The Problem

U.S. Energy Consumption by Sector

- **Building Operations**: 41.7%
- **Industry**: 24.4%
- **Building Construction and Materials**: 5.9%
- **Transportation – Other** (rail, air, bus, truck, ship): 11.8%
- **Transportation – Light Duty** (auto, SUV, pickup, minivan): 16.3%

The Problem

U.S. CO₂ Emissions by Sector

- **Buildings**: 44.6% (2358 MMT CO₂e)
- **Transportation**: 34.3% (1816 MMT CO₂e)
- **Industry**: 21.1% (1116 MMT CO₂e)

The Problem - 67% from Fossil Fuels*

U.S. Electricity Consumption by Sector


*US-EIA 2014
Useful work = 13% of Primary Exergy

Mtoe = million ton of oil equivalent / 1 toe = 11630 kWh

Source: http://pubs.acs.org/journal/esthag
University of Leeds, Leeds LS2 9JT, United Kingdom
The Solution for Buildings

Passive House Buildings

PH Concept Explained in 90 Seconds
PASSIVE BUILDING PRINCIPLES

Five key principles:

1. Climate Specific Insulation Levels
2. Thermal Bridge Free Connections
3. High-Performance Windows/Doors
4. Airtightness
5. High Efficiency Heat Recovery Ventilation
Rational Behind Passive House Approach

Roadmap to High Performance

- Increased airtightness
- HRV
- High R-value envelope
- High performance windows

Cost

Construction Budget

Energy Efficiency

High Performance Home

eliminate conventional heating/cooling system
EU Passive House Energy Standard
Clearly Defined

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating Demand (Site):</td>
<td>4.75 kBTU/Ft2-YR</td>
</tr>
<tr>
<td>Cooling Demand (Site):</td>
<td>4.75 kBTU/Ft2-YR</td>
</tr>
<tr>
<td>Peak Heat Load:</td>
<td>3.14 BTU/Ft2-Hr</td>
</tr>
<tr>
<td>Peak Cooling Load:</td>
<td>2.54 BTU/Ft2-Hr</td>
</tr>
<tr>
<td>Total Energy Demand (Source):</td>
<td>38 kBTU/SF-YR</td>
</tr>
<tr>
<td>Air Tightness:</td>
<td>0.6 ACH @ 50pa (based on interior floor area)</td>
</tr>
</tbody>
</table>
PHIUS Climate Specific Criteria

PASSIVE STANDARDS IN VARYING CLIMATES

Seattle

- State: WA
- Location: Tacoma Intl AP
- Zone: 4C
- Annual Heating Demand: 5.4
- Annual Cooling Demand: 1
- Peak Heating Load Btu/ft²: 3.3
- Peak Cooling Load Btu/ft²: 3.4
- Manual J Peak Heating: 5.6
- Manual J Peak Cooling: 4.8
### USA PHIUS+ 2015 Building Criteria

#### Heating Demand (Site):
- 1 - 12 kBTU/Ft2-YR

#### Cooling Demand (Site):
- 1 - 21.4 kBTU/Ft2-YR

#### Peak Heat Load:
- 0.8 - 5.4 BTU/Ft2-Hr

#### Peak Cooling Load:
- 1.8 - 8.9 BTU/Ft2-Hr

#### Total Energy Demand (Source):
- Beds+1 / 6200 kWh/PERSON-YR (Temporary)
- Beds+1 / 4200 kWh/PERSON-YR (Future)

#### Air Tightness:
- 0.05 cfm/gross sqft shell @ 50 pa
- 0.08 cfm/gross sqft shell @ 75 pa
The Solution – Reduce **Energy Waste**

Comparison of Energy Standards

![Annual Site Energy Usage Chart]

- **Passive House**
- **Building America Program - DOE**
- **Energy Star**
- **IECC 2009 International Energy Conservation Code**
- **Old Buildings**

Bars represent different uses of energy:
- Yellow: household
- Green: ventilation
- Blue: hot water
- Red: heating

