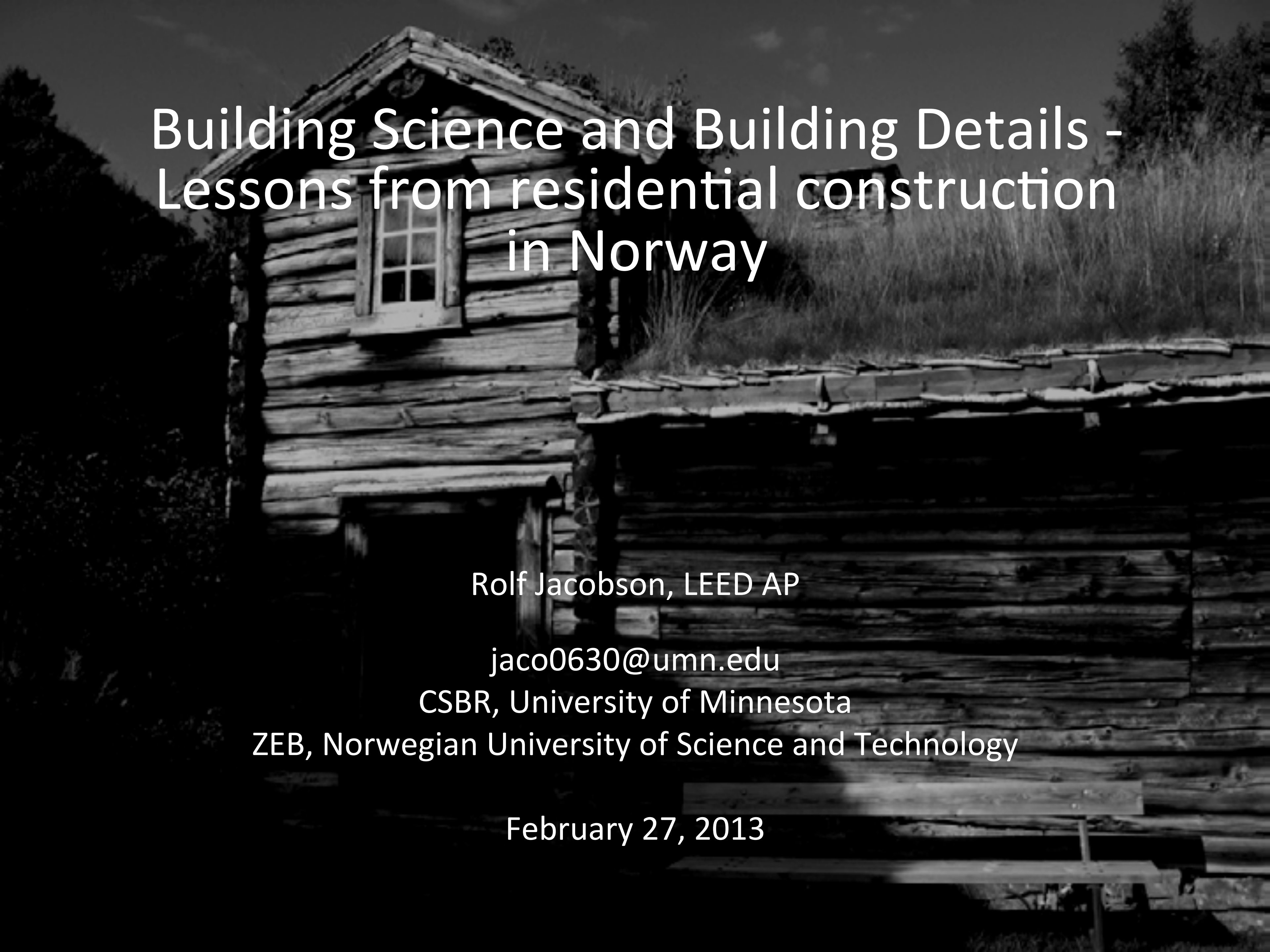

Building Science and Building Details - Lessons from residential construction in Norway

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ZEB, Norwegian University of Science and Technology

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Outline

1. Background - climate and energy code comparison
2. Typical Norwegian residential envelope
3. Section 1 – Framing factors and true R-values
4. Section 2 – Thermal bridges
5. Section 3 – Moisture and air leakage
6. Section 4 – Life cycle environmental impacts

Outline

1. Background - climate and energy code comparison
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5. Section 3 – Moisture and air leakage
6. Section 4 – Life cycle environmental impacts

The goal is to use a typical Norwegian envelope as a means to discuss building science issues and building details that are critical for high-performance homes in cold climates.

Background

- Worked as a framer building homes from 2002 - 2005
- Master's Degree in Architecture, 2007
- Fulbright scholarship to complete Master's of Science degree on cold climate envelopes in Norway in 2010/2011

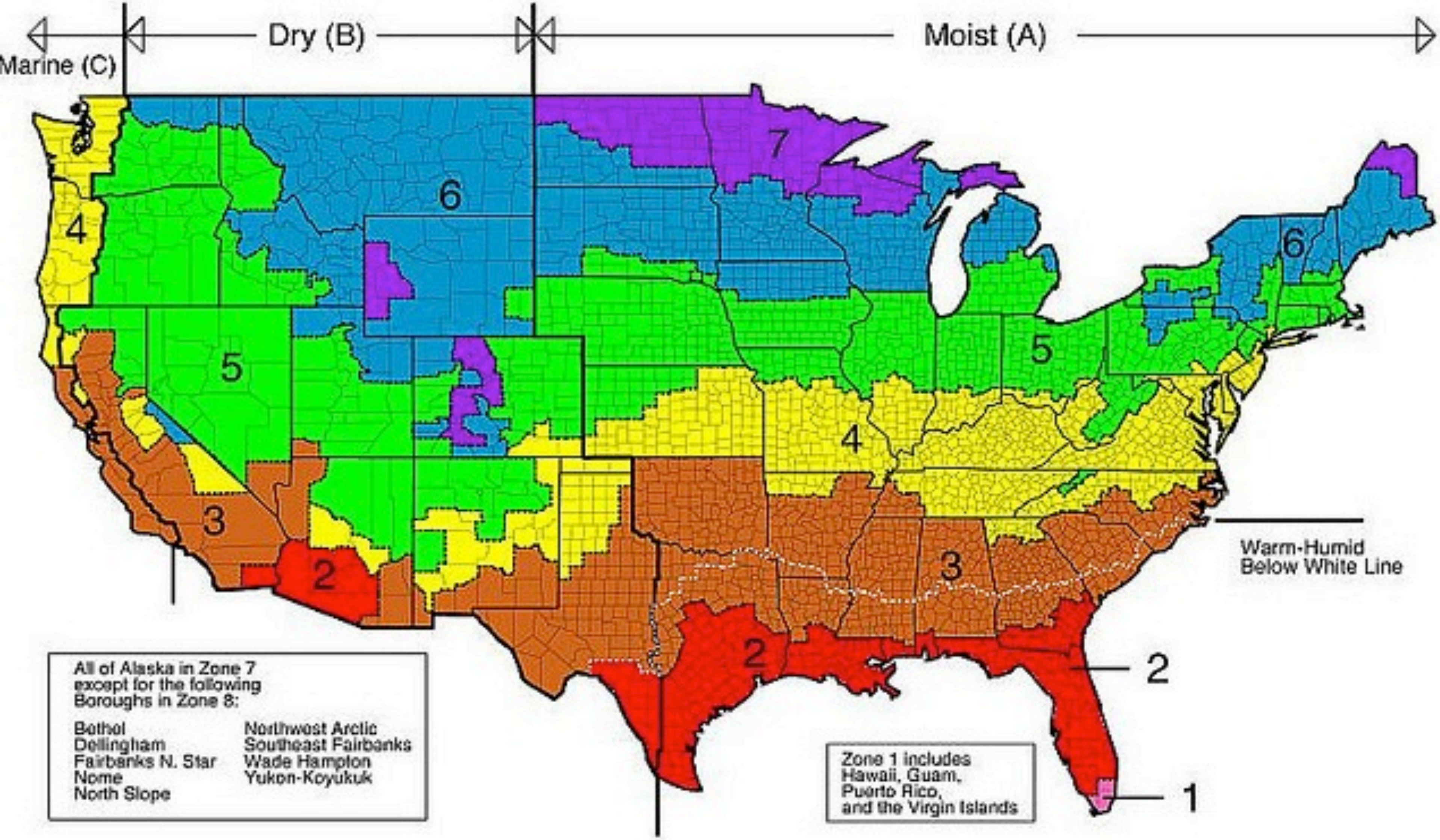
Background

- In Norway, studied at the Center for Zero Emissions Buildings (ZEB)

