

Slide 1



## Passive House

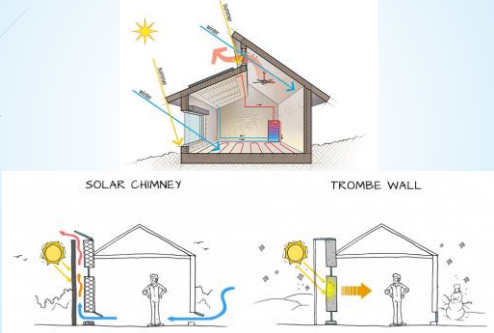
The Design, Construction, Testing and Lessons Learned  
[RochesterPassiveHouse.blogspot.com](http://RochesterPassiveHouse.blogspot.com)

Matt Bowers  
Passive House Designer, Passive House Tradesman, HERS Rater

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### Other types of "Green" buildings




SOLAR CHIMNEY      TROMBE WALL

For every super efficient "green" project, there are plenty of examples of project downfalls - Earth Bermed, Passive Solar, Enertia, Thermal Massive, Geo Thermal, etc. They all have examples of not working the way they are intended.

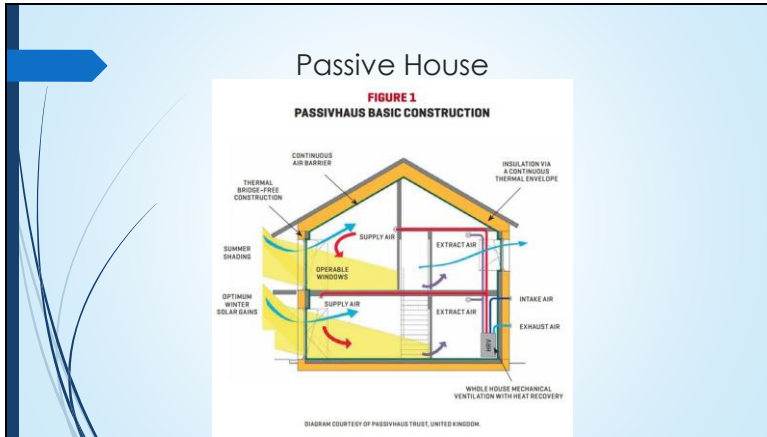
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### Other types of "Green" buildings



For every super efficient "green" project, there are plenty of examples of project downfalls - Earth Bermed, Passive Solar, Enertia, Thermal Massive, Geo Thermal, etc. They all have examples of not working the way they are intended.

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Passive House is the exception. There are over 50,000 in the world, and they ALL work the way they were intended. However the biggest deterrent is "It's too expensive!"

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- ### Passive House (PHI – International)
- Designed and Built to achieve
    - 4.75 kBtu/sqft/yr (Heating Demand)
    - 5.16 kBtu/sqft/yr (Cooling Demand)
    - 0.6 ACH50 as an average of Pressurization and Depressurization tests
      - Volume is calculated as drywall to drywall
      - Excludes interior wall volume
    - 38.0 kBtu/sqft/yr Primary Energy usage
      - Includes all Heating Energy, Cooling Energy, Hot Water, Lighting, Appliances
      - Accounts for the source of electricity and grid losses

These are the Passive House International Standards. The PHIUS Standards are slightly different and very much more due to specific climate data.

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- ### Passive House (PHI – International)
- Other important Aspects (Not necessarily required)
    - Proper Orientation with appropriate overhangs
    - Super Efficient Window (R-10)
    - Whole House Ventilation with Heat Recovery
    - Thermal Bridge Free

Other important items that will make a Passive House Project a success

- Proper Orientation with appropriate overhangs
- Super Efficient Window (R-10)
- Whole House Ventilation with Heat Recovery
- Thermal Bridge Free

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None of this matters  
Passive House is too expensive


- Rochester Passive House Details:
  - ~2800 square feet
    - 2500 sqft 1<sup>st</sup> and 2<sup>nd</sup> floor interior dimensions, no basement
    - 2831 sqft according to Passive House Planning Package (PHPP)
    - 2944 sqft according to Tax Roll
    - 4300 sqft according to RESNET

We will be looking at Rochester Passive House for a majority of this presentation. I like to start with the financials 1<sup>st</sup> to help keep you engaged in the process. The house is basically 2800 sqft – but it depends on who you ask

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None of this matters  
Passive House is too expensive

- Rochester Passive House Details:
  - 2.5 car garage (25' x 30')




Here are some “extras” that are included in the cost of the project, but don’t actually add to the living area of the home.  
2.5 car garage

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None of this matters  
Passive House is too expensive

- Rochester Passive House Details:
  - Garage roof is raftered with raised dormer for full storage




The area over the garage can be used for storage, or finished off in the future for extra guest space.

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None of this matters  
Passive House is too expensive

- Rochester Passive House Details:
  - 140 Sqft breezeway between garage and house



The breezeway helps add an air lock entry, and keep the garage attached to the house. Since Passive House doors are so heavy, they don't make them spring loaded – you'd lose a finger or 2. we needed the spring loaded fire door to have the garage attached to the house.

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None of this matters  
Passive House is too expensive

- Rochester Passive House Details:
  - Raised Fill Septic System
  - 7 Acres of Land
  - 200' Driveway
  - 450 sqft front porch
  - Full Conditioned Basement

Misc site work can vary quite a bit from project to project. The basements of a Passive House are just as insulated as the rest of the house, so they really should be included in the sqft price of the house (we are only including about 60% of it for our numbers. The front porch aids to the shading of the windows, but is not required. Each passive house project is a little different.

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Passive House  
Costs

\*Garage and Breezeway are included in the Building Construction Costs

Total Cost of Build	\$ 456,463	100%
Land	\$ 35,000	8%
Soft Costs	\$ 11,250	2%
Sitework and Septic System	\$ 43,247	9%
Supervisory Costs	\$ 22,221	5%
<b>Building Construction Costs</b>	<b>\$ 344,746</b>	<b>76%</b>
Foundation	\$ 44,990	10%
Framing	\$ 71,376	16%
Roofing	\$ 9,937	2%
Windows and Doors	\$ 32,100	7%
Electric	\$ 19,408	4%
Plumbing	\$ 16,869	4%
HVAC	\$ 16,300	4%
Insulation	\$ 20,300	4%
Drywall	\$ 13,200	3%
Siding	\$ 33,758	7%
Kitchen	\$ 21,800	5%
Interior Finishes	\$ 41,492	9%
Misc	\$ 3,215	1%

Even more potential savings:  
Siding is LP smart side, not vinyl.  
Amish Kitchen with quartz countertops  
50 year laminate floors  
Upgraded trim package

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**Cost per Square Foot**

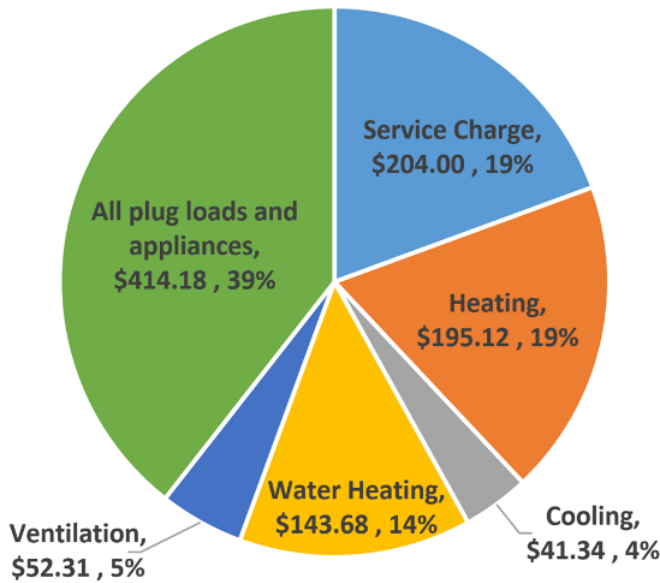
- Really dislike this metric, due to varying site circumstances
  - Cost of Land, Septic System, Driveway length, Garage Size, etc.
  - The basement is conditioned to the same extent the rest of the house is.

