Image Credit: Stacie Renne/Leah Karmaker for Green New Deal Housing

Zero Net Energy For the Rest of Us

24 February 2021
Energy Design Conference

Rachel Wagner
through design LLC

Zero Net Energy For the Rest of Us

1. Defining Zero Net Energy
2. An approach to standardization
3. Design Methodology
4. Materials and Assemblies
5. Details and Documentation
6. From Theory into Practice

A building is Zero Net Energy when the total amount of energy consumed in a year is less than or equal to the total amount of energy generated by renewables on-site during that year.

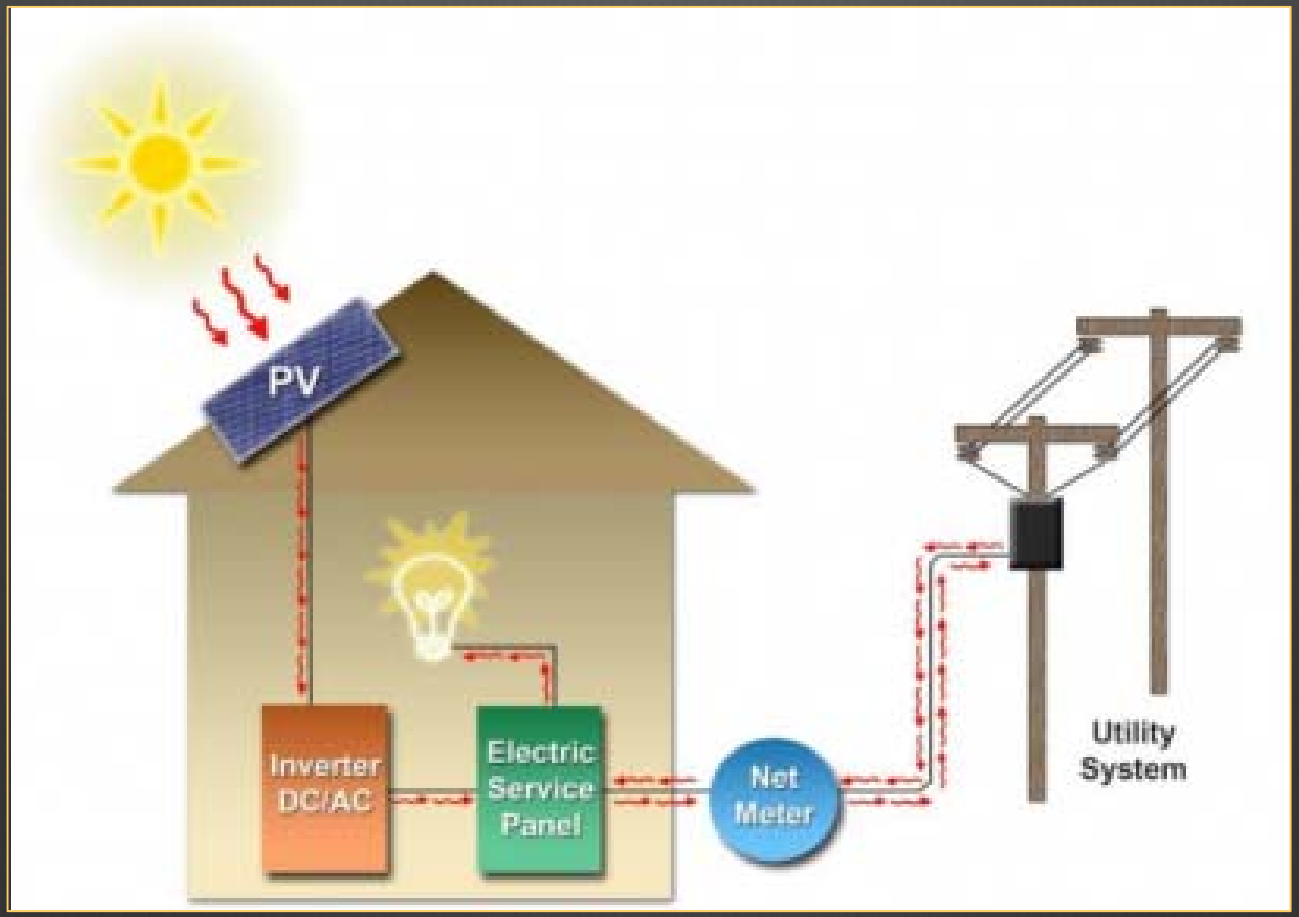
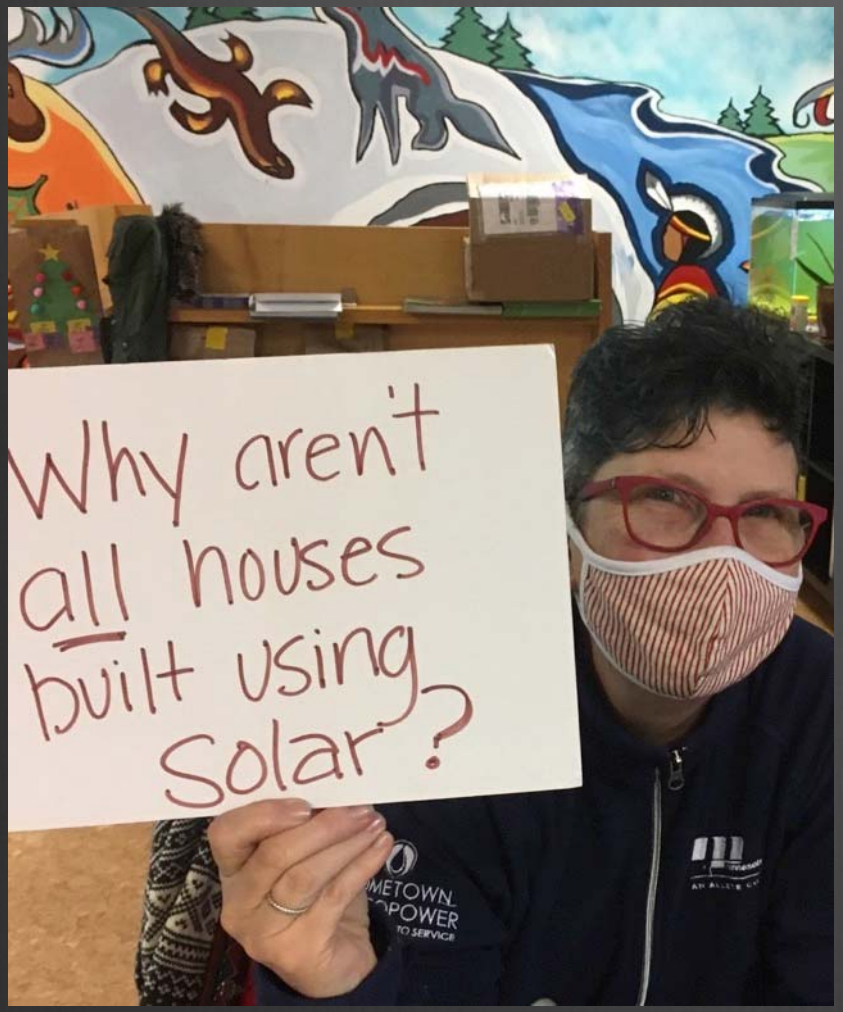


Image courtesy Harper, harperlimbach.com

Zero Net Energy in a Cold Climate

- It Works, with …
- Passive solar design
- Super insulation, often 2X code requirements
- Efficient, cold climate-appropriate mechanicals.
- PV system size balanced with superior building and systems design.
- Consideration of snow

Customized vs Standardized



Standardizing Zero Net Energy (Here)

GOALS

- ✓ Cost-effective
- ✓ Understandable
- ✓ Durable
- ✓ Available
- ✓ Reliable
- ✓ Repeatable

HURDLES

- Initial First Costs
- No “one size fits all”
- Standardized but Adjustable
- Continuous Insulation
- Reproducible details
- Accounting for the compass

What can be standardized and how?

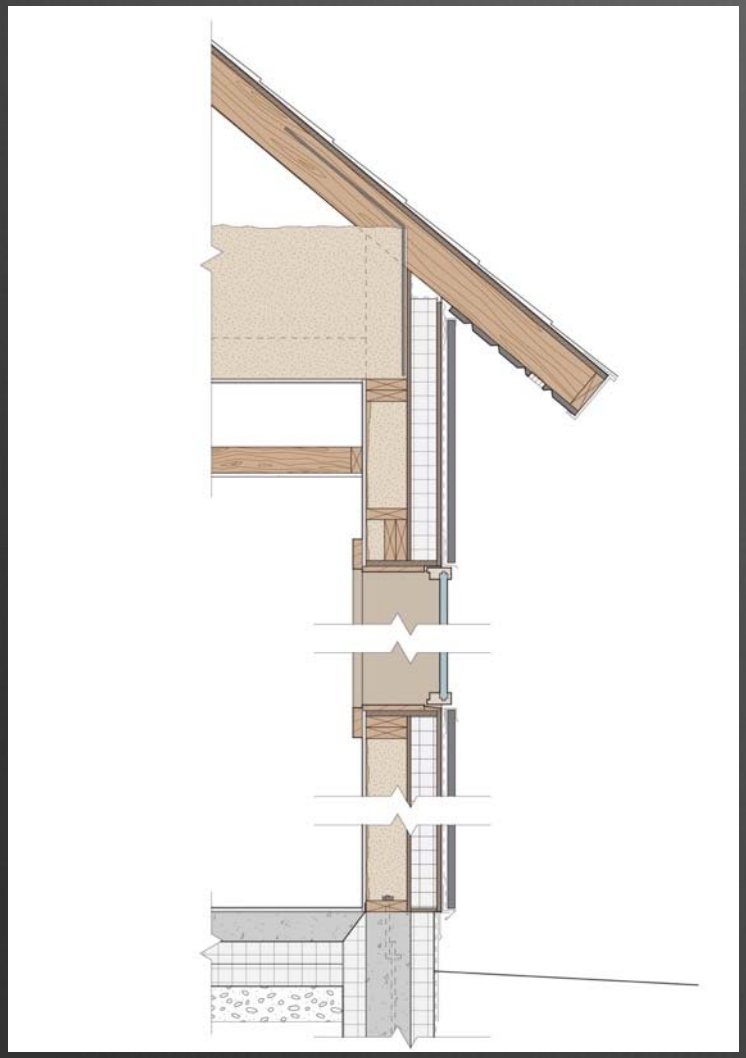


Image Credit Rachel Wagner and Leah Karmaker for Green New Deal Housing

- Foundation details
- Wall assemblies
- Window details
- Roof assemblies
- Porch details
- Air sealing details
- HVAC systems
- House designs?

An Approach to Standardization

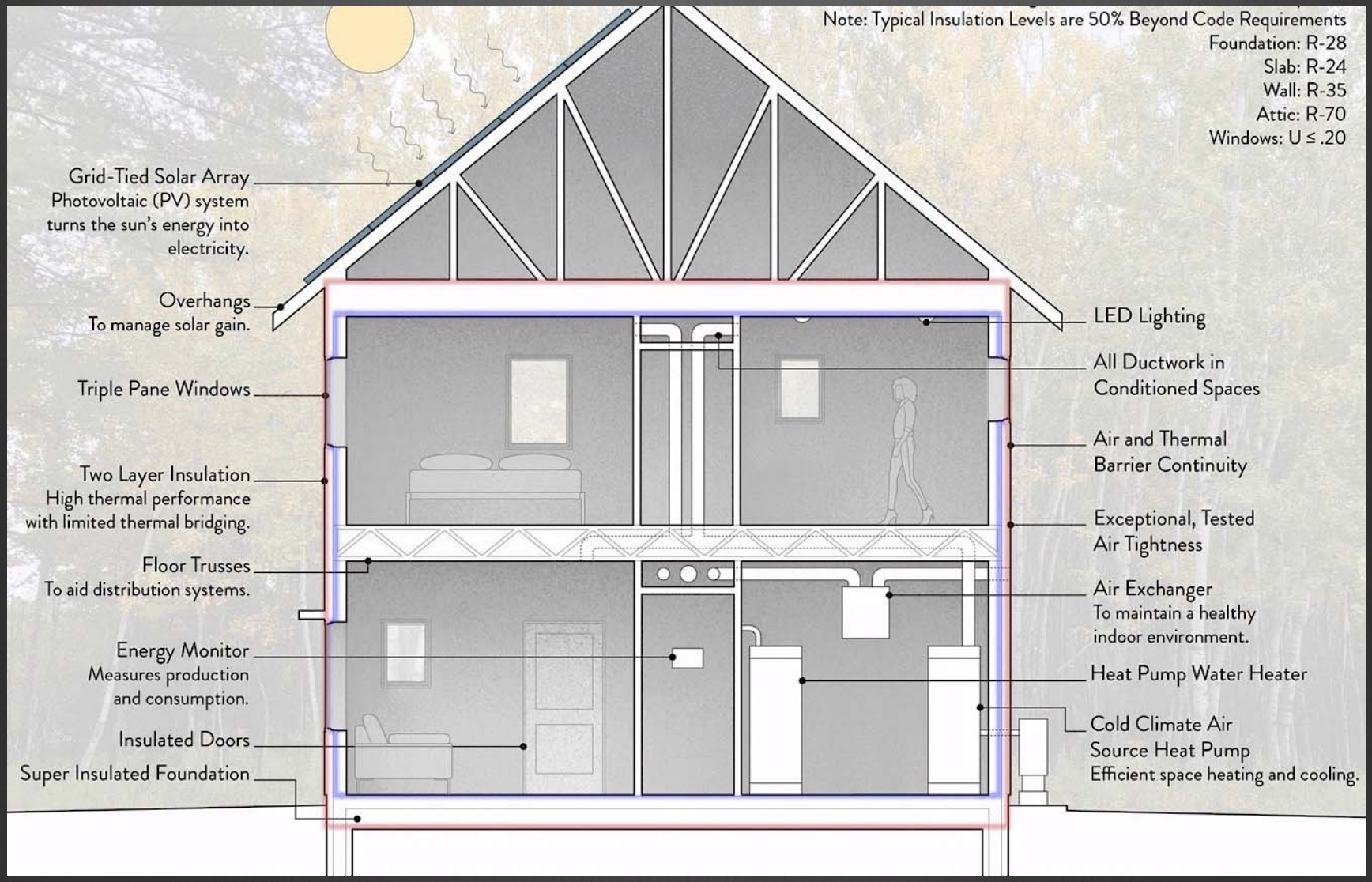
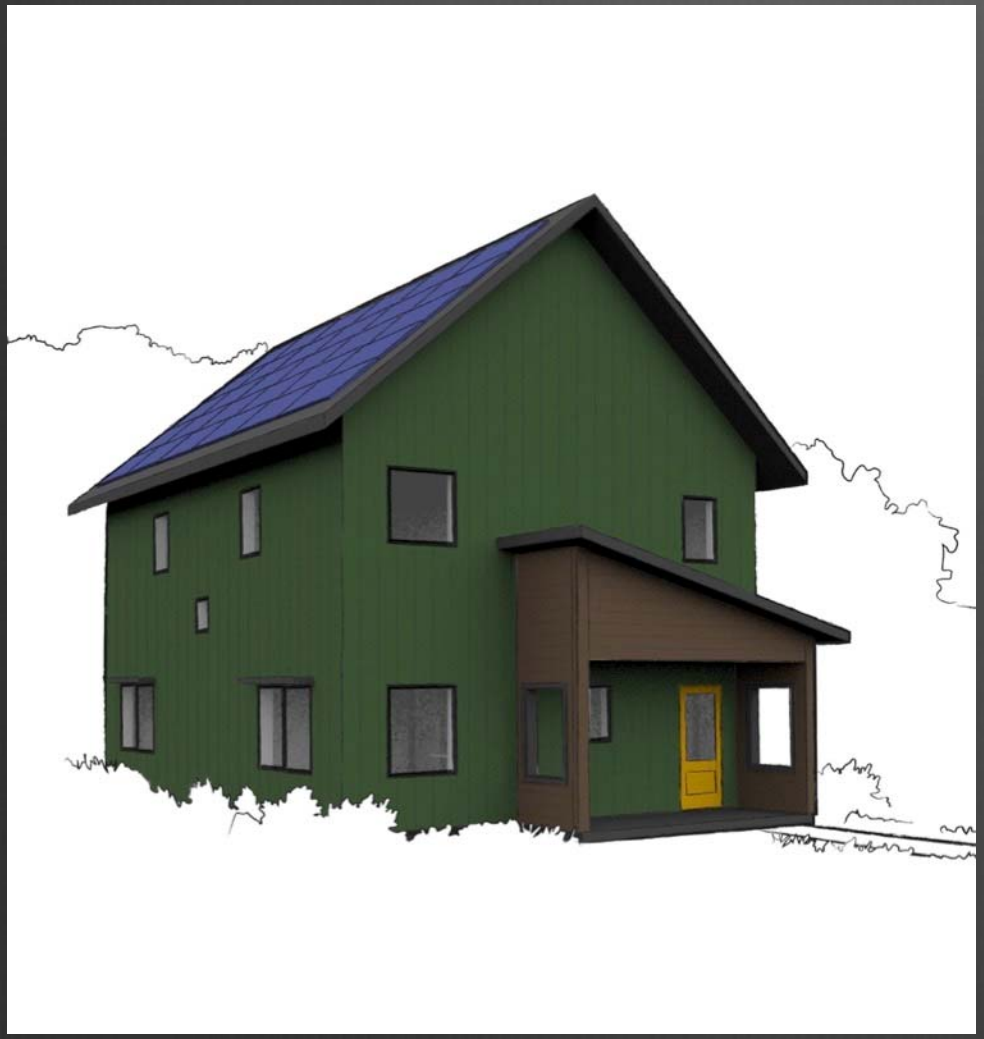