- Housed within the Norwegian technical university, NTNU, in Trondheim

- ZEB has close ties with SINTEF Byygforsk – SINTEF is similar to the Buildings Technology Center (BTC) at ORNL, but greater cooperation between industry and university research. Also responsible for national building/energy code development.

Climate Comparison



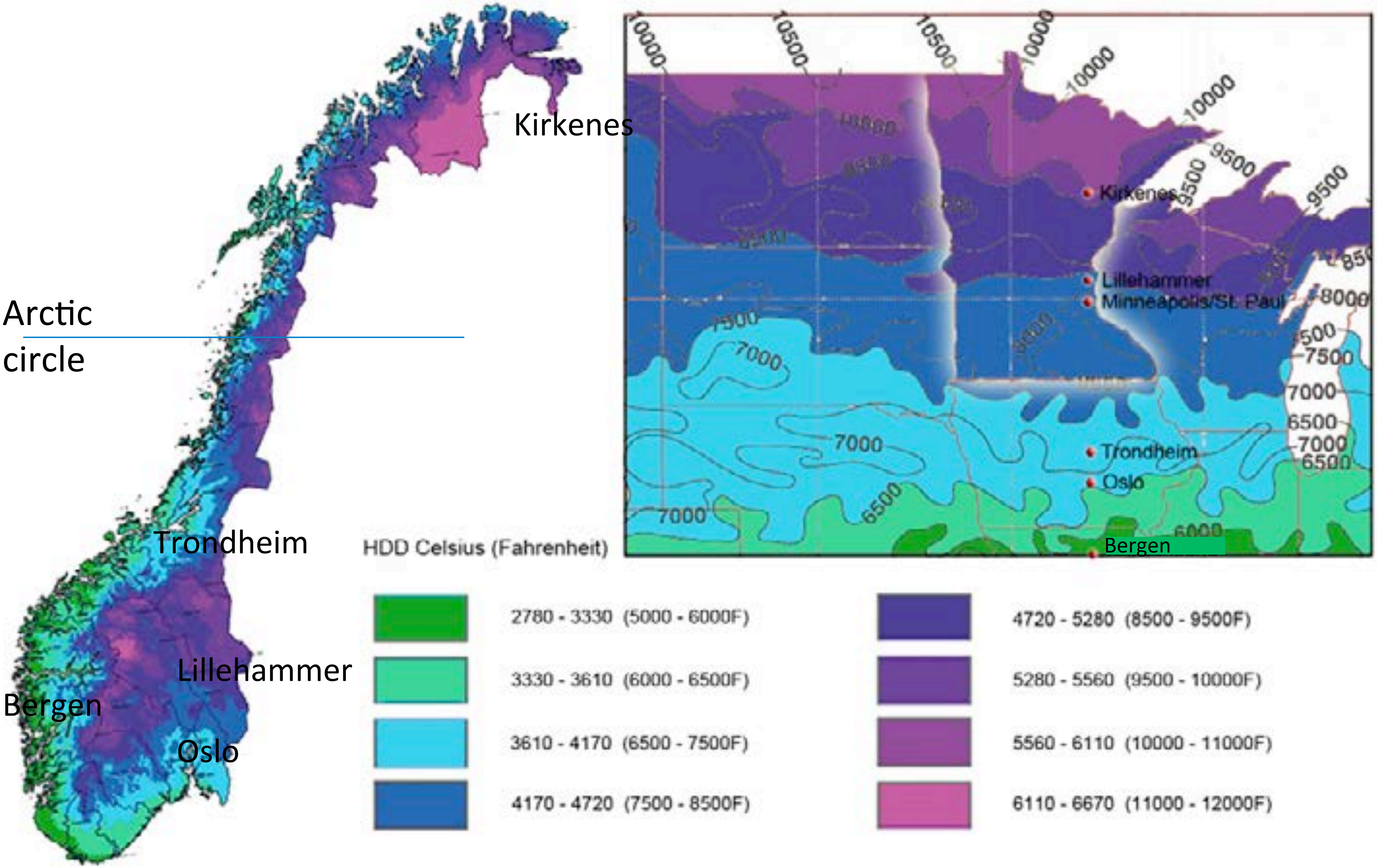
Warm-Humid Below White Line

All of Alaska in Zone 7 except for the following Boroughs in Zone 8:

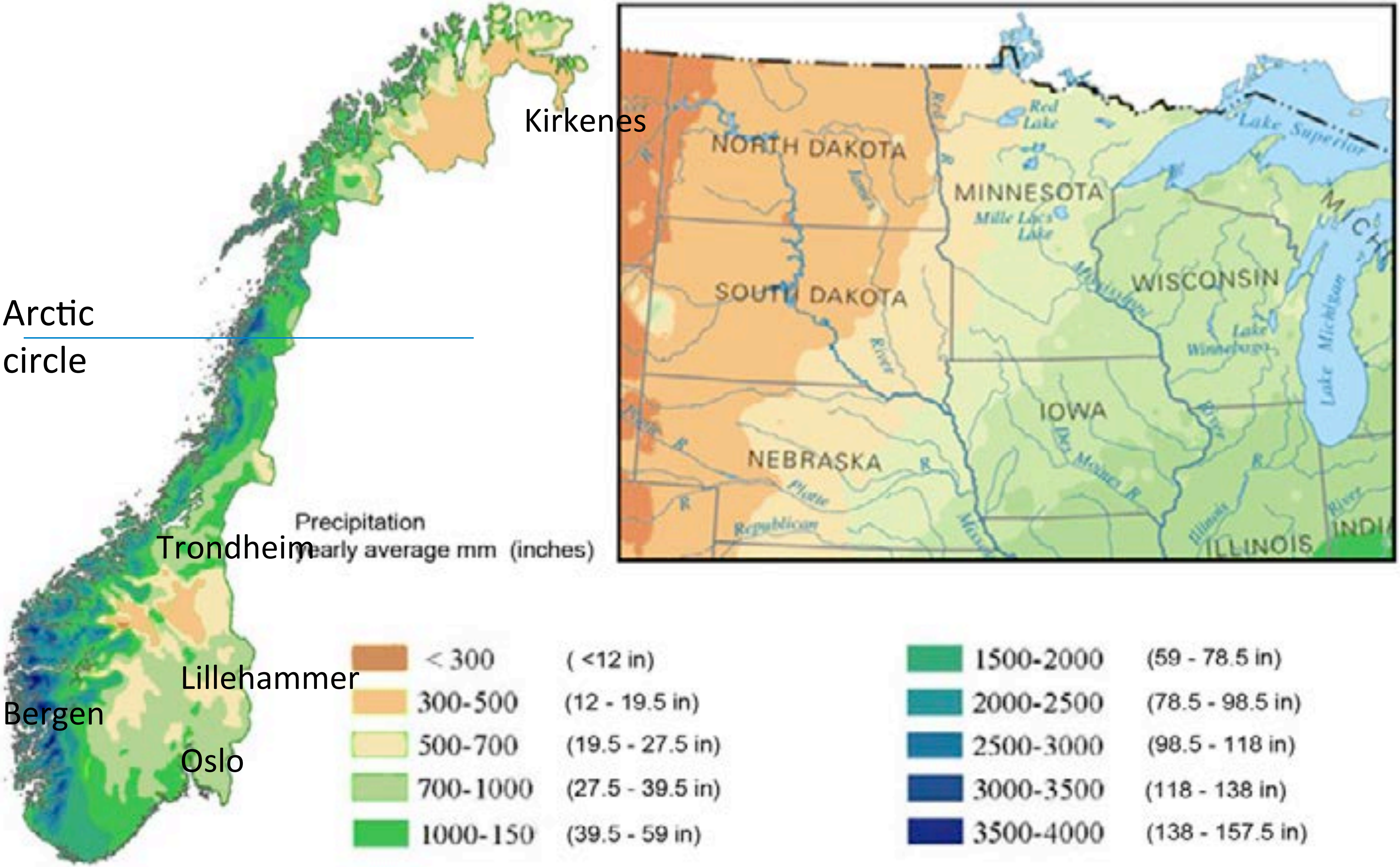
Bethel	Northwest Arctic
Dellingham	Southeast Fairbanks
Fairbanks N. Star	Wade Hampton
Nome	Yukon-Koyukuk
North Slope	