**\$163 per sqft including all expenses**  
**\$123 per sqft excluding land and site work**

- We were able to spend an extra \$32,000 on the energy efficiency upgrades and still have the same monthly payment (Mortgage and Utilities)

Really dislike this metric, due to varying site circumstances  
 Cost of Land, Septic System, Driveway length, Garage Size, etc.  
 The basement is conditioned to the same extent the rest of the house is.  
**\$163 per sqft including all expenses**  
**\$123 per sqft excluding land and site work**

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Heating Energy for 2017 was 1919 kWh - \$195  
 Cooling Energy for 2017 was 382 kWh - \$41  
 Water Heating Energy for 2017 was 1381 kWh - \$144  
 Ventilation Energy for 2017 was 498 kWh - \$52  
 Our Service Charge (\$17/month) was our largest expense  
 \*Perspective – we spend more each month on cell phones than we do to heat our house ALL year

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Now that I have your attention...  
**Welcome to Rochester Passive House**

Rochester Passive House was built affordably, and with such low utility bills, there is not much difference in monthly payment. I should note, we are not in an area with Natural Gas – we'd be on propane, so that makes the "payback" even faster.

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### Rochester Passive House Technical Data

Basement Slab	R-38	8" of EPS Foam (2 layers of 4")
Basement Walls	R-62	13" AMVIC ICF + 2x4 walls 8" inside of ICF insulated with dense packed cellulose
Above Grade Walls	R-54	Double 2x4 wall construction with 8" space between walls insulated with cellulose
Windows	R-7 (U-0.14)	Zola UPVC tilt and turn windows
Attic Insulation	R-95	25" of settled open blown cellulose
Airtight Construction	48 CFM <sub>50</sub> / 0.08 ACH <sub>50</sub>	The equivalent leakage area for this house is less than a 2" diameter hole
Whole House Ventilation	ComfoAir 350	Up to 86% heat recovery ensuring full volume of air replaced with fresh filtered air every 3 hours
Heating / Cooling	2 x 9000BTU/hr Mr. Slim Heat Pumps	30.5 SEER, 13.5 HSPF – heat load calculation only requires 1, 2 <sup>nd</sup> installed for redundancy
Water Heater	Sanden CO2 Heat Pump	COP 4.5, can supply over 1.5 hours of continuous hot water

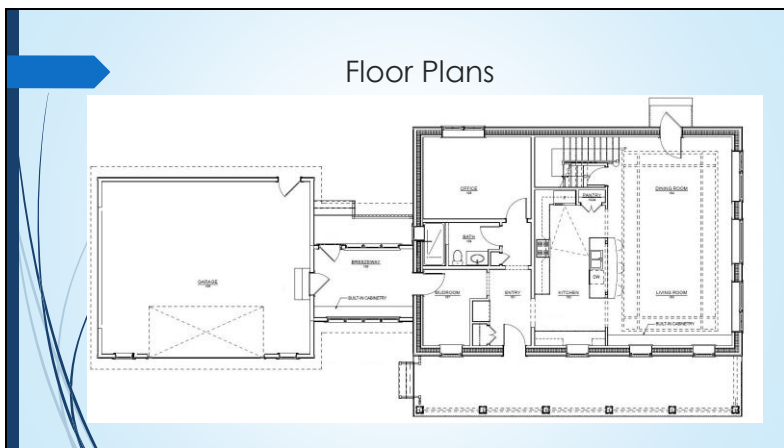
Lots of insulation, Airtight Construction, very efficient heating, cooling and water heater keep the utility bills extremely low.

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- ### Design Optimization
- Simplify Floor Plan Shape
  - Window Sizes and Orientation
    - Maximize Southern Exposure
    - Provide proper Overhangs
      - South overhang allow full shade in the summer and full sun in the winter
  - Window Placement in Wall Assembly
    - Window installed in the middle of the R-Value of the wall

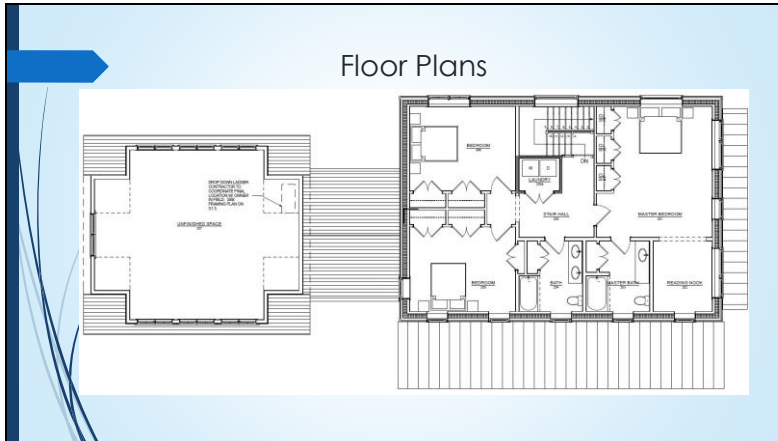
Use of Passive Solar techniques helps keep the house warm – but the sun doesn't always shine in Western NY.

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Simple shape, open floor plan, nothing out of the ordinary. Possible 1<sup>st</sup> Floor master by transforming the office into a bedroom.

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3 large bedrooms, 2<sup>nd</sup> floor laundry – with the use of a ventless dryer. 2 full 2<sup>nd</sup> floor bathrooms.

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Front of the house faces due west. Smaller windows, lots of shading where possible to help control the solar gain from the west. We also had the windows glazed for a SHGC for 0.3 on the west side of the house.

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South side of the house has 24" overhangs on the 2<sup>nd</sup> floor and 36" overhang on the 1<sup>st</sup> floor for summer shading.

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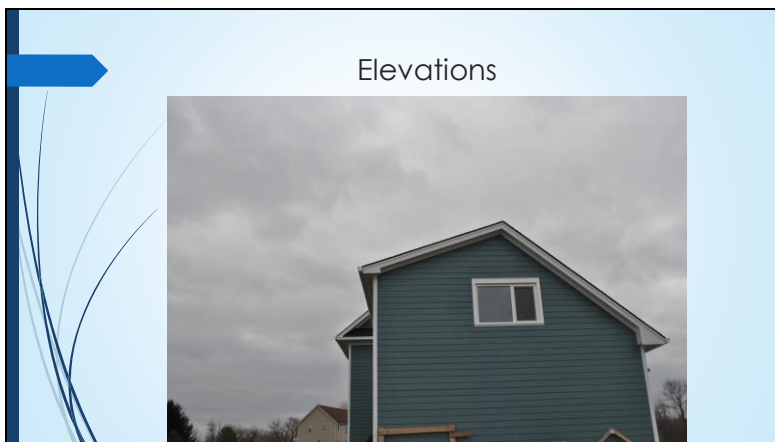
Maximized southern exposed glass. The SHGC of these windows is 0.6 – while the glass is also an R-11. 1<sup>st</sup> floor windows are taller (thus the larger overhang).

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The back of the house faces east. These windows are glazed with R-11 Glass and a SHGC of 0.3. Facing east, not much can be done regarding exterior shading.

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Back of the garage has a full dormer for storage, and the Passive House window on the gable end.



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North Side of the house has minimal glass (only for egress).