Energy usage scales from 16 to 95 Kbtu/ft²/yr.
The Solution – Passive House

- Dramatic reduction in wasted energy
- Superior indoor air quality
- Superior occupant comfort
- Lower annual energy costs
- Smaller carbon footprint
- Reduces Maintenance and building deterioration
- Eliminates Dependence on Fossil Fuel
- Equal or Lower Out of Pocket expense for Mortgage plus Energy
Climate Specific Level of Thermal **INSULATION** to control heat loss

For Climate Zone 6
R60 WALLS: R90 CEILING: R60 SLAB
High Performance WINDOWS U value < 0.13 (R-7)
Insulated Slab on Grade
Insulated Slab on Grade
Passive House Concept: Controlling Gains Seasonally - Windows and Orientation

TRIPLE GLAZED: U VALUE < 0.13; 0.60 Solar Heat Gain Coefficient on South Windows for Climate Zone 6
Passive house Concept: Controlling Heat Loss - Eliminate Air In/Ex-filtration

Max. 0.6 ACH @ 50 PA (based on interior floor area)
Max. 0.05 cfm/gross sqft shell @ 50 pa
Effects of Air Infiltration on Heat Loss

HEAT LOSS FACTS EXISTING BUILDINGS

- 30-50% of Space Conditioning Energy (DOE)
- 8 MPH wind = -30% R Value (DuPont, 2007)
- Average US house: 3 ft² of holes
- Typical 2500 ft² home: ½ mile of cracks

Investigation of the Impact of Commercial Building Envelope Airtightness on HVAC Energy Use (NISTIR 7238) - NIST, US D.O.C.
AIR BARRIER | VCL | WRB MATERIAL
ASSURING DURABILITY OF ASSEMBLY

MOISTURE TRANSFER
Air Movement = 98%+ Water Vapor Movement in Building Cavities

**Infiltration:** 1 in² hole = 30 quarts of water
**Diffusion:** 4’x8’ sheet of drywall (4608 in²) = 1/3 quart of water

One Heating Season (Indoors @ 70°F, 40% Relative Humidity)

“**In Quickly**” (Infiltration)

90:1 ratio infiltration vs diffusion

“**Out Slowly**” (Diffusion)

Accumulation

Source: Building Science Corp.
Moisture Dynamics in Wall Assembly

Outside
- Vapor open
- Drying Out

Winter

Inside
- Vapor Closed (retarding/variable)
- How variable?
- Minimize potential wetting from inside

WUFI Analysis Comes Handy
Passive House Concept: Controlling Heat Loss – Eliminate Thermal Bridges

\[ \text{Psi} < 0.006 \text{ BTU/hr*ft*°F} \]
Thermal-bridge-free construction - Roof Assembly, Wall Assembly, Floor Assembly

With Thermal-bridge-free construction temperature bridges are eliminated and in turn homogenous temperature throughout the structure are achieved.
MINIMIZE LOSS:
ELIMINATING THE THERMAL BRIDGE MINIMIZES HEAT LOSS
CONDENSATION/BUILDING DETERIORATION

BAD = high heat loss + risk of condensation

GOOD = low heat loss, warm interior surface + no condensation

Minimum temperature 48 F below dew-point, risk of condensation

Minimum temperature 58 F above dew-point, no risk of condensation
Passive House Concept: Provide Fresh Air...

Heat Recovery Ventilation

MINIMUM of 0.30 ACH
HRV Energy to Meet IAQ Needs

Indoor Air Quality and HRV Energy Usage

Source: Peter Schneider - VEIC
Heating Energy Needed to Meet Comfort

Temperature Variation with Point Source Heating & Heat Pump Energy Usage (135kWh)

Source: Peter Schneider - VEIC
RH and Comfort

Relative Humidity in August

Source: Peter Schneider - VEIC
RH and Comfort

Relative Humidity in December

Source: Peter Schneider - VEIC
Passive House Concept: Capturing Heat Gains - People
Passive House Concept: Capturing Heat Gains... Equipment
Passive House Concept: Once the Wasted Energy is Reduced to the maximum…

Then you can apply little renewable sources like Solar Thermal or PV
Figure 1: Comparing finite and renewable planetary energy reserves (Terawatt-years). Total recoverable reserves are shown for the finite resources. Yearly potential is shown for the renewables.
Energy Usage Comparison

Annual Site Energy Use Comparison

Source: Peter Schneider - VEIC
How does it relate to other programs?