Zone 1 includes Hawaii, Guam, Puerto Rico, and the Virgin Islands

Climate Comparison - heating degree days (HDD)



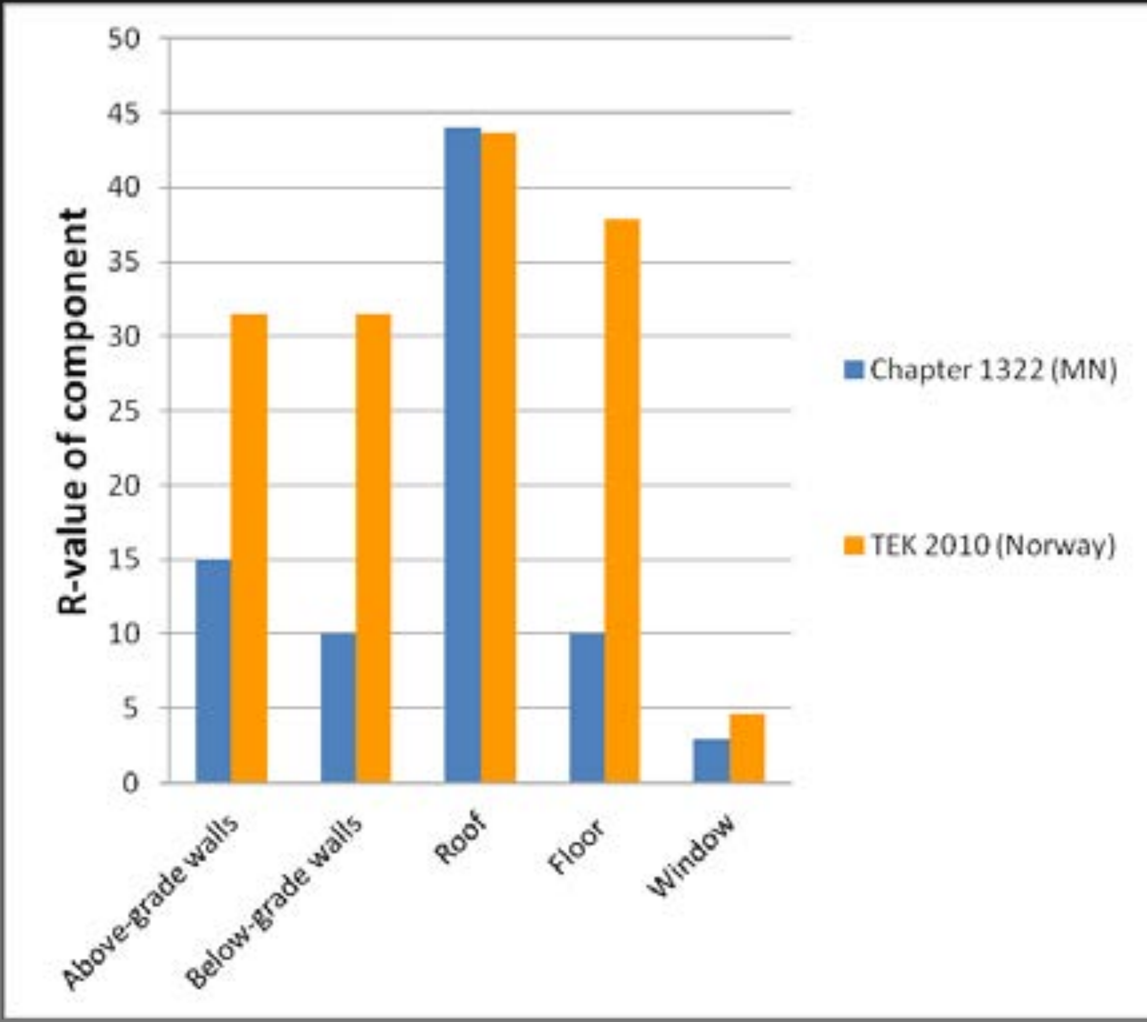
Climate Comparison – average yearly precipitation



Energy Code Comparison – TEK 2010 vs Chapter 1322

Norwegian envelope:

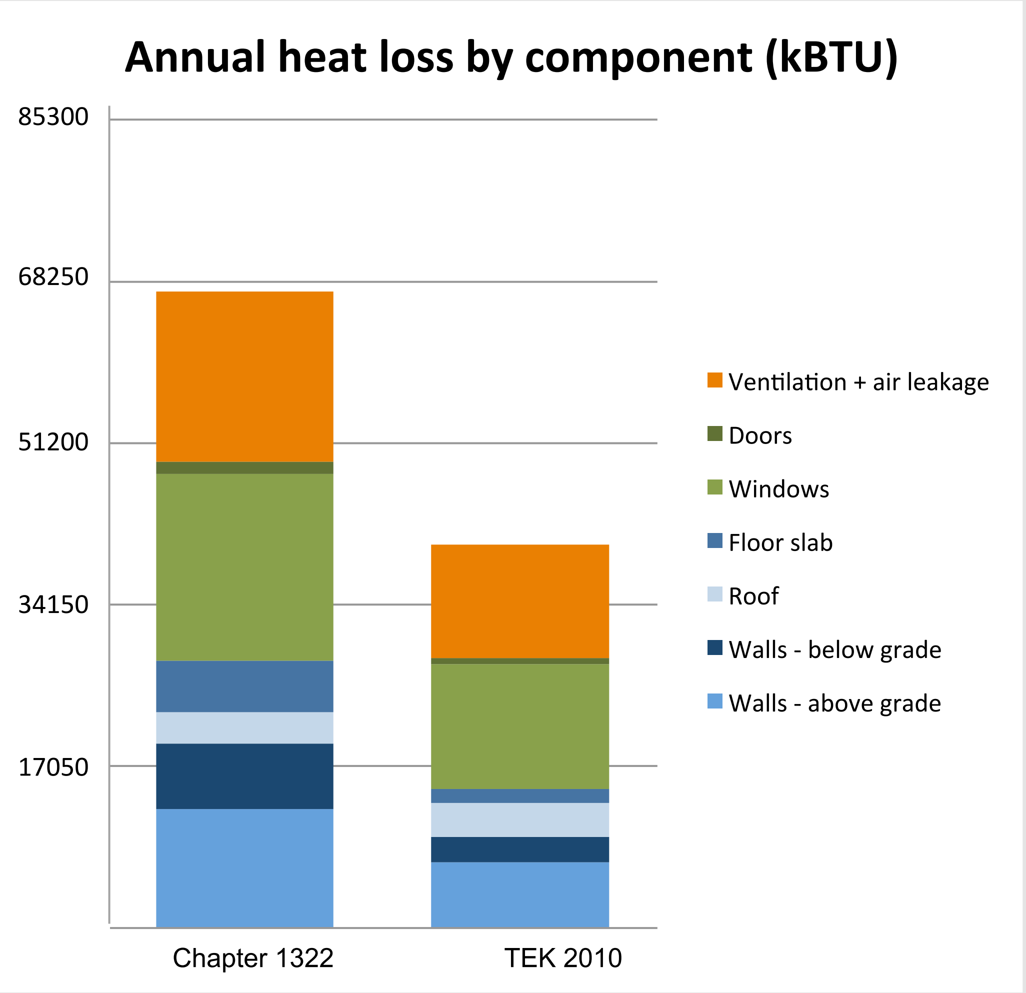
- Above-grade walls – R-31 (2x higher)
- Below-grade walls – R-31 (3x higher)
- Roof = R-44 (same)
- Floor slab = R-38 (4x higher)
- Windows = R-4.7 (> 50% better)