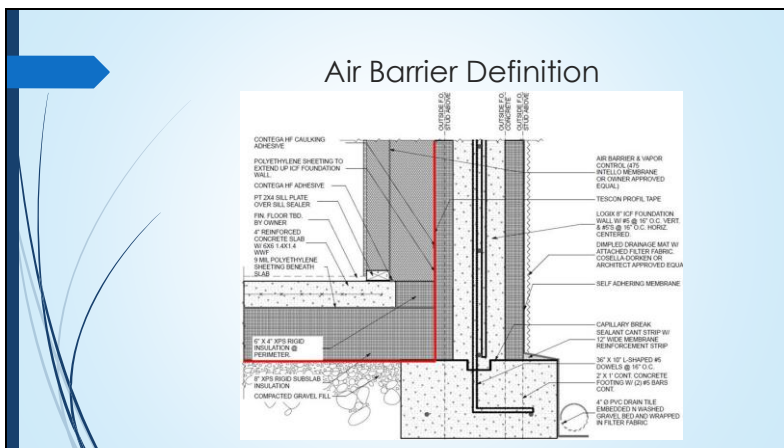
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**Construction Details**

<b>Air Barrier Definition</b>	<b>Hot Water Circ. Pump</b>
<b>Foundation</b>	<b>Drain Water HX</b>
<b>Rim Joist</b>	<b>Blower Door Testing</b>
<b>Above Grade Walls</b>	
<b>Roof/Ceiling</b>	
<b>Window Installation</b>	
<b>Ventilation System</b>	
<b>Mini Split Heat Pumps</b>	
<b>Water Heater</b>	

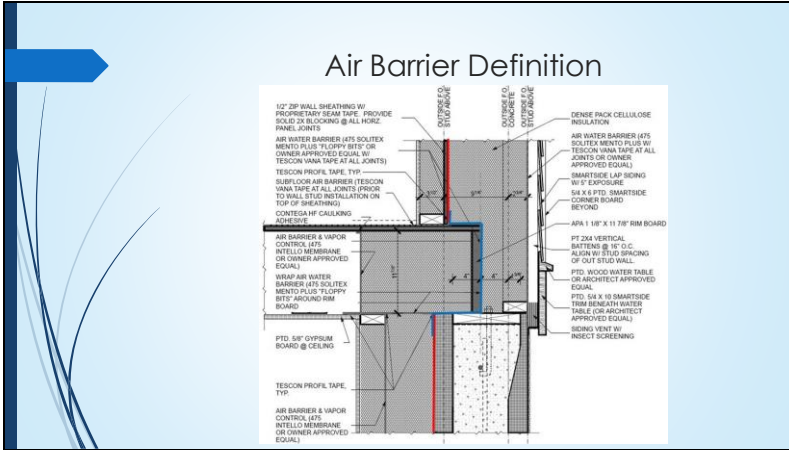
There is quite a bit of detail with all of the exterior aspects of the house we will go into, as well as the mechanicals of the house. Airtightness must be designed into the house. The redline exercise is very important. Once it is defined on paper, we can implement it in the field. "How are we connecting the air barriers together?"

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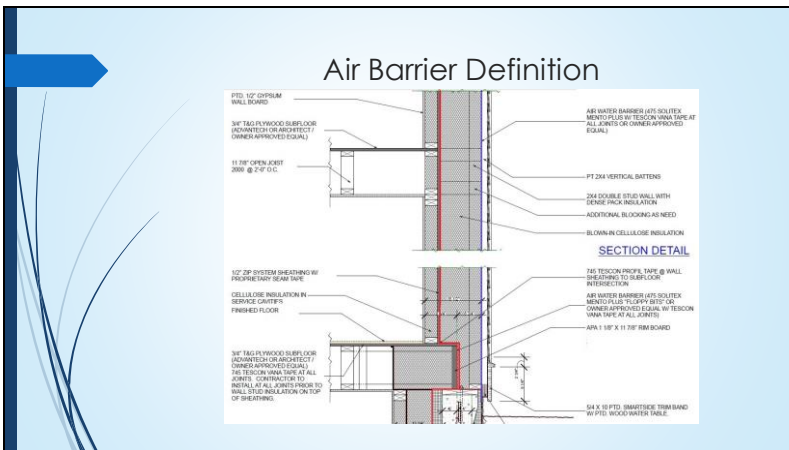
Sub slab radon barrier is sealed to the inside face of the ICF foundation

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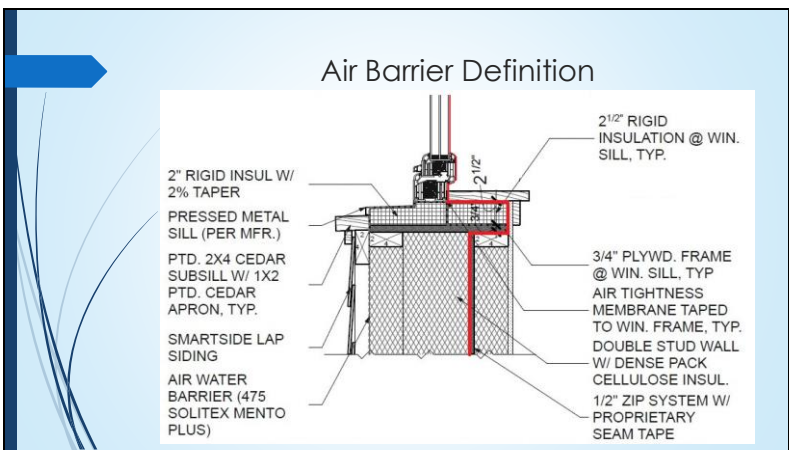
A floppy bit was installed prior to setting our 1<sup>st</sup> floor deck. This piece of fabric can be connected at a later time to other air barriers.

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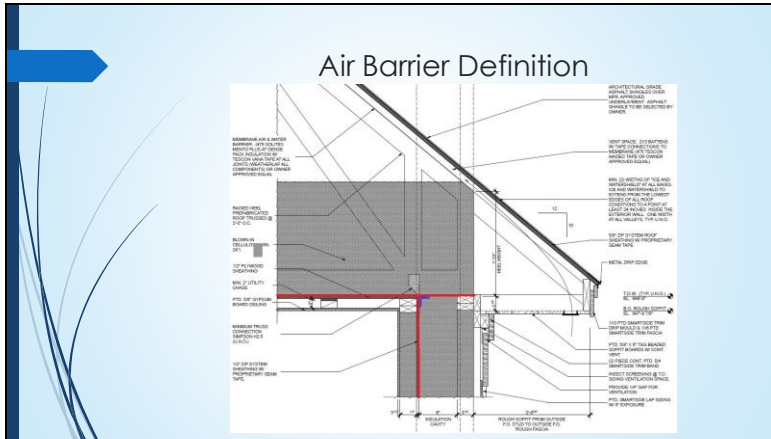
Interior wall is load bearing. The sheathing on the interior wall is our air barrier. This was chosen because it is protected from holes – either from the siding installation or from drywall installation. Keeping the air barrier intact is critical.