Energy Efficient Housing Concepts in the US:

- Vermont Energy Code (RBES): required for all new construction
- Energy Star 3.0: DoE Program (30% more efficient than Code)
- Building America: DoE super energy savings Program (15% better than EStar)
- Passive House: 90% more efficient than Code
  - 70% more efficient than Energy Star
  - 55% more efficient than Building America
- Can be cost equivalent to conventional building for single family and equal or less for multifamily and commercial construction.
How does it relate to other programs?
PH Norwich VT
2457 sqft of conditioned area

Source: Owner

Independently monitored by Efficiency VT
PH Norwich VT
Coldest Day Jan. 2013 –
No Heat! – No Occupants

Space Temperatures with Heating and HRV Energy Usage
Residence G, Jan 24, 2013
Electric Radiant Heat: 0 kWh; HRV: 1 kWh

Source: Peter Schneider - VEIC
Independently monitored by Efficiency VT
PH Norwich VT
Coasting February 2015

With only 1 kWatt of floor matt heater
No occupants and minimal Solar Gain

Source: Peter Schneider - VEIC
Independently monitored by Efficiency VT
It is no Rocket Science and applies to retrofits too

Frankfurt Teverstrasse, Refurbishment using Passive House Principles

Source: Passivehouse Institute / DENA

© Jens Laustsen 2011
McKeesport Downtown Housing (Residential)  
McKeesport, PA  
84 units - 36643 sqft

Source PHIUS Projects Database
Retrofit of Existing Buildings
Glasswood – Portland OR
Mixed-Use Commercial

Floor Area: 1397 ft²
Air-tightness: 0.39 ACH50
Cold Spring, NY
Small Commercial

Floor Area: 1097 sqft
HHD: 6035
North Street Passive House – Cold Spring NY Residential

Floor Area: 1845 sqft
Air-tightness: 0.86 ACH50
Passive Lodge at Silver Lake – Sharon CT
Residential

Floor Area: 2423 ft²
Air-tightness: 0.0317 CFM50/ft²-envelope
Weinberg Commons – Washington DC
Multi-Family

13 Units
Floor Area: 9380 ft²
Air-tightness: 0.56 ACH50
Shading by Objects is also taken in consideration in PHPP
Shading by Objects is also taken in consideration in PHPP

Shading Representation February @ Noon
Passive House Projects Worldwide

Passive Houses for Different Tasks

- School
- Social Housing
- Office Buildings
- Swimming Hall
- Kindergarten
Passive Apartments NHT Lodenareal, Innsbruck
Largest certified "Passive House" complex in the world, 2009

- Pilot project in Tirol, 354 apt.
- Construction cost 54 Mil euro
- 250 Excursions since 2009

Neue Heimat Tirol has built over 1000 apt. with PH Consulting since 2007

"The Lodenareal is the key project for the future of housing in Europe"
Wolfgang Feist 2009

Monitoring 2009-2012: Best PH in Austria

Source: nht, din a4, team k2
Passive House Projects
North East USA

Handel Architects
High Rise – Cornell-Tech - NYC

School
Portland ME

Affordable Housing
Brewer - ME
PH Projects Vermont

Affordable Senior Housing
Elm Place - Milton VT
Only 127,651 kBTU/yr at 2°F for 27,690 sqft floor area

Habitat for Humanity
East Montpelier
PH Projects
Vermont

THIRD ANNUAL PASSIVE PROJECTS COMPETITION WINNERS!

ELM PLACE - Best Overall Passive Building Winner
Multifamily project category Winner
Affordable project category Honorable Mention
2017 PHIUS Passive House Projects Competition

83% less energy for heating/cooling
@ only 2% more than conventional building cost
51 Upper Pines – Warren VT

Case History

Built in the early 70’s. Simple in construction. Slab on grade floor. Inexpensive widows. Fiberglass insulation. Fireplace in great room and cathedral ceilings with no attic.
The 516 gallon of propane usage at 62-65 degrees in a 1440 sq ft home indicated the boiler was running often to keep up. Averaged in all the categories the house performed at a 60% efficiency which is below average.