Energy Code Comparison – TEK 2010 vs Chapter 1322

	TEK 2010	Chapter 1322
Thermal bridges	< 0.03 W/m2K	prescriptive requirements only
Air infiltration	< 2.5 ACH@50Pa	prescriptive requirements only
Heat recovery ventilation	> 70% efficiency	heat recovery ventilation not required
Specific fan power	< 2.5 kW/m3/s	no efficiency requirement

Energy Code Comparison – TEK 2010 vs Chapter 1322


Annual heat loss by component (kBTU)

Heat loss reductions

Ventilation - reduced by 70%

Air leakage - remains the same

Windows and doors - reduced by 34%

Walls and roof - reduced by 34%

Floor slab and basement - reduced by 67%

Overall reduction – 40%

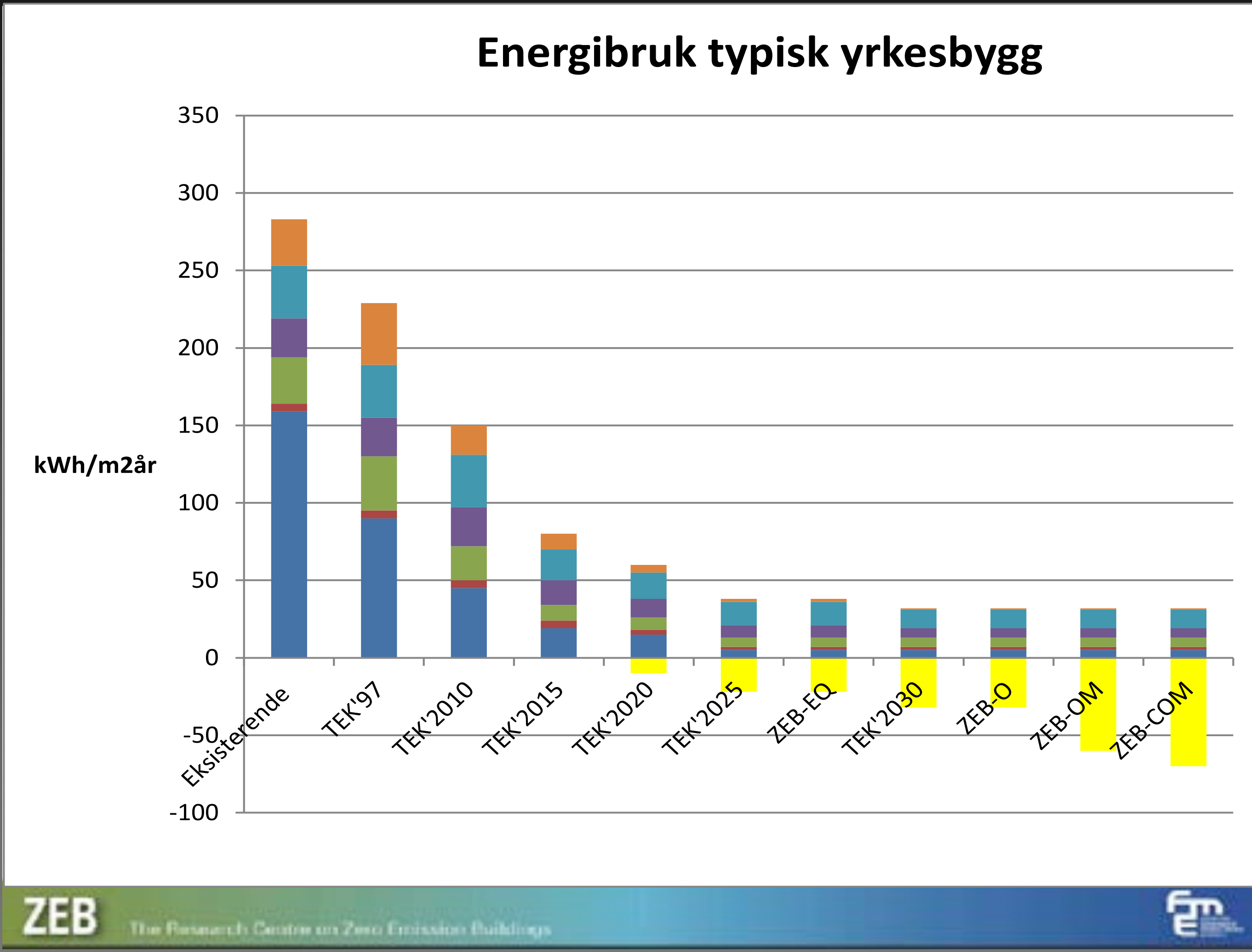
Energy Code Comparison

Future energy codes will require even higher levels of energy efficiency.

Goals:
By 2015: “Passivhus” level: R-38 walls, R-44 roof, R-38 floor slab, R-7 windows

By 2030: net zero energy homes (ZEB-O), includes renewable energy

Eventually: plus energy homes which also pay back their embodied energy (ZEB-OM)