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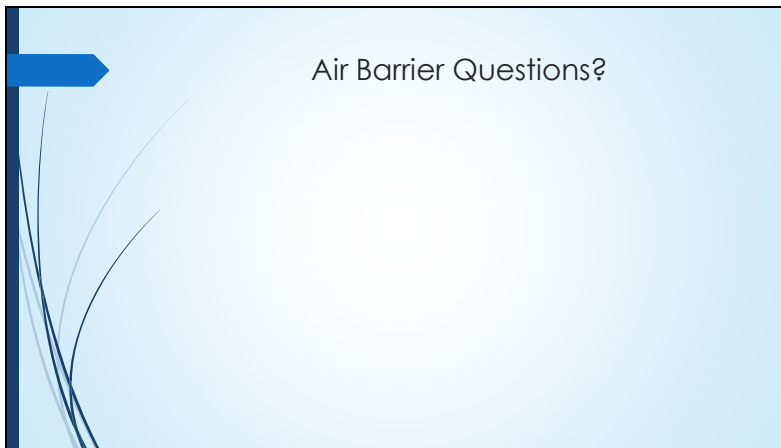
Window installation detail, connecting the air barrier to the window frame is very important

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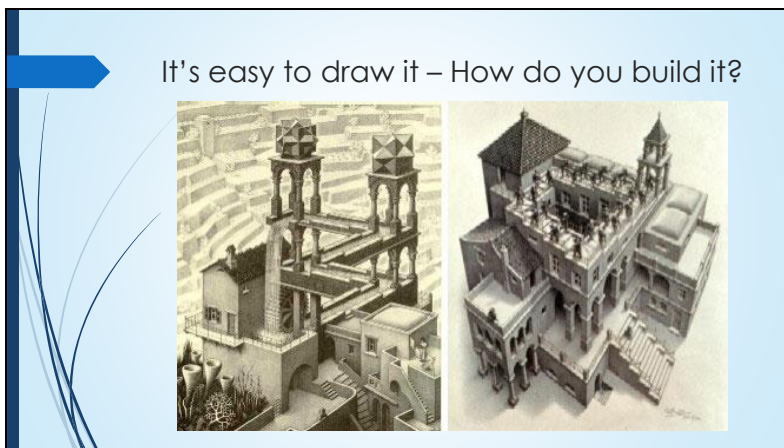
Above grade wall to 2<sup>nd</sup> floor ceiling connection. Again the air barrier is protected from future holes in drywall (adding light fixtures, etc.)

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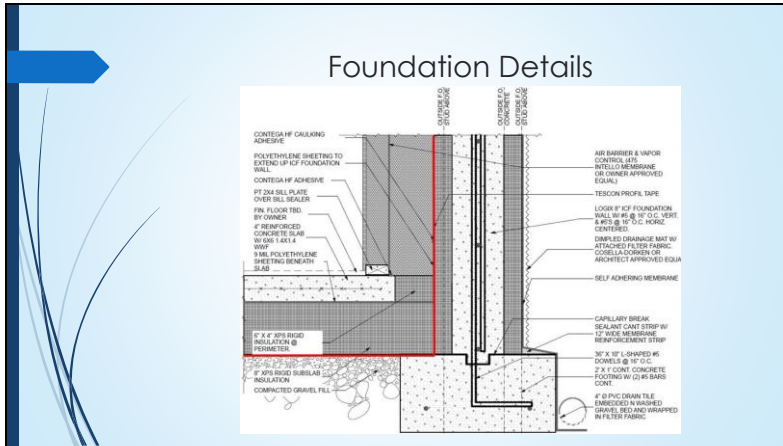
We will go into much more detail on each of these, This was to show you the red line exercise we did in the design phase of the project.

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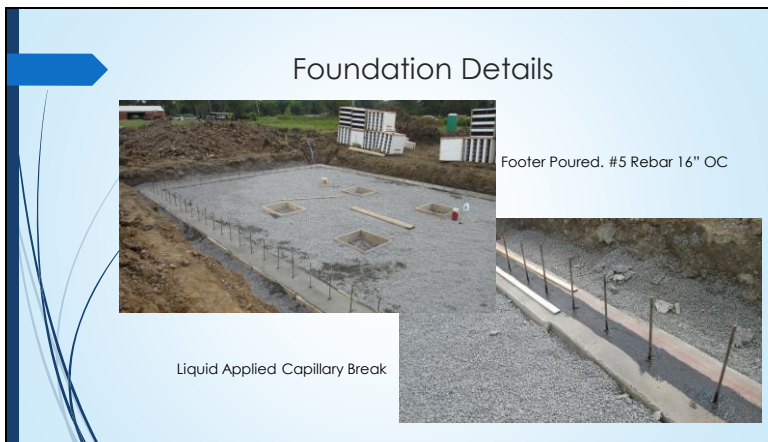


We will go into much more detail on each of these, This was to show you the red line exercise we did in the design phase of the project.

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Slab prep

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ICF assembly

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### Foundation Details




Straighten Frame with String Line

Foamboard installed for Basement Window

Pre-concrete scaffolding

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### Foundation Details



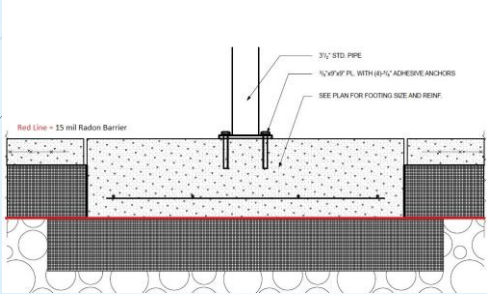
Concrete pumper truck filled between foam

Screed used to recess Sill plate into assembly

Standard ICF construction

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### Slab Details



Red Line = 15 mil Radon Barrier

3/4" STD PIPE

1/2"X1/2" PL WITH (6)-1/2" ADHESIVE ANCHORS

SEE PLAN FOR FOOTING SIZE AND REIN.

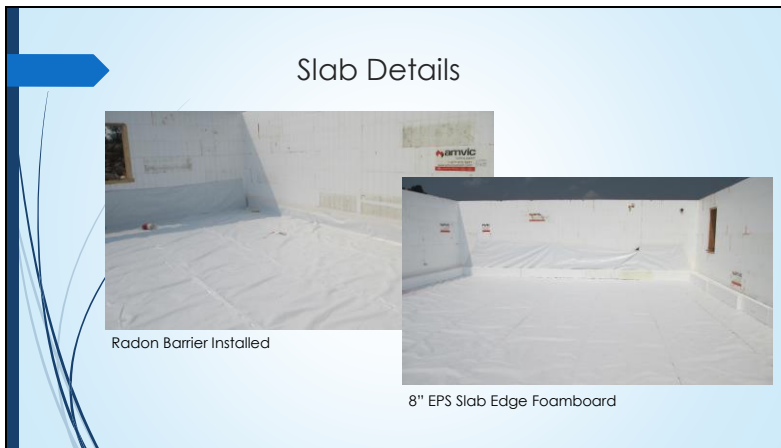
Sub slab air barrier. Keeping it simple!

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Prepped for slab pour with crushed stone, added 8" of EPS foam under post location. The EPS foam used has a compressive strength of 40 PSI (5760 PSF) – Assumed soil bearing pressure is 3000 PSF.

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Radon Barrier laid flat


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8" EPS foam laid down sub slab. Post column frame made out of foam. This will help minimize "floating the foam".

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### Slab Details



8" EPS Installed with 2" XPS Column Frame

Poured Slab to top of edge foam

Slab edge insulated with 8" of EPS foam plus R-20 ICF.