The 2 bathrooms have poor ventilation with potential to mold formation. One fan was pulling only 6-10 CFM, while a BR-fan should be pulling 50-80 CFM.
51 Upper Pines – Warren VT
Initial Condition

Thermal Bridges Everywhere
51 Upper Pines – Warren VT
Initial Condition

Thermal Bridges Everywhere
51 Upper Pines – Warren VT
Initial Condition

Air Leaks Everywhere

1740 CFM
A lot of infiltration for a 1440 ft² house
First Phase of the Project
The Roof Overhaul
First of 7 lifts
ISO sealed to insulation box

All Joints Carefully Taped
First Phase of the Project
The Roof Overhaul

12” Polyliso for R-83 Finished Roof
First Phase of the Project
Finished Roof

12” Polyliso for R-83 Finished Roof
Second Phase of the Project
The Passive House Planning Package Energy Model

PHPP = PASSIVE HOUSE PLANNING PACKAGE

The energy modeling software developed by Passivhaus Institut - Germany

- Climate and orientation data input
# Energy Balance

## PHPP Population Process

### Climate Data

**EnerPHit planning:**

**CLIMATE DATA**

<table>
<thead>
<tr>
<th>Parameters for PHPP calculated ground temperature:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monthly data: Montpelier AP VT - Montpelier AP VT</td>
</tr>
<tr>
<td>Heating load: 1427 kBTU(h)</td>
</tr>
<tr>
<td>Primary energy: 54.85 kBTU(h)</td>
</tr>
</tbody>
</table>

**Solar radiation + Ambient temperature**

### Building:

- **51 Pines - Warren VT**

**Climate building:** Montpelier AP VT

- **Hr:** 2420
- **TDay/yr:** 7680

**Region:**

- User Data

**Climate data set:** Montpelier AP VT - Montpelier AP VT

**Weather station (altitude):**

- Building location (altitude): 596 ft

**Month:**

<table>
<thead>
<tr>
<th>Month</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<td>29</td>
<td>31</td>
<td>30</td>
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<tr>
<td>Data</td>
<td>21.4</td>
<td>Radiation data: kBTU/h/month</td>
<td>Radiation ETU/h/yr</td>
<td>Radiation ETU/h/yr</td>
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<tr>
<td>East</td>
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</tr>
<tr>
<td>South</td>
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<td>22.2</td>
<td>22.2</td>
<td>22.2</td>
<td>22.2</td>
<td>22.2</td>
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<td>22.2</td>
<td>22.2</td>
<td>22.2</td>
<td></td>
</tr>
<tr>
<td>West</td>
<td>22.2</td>
<td>22.2</td>
<td>22.2</td>
<td>22.2</td>
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<td>Global</td>
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<td>22.2</td>
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<td>22.2</td>
<td>22.2</td>
<td></td>
</tr>
<tr>
<td>Average Temperature (°F)</td>
<td>59</td>
<td>59</td>
<td>59</td>
<td>59</td>
<td>59</td>
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<td>59</td>
<td>59</td>
<td>59</td>
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</tr>
</tbody>
</table>

**NECCO INC**

NEW ENGLAND CONSTRUCTION CO.
ENERGY BALANCE

PHPP POPULATION PROCESS

Orientation- Windows Input and Shading Analysis

Notes:  South Angle Estimator
PHPP = PASSIVE HOUSE PLANNING PACKAGE

The energy modeling software developed by Passivhaus Institut - Germany

- Climate and orientation data input
- Assemblies’ R-value Calculation
# Energy Balance