Image Credit Rachel Wagner and Leah Karmaker for Green New Deal Housing

Design Methodology:
Utilizing Best Practice + Familiarity
(and KISS)

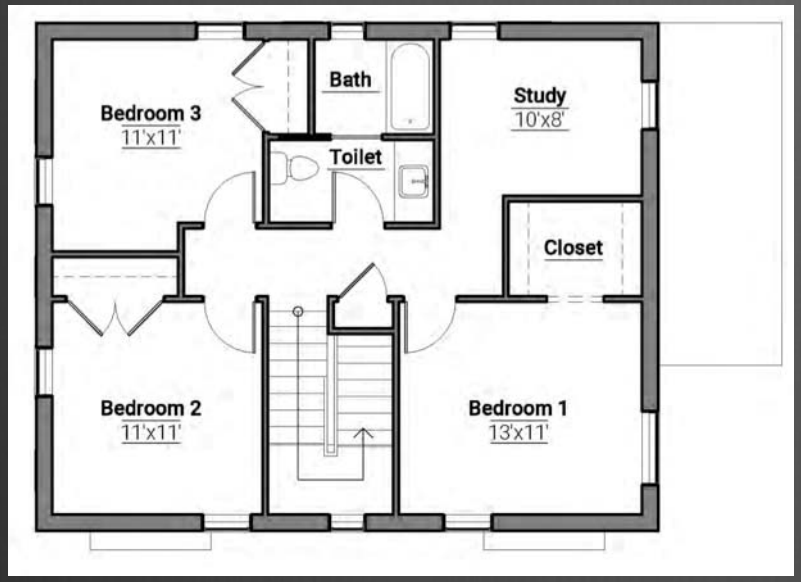
1. Building Form
2. Construction Methods
3. Energy Modeling
4. Mechanical Systems

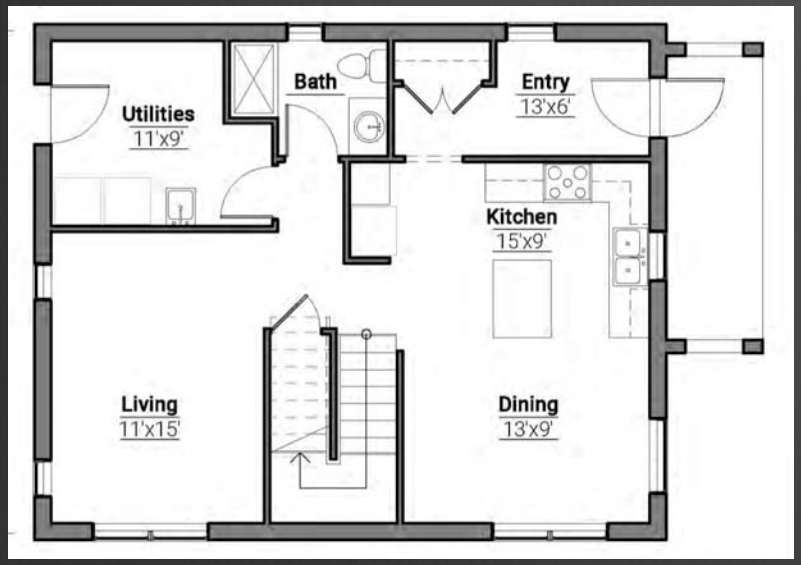
Building Form: KISS = Keep It Simple & Stacked



- Stacked stories above grade and/or below (and stacked bathrooms)
  - No cantilevers
  - No bays
- Simple rooflines
- Porches for protected outdoor space
- Avoid attached garages
- Also: Keep It Small

Rectangles are Good





- Simple (cost-effective)
- Inherently efficient
- Material friendly
- Functional
- Can be elegantly proportioned
- Work well with gable or shed roof forms

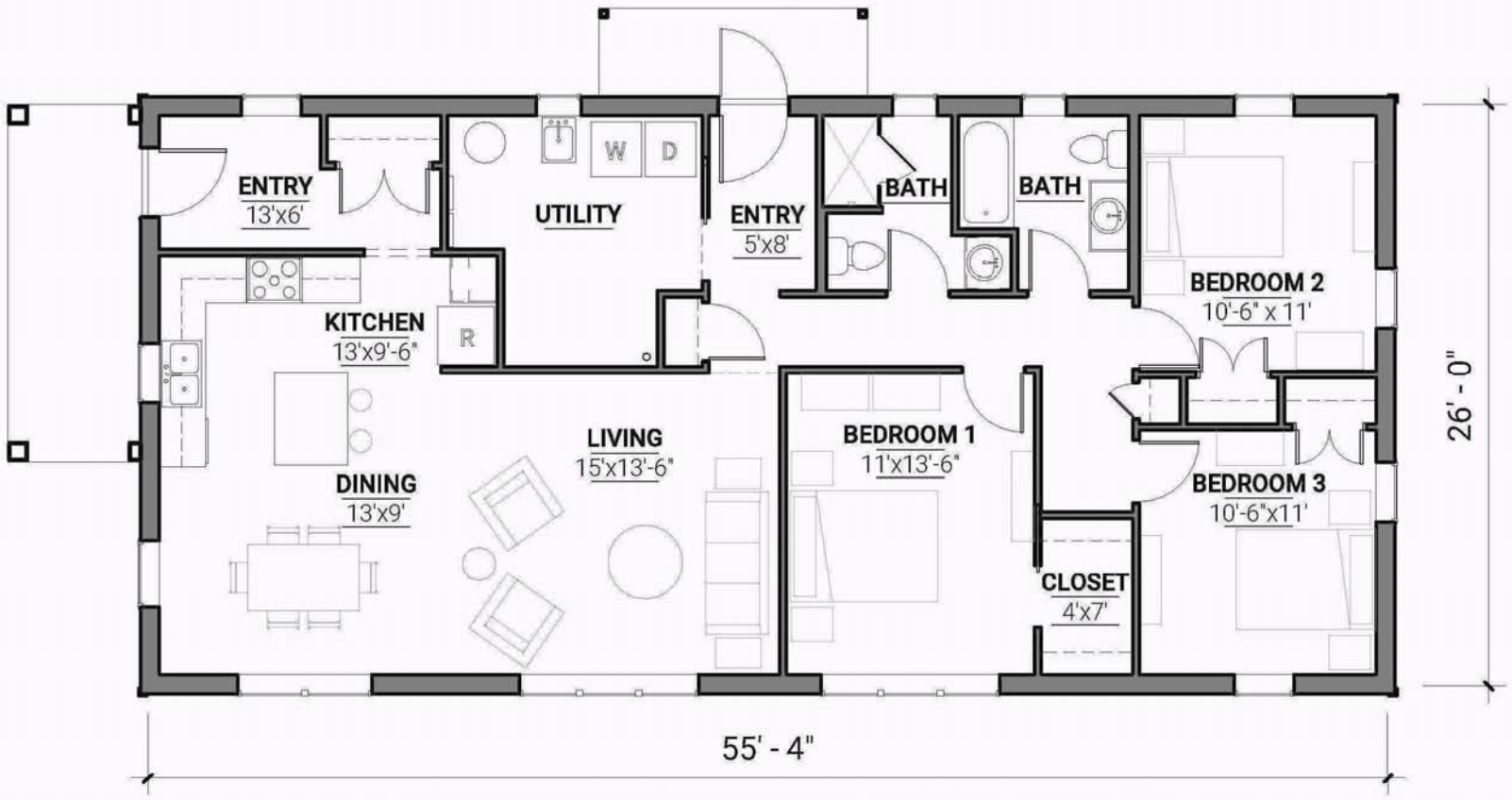
Solar Optimization:
KISS = Keep It Simple & Southern

PV array placed on (closest to) south-facing roof

More windows south/fewer windows north

South overhangs sized to block summer sun and let winter sun in

Solar Optimized Space Plan



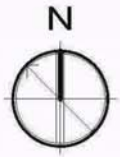
First Floor Plan

1494 square feet

Addressing the hurdle of the compass:

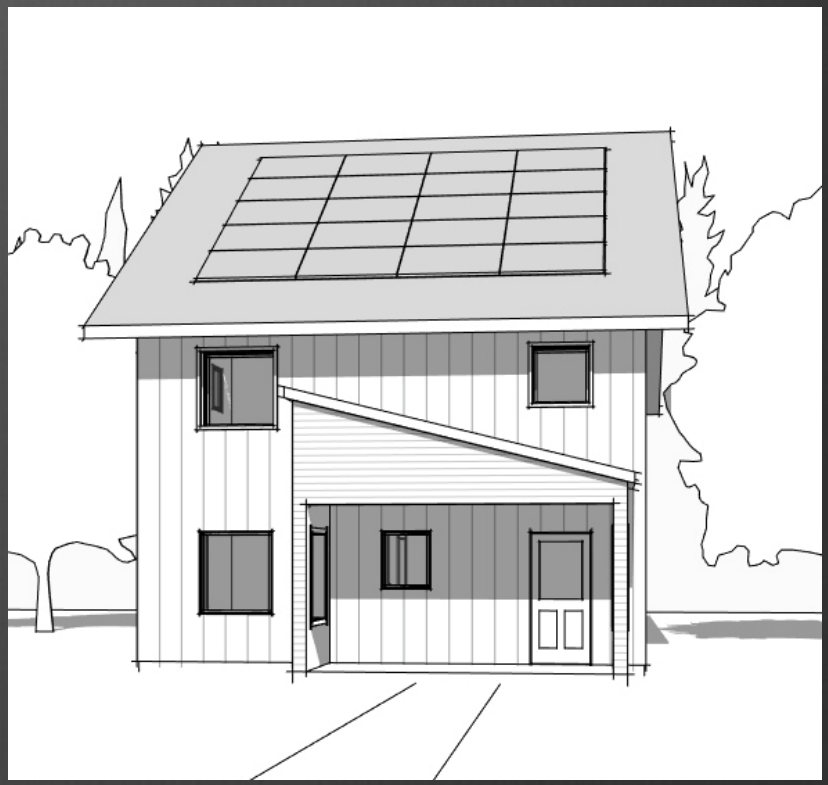
Plan south needs to be site south, or close to it.

This plan can be flipped east-west.