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### Steel Beam Detail



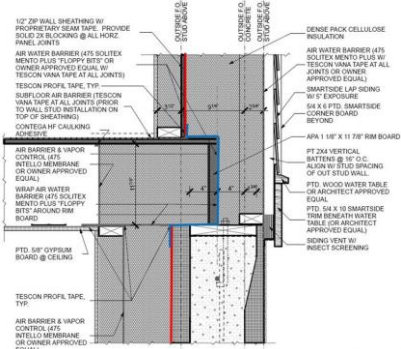
Steel Delivery

Steel I-Beam Insulated by 6.5" EPS

Steel Beam pocket insulated with rigid foam – R-25.7 to the outside of the steel

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### Rim Joist Detail



- 1/2" GYP SHEATHING BY PROPRIETARY SEAM TAPE. PROVIDE SILENT JOINTING @ ALL HORIZ. PANEL JOINTS
- AIR BARRIER (A/C, SOLUTEX MENTO PLUS, FLOPPY BITS®) OR OWNER APPROVED EQUAL W/ TESCON VANA TAPE AT ALL JOINTS
- TESCON PROFIL TAPE, TYP
- SUBFLOOR AIR BARRIER (TESCON VANA TAPE AT ALL JOINTS) PRIOR TO ALL STUD INSTALLATION OR (1/2" GYP SHEATHING) CONTINGENT ON CALKING CONTIGUOUS
- AIR BARRIER & VAPOR CONTROL LATE INTELLI MEMBRANE OR OWNER APPROVED (EQUAL)
- WRAP AIR BARRIER (A/C, SOLUTEX MENTO PLUS, FLOPPY BITS®) AROUND RIM BOARD
- PTD 5/8" GYPSUM BOARD @ CEILING
- TESCON PROFIL TAPE, TYP
- AIR BARRIER & VAPOR CONTROL LATE INTELLI MEMBRANE OR OWNER APPROVED (EQUAL)
- OUTSIDE FINISH
- CONCRETE
- OUTSIDE FINISH
- DENSE PACK CELLULOSE INSULATION
- AIR BARRIER (A/C, SOLUTEX MENTO PLUS W/ TESCON VANA TAPE AT ALL JOINTS) OR OWNER APPROVED (EQUAL)
- SMARTSIDE LAP SCISS W/ F EXPOSURE
- 5/8" X 6" PTD SMARTSIDE CORNER BOARD BEYOND
- APA 1 1/2" X 11 7/8" RIM BOARD
- PT 2X4 VERTICAL BATTENS @ 16" O.C. ALIGN W/ STUD BRACING OF OUT STUD WALL
- PTD WOOD WATER TABLE OR ARCHITECT APPROVED EQUAL
- PTD 5/4 X 10 SMARTSIDE TRIM BENEATH WATER TABLE OR ARCHITECT APPROVED (EQUAL)
- SCREEN VENT W/ INSECT SCREENING

Rim Joist detail – floppy bit installation

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Belt and suspenders – acoustical sealant, sill plate gasket, acoustical sealant.

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PT sill plate then the floppy bit fabric.

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1<sup>st</sup> floor deck set on top of floppy bit. Rim board installed





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Above Grade Wall Detail



Wall sheathing covers windows and doors

Interior 2x4 wall is load bearing

Sheathed over windows and door and built an airtight box

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Above Grade Wall Detail



Zip board covers band joist between floors

Only front door and 1<sup>st</sup> floor southern windows not covered in sheathing

Zip system, all seams taped

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Above Grade Wall Detail



All seams taped solid gusset installed at top of 2<sup>nd</sup> floor wall to tie walls together and connect 2<sup>nd</sup> floor ceiling air barrier

Exterior wall installed from top of sill plate to underside of upper gusset

Gusset installed at the top of the 2<sup>nd</sup> floor wall to tie the inner and outer walls together. Outer Wall built

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Above Grade Wall Detail

8" between walls, outer wall covers rim joist

Exterior wall installed fully installed

Outer wall covers the rim joist, and sits on the foundation wall. All of the RO for the windows are framed in the outer wall.

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Above Grade Wall Detail

Ready for Trusses!

Gussets tie both walls together where window bucks won't

8" space between walls – to be insulated with dense packed cellulose. Gussets tie the walls together.

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Roof / Ceiling Detail

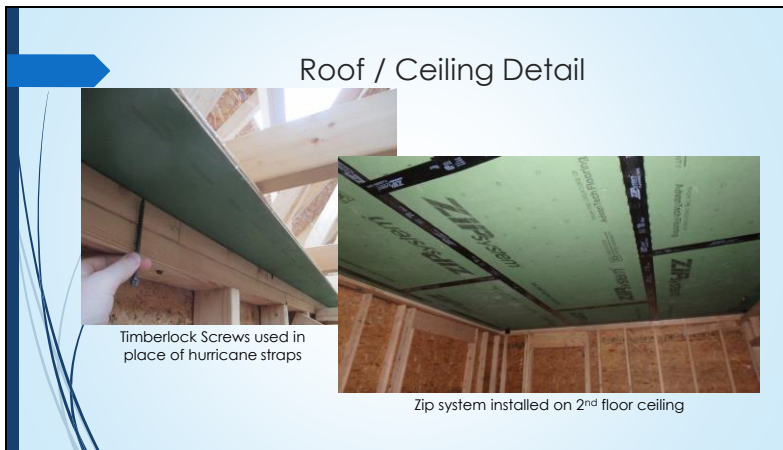
Time for the truss installation

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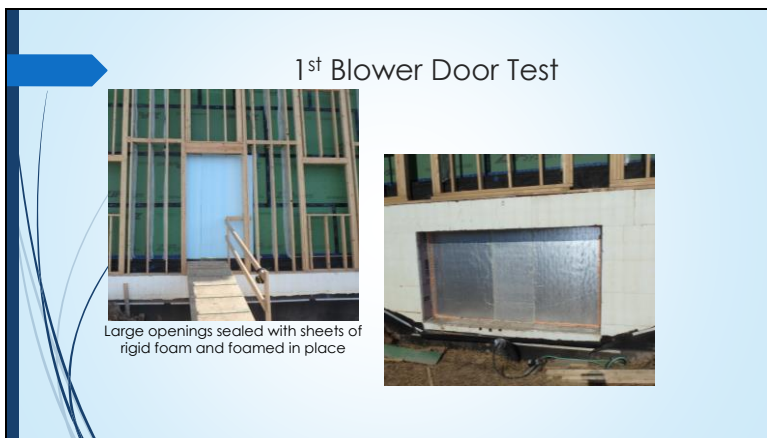
Trusses sit on the zip system gusset. We have over 24" at the outside edge of the outside wall to ensure our continuous thermal envelope.

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Hurricane straps would be problematic with an OSB ceiling – we used the Timberlock screws. Much Faster and Easier! After the roof was on, we sheathed the ceiling with Zip and tape all seams.

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1<sup>st</sup> Blower Door prep – sealed all openings with rigid foam prior to test

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### 1<sup>st</sup> Blower Door Test



Test set up in east facing basement window with duct blaster fan

Used the duct blaster fan in a basement window for test


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### 1<sup>st</sup> Blower Door Test

We calculated 2 volumes based on the 2 standards:  
 RESNET/BPI/ASTM – 38,698 CUFT  
 Passive House ISO-9972 – 29356 CUFT

**83 CFM<sub>50</sub>**

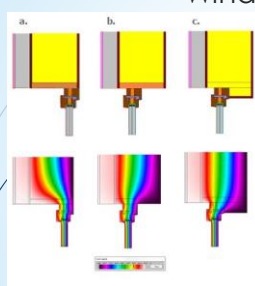
This translates to:  
 RESNET/BPI/ASTM - **0.12 ACH<sub>50</sub>**  
 Passive House - **0.17 ACH<sub>50</sub>**



83 CFM<sub>50</sub> – well under passive house airtightness requirements. This was our goal, since we will only be putting holes in the air barrier from this point on.

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### Window Installation



To be useful an analysis should be done on all sides of the window (left and right if the materials the window sits in differs, like say with a mullion).

So you ask, what is the savings for this type of detailing? Is it worth it?

Here are the numbers on this analysis:

U-whole Psi-install Relative Energy Cost			
a	0.0463	0.019	+0.57 kBtu/sqft yr*
b	0.0453	0.013	+0.39 kBtu/sqft yr
c	0.0360	-0.036	-1.42 kBtu/sqft yr

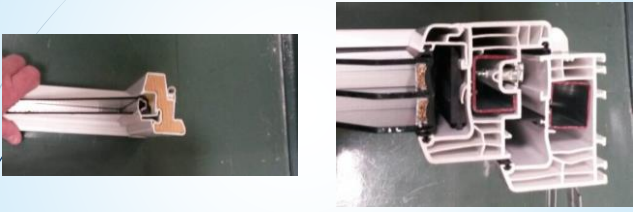
\*These numbers are relative based on a particular wall construction, type of window and the number of windows. The Relative Energy Cost are based on a Psi of 0.06. A Psi install of 0.06. A Psi install of 0.00 in this instance would not increase nor decrease the Relative Energy Cost.