## Compiling Energy Losses

### Assemblies’ R-Value Calculation

<table>
<thead>
<tr>
<th>Assembly no.</th>
<th>Building assembly description</th>
<th>Interior insulation?</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Roof</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Surface Film Resistance [hr.ft².F/BTU]</th>
<th>interior Rsi</th>
<th>exterior Rse</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.57</td>
<td>0.23</td>
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<table>
<thead>
<tr>
<th>Area section 1</th>
<th>Area section 2 (optional)</th>
<th>Area section 3 (optional)</th>
<th>Thickness [in]</th>
</tr>
</thead>
<tbody>
<tr>
<td>T&amp;G board</td>
<td></td>
<td></td>
<td>1.500</td>
</tr>
<tr>
<td>Glass-Fiber Batts</td>
<td>3.330 sleepers 24&quot; OC</td>
<td>1.280</td>
<td>1.500</td>
</tr>
<tr>
<td>Plywood</td>
<td>1.470</td>
<td></td>
<td>0.500</td>
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<tr>
<td>Polyiso unfaced</td>
<td>6.200</td>
<td></td>
<td>12.000</td>
</tr>
<tr>
<td>OSB</td>
<td>1.390</td>
<td></td>
<td>0.625</td>
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</table>

<table>
<thead>
<tr>
<th>Percentage of sec. 1</th>
<th>Percentage of sec. 2</th>
<th>Percentage of sec. 3</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>75%</td>
<td>25.0%</td>
<td></td>
<td>16.13</td>
</tr>
</tbody>
</table>

**U-value supplement**: BTU/hr.ft².°F

**R-Value**: 82.6 hr.ft².°F/BTU
ENERGY BALANCE
COMPILING ENERGY LOSSES

PHPP = PASSIVE HOUSE PLANNING PACKAGE

The energy modeling software developed by Passivhaus Institut - Germany

- Climate data input
- Assemblies’ R-value Calculation
- Heat loses through the ground
- Areas and Thermal Bridges’ input
ENERGY BALANCE
COMPILING ENERGY LOSSES

Thermal Bridges’ input
Each one positive or negative is accounted for

\[ \Psi_e \text{ (for PHPP)} \quad 0.010 \text{ Btu/hr*ft*F} \]

RSI at 68 °F / 23 °F 0.96
ENERGY BALANCE
COMPILING ENERGY LOSSES

Thermal Bridge Pitfall

\[ L2D - (U1 \cdot A1 + U2 \cdot A2) = \psi \cdot L \]

(from THERM)
ENERGY BALANCE
COMPILING ENERGY LOSSES

PHPP = PASSIVE HOUSE PLANNING PACKAGE

The energy modeling software developed by Passivhaus Institut - Germany

- Climate data input
- Assemblies’ R-value Calculation
- Heat loses through the ground
- Areas and Thermal Bridges’ input
- Orientation- Windows Input and Shading Analysis
**ENERGY BALANCE**

**COMPILING ENERGY LOSSES**

### Orientation, Windows Input and Shading Analysis

**REDUCTION FACTOR SOLAR RADIATION, WINDOW U-VALUE**

| Building: 51 Pines - Warren VT | Annuall heating demand: 7.08 MMBTU/yr |

| Climate: MONTPELIER AP VT - Montpelier AP VT | Heating degree days: 7460 | 1244 |

<table>
<thead>
<tr>
<th>Window area orientation</th>
<th>Global radiation (cardinal points)</th>
<th>Skading</th>
<th>Dirt</th>
<th>Non-perpendicular incident radiation</th>
<th>Glazing fraction</th>
<th>SHGC</th>
<th>Solar irradiation reduction factor</th>
<th>Window area</th>
<th>Window U-Value</th>
<th>Glazing area</th>
<th>Average global radiation</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>1000 Btu/hr</td>
<td>0.75</td>
<td>0.85</td>
<td>0.85</td>
<td>0.68</td>
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<tr>
<td>North</td>
<td>66</td>
<td>0.46</td>
<td>0.85</td>
<td>0.85</td>
<td>0.51</td>
<td>0.37</td>
<td>0.23</td>
<td>13</td>
<td>0.16</td>
<td>8</td>
<td>66</td>
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<tr>
<td>East</td>
<td>118</td>
<td>0.33</td>
<td>0.85</td>
<td>0.85</td>
<td>0.60</td>
<td>0.37</td>
<td>0.19</td>
<td>42</td>
<td>0.16</td>
<td>25</td>
<td>118</td>
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<tr>
<td>South</td>
<td>200</td>
<td>0.35</td>
<td>0.85</td>
<td>0.85</td>
<td>0.67</td>
<td>0.54</td>
<td>0.19</td>
<td>62</td>
<td>0.17</td>
<td>41</td>
<td>200</td>
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<tr>
<td>West</td>
<td>121</td>
<td>0.38</td>
<td>0.85</td>
<td>0.85</td>
<td>0.53</td>
<td>0.37</td>
<td>0.16</td>
<td>25</td>
<td>0.17</td>
<td>13</td>
<td>121</td>
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<tr>
<td>Horizontal</td>
<td>158</td>
<td>1.00</td>
<td>0.85</td>
<td>0.85</td>
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<td>0.00</td>
<td>0</td>
<td>0.00</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total average value for all windows.</td>
<td></td>
<td>0.45</td>
<td>0.13</td>
<td>142</td>
<td>0.16</td>
<td>88</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- All windows and doors thermal data is cataloged
- Every single window, location and shading input is registered
Ventilation Heat Losses

