5	0.8219271	$ 691.00	$ 567.95		
Electric Water Heater	15	0.5552645	$ 691.00	$ 383.69		
Electric Water Heater	25	0.3751168	$ 691.00	$ 259.21		
HRV	20	0.4563869			$ 1,916.00	$ 874.44
Mini Split Heat Pump	20	0.4563869			$ 4,000.00	$ 1,825.55

Solar DHW Pump/Sensor	10	0.6755642			$ 200.00	$ 135.11
Solar DHW Pump/Sensor	20	0.4563869			$ 200.00	$ 91.28
Solar DHW Pump/Sensor	30	0.3083187			$ 200.00	$ 61.66
Combo Solar Storage Tank/ Electric Water Heater	16	0.5339082			$ 2,200.00	$ 1,174.60

Total Replacement Costs (Present Worth)	**$ 3,816.53**	**$ 2,988.04**

Annual Costs	Escalation Rate	PWA w/ Escal.	Estimated Cost	Present Worth	Estimated Cost	Present Worth
Energy, Electric	0.30%	17.964302	$ 1,142.00	$ 20,515.23	$ 274.08	$ 4,923.66
Energy, Natural Gas	0.40%	18.196241	$ 905.00	$ 16,467.60	$ 90.50	$ 1,646.76

Total Annual Costs (Present Worth)	**$ 36,982.83**	**$ 6,570.42**

End of Life Credits	Appreciation Rate	Estimated Value	Present Worth	Estimate Value	Present Worth
Resale Value	1.5%	$ 625,232.09	$ 192,770.72	$ 678,376.82	$ 209,156.24

Total End of Life Credits (Present Worth)	$ 192,770.72	$ 209,156.24
End of Life Value Difference (Present Worth)		**$ 16,385.51**
Total Life Cycle Costs (Present Worth)	**$ 40,799.36**	**$ 44,596.55**

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