Why the middle? A 2 dimensional thermodynamic analysis will show that the window will perform better when you install it in the middle and cover as much of the frame with insulation as possible.

Window installation optimized. We put the window in the middle of the wall assembly, and insulated as much of the frame as possible to make sure the window would perform better than normal

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### Passive House Windows



The image shows two cross-sections of window frames. On the left is an Energy Star R-3 Window, which has a simple double-pane design with a thin aluminum spacer. On the right is a Passive House Window, which is significantly more complex, featuring triple glass panes, a thick insulated spacer, and a thermally broken frame with multiple air voids and gaskets.

Energy Star R-3 Window

Passive House Window

There is a noticeable difference in the construction of the windows! The window on the left is an Energy Star Rated Window, the window on the right is a Passive House Window

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### Passive House Windows

<b>Energy Star Window</b> <ul style="list-style-type: none"><li>Thin Glass – double pane</li><li>Smaller space between the glass</li><li>Aluminum spacer</li><li>Solid wood frame (only R-1 per inch)</li><li>Single gasket - leaky</li></ul> <p>Total window U – 0.3 ish</p>	<b>Passive House Window</b> <ul style="list-style-type: none"><li>Thick glass – triple pane</li><li>Large space between windows</li><li>Silica or Cord insulated spacer</li><li>Thermally broken frame with many air voids</li><li>Triple gasketed - airtight</li></ul> <p>Total window U – 0.13 ish</p>
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**THERE IS NO CORRELATION BETWEEN WINDOW COST AND PERFORMANCE BETWEEN DIFFERENT MANUFACTURERS**

Some of the differences between the windows – bottom line – I got quotes that varied as much as \$70,000 – and the most expensive was NOT the best performing.

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### Window Installation



The first photo shows a construction worker using a hand saw to cut through the sheathing of a wall to create a window opening. The second photo shows the completed opening with the window frame lined up, ready for installation.


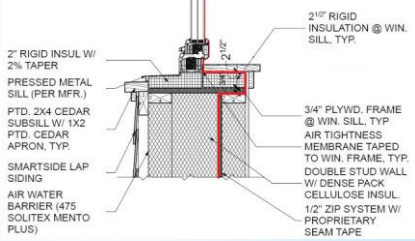
Cut open the window rough openings

Phew – the opening line up!

We cut the sheathing back, and all of the window RO's lined up!

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### Window Installation

2" RIGID INSUL W/  
2% TAPER  
PRESSED METAL  
SILL (PER MFR.)  
PTD. 2X4 CEDAR  
SUBSILL W/ 1X2  
PTD. CEDAR  
APRON, TYP.  
SMARTSIDE LAP  
SIDING  
AIR WATER  
BARRIER (475  
SOLITEX MENTO  
PLUS)


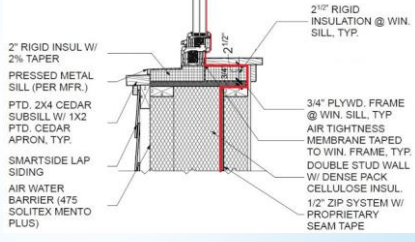
2 1/2" RIGID  
INSULATION @ WIN.  
SILL, TYP.  
2 1/2"  
3/4" PLYWD. FRAME  
@ WIN. SILL, TYP.  
AIR TIGHTNESS  
MEMBRANE TAPED  
TO WIN. FRAME, TYP.  
DOUBLE STUD WALL  
W/ DENSE PACK  
CELLULOSE INSUL.  
1/2" ZIP SYSTEM W/  
PROPRIETARY  
SEAM TAPE

Flash interior wall with 6" Grace Tape  
to bring air barrier into house

We prepped each window opening to ensure a continuous air barrier connection. We brought the air barrier to the inside face of the inside wall with flashing tape

Slide 68

### Window Installation

2" RIGID INSUL W/  
2% TAPER  
PRESSED METAL  
SILL (PER MFR.)  
PTD. 2X4 CEDAR  
SUBSILL W/ 1X2  
PTD. CEDAR  
APRON, TYP.  
SMARTSIDE LAP  
SIDING  
AIR WATER  
BARRIER (475  
SOLITEX MENTO  
PLUS)


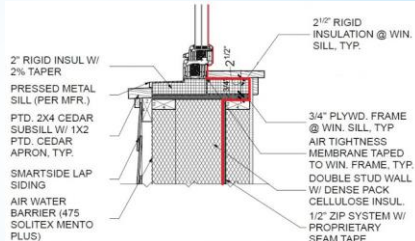
2 1/2" RIGID  
INSULATION @ WIN.  
SILL, TYP.  
2 1/2"  
3/4" PLYWD. FRAME  
@ WIN. SILL, TYP.  
AIR TIGHTNESS  
MEMBRANE TAPED  
TO WIN. FRAME, TYP.  
DOUBLE STUD WALL  
W/ DENSE PACK  
CELLULOSE INSUL.  
1/2" ZIP SYSTEM W/  
PROPRIETARY  
SEAM TAPE

Tie 2 walls together with OSB  
We used 3/4" on the bottom and 1/2" on  
the sides

Now we connected the walls with solid scrap OSB. For the bottoms we used 3/4" due to the weight of the windows

Slide 69

### Window Installation

2" RIGID INSUL W/  
2% TAPER  
PRESSED METAL  
SILL (PER MFR.)  
PTD. 2X4 CEDAR  
SUBSILL W/ 1X2  
PTD. CEDAR  
APRON, TYP.  
SMARTSIDE LAP  
SIDING  
AIR WATER  
BARRIER (475  
SOLITEX MENTO  
PLUS)

2 1/2" RIGID  
INSULATION @ WIN.  
SILL, TYP.  
2 1/2"  
3/4" PLYWD. FRAME  
@ WIN. SILL, TYP.  
AIR TIGHTNESS  
MEMBRANE TAPED  
TO WIN. FRAME, TYP.  
DOUBLE STUD WALL  
W/ DENSE PACK  
CELLULOSE INSUL.  
1/2" ZIP SYSTEM W/  
PROPRIETARY  
SEAM TAPE

Insulate the buck with 2" Rigid foam

We insulated the window buck with 2" XPS foam

Slide 70

### Window Installation



Bevel the bottom piece of foam at about 2% to allow for exterior drainage

We tapered the bottom foam to allow for drainage.

Slide 71

### Window Installation



Cover the foamboard with our Weather Resistant Barrier. This will allow us to connect the grace flashing tape air barrier to the window frame. This gives us our continuous air barrier.

- 2" RIGID INSUL W/ 2% TAPER
- PRESSED METAL SILL (PER MFR.)
- PTD. 2X4 CEDAR SUBSILL W/ 1X2
- PTD. CEDAR APRON, TYP.
- SMARTSIDE LAP SIDING
- AIR WATER BARRIER (475 SOLITEX MENTO PLUS)
- 2 1/2" RIGID INSULATION @ WIN. SILL, TYP.
- 3/4" PLYWD. FRAME @ WIN. SILL, TYP.
- AIR TIGHTNESS MEMBRANE TAPED TO WIN. FRAME, TYP.
- DOUBLE STUD WALL W/ DENSE PACK CELLULOSE INSUL.
- 1/2" ZIP SYSTEM W/ PROPRIETARY SEAM TAPE

We covered the foam in our weather resistant barrier.

Slide 72

### Window Installation



Stop blocks were installed on the outside of the rough opening to prevent the window from falling into the yard

Now we installed shims on the bottom where necessary. Installed our stop blocks and set the windows in place



Slide 73

### Window Installation



Fixed windows have steel clips the hold the window in place. Operable windows are screwed in place with an "all thread" screw to allow shims to be removed.

We planned to 1/2" gap to allow us to adequately foam the window to the RO.

Slide 74

### Window Installation




Windows were foamed in place and the air barriers were taped together

Then we sealed the window to the weather resistant barrier and the weather resistant barrier to the flashing tape we installed in step 1.