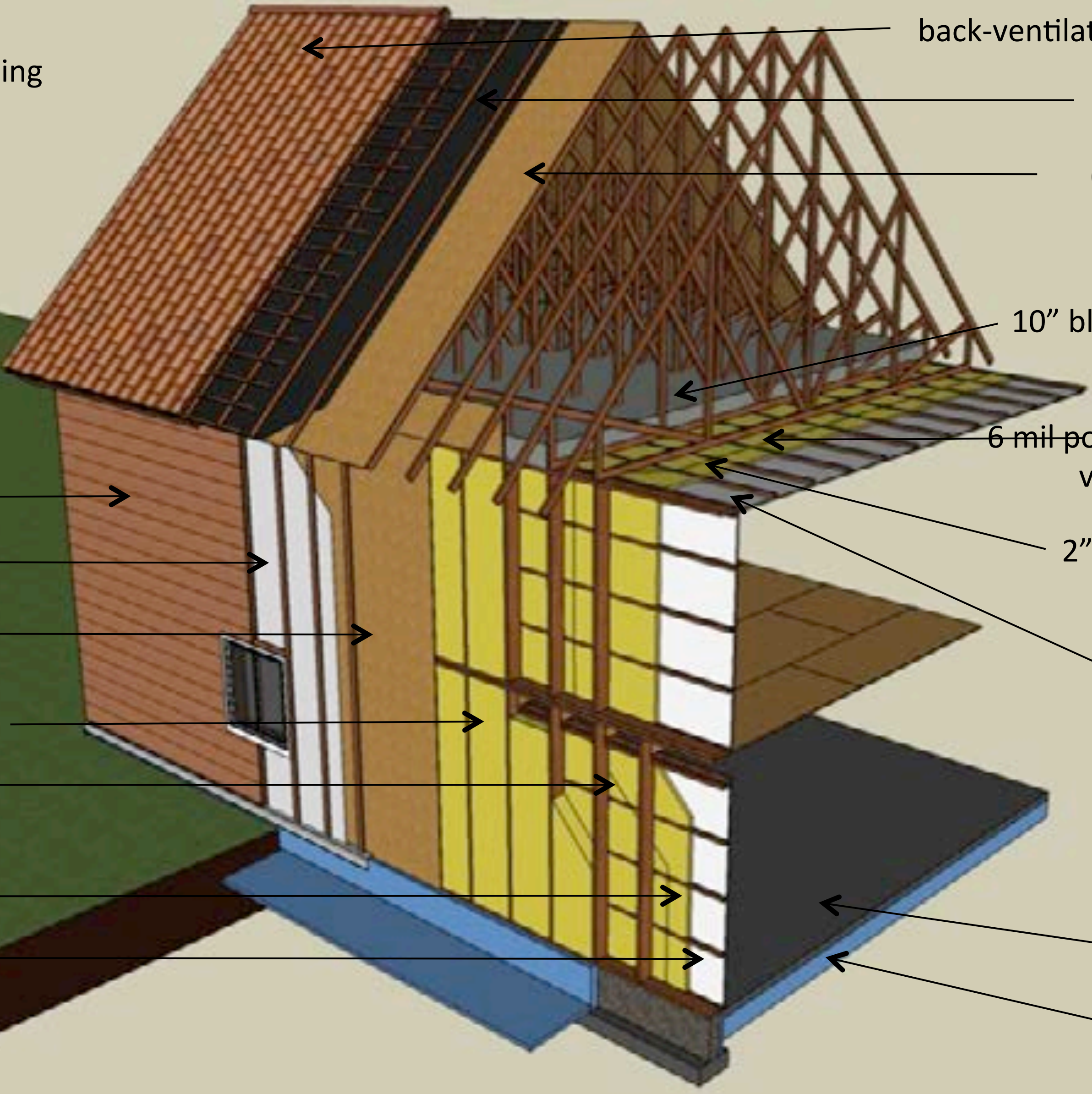
Norwegian cross-batten envelope

Historically, residential envelopes in Norway were built using a technique called "Massivtre" – essentially log construction.

Modern framing techniques were brought to Norway after WWII from the U.S.

From this common starting point, Norwegian residential envelopes have evolved to meet specific environmental challenges, and continue a fast evolution today to meet new energy efficiency goals.

Norwegian cross-batten envelope



2x8 studs, 24” o.c. spacing
2x2 cross battens, 24” o.c. spacing
truss roof, 24” o.c. spacing

Exterior wall R-31

back-ventilated cladding

weather barrier

0.5” sheathing

7.5” mineral wool, R – 3.8/inch

6 mil poly (air barrier/vapor retarder)

2” mineral wool, R – 3.8/inch

5/8” gypsum

back-ventilated roofing tile

roofing paper

0.5” sheathing

10” blown cellulose, R – 3.6/inch

6 mil poly (air barrier/ vapor retarder)

2” mineral wool, R – 3.8/inch

5/8” gypsum

Roof R-44

Floor R-38

4” concrete

10” EPS, R-4/inch

Norwegian cross-batten envelope

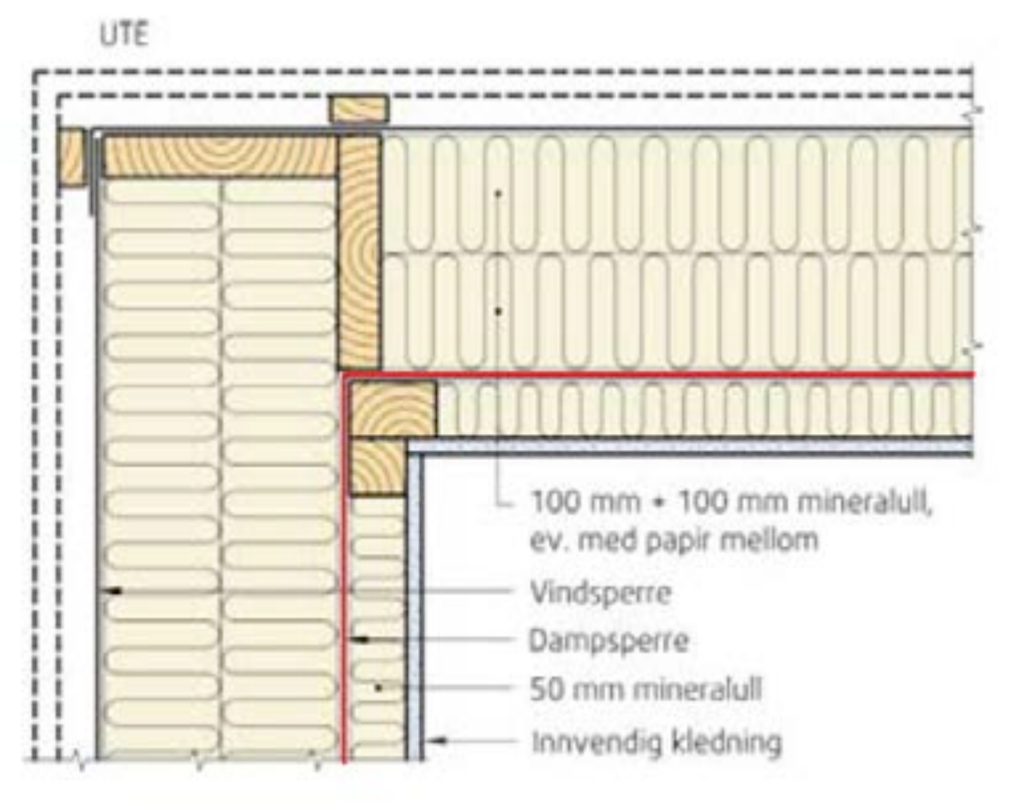


Image from Byggdetaljer 2007

Wall corner detail

2x8 studs and 2”x2” cross battens insulated with mineral wool batts

2-stud corner – advanced framing detail reduces thermal bridging

Interior vapor retarder and air barrier is protected from puncture by cross batten layer