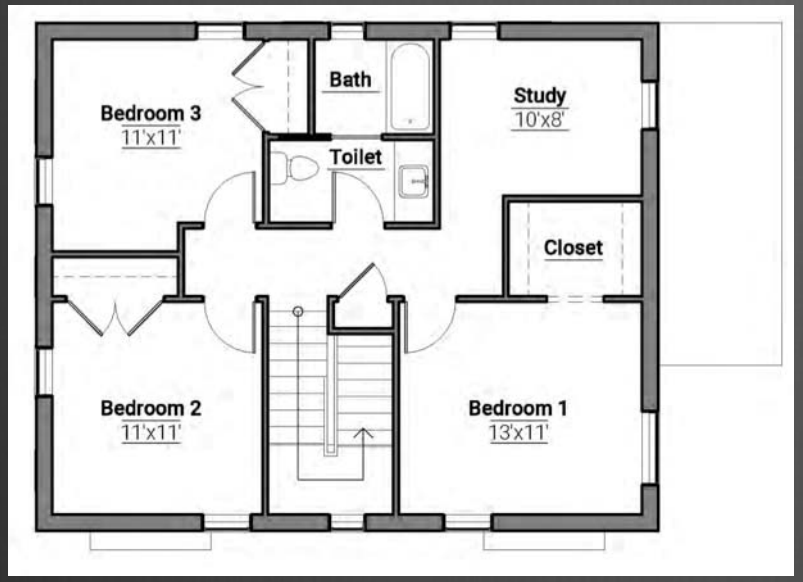
Addressing the hurdle of the compass: Same Plan, Different Roof Orientation

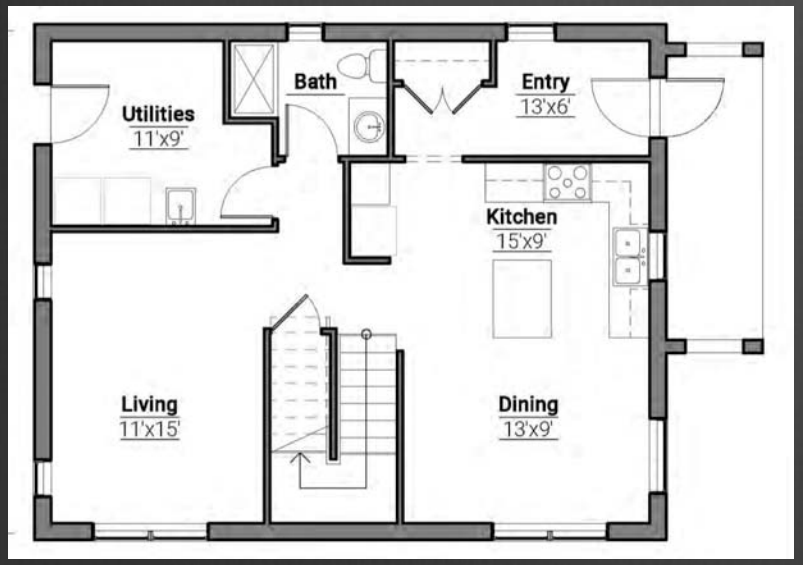
East-Facing Entrance



South-Facing Entrance

One Design, Two Options





Construction Methods:
KISS = Keep It Simple and Strong*

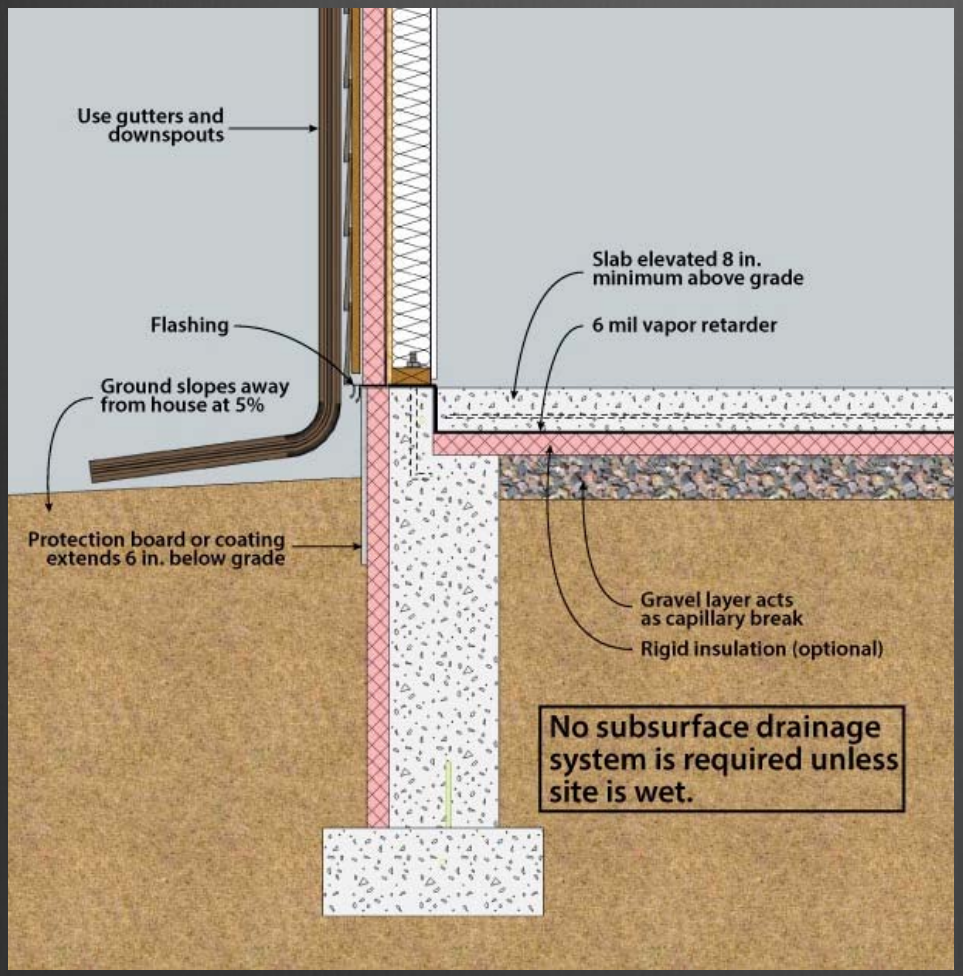


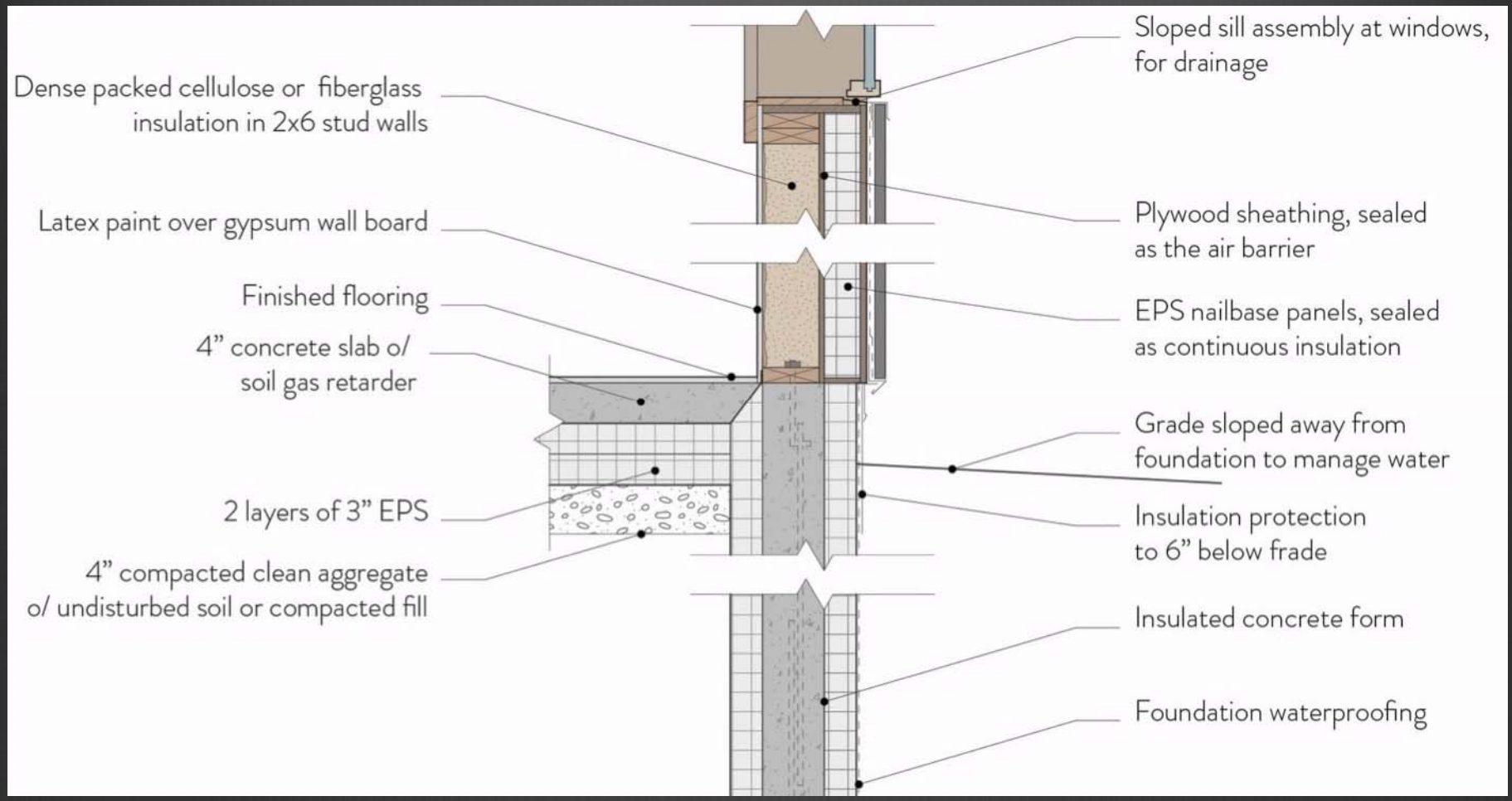
Image from Oak Ridge National Lab guide to foundations

* Strong = Robust + Durable

A simple starting place:

- Foundation that can be readily adapted to a basement
- Insulated slab
- Single stud framed wall

Familiar Foundation w/increased insulation
2 x 6 framed wall plus continuous insulation

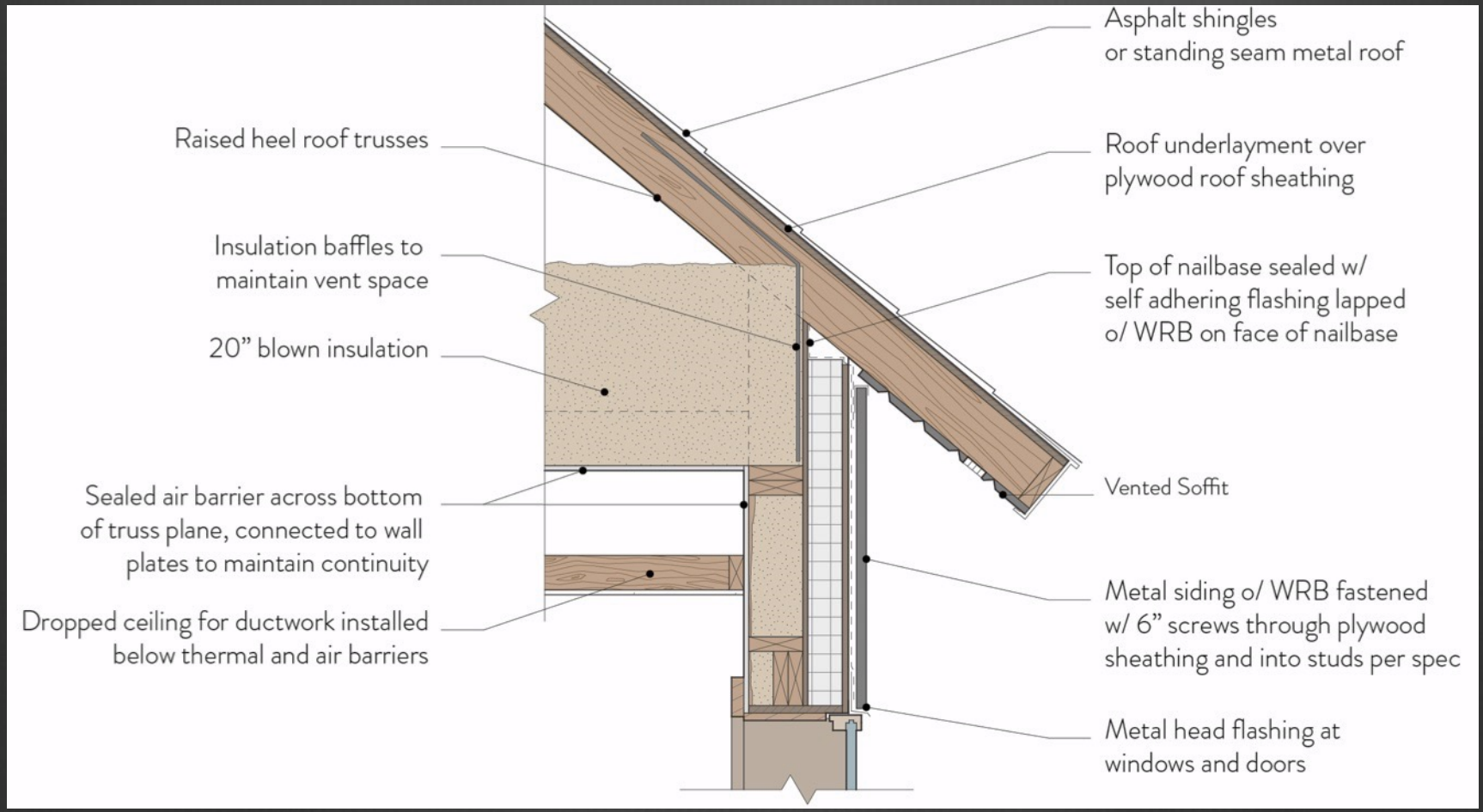


The continuous insulation conundrum

Climate Zone	IRC Interior Vapor Retarder Requirements [A]
Cold	Class I or Class II required; Class III permitted with:
Marine 4	Vented cladding (over wood structural panels, fiberboard, or gypsum) or continuous insulation (≥ R-2.5 over 2x4 wall or ≥ R-3.75 over 2x6 wall)
5	Vented cladding (over wood structural panels, fiberboard, or gypsum) or continuous insulation (≥ R-5 over 2x4 wall or ≥ R-7.5 over 2x6 wall)
6	Vented cladding (over fiberboard or gypsum) or continuous insulation (≥ R-7.5 over 2x4 wall or ≥ R-11.25 over 2x6 wall)
7 and 8	Continuous insulation (≥ R-10 over 2x4 wall or ≥ R-15 over 2x6 wall)

Goals:
1. a robust assembly that can dry in both directions
2. a continuous insulation system with the fewest steps in assembly
3. a method easily adjusted for cold climate zones 6 and 7

Familiar, Robust + Cost-Effective Attic



Energy Modeling: KISS = Keep It Simple and Systemic

MARC'S BUILDING LOAD COEFFICIENT CALCULATOR

Input cells are yellow | Mouse over cells with a red mark in the upper right hand corner to read inserted comments

		Design Temperature Difference,	90	Building Area, ft2	1494.00
R VALUES, ft2-hr-°F / BTU					
Wall R Value	34.11	Flat Ceiling R Value	72.93	Slab on grade R Value	26.40
Floor over outdoors R Value		Skylight R Value		Foundation(heated) R Value	
Window R Value	5.30	Opaque Door R Value	10.00		
Sloped Ceiling R Value		Glass Door R Value	7.00		

ELEMENT	AREA, ft2	UA, BTU / hr-°F
Walls	1245	36
Floor over outdoors		0
Windows	205	39
Sloped Ceiling		0
Skylight		0
Flat Ceiling	1494	20
Opaque Door	0	0
Glass Door	38	5
Slab on grade	163	22
Foundation Wall (heated space)		0
Foundation wall height		
Slab area	1439	
Shell area	4421	
CFM50/ssf	0.05	
Infiltration		14
Ventilation effectiveness	0.70	
Ventilation, CFM	80	26

ELEMENT	AREA, ft2	UA, BTU / hr-°F
Walls	1245	36
Floor over outdoors	0	0
Windows	205	39
Sloped Ceiling	0	0
Skylight	0	0
Flat Ceiling	1494	20
Opaque Door	0	0
Glass Door	38	5
	PERIMETER	
Slab on grade	163	22
Foundation Wall (heated space)	0	0
Foundation Wall height	0	
Slab area	1439	
Shell area	4421	
CFM50/ssf	0.05	
Infiltration		48
Ventilation effectiveness	0.70	
Ventilation, CFM	80.00	26
Total UA - Building load coefficient		196
Heat loss, BTU/hr		*17,672*

Energy Modeling helped set the specifics:

Element	MN Energy Code (zone 7)	Zero-net energy
Basement Walls	R-15 (sometimes R-10)	R-28
Slab Insulation	R-10	R-24
Slab Edge	R-10 (R-15 if heated)	R-14
Framed wall: cavity	R-21 (whole wall ~R-17)	R-21 (whole wall ~R-34)
Framed wall: continuous	None required	R-15
Windows	U 0.32 (R-3.1)	U 0.20 (R-5)
Attic	R-49	R-70
Air Tightness	3 ACH50	1 ACH50

Two models:

Identical Inputs

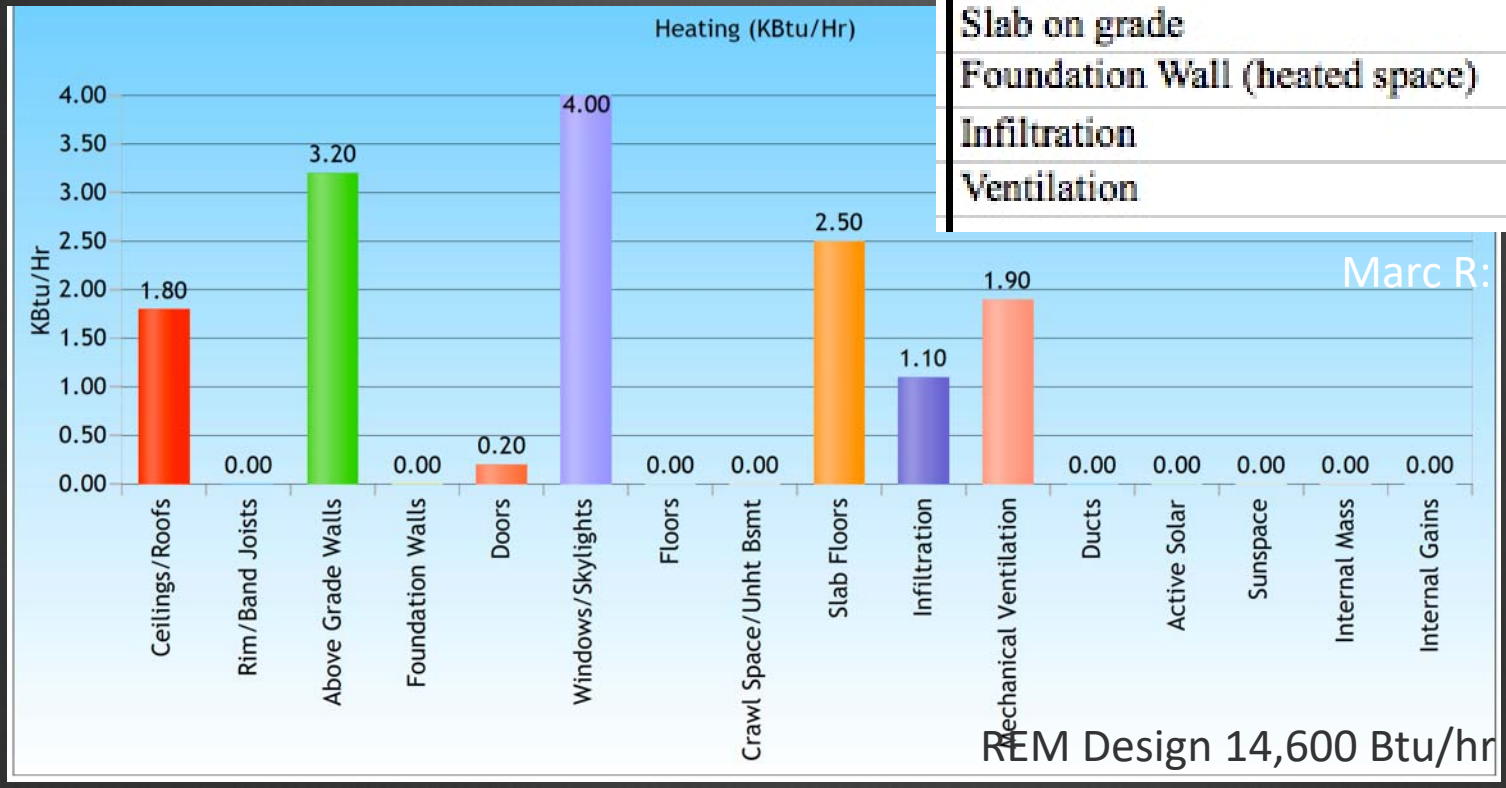
Very similar results for heating and cooling loads.

EXCEPT

with regard to air tightness.

	Heat loss, BTU/hr
Walls	3,285
Floor over outdoors	-
Windows	3,481
Sloped Ceiling	-
Flat Ceiling	1,844
Skylight	-
Opaque Door	-
Glass Door	489
Slab on grade	1,943
Foundation Wall (heated space)	-
Infiltration	4,297
Ventilation	2,333

Marc R: 17,672 Btu/hr



REM Design 14,600 Btu/hr

Predicting actual energy production or consumption?

Annual	4.46	9,169

Location and Station Identification

Requested Location	108 E 11th St. Duluth MN	
Weather Data Source	Lat, Lon: 46.81, -92.1	1.1 mi
Latitude	46.81° N	
Longitude	92.1° W	

PV System Specifications *(Residential)*

DC System Size	8 kW
Module Type	Premium
Array Type	Fixed (roof mount)
Array Tilt	39.8°
Array Azimuth	220°

ANNUAL ENERGY USAGE AND PV ARRAY SIZING

Heating COP	2.40
Monthly electrical usage applied to heat offset	300
Monthly electrical usage not applied to heat offset	150
PV Annual Production, kWh/kW	9,186

End Use	kWh/year
Heating	1,967
DHW	1,671
HPWH load	304
Electricity	5,400
Cooling	149
Total	***9,492***

Solar Electric System Size, kW	***7.8***

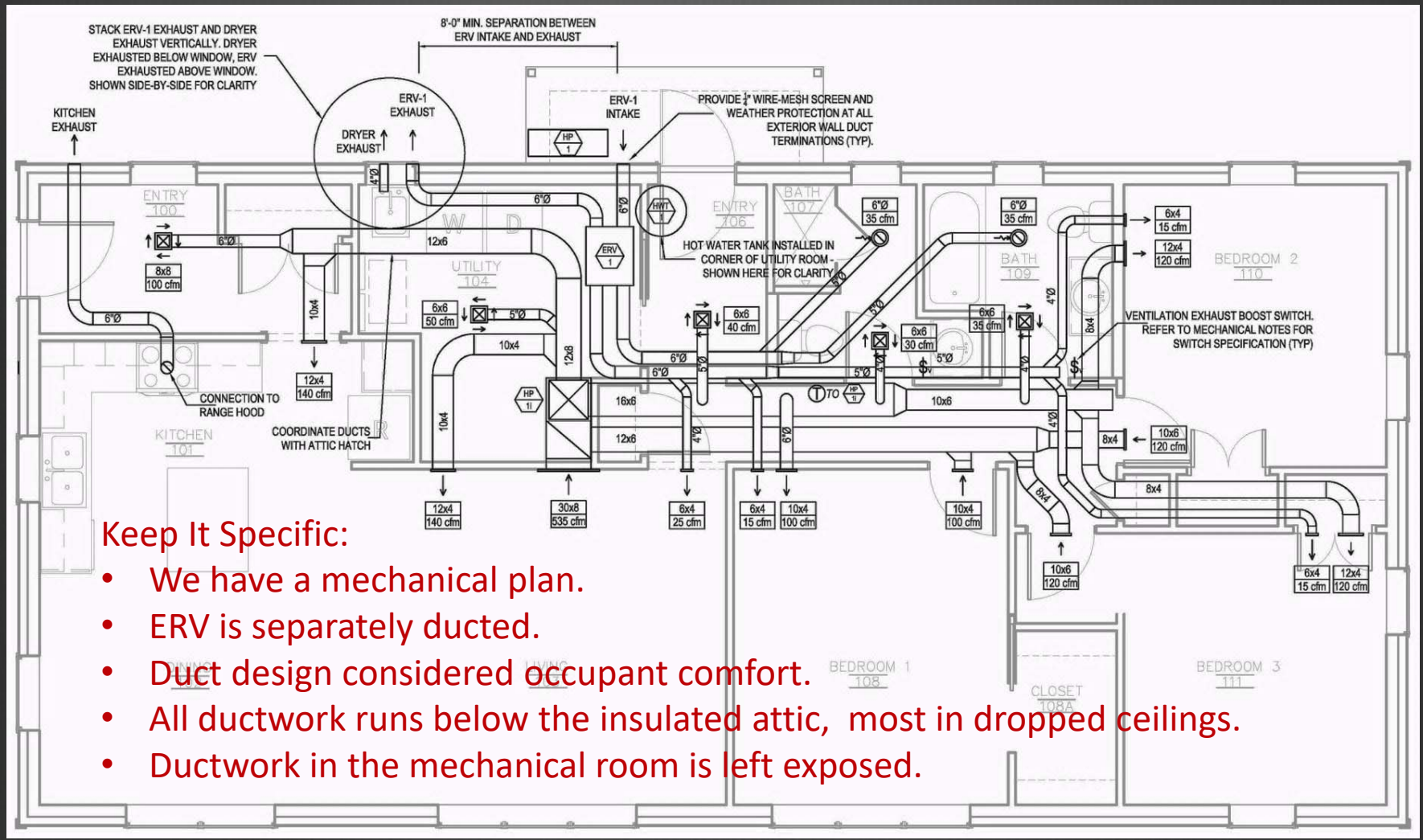
Mechanical Systems Approach:
KISS = Keep It Simple and Supportive

1. All-Electric Home supports net-zero goal.
2. Appliances and Equipment will be replaced more often than building enclosure.
   - Create an enclosure that supports this.
3. Dropped ceilings and/or chases support distribution, installation, and change.
4. Make it easy to operate for the occupants.

Standards for the Mechanical Design

1. Energy calculations used to size systems
   - Should be redone for each new location
2. Grid-tied PV array sized according to the energy calculations & site assessment
3. A mechanical plan w/equip & duct layouts
4. Electrical plan w/thoughtful lighting layout

Mechanical Distribution – things to notice



Keep It Specific:

- We have a mechanical plan.
- ERV is separately ducted.
- Duct design considered occupant comfort.
- All ductwork runs below the insulated attic, most in dropped ceilings.
- Ductwork in the mechanical room is left exposed.

Image and content credit: Zero Energy Design

Some Mechanical Selections

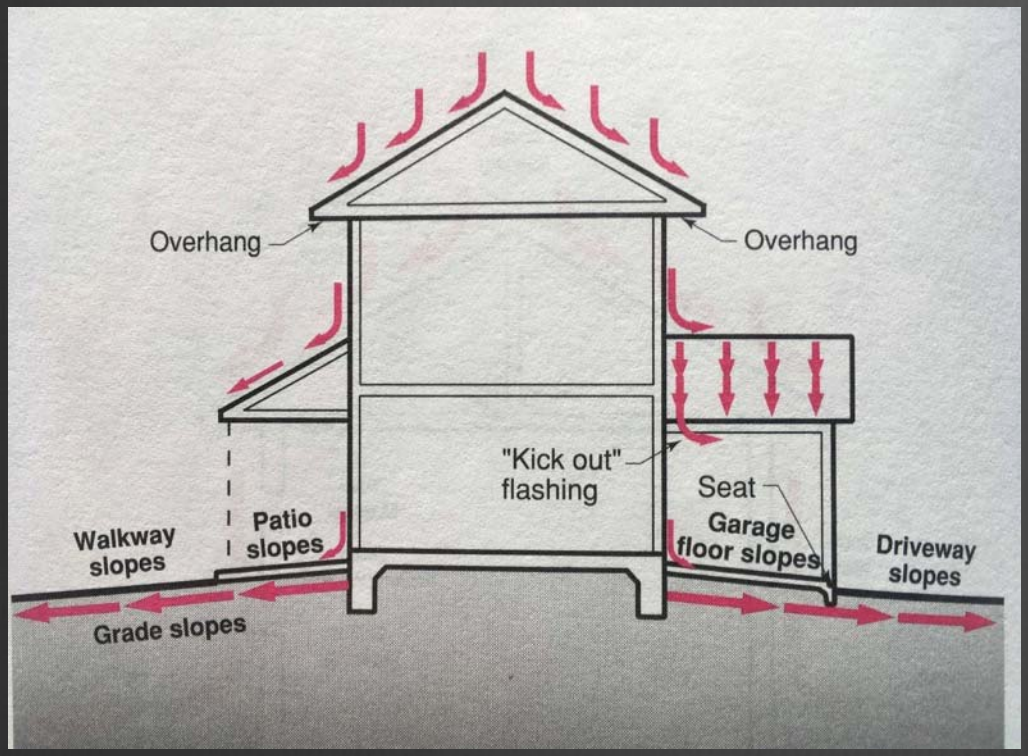
1. Air Source Heat Pump (ASHP)
   - integral back-up heat within the ductwork
2. ERV – 2 exhaust (bathrooms), 4 fresh
3. Induction range with exhaust hood = better IEQ
4. Heat Pump Water Heater
5. Energy monitor
6. LED lighting pretty much everywhere

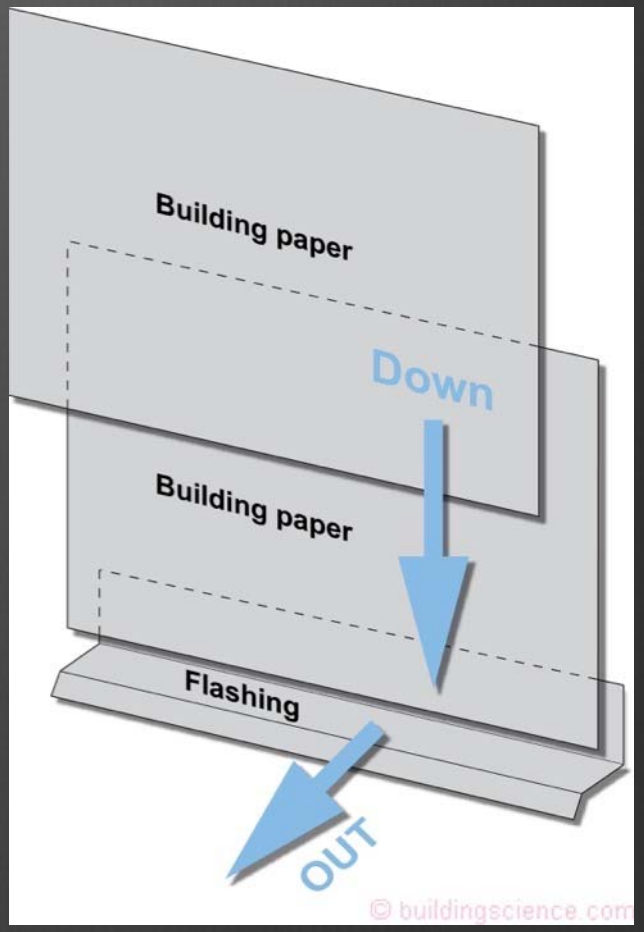
Materials and Assemblies: What and Why

1. Water Management
2. Insulated Foundation
3. 2 x 6 exterior walls + nailbase panel continuous insulation
4. Triple pane windows
5. The Air Barrier Assembly