In cases of direct venting, the PHIUS Make Up Air calculator must be used to account for direct venting of:

- Exhaust Dryer
- Exhaust Range Hood at Kitchen

This provided a new CFM average and a new efficiency of the ERV down from the one specified by the manufacturer.
ENERGY BALANCE OPTIMIZATION

Once all losses are accounted for... then

We can start to compile the heat gains

- South Windows SHGC 60
- West Windows SHGC 37 to control Summer overheating
- DHW recirculation line gains if required

And leave the building Net Zero ready
ENERGY BALANCE OPTIMIZATION

Once all losses are accounted for...then

The Primary Energy load is also considered in PHPP since:

- For each kW required on site, the power plant must produce 3.2 kW

- PHPP also correlates this with the source of fuel (coal, natural gas, renewables, etc.) used in generation to calculated the CO2 impact
Mechanicals for supplemental heating/cooling & ventilation

**Heating / Cooling**
- Fujitsu 12000 BTU – Single Source located in the living room

**Ventilation**
- Lunos e² – Two pairs located in the bedrooms and living room
- Lunos eGO – One unit in each bathroom
The Passive House Retrofit has a heating demand of only 7655 kBTU/yr for 1440 sqft floor home and a Peak Heat Load of 5139 BTU/hr
Execution of Second Phase Inside Slab Insulation

Remove Old Floor and cover Slab with 5” of Polylso
Execution of Second Phase
Inside Slab Insulation

Interior floor plywood over ISO board
Execution of Second Phase
Inside Slab Insulation

Joints and perimeter air sealed
Execution of Second Phase
Finished Floor
Execution of Second Phase
Outside Frost-Wall Insulation

Dig Trench and cover
Frost Wall with 6” of XPS
Execution of Second Phase
Foundation Insulation Complete
Foundation/floor insulated & Heat pump installed

End Phase II
Third Phase
Air-Sealing/Insulation of Walls
and Replacement of Windows

Begin Phase III
Sheathing Removed
At South Wall
Third Phase
Air-Sealing/Insulation of Walls and Replacement of Windows

Rear at chimney, actual insulation
Third Phase
Air-Sealing/Insulation of Walls and Replacement of Windows

Rear and West wall sill repair
Third Phase
Air-Sealing/Insulation of Walls and Replacement of Windows

East wall cantilevered beam
Third Phase
Air-Sealing/Insulation of Walls and Replacement of Windows

Naked with air sealing at joints
Third Phase
Air-Sealing/Insulation of Walls and Replacement of Windows

stud with tape
Third Phase
Air-Sealing/Insulation of Walls and Replacement of Windows

stud with tape
Third Phase
Air-Sealing/Insulation of Walls and Replacement of Windows

All joints sealed with tape
Third Phase
Air-Sealing/Insulation of Walls and Replacement of Windows

All joints/studs sealed with tape
Third Phase
Air-Sealing/Insulation of Walls and Replacement of Windows

Insulation
Dam Rear
Wall Chimney
Cavity
Third Phase
Air-Sealing/Insulation of Walls and Replacement of Windows

East Side air sealed
Third Phase
Air-Sealing/Insulation of Walls and Replacement of Windows

Taped joints overlapped corners
Third Phase
Air-Sealing/Insulation of Walls
and Replacement of Windows

Rear wall SPF complete
East wall foam complete
Third Phase
Air-Sealing/Insulation of Walls
and Replacement of Windows