Cladding is back-ventilated using furring strips

Norwegian cross-batten envelope

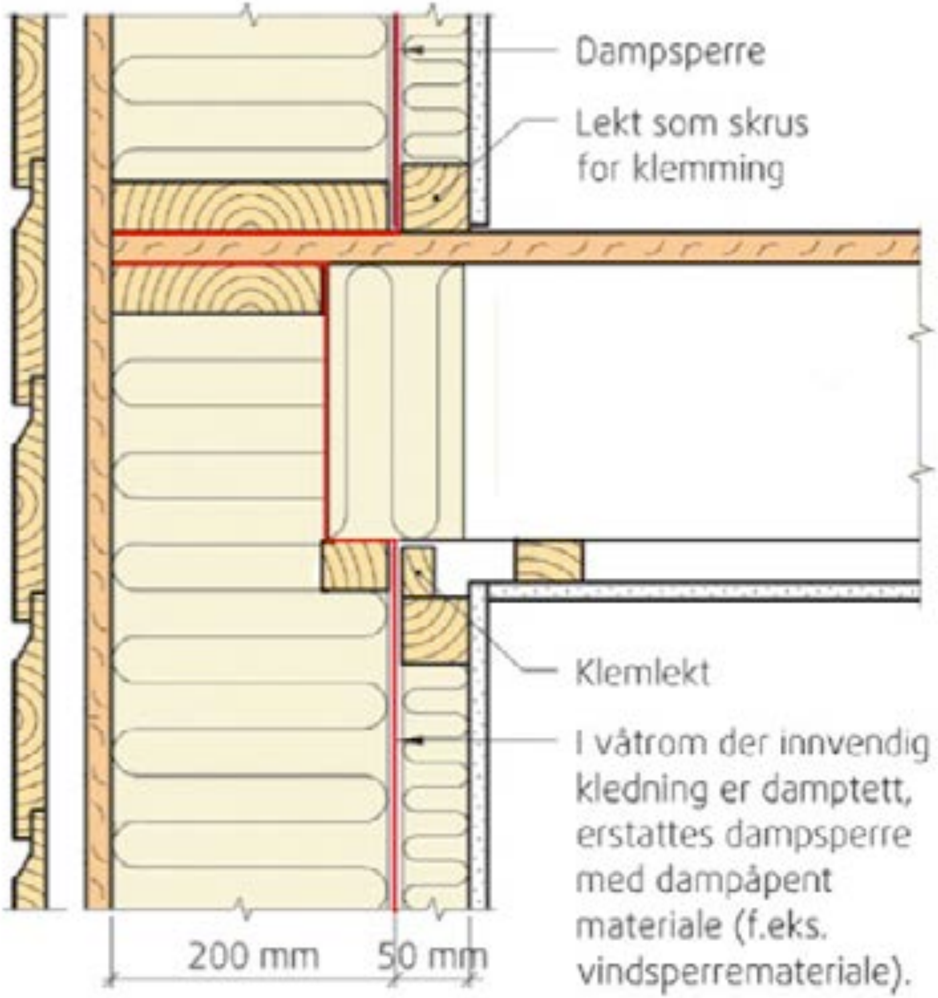


Image from Byggdetaljer 2012

Rim joist detail

2x8 studs cut to create 2" ledge for plate and floor joists.

Allows interior vapor retarder and air barrier to wrap around the rim joist, then sealed to the floor deck

Reduces thermal bridging at rim joist

Norwegian cross-batten envelope

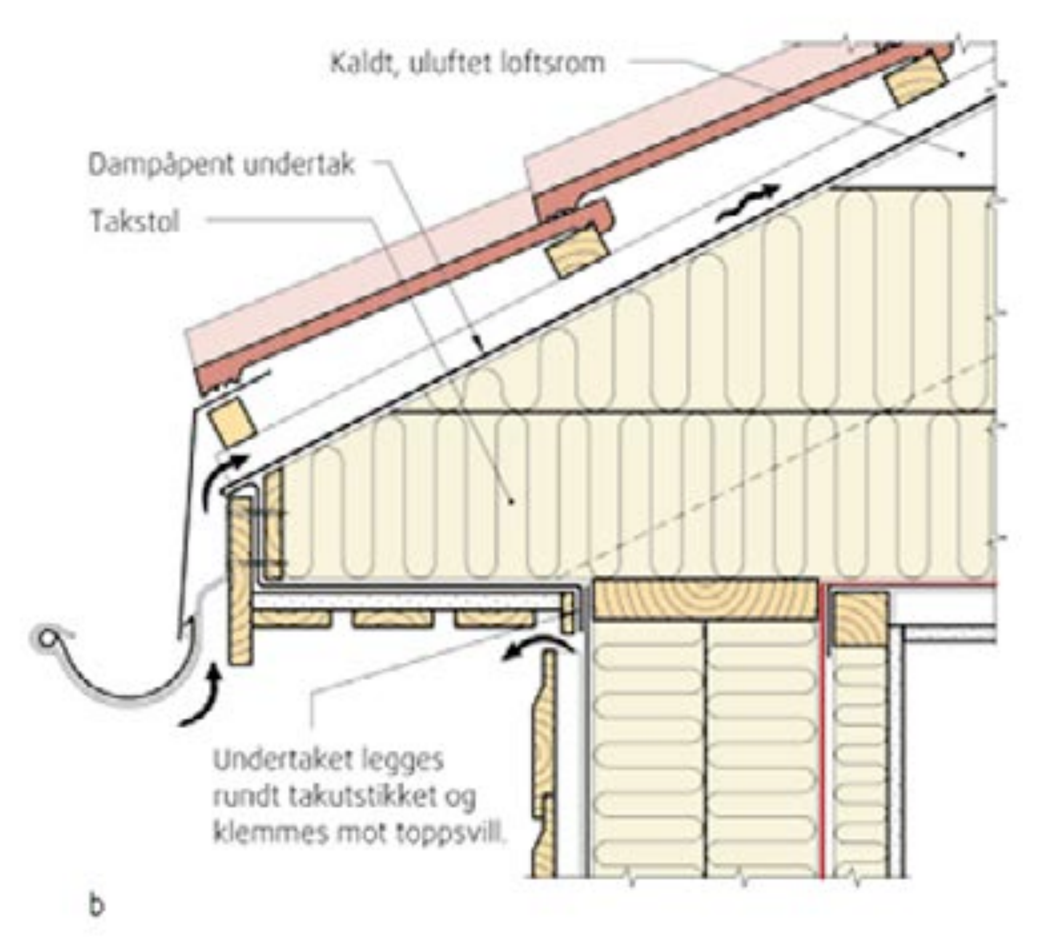


Image from Byggdetaljer 2007

"Cold attic" corner detail

Primary roof deck sheathing is back-ventilated with open attic.

Roofing is also back-ventilated

Interior vapor retarder and air barrier is continuous (joints lapped and sealed) and protected from puncture by cross batten layer