Water Management

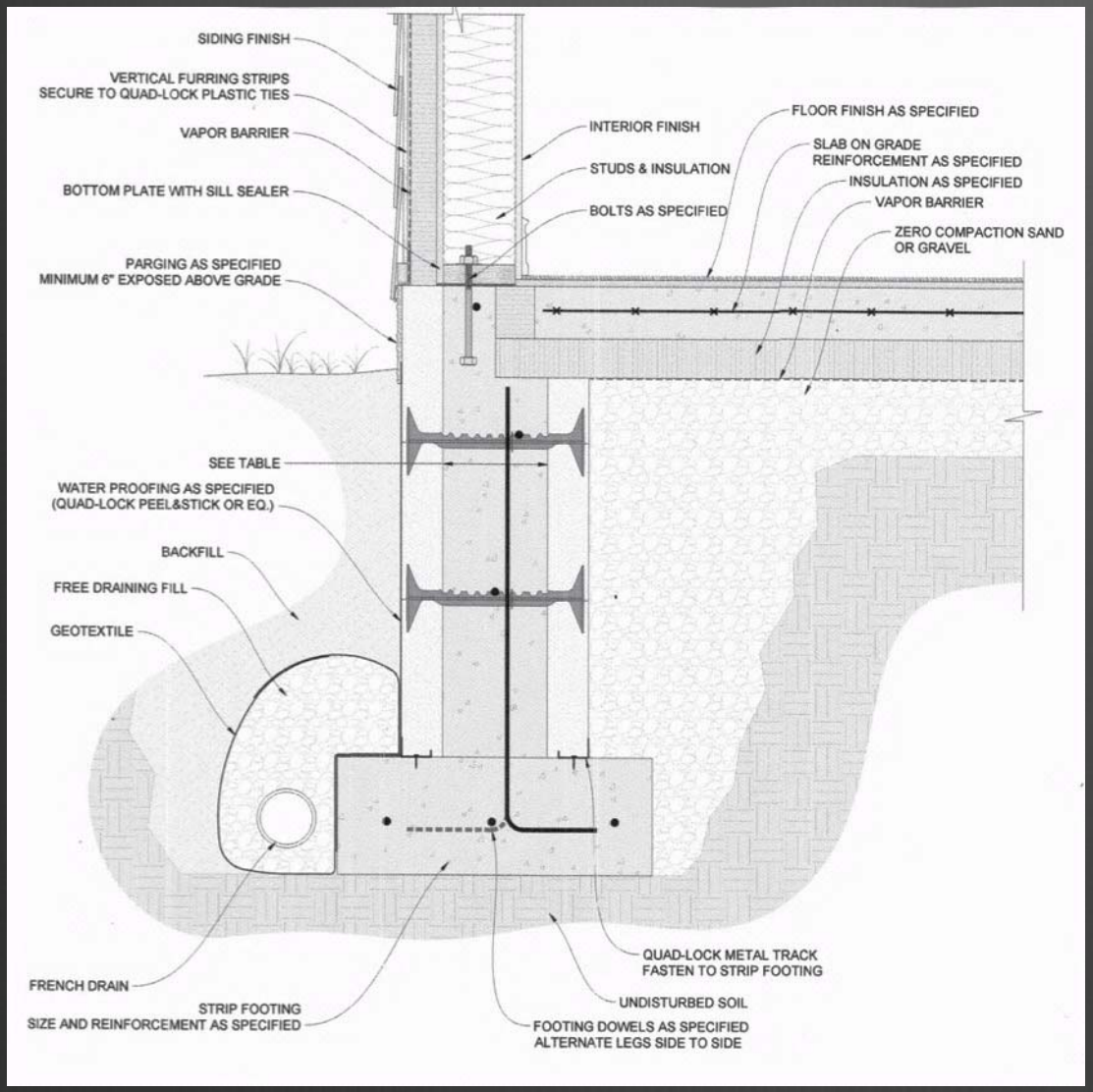
For durability, this is first.
Everything else is second.
Thank you Building Science Corporation.





buildingscience.com

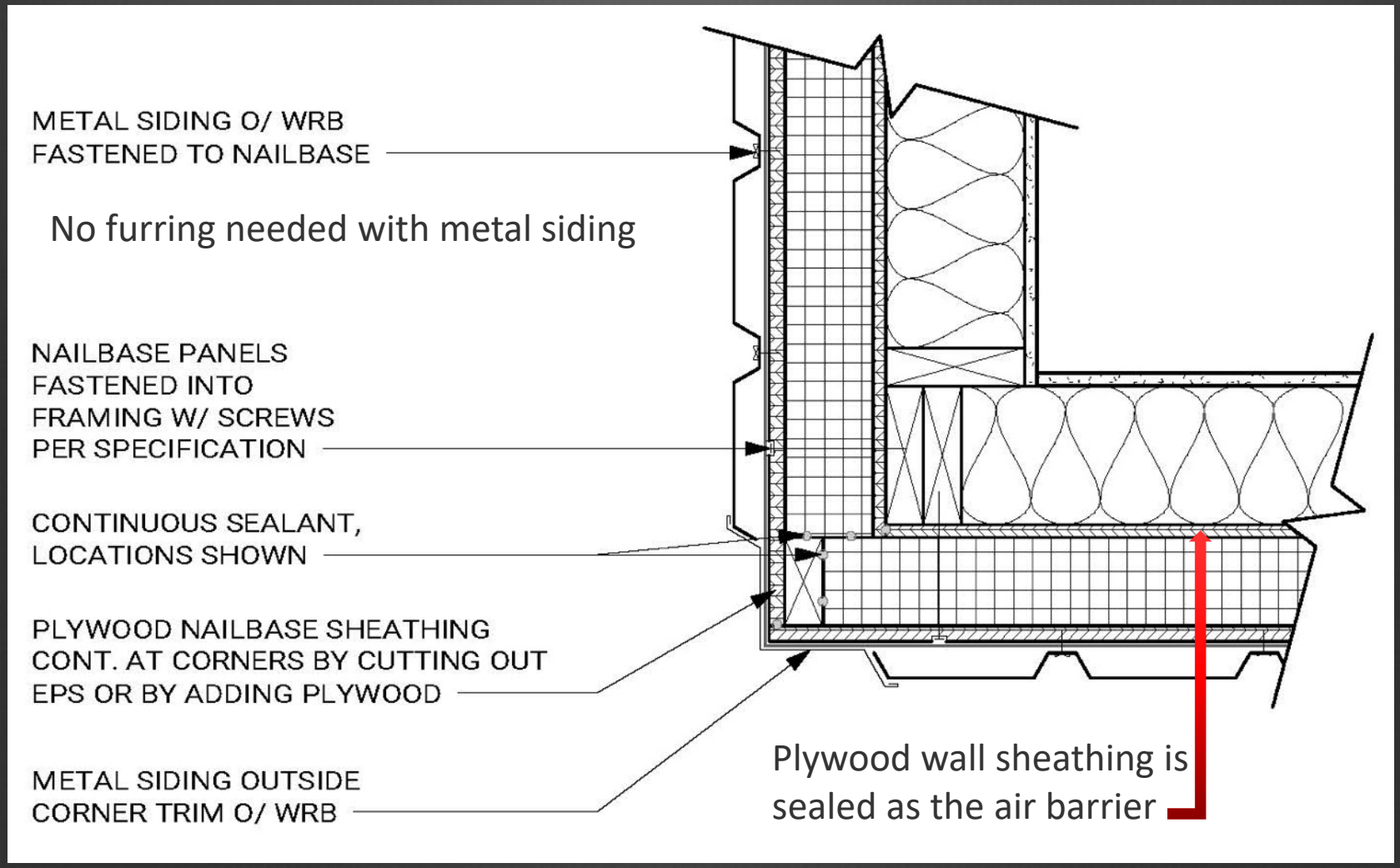
Insulated Foundation



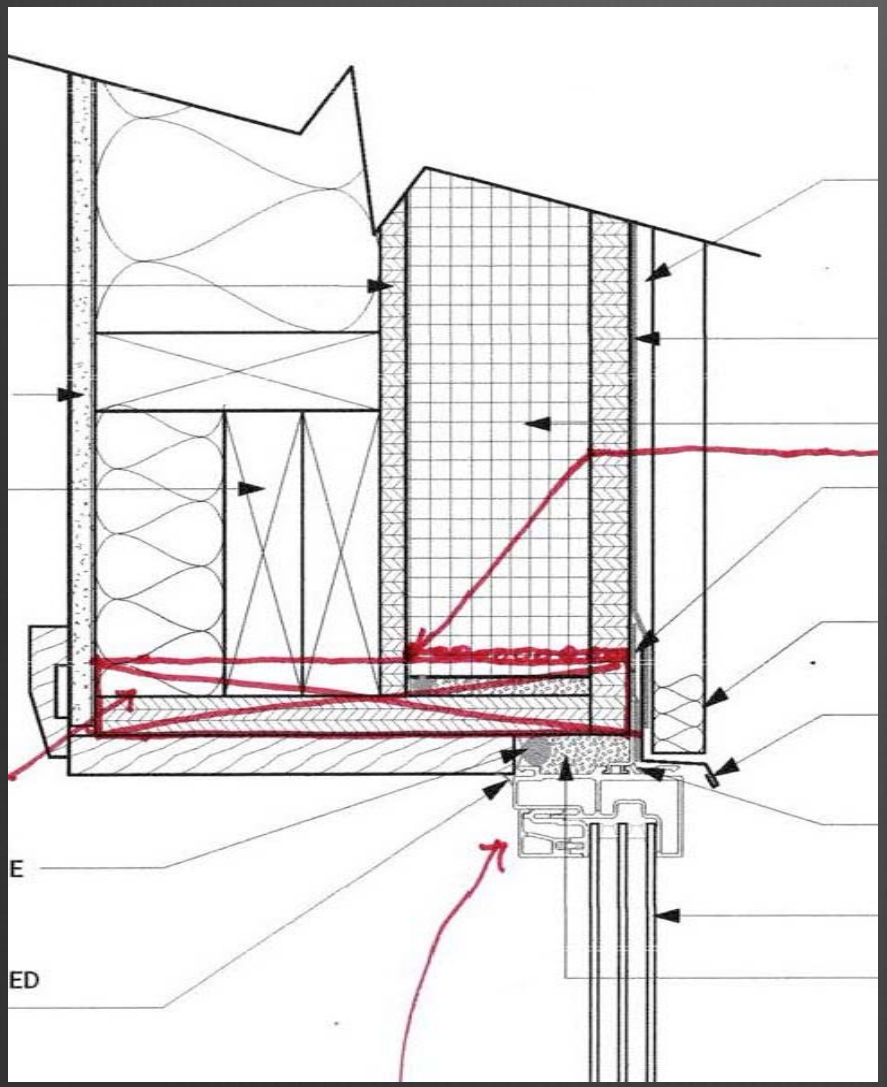
Image/detail credit: Quad-Lock Building Systems

- ICF heights and core thicknesses can readily be adjusted to specific site or climate conditions
- Easy to adjust details from slab on grade to full basement
- Many standard products now with at least R-14 to the outside
- ICF not required, but easily standardized

2 x 6 wall + nailbase panel

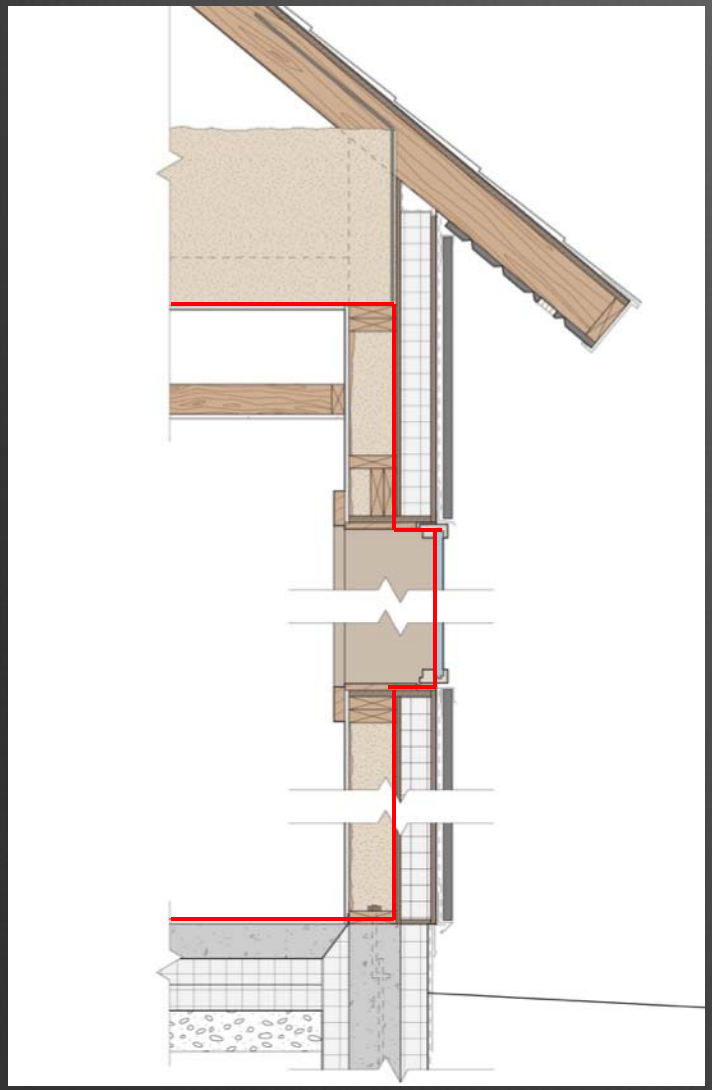


Windows



- Nail fin is familiar
- Fiberglass is durable
- Tripane essential
- Fastening to the exterior allows known robust flashing and WRB details
- The biggest difference is the use of a tripane