Slide 75

### Above Grade Wall Detail



With windows installed, we can continue with our exterior rain screen

Solitex Mento Plus is installed over exterior framing and 2x4 furring strips hold the wrap on the house

With the windows installed, we can finish our above grade wall assembly. We covered the exterior framing with our weather resistant barrier, and installed 2x4 furring strips over that to hold it in place

Slide 76

Above Grade Wall Detail




South overhand installed over 2x4 furring strips

Front porch roof installed over 2x4 furring strips

Now we added the overhangs and front porch roof. We have a complete thermal break between the roofs and the structure of the house. With all of this installed we insulated the wall assembly with dense packed cellulose.

Slide 77

Above Grade Wall Detail




LP Smart Side installed over furring strips

Siding installation over the furring strips after the insulation was completed

Slide 78

Roof / Ceiling Detail



Ceiling furred down 2" for electric chase.

We furred down the 2<sup>nd</sup> floor ceiling 2" to allow an electrical chase and overhead lighting

Slide 79

### Roof / Ceiling Detail



Plumbing penetrations sealed with appropriate gaskets.  
Electrical fixtures chosen would all fit in a junction box – even "recessed lights"

There are 2 penetrations in the 2<sup>nd</sup> floor ceiling – 1 plumbing stack sealed with a rubber gasket and a coax cable to an HD antenna in the attic – also sealed with a rubber gasket. All of our lighting is surface mounted – and the “recessed lights” we used fit in standard junction boxes.

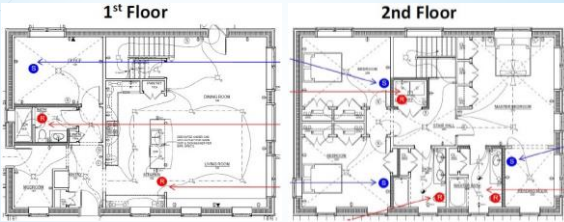
Slide 80

### Construction Details Questions?

We just covered quite a bit of stuff. We will be going into the mechanicals next.

Slide 81

### Whole House Ventilation



The goal of the ventilation is to remove the stale stinky air from the house while bringing in fresh filtered air. We remove air from the kitchens and bathrooms and supply to the bedrooms and living spaces.

The goal of passive house ventilation is to ensure optimal indoor air quality while maintaining comfort and energy efficiency. Typically we want to exchange all of the air in the house every 3 hours. We bring in fresh filtered air and exhaust the stale stinky air. This is done with heat recovery to ensure we maintain the indoor air temperature.

Slide 82

Whole House Ventilation

Air enters the ground loop heat exchanger where it is heated to 40 degrees. Then it goes into the air to air heat exchanger where it is heated to 66-68 degrees utilizing a cross counter flow heat exchanger. The outgoing air is thus cooled off keeping the heat inside the house.

Slide 83

Whole House Ventilation

The optional geothermal loop will help temper in the cold winter air before it goes to the air to air heat exchanger and will provide dehumidification in the summer. We can get roughly a half ton of cooling for the electrical load of about 25 watts. - around 240 SEER


Slide 84

Whole House Ventilation

Air is distributed throughout the house with 3" tubes (all home runs) providing roughly 12 CFM per tube. Low air flow translates to low energy use, draft free and optimal mixing of air.

Slide 85

Ductless Minisplit Heat Pumps




1<sup>st</sup> Floor (Mainly used for heating)

2<sup>nd</sup> Floor (Mainly used for cooling)

We installed 2 9000 BTU/hr mini split heat pumps. For the multi heat units we have noticed that the efficiency drops off, so we went with 2 separate units – which also provides for redundancy. At the time we were building the 6000 BTU/hr units were just beginning production.

Slide 86

Ductless Minisplit Heat Pumps



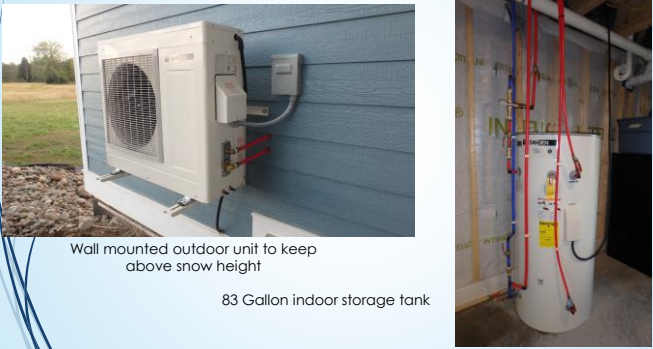
Wall mounted to keep above snow height

Kept away from the house to allow for air circulation

We mounted them up on the wall to keep free of snow loads.

Slide 87

Sanden CO2 Heat Pump Water Heater



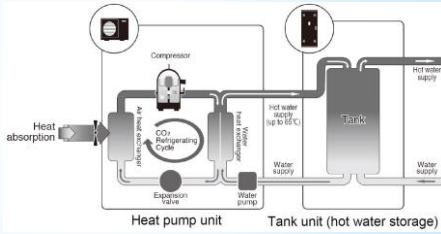

Wall mounted outdoor unit to keep above snow height

83 Gallon indoor storage tank

The water heater is a split heat pump. A standard heat pump water heater would double the heat load for the house – as the byproduct of the heat pump water heater is air conditioning.

Slide 88

### Sanden CO2 Heat Pump Water Heater





The refrigeration cycle is entirely outdoors and contained in 1 unit. Any plumber can install.

It is extremely efficient, and fairly simple to install. The heat pump heats water up to 160 degrees F and pumps it to the storage tank. At the outlet of the storage tank is a mixing valve. With 83 Gal of 160F water and a decent recovery efficiency we can supply a single shower with 1.5 hours of hot water (more when you use low flow heads and drain water heat recovery).

Slide 89

### Hot Water Circulating Pump





The push button sends a wireless signal to the controller.

The circ pump was installed because of the distance between the master bedroom and location of the water tank. It also makes the water heater that much more efficient. When you drain the cold water from a the faucet – the water in the tank is replaced with street temperature water (about 40-50 degrees). When you turn on the circ pump, the water in the loop is roughly 70 degrees. You water heater doesn't have to work as hard.

Slide 90

### Hot Water Circulating Pump

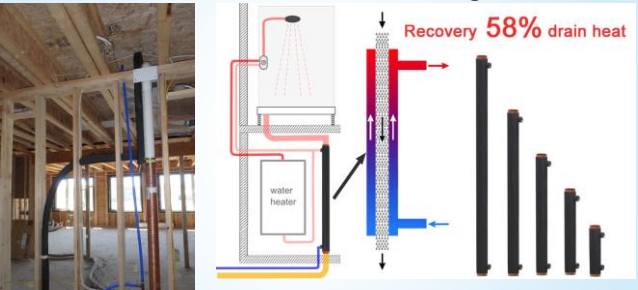


The controller turns on the pump until the sensor detects 100F on the dedicated return line. The pumps runs for roughly 4 minutes. We waste about 1-2 cups of water to drain our branches before we have hot water at the faucet's

The amount of water wasted is much less also – it relieves a lot of stress on the septic system.

Slide 91

### Drain Water Heat Exchanger



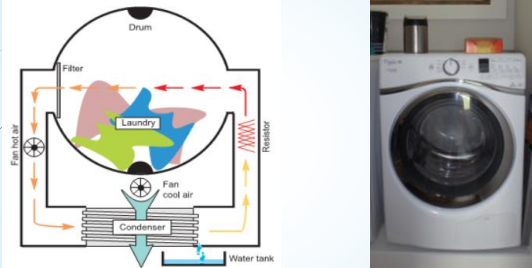
Recovery 58% drain heat

The drain water heat exchanger will recover ~50% of the drain water heat and preheat the cold tap on the shower and the cold water entering the water heater

The drain water heat exchanger is another way we can temper the water before it enters the hot water heater. It only works when you are draining and drawing at the same time (showers). But the cold water at the shower mixing valve is warmer, so you don't use as much hot water. The water entering the tank is also much warmer.