Norwegian cross-batten envelope

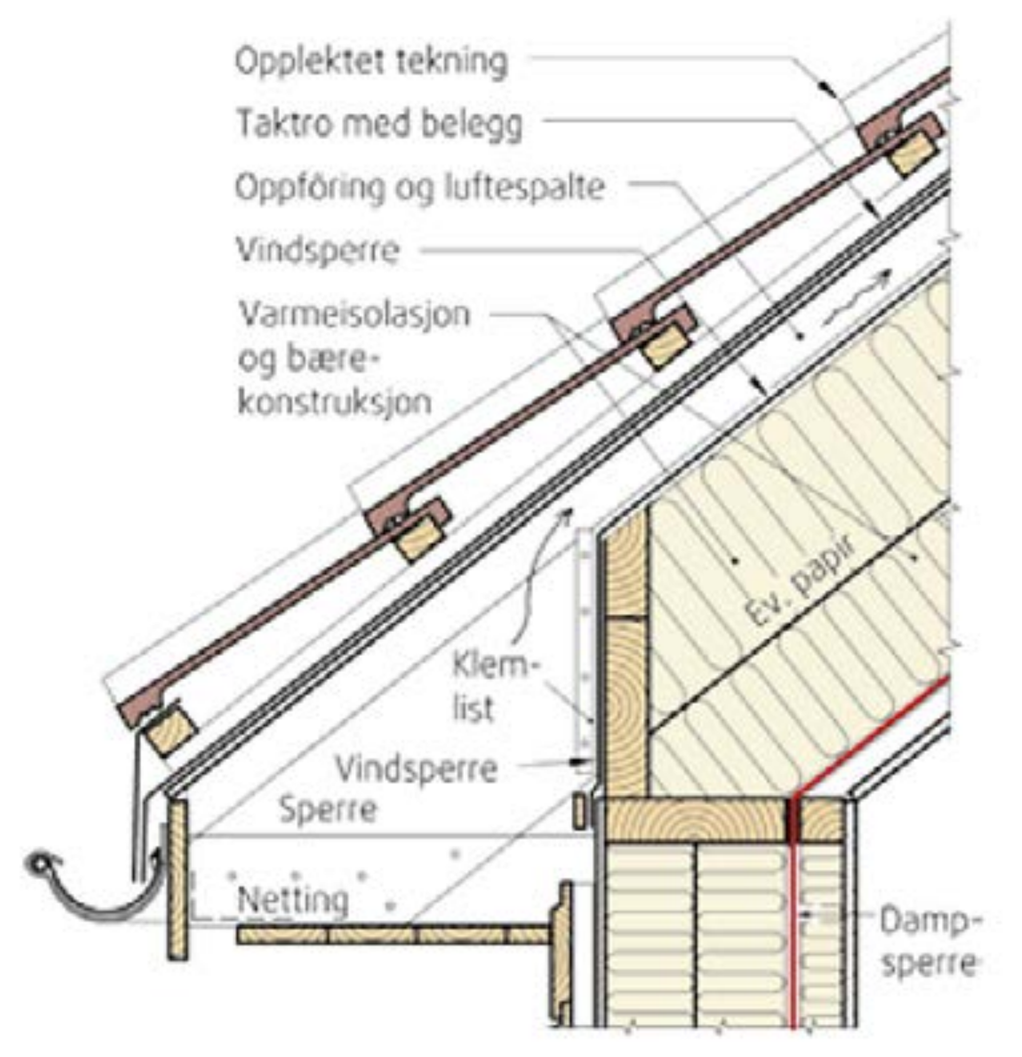


Image from Byggdetaljer 2007

"Compact roof" corner detail

Primary roof deck sheathing is back-ventilated

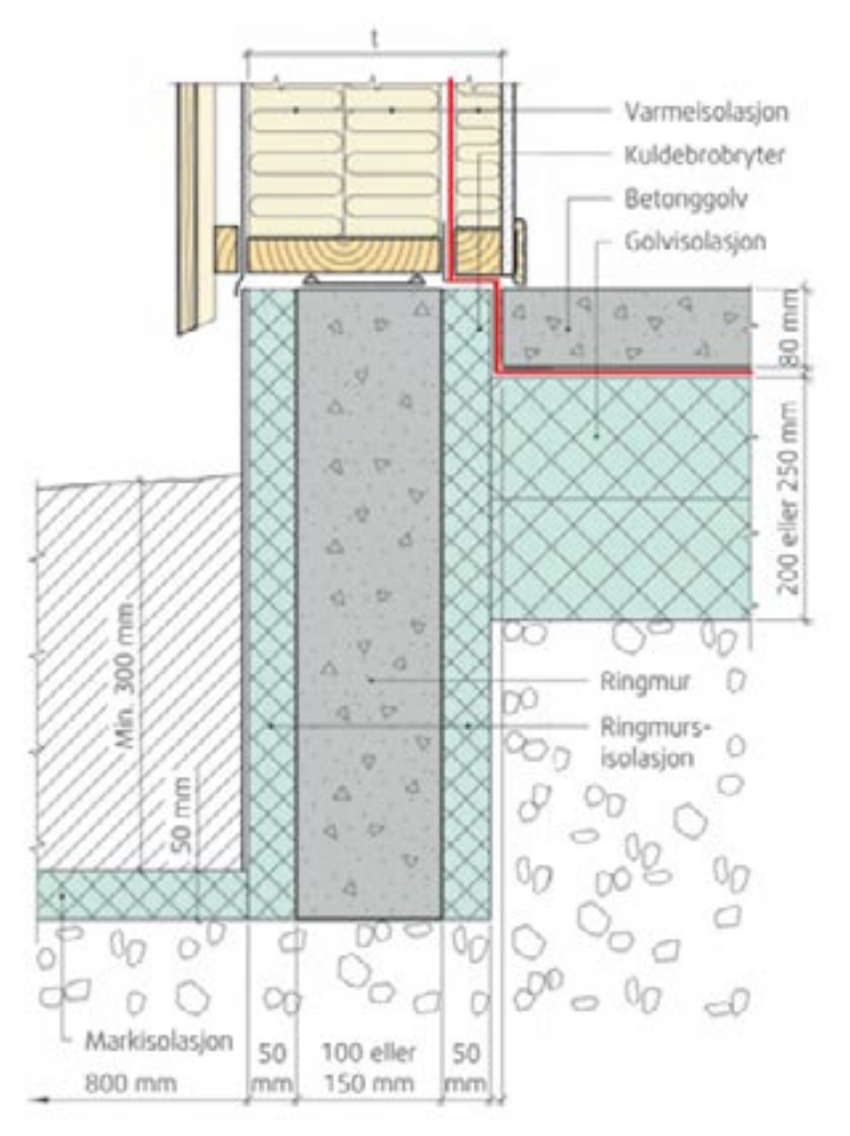
Roofing is also back-ventilated

Insulation is protected from wind by continuous weather barrier

Interior vapor retarder and air barrier is continuous (joints lapped and sealed) and protected from puncture by cross batten layer

Possible problem point – warmed air behind sheathing rises into soffit space and under roof deck

Norwegian cross-batten envelope



Stem wall foundation detail

Stem wall does not extend to frost depth – uses frost-protected shallow foundation approach. A footing may be neccesary

2” insulated gap between floor slab and stem wall creates a thermal break and keeps slab edge warm

Layers of insulation in wall are aligned with insulation layers below grade.

Vapor retarder and air barrier is continuous from below slab to wall (joints lapped and sealed)

Image from Byggdetaljer 2008

Norwegian cross-batten envelope

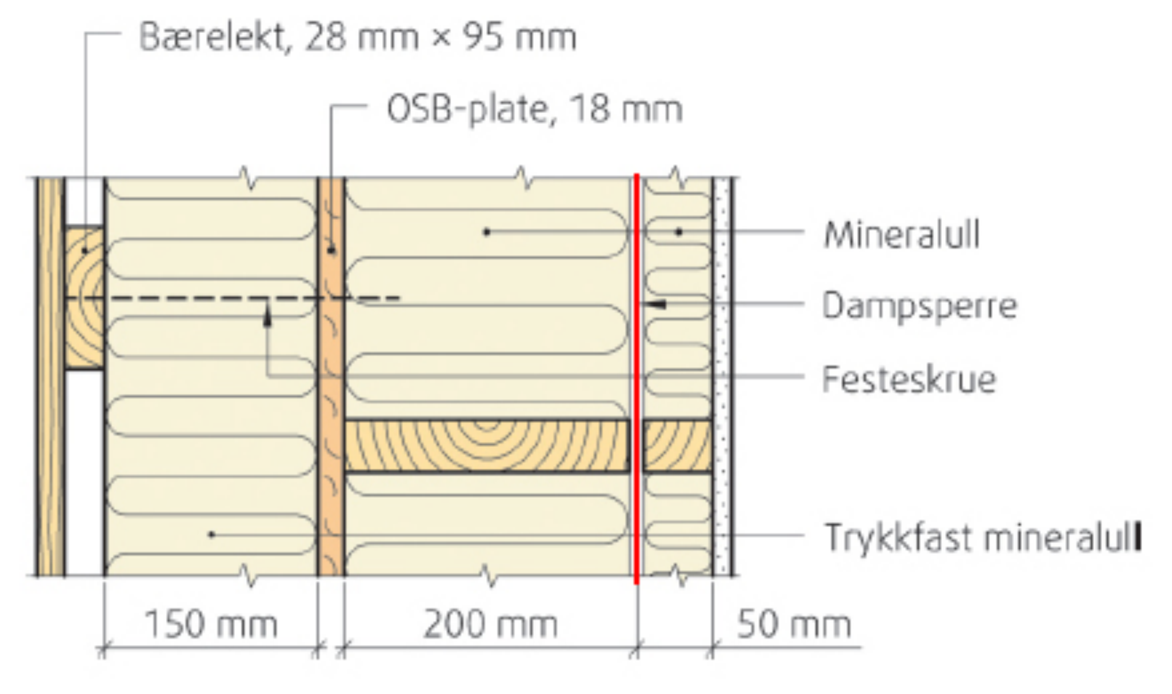


Image from Byggdetaljer 2012

Next generation wall section

Adds rigid exterior mineral wool, 3 to 6 inches

Provides thermal break for studs and plates

Keeps the sheathing warmer, added heat drives down moisture levels and reduces mold-growth risk