The Air Barrier Assembly



Ceiling membrane connected to framing

Window frames connected to bucks

Door frames connected to bucks

Window and door bucks connected to sheathing

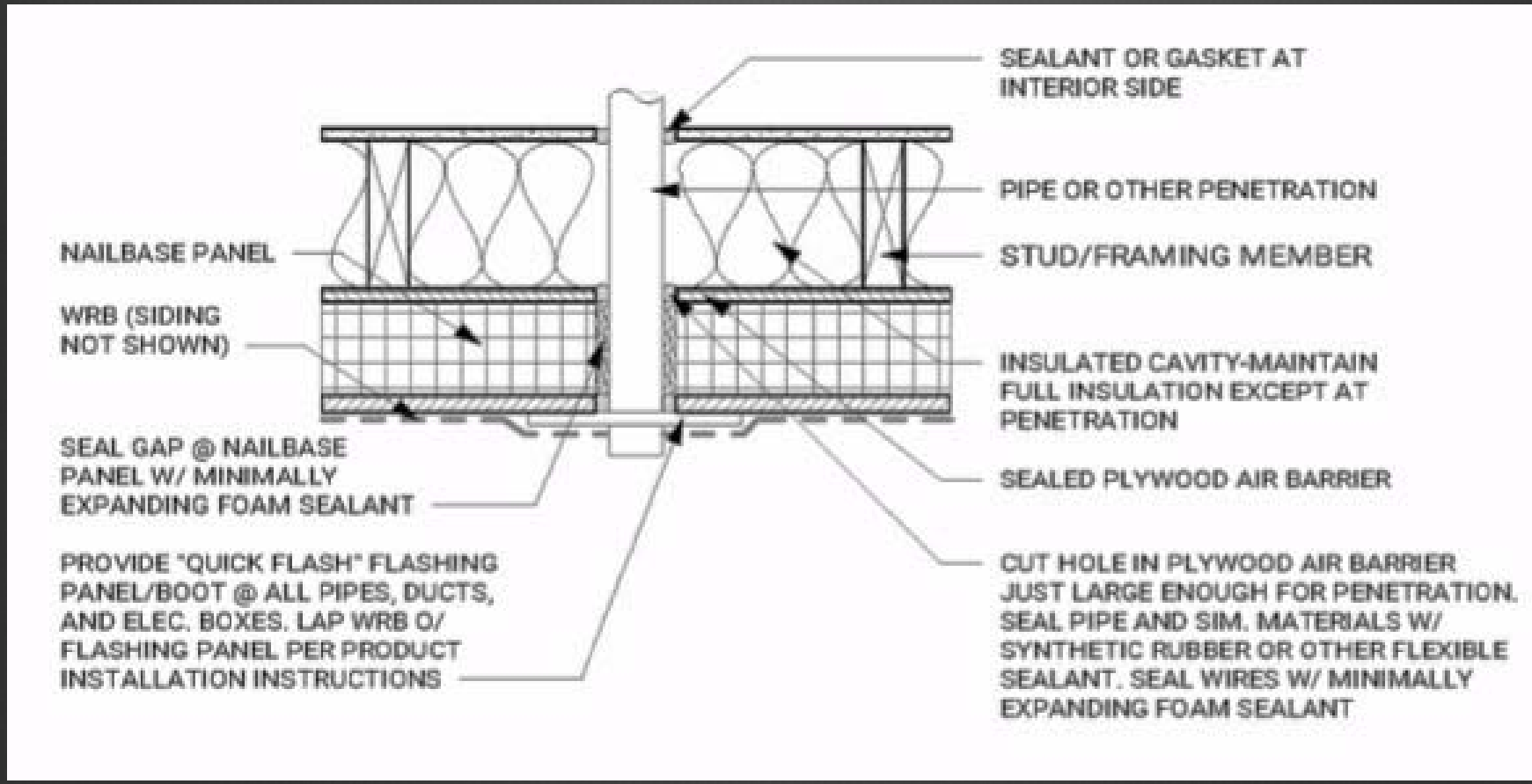
Plywood wall sheathing connected to slab and framing

Concrete slab

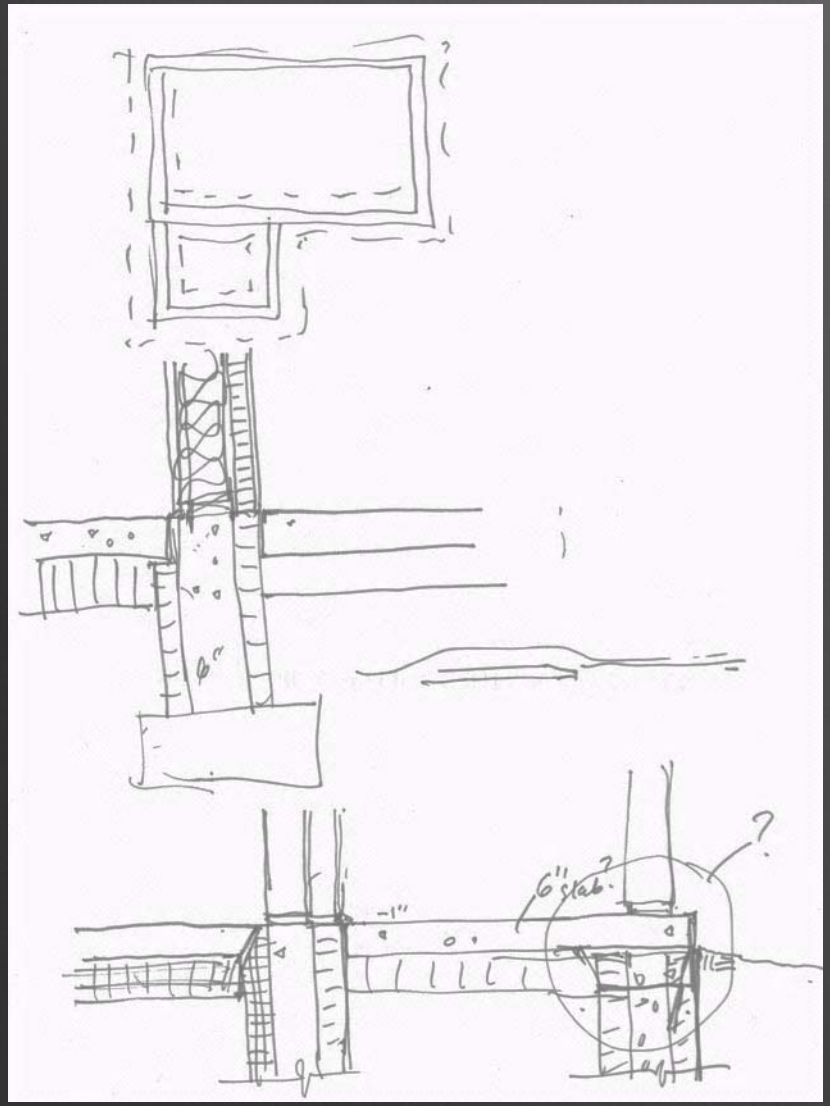
Well, your toe bone connected to your foot bone
Your foot bone connected to your heel bone
Your heel bone connected to your ankle bone
Your ankle bone connected to your leg bone

- From “Dry Bones” by the Delta Rhythm Boys

The location and protection of the air barrier and water management layers are critical to long-term building performance.

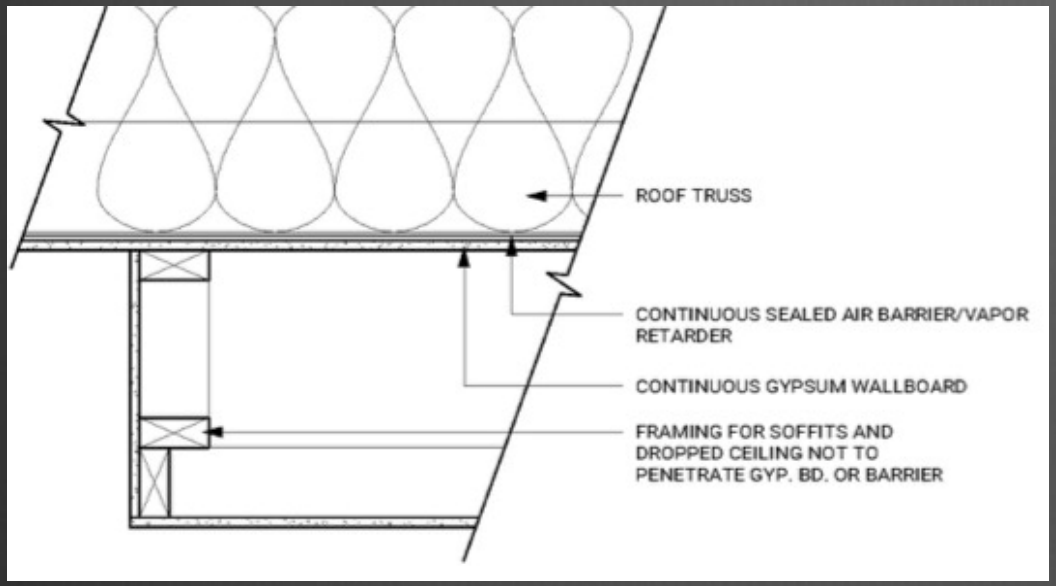


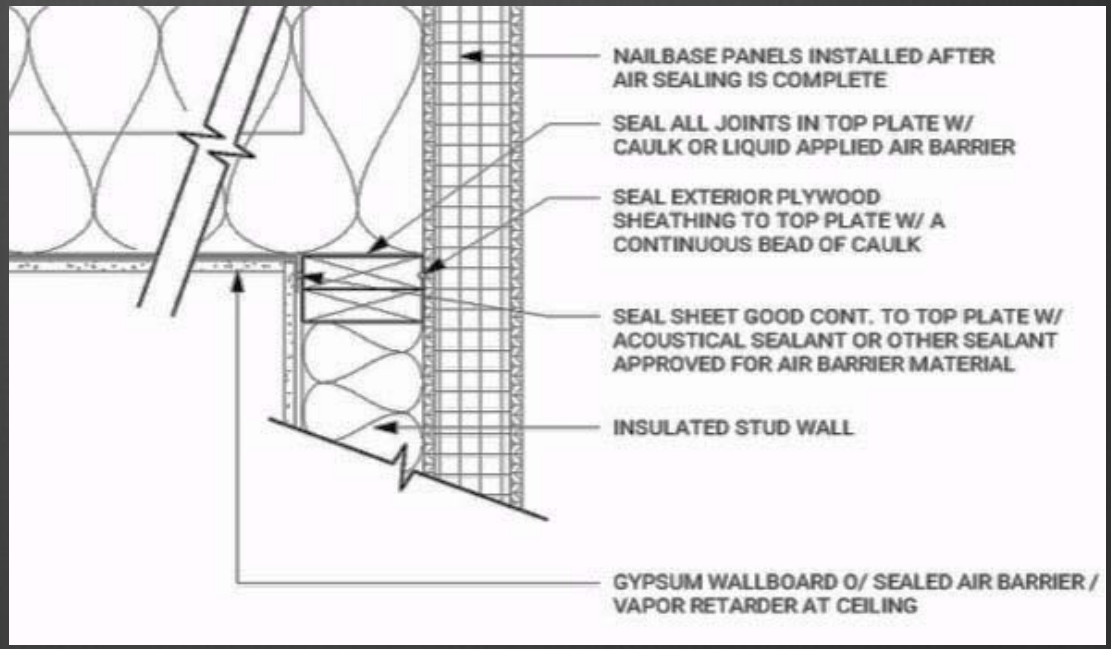
Details and Documentation



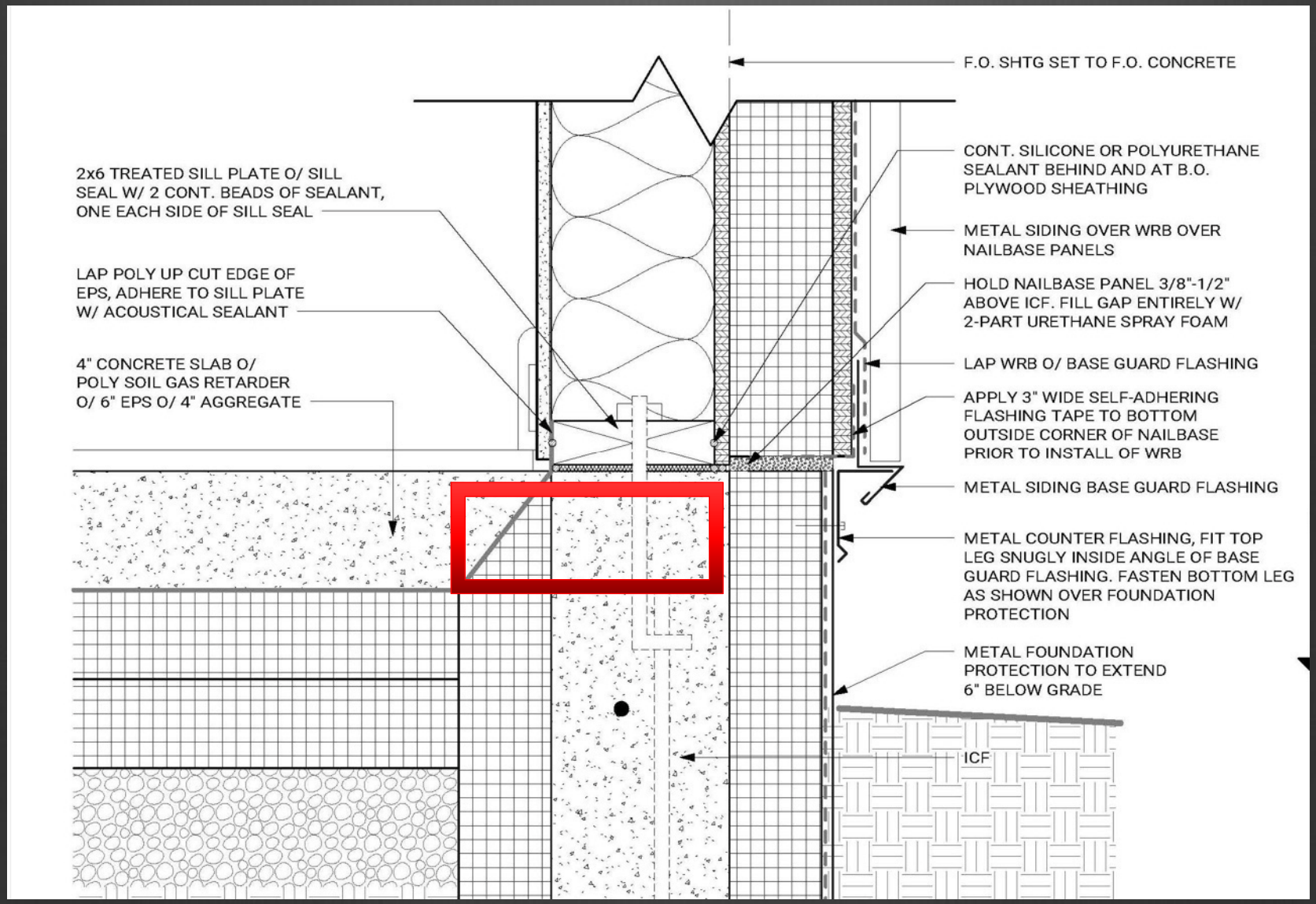
- Readable
- Understandable
- Buildable
- Repeatable