Slide 92

### Heat Pump Dryer




Basically a clothes dehumidifier. Because it is ventless there is less penetration in the house and we are capturing more heat. The convenience of 2<sup>nd</sup> floor laundry far outweighs the "extra" dry time.

This is a whirlpool model – it is a full sized model. There are starting to be more and more brands going in this direction. This is also the beginning of "Washer and Dryer Combo" units.

Slide 93

### Induction Cooktop



The induction cooktop is a very efficient way to heat things on the stove fast with similar control to gas. We can boil water faster on the stove top than in the Microwave!

So far we love the induction cooktop – we can boil water faster on the stove top than in the microwave, we have the same control and reaction time as gas and when something boils over on the stove, nothing gets crusted into the top – because it is still cool.

Slide 94

### Questions on Mechanicals?

- Ventilation system
- Air Source Heat Pumps
- Split Heat Pump Hot Water
- Hot Water Circulation
- Drain Water Heat Recovery
- Heat Pump Dryer
- Induction Cooktop

Questions?

Slide 95

### Passive House Blower Door Testing

- We conducted a blower door test at 4 different stages of the build
  - Before windows and insulation
  - After windows, insulation and rough mechanicals
  - After final mechanicals, before water heater and cable
  - Final before C of O
- Each test was done to identify "new holes" in the air barrier from the different stages

Blower door testing is vital at multiple stages of the build to help identify leaks before you can't find them anymore. 0.6 ACH50 is VERY tight.

We conducted a blower door test at 4 different stages of the build

Before windows and insulation  
After windows, insulation and rough mechanicals

After final mechanicals, before water heater and cable

Final before C of O

Each test was done to identify "new holes" in the air barrier from the different stages

Slide 96

### Blower Door Testing

Blower Door Test	CFM <sub>50</sub>	ACH <sub>50</sub> RESNET	ACH <sub>50</sub> PH	Changes to Envelope
1 <sup>st</sup>	83	0.12	0.17	Zip system only, windows not installed
2 <sup>nd</sup>	74	0.11	0.15	Windows installed (except basement windows and front door), Insulation done, rough mechanicals, Hose bibs installed
3 <sup>rd</sup>	52	0.08	0.11	All windows installed, test location changed to above wall window, New test rig built that is much more airtight.
4 <sup>th</sup>	48	0.07	0.10	Average taken of Pressurization and Depressurization test, Blower Door with D-Ring used to verify.

Blower door testing results at various stages



Slide 97

Blower Door Testing Depressurization Photos



Utilizing ring 3 from the duct blaster, and sealing the rig to the window frame with a gasket and custom bracket we got a very accurate blower door result. **49 CFM<sub>50</sub>**

This slide features three photographs. The leftmost photo shows a technician in a light blue shirt adjusting a white blower door unit on a window. The middle photo shows the same technician from a different angle, working on the window frame. The rightmost photo is a close-up of the blower door unit, which is a circular black device with a silver ring and a central fan. A digital display on the left shows the test result.

Depressurization set up.

Slide 98

Blower Door Testing Pressurization Photos



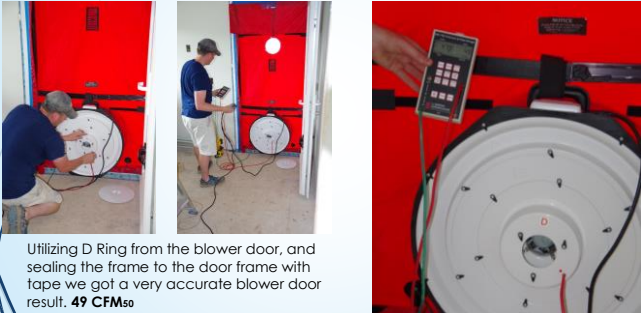
Turning the duct blaster around, using the flow stabilizer and the extra pressure hose we mimicked the Depressurization and we got a very accurate blower door result. **65 CFM<sub>50</sub>**

This slide features three photographs. The leftmost photo shows a technician in a light blue shirt working on a window frame. The middle photo shows a close-up of the blower door unit, which is a circular black device with a silver ring and a central fan. The rightmost photo shows a hand holding a digital display that reads '50.1' and '65'. The display is labeled 'DG-700 Pressure & Flow Gauge'.

You can see the outside frame has not been fastened with the screw blocks. Oddly enough getting the assembly to be installed airtight was the hardest part – and it made a measureable difference. Once we did that we got the test down to 47 CFM<sub>50</sub>

Slide 99

Blower Door Testing Depressurization Photos



Utilizing D Ring from the blower door, and sealing the frame to the door frame with tape we got a very accurate blower door result. **49 CFM<sub>50</sub>**

This slide features three photographs. The leftmost photo shows a technician in a blue shirt working on a door frame. The middle photo shows a technician in a blue shirt working on a door frame. The rightmost photo is a close-up of the blower door unit, which is a circular white device with a black ring and a central fan. A digital display on the left shows the test result.

Utilizing D Ring from the blower door, and sealing the frame to the door frame with tape we got a very accurate blower door result. **49 CFM<sub>50</sub>**

Slide 100

### Blower Door Testing Pressurization Photos



Turning the blower door around, using the extra pressure hose we mimicked the Depressurization and we got a very accurate blower door result **53 CFM<sub>50</sub>**

Turning the blower door around, using the extra pressure hose we got almost the same result as the Depressurization test. **53 CFM<sub>50</sub>**

Slide 101

### Blower Door Testing

- Why the difference between the blower door and duct blaster?
  - The blower door Pressurization test was done inside the breezeway
    - very protected from the wind pressures
  - Seals between the assemblies were different
  - Weep holes from the window frame were not sealed
    - We identified this after the test was over

Why the difference between the blower door and duct blaster?

The blower door Pressurization test was done inside the breezeway which is very protected from the wind pressures  
Seals between the assemblies were different  
Weep holes from the window frame were not sealed  
We identified this after the test was over

Slide 102

### Blower Door Testing

- Why the difference between the pressurization and depressurization test?
  - When the house is pressurized the force on window gaskets are different.
  - Seals between the assemblies were different
    - clean frame inside, dirty outside

Why the difference between the pressurization and depressurization test?


When the house is pressurized the force on window gaskets are different.  
Seals between the assemblies were different clean frame inside, dirty outside

Slide 103

### Blower Door Testing

- Concern with Air Admittance Valves for the Pressurization test

We pressurized the house to 90 Pa and there was no large difference in test result.  
**53 CFM<sub>50</sub> to 60 CFM<sub>50</sub>**



The use of Air Admittance Valves was used in many of the plumbing drains – to minimize plumbing penetrations. They work on opening when a sufficient pressure difference occurs allowing the water to fall and be followed by air. The pressurization test creates a similar situation, but the values didn't open enough to make a difference.

Slide 104

### Review

- Rochester Passive House was built affordably
  - \$123-\$163 per sqft
  - KEEP IT SIMPLE
- Air Barrier / Super Insulation Constructed
- Passive House components
  - Windows
  - Ventilation
  - Mechanicals
- Blower Door Testing

Rochester Passive House was built affordably  
\$123-\$163 per sqft  
KEEP IT SIMPLE  
Air Barrier / Super Insulation Constructed  
Passive House components  
Windows  
Ventilation  
Mechanicals  
Blower Door Testing

Slide 105

### Rochester Passive House

#### Questions?

Matt Bowers  
RPH Consulting LLC.  
RochesterPassiveHouse@gmail.com

# Questions?

Matt Bowers  
RPH Consulting LLC  
RochesterPassiveHouse@gmail.com