Rough opening prep
Third Phase
Air-Sealing/Insulation of Walls and Replacement of Windows

Sill, membrane, window
Third Phase
Air-Sealing/Insulation of Walls and Replacement of Windows

Air and water sealed
Third Phase
Air-Sealing/Insulation of Walls and Replacement of Windows

South Wall
Partially Foamed
Third Phase
Insulation of Walls and Replacement of Windows

West Wall Foam Complete
Third Phase
Air-Sealing/Insulation of Walls and Replacement of Windows

Rear wall
1st Layer
3” ISO
Third Phase
Air-Sealing/Insulation of Walls and Replacement of Windows

West Wall
ISO Complete
Third Phase
Air-Sealing/Insulation of Walls and Replacement of Windows

First layer of 3” ISO board with window box
Third Phase
Air-Sealing/Insulation of Walls and Replacement of Windows

1st layer ISO sealed, second layer installed
Third Phase
Air-Sealing/Insulation of Walls and Replacement of Windows

Typical 1st layer sealing
Third Phase
Air-Sealing/Insulation of Walls
and Replacement of Windows

1st ISO taped to XPS found insulation
Third Phase
Air-Sealing/Insulation of Walls and Replacement of Windows

Rear 2nd Layer ISO w/strapping
Third Phase
Air-Sealing/Insulation of Walls and Replacement of Windows

Air seal penetrations
Third Phase
Siding Finishing
Third Phase
Siding Finishing
End
Third Phase
End Results
Third Phase

Living Room East

Before - After
End Results
Third Phase

2nd floor BR rear

Before - After
Mechanicals

Ductless Mini-Split Heat Pump
Outdoor unit -- Indoor unit

Lunos e²

Lunos eGO
Ventilation ERV's Locations 1st Floor

LUNOS e2 Pair 1, Fan A
Possible LUNOS eGO in joined tubes
LUNOS e2 Pair 1, Fan B
Final Results
Blower Door Test

The final Blower Door Test was

48cfm@50Pa

a reduction of 97% air infiltration from the 1740 CFM (10 ACH50) in the initial condition
Final Results
Blower Door Test

48cfm@50Pa

Is equivalent to

0.27 ACH50
Estimated BEFORE Renovation

<table>
<thead>
<tr>
<th>Category</th>
<th>Heating demand</th>
<th>Heating load</th>
<th>Primary energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space heating</td>
<td>65.25 kBTU/(ft²·yr)</td>
<td>36.58 BTU/(hr·ft²)</td>
<td>Heating, cooling, dehumidification, DHW, auxiliary electricity, lighting, electrical appliances</td>
</tr>
<tr>
<td>Estimated BEFORE Renovation</td>
<td>870% of 7.50 kBTU/(ft²·yr)</td>
<td>717% of 5.10</td>
<td>167% of 70.6 kBTU/(ft²·yr)</td>
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</tbody>
</table>
Passive House Planning Package – PHPP modeling comparison

Forecasted with Renovation

<table>
<thead>
<tr>
<th></th>
<th>Heating demand</th>
<th>Heating load</th>
<th>Primary energy</th>
<th>85% of</th>
<th>7.50 kBTU/(ft² yr)</th>
<th>84% of</th>
<th>5.10</th>
<th>77% of</th>
<th>70.6 kBTU/(ft² yr)</th>
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</thead>
<tbody>
<tr>
<td><strong>Space heating</strong></td>
<td>6.39 kBTU/(ft² yr)</td>
<td>4.29 BTU/(hr ft²)</td>
<td>Heating, cooling, dehumidification, DHW, lighting, electrical appliances</td>
<td>54.5</td>
<td>KBTU/(ft² yr)</td>
<td>77%</td>
<td>70.6 kBTU/(ft² yr)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

90% Reduction in Heating Demand
THE TAKE-AWAY

If we want to make renewable energy sustainable we must start by eliminating the energy waste to the last kWatt possible.
Thank you

Because we care about you saving money and living healthy, and care about the environment, our legacy and our future, we make energy efficient buildings.

Enrique Bueno – ebueno@eplusbuildings.com
Paul Sipple – necco@gmavt.net