Air Sealing: Standard Details

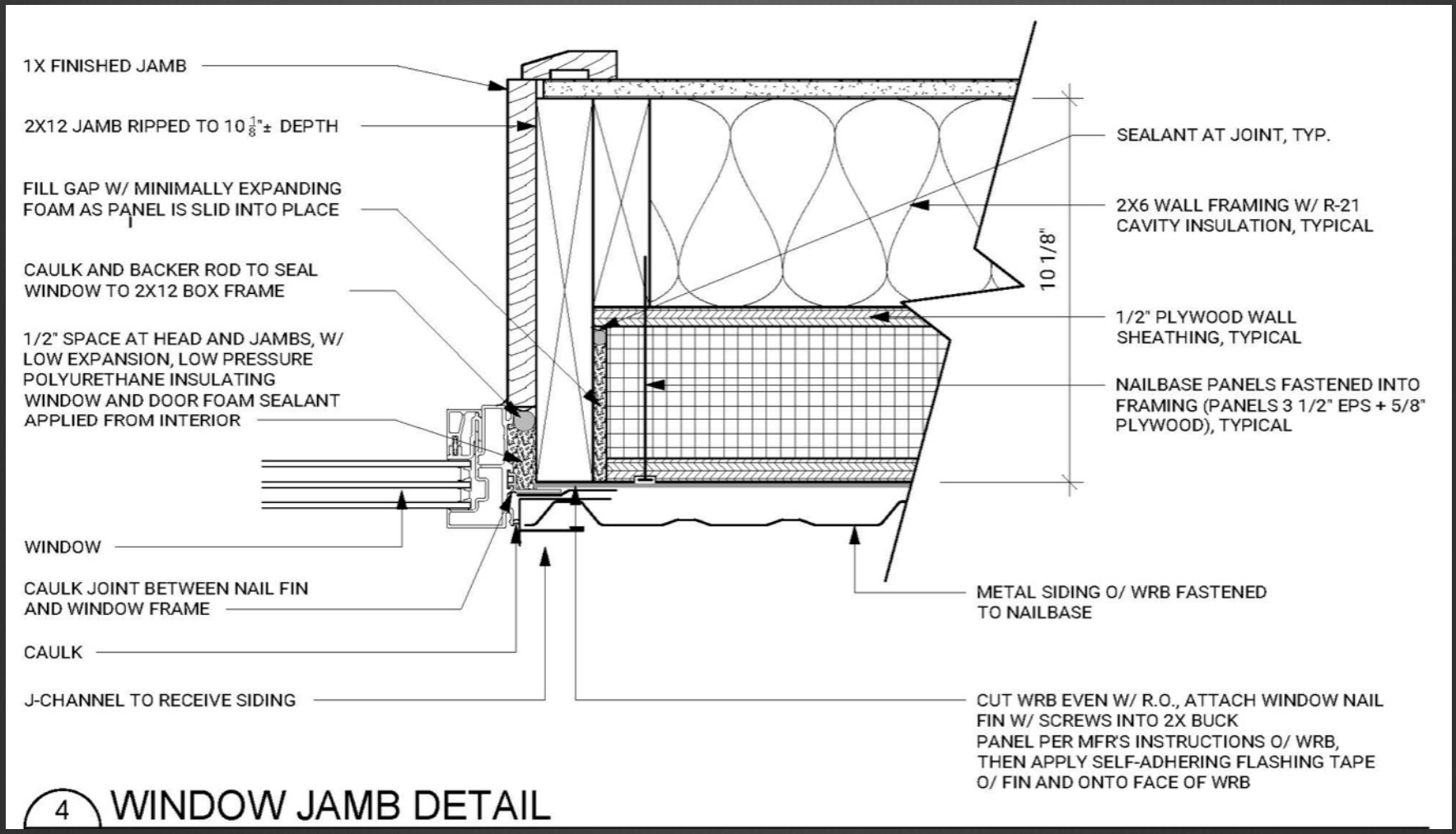




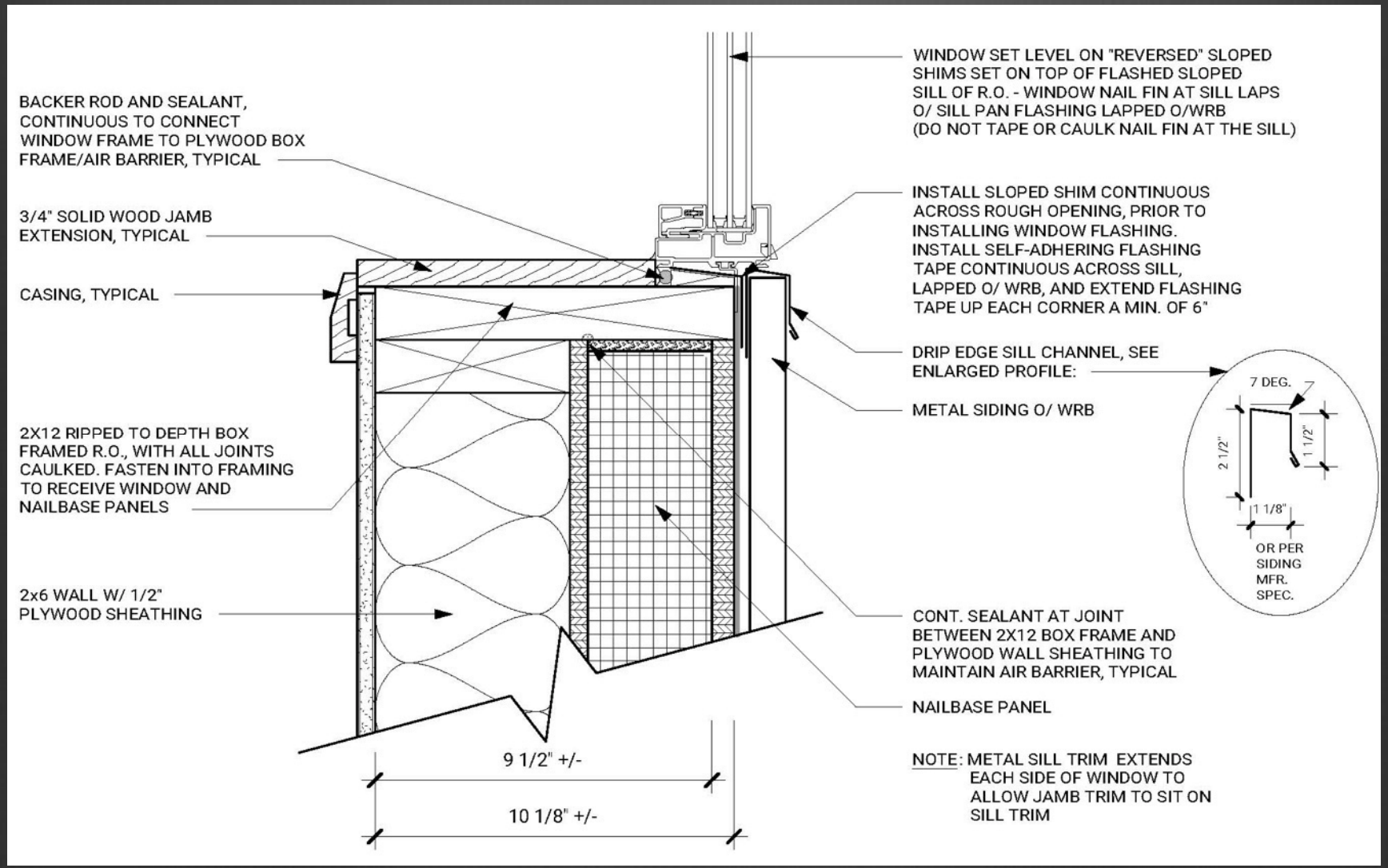
Foundation Detail …



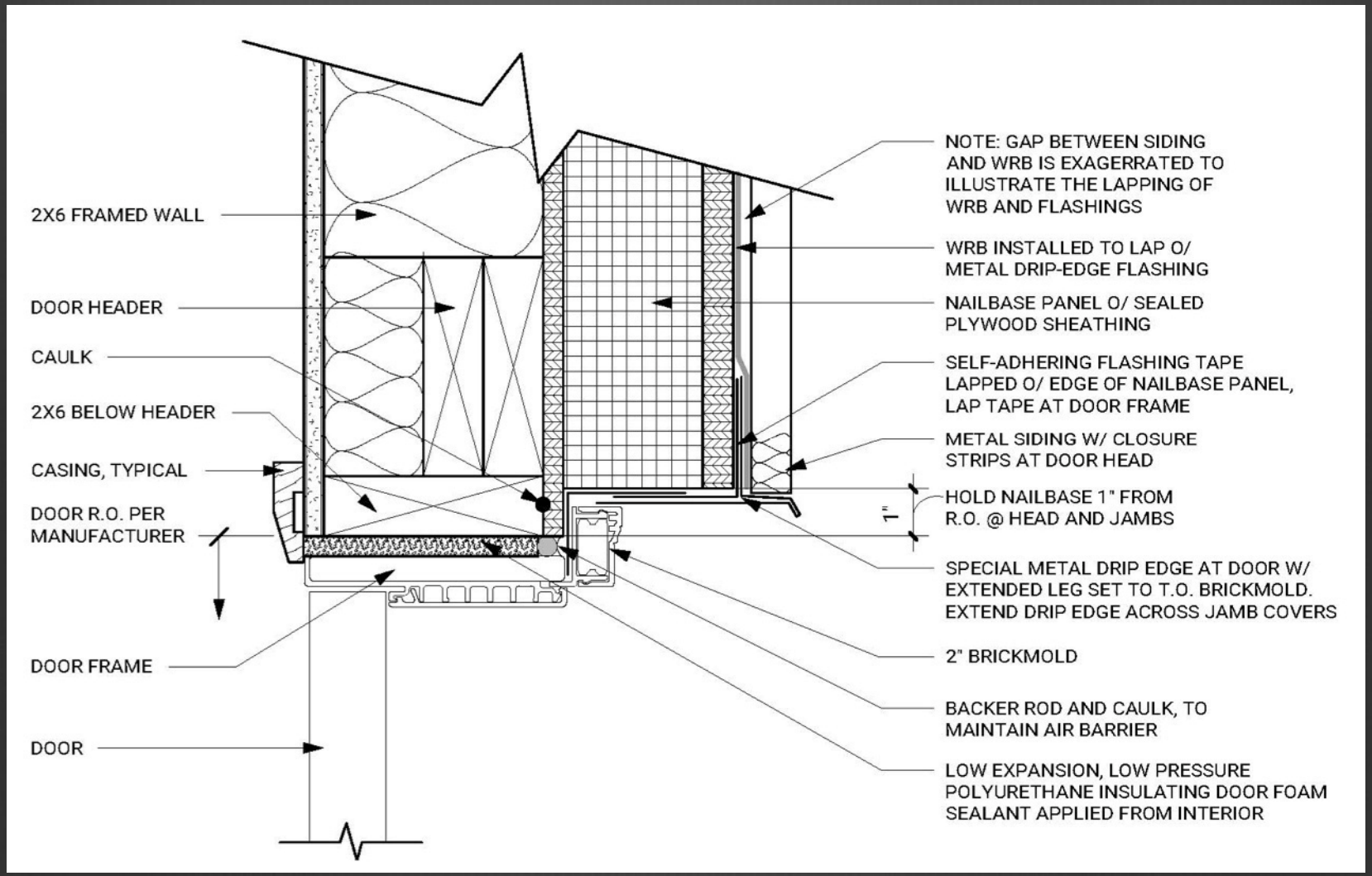
Window Jamb


1X FINISHED JAMB
2X12 JAMB RIPPED TO 10 1/8"± DEPTH
FILL GAP W/ MINIMALLY EXPANDING FOAM AS PANEL IS SLID INTO PLACE
CAULK AND BACKER ROD TO SEAL WINDOW TO 2X12 BOX FRAME
1/2" SPACE AT HEAD AND JAMBS, W/ LOW EXPANSION, LOW PRESSURE POLYURETHANE INSULATING WINDOW AND DOOR FOAM SEALANT APPLIED FROM INTERIOR
WINDOW
CAULK JOINT BETWEEN NAIL FIN AND WINDOW FRAME
CAULK
J-CHANNEL TO RECEIVE SIDING
SEALANT AT JOINT, TYP.
2X6 WALL FRAMING W/ R-21 CAVITY INSULATION, TYPICAL
10 1/8"
1/2" PLYWOOD WALL SHEATHING, TYPICAL
NAILBASE PANELS FASTENED INTO FRAMING (PANELS 3 1/2" EPS + 5/8" PLYWOOD), TYPICAL
METAL SIDING O/ WRB FASTENED TO NAILBASE
CUT WRB EVEN W/ R.O., ATTACH WINDOW NAIL FIN W/ SCREWS INTO 2X BUCK
PANEL PER MFR'S INSTRUCTIONS O/ WRB, THEN APPLY SELF-ADHERING FLASHING TAPE O/ FIN AND ONTO FACE OF WRB
4 WINDOW JAMB DETAIL

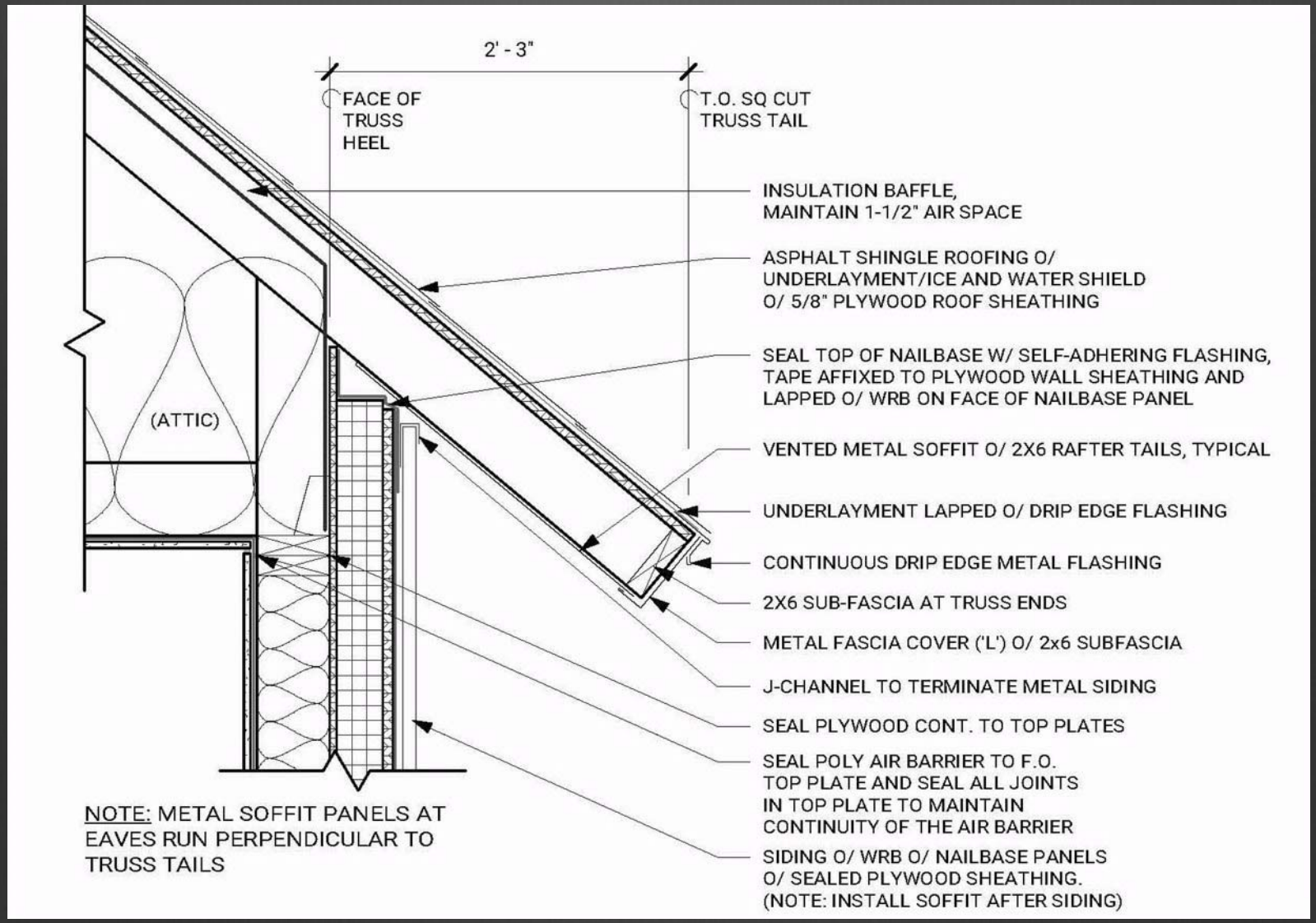
Window Sill


BACKER ROD AND SEALANT, CONTINUOUS TO CONNECT WINDOW FRAME TO PLYWOOD BOX FRAME/AIR BARRIER, TYPICAL
3/4" SOLID WOOD JAMB EXTENSION, TYPICAL
CASING, TYPICAL
2X12 RIPPED TO DEPTH BOX FRAMED R.O., WITH ALL JOINTS CAULKED. FASTEN INTO FRAMING TO RECEIVE WINDOW AND NAILBASE PANELS
2x6 WALL W/ 1/2" PLYWOOD SHEATHING
WINDOW SET LEVEL ON "REVERSED" SLOPED SHIMS SET ON TOP OF FLASHED SLOPED SILL OF R.O. - WINDOW NAIL FIN AT SILL LAPS O/ SILL PAN FLASHING LAPPED O/WRB (DO NOT TAPE OR CAULK NAIL FIN AT THE SILL)
INSTALL SLOPED SHIM CONTINUOUS ACROSS ROUGH OPENING, PRIOR TO INSTALLING WINDOW FLASHING. INSTALL SELF-ADHERING FLASHING TAPE CONTINUOUS ACROSS SILL, LAPPED O/ WRB, AND EXTEND FLASHING TAPE UP EACH CORNER A MIN. OF 6"
DRIP EDGE SILL CHANNEL, SEE ENLARGED PROFILE:
METAL SIDING O/ WRB
CONT. SEALANT AT JOINT BETWEEN 2X12 BOX FRAME AND PLYWOOD WALL SHEATHING TO MAINTAIN AIR BARRIER, TYPICAL
NAILBASE PANEL
9 1/2" +/-
10 1/8" +/-
7 DEG.
2 1/2"
1 1/2"
1 1/8"
OR PER SIDING MFR. SPEC.
NOTE: METAL SILL TRIM EXTENDS EACH SIDE OF WINDOW TO ALLOW JAMB TRIM TO SIT ON SILL TRIM

Doors set into the 2 x 6 wall

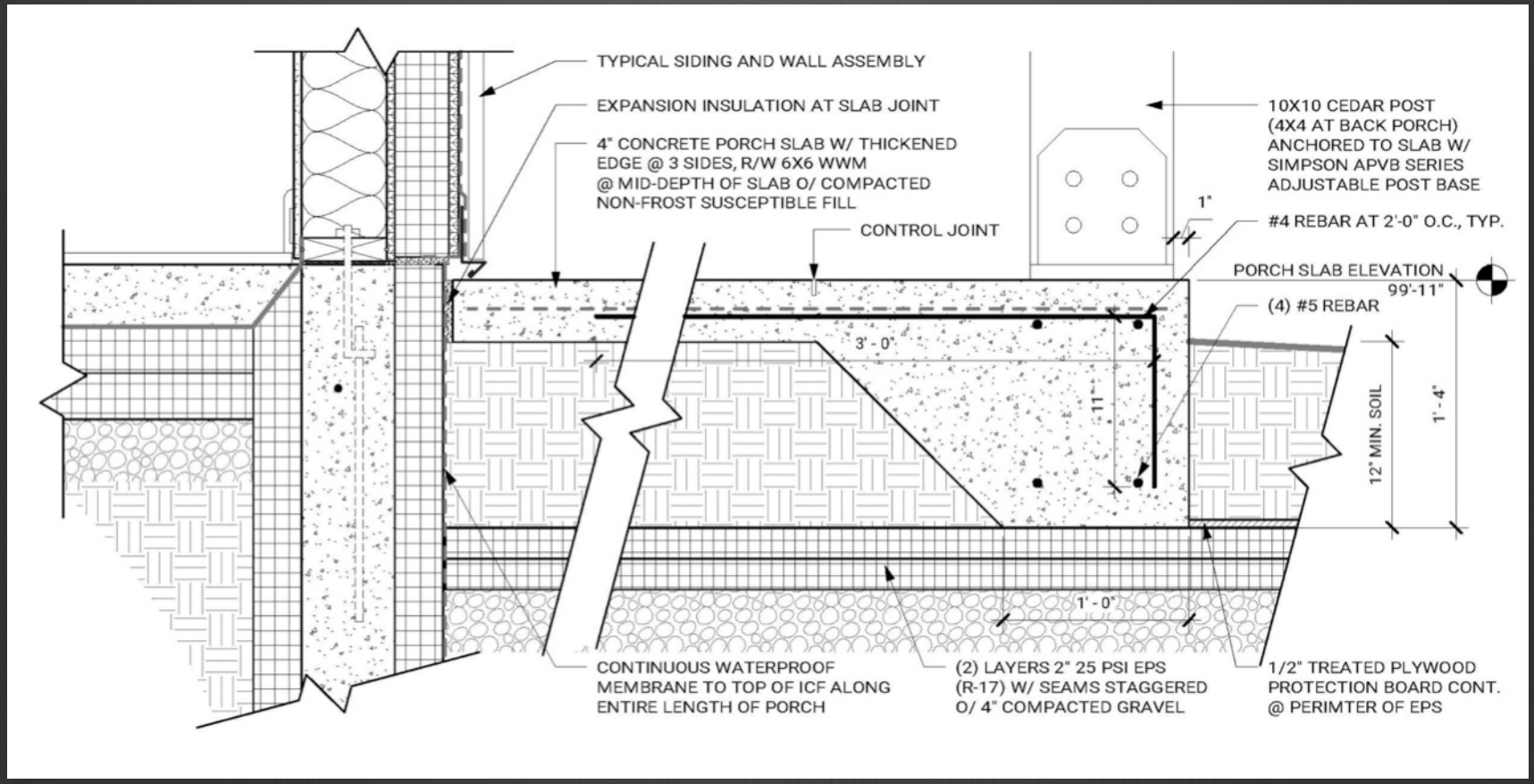


Roof and Attic

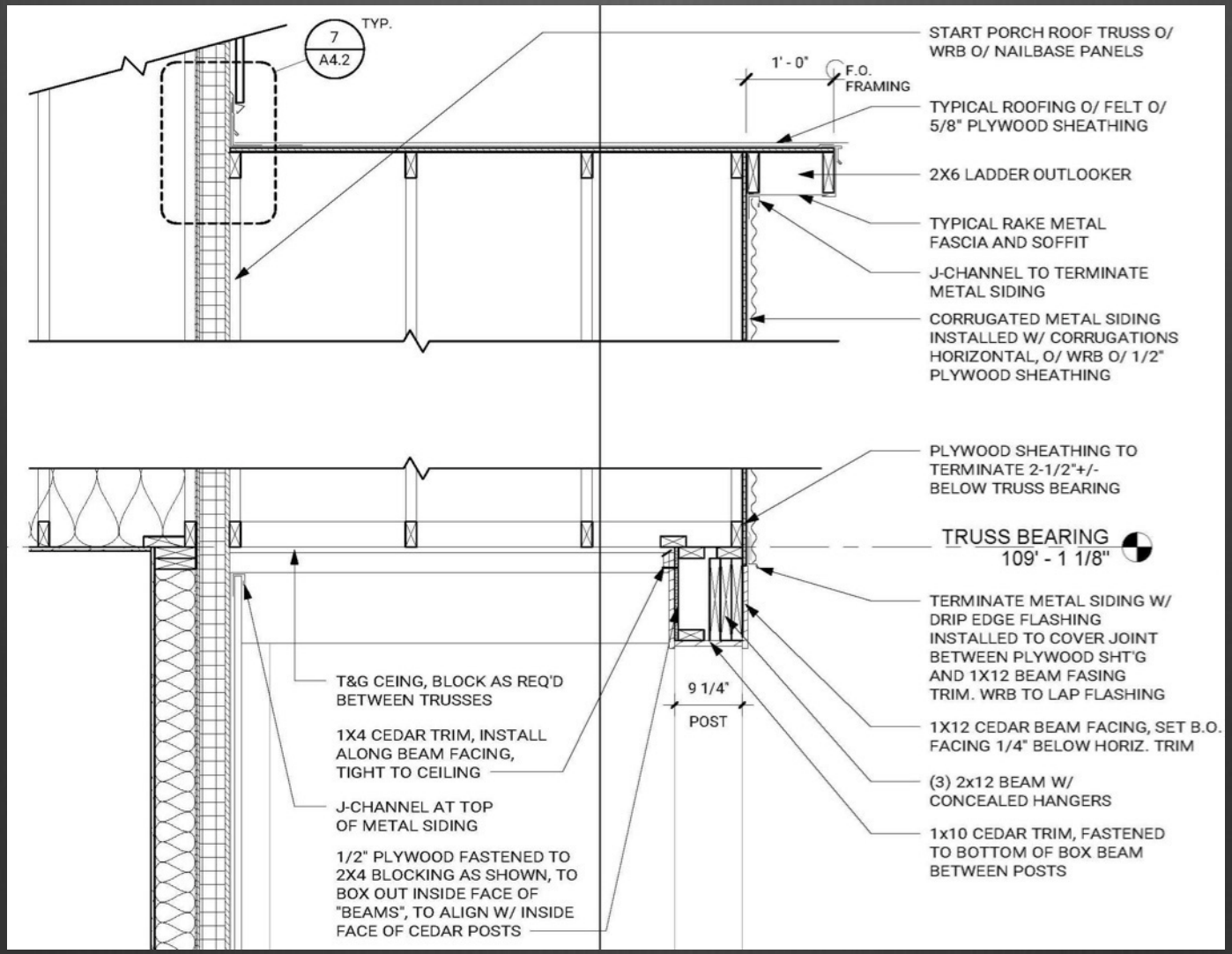


Attached Porches

Robust, reproducible details that reduce thermal bridging.



Attached Porches

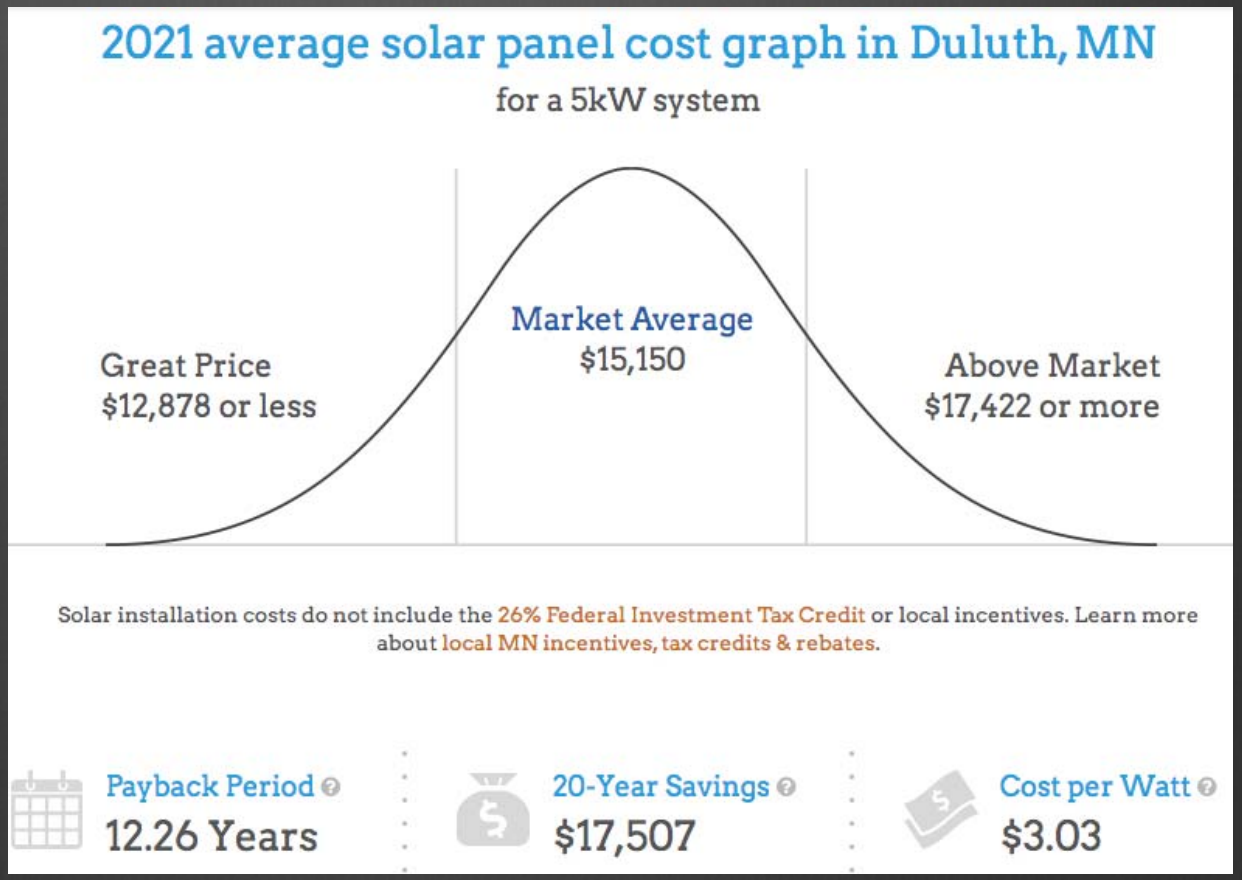


From Theory into Practice

Construction Costs estimated at ~ $230/ft2

Not including land, PV system or detached garage.

8 kW PV array for Potential net zero performance:
estimated cost $17,938 after tax credit, not including any potential local rebates.



Data from energysage.com/local-data/solar-panel-cost/

Coming Soon …

greennewdealhousing.org

Additional Resources

greennewdealhousing.org

buildingscience.com

zeroenergyproject.org

Building Science Corporation BSI Insight-081: Zeroing In

Making Sense of Minisplits by Jordan Goldman, Fine Homebuilding No. 296

Acknowledgements and thank you to the following organizations and people who have supported this effort.

the Board of Green New Deal Housing
University of MN Extension Regional Sustainable Development Partnership
Leah Karmaker
Stacie Renee
Tiersa Wodash
Greg Gilbert

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