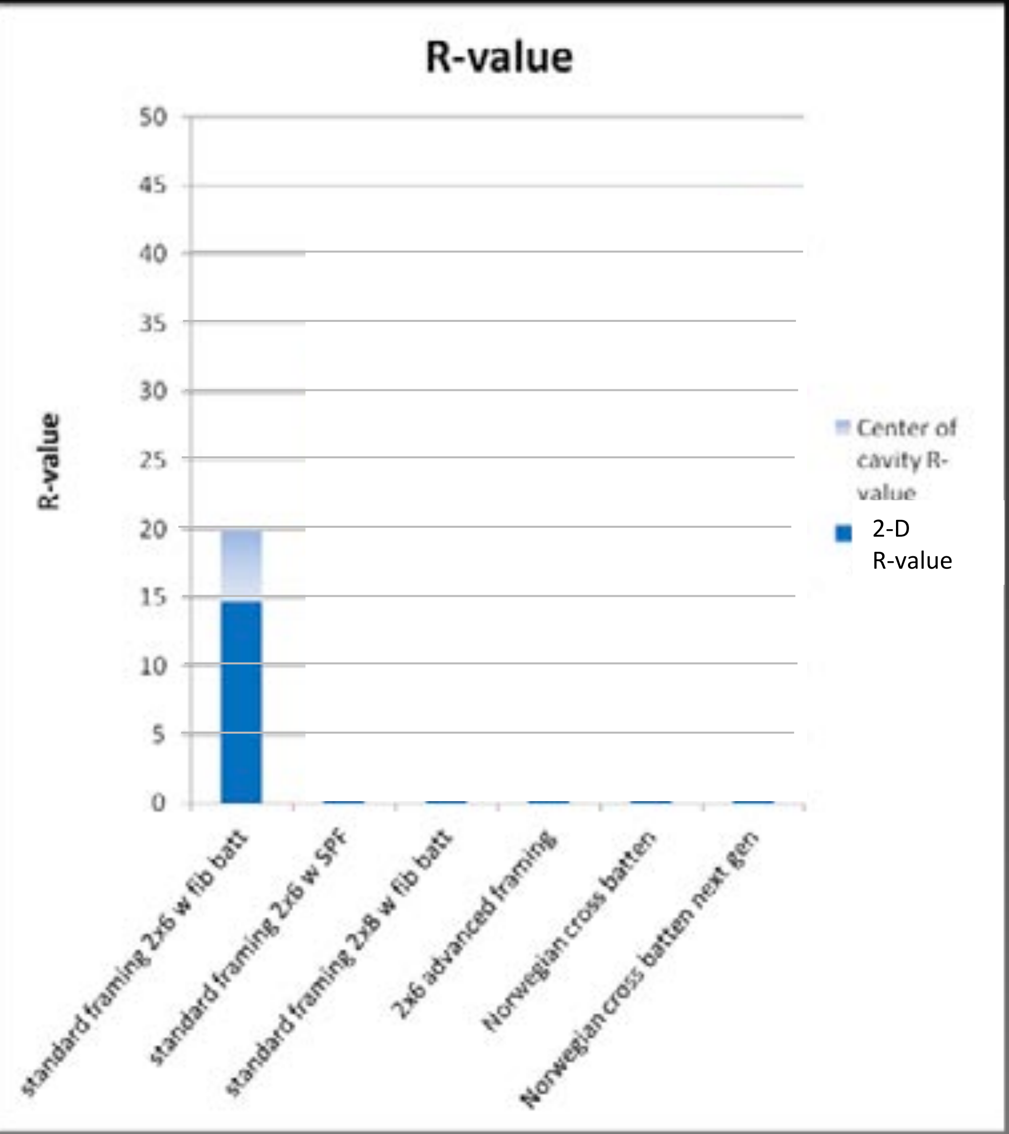
Section 1 – 2-D R-value calculations

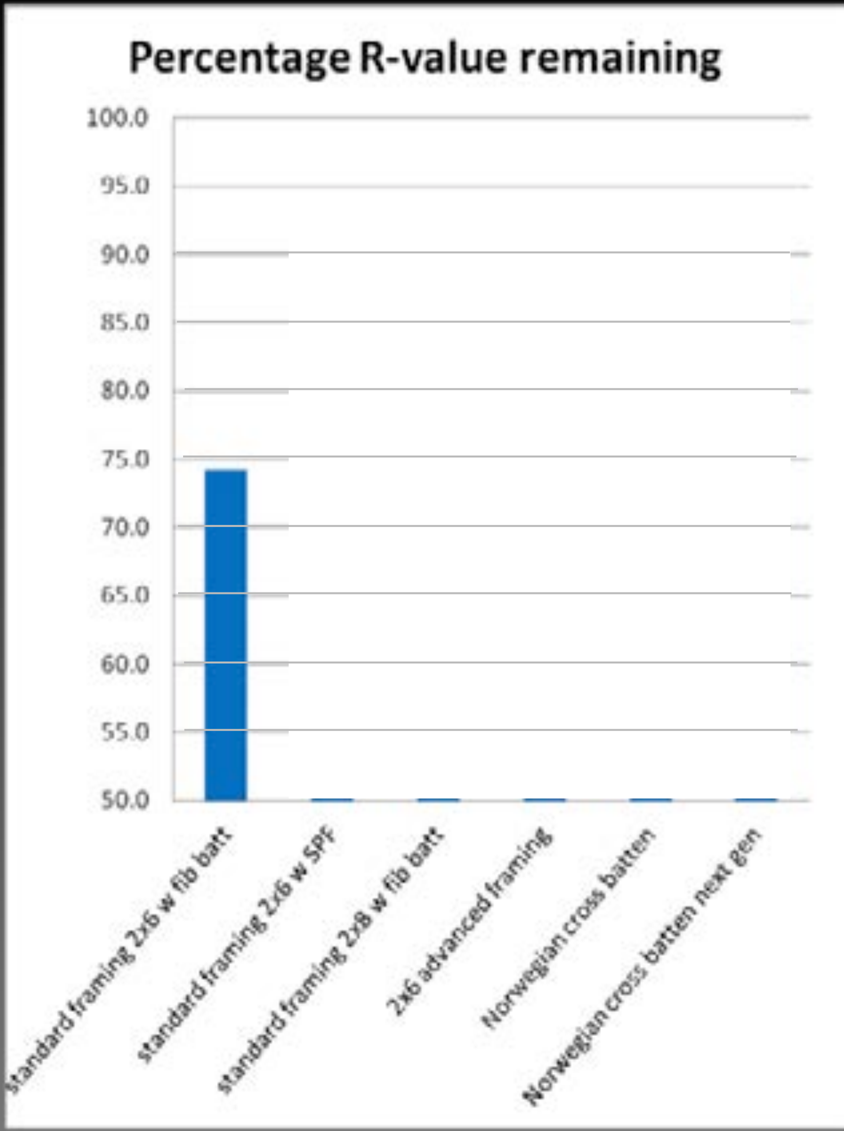
- Center of cavity R-value – the R-value calculated through the center of the wall, with no framing. (R-19) Very inaccurate.

- Clear wall R-value – the R-value calculated for a “clear” section of the wall (no windows, doors, other penetrations), includes framing, which can make up 25% of the wall area in typical residential construction. (R-16) This is the typical “parallel paths” or “UA method” used in U.S.

- 2-D R-value – based on the “clear wall” calculation, but adds lateral heat flow in the wall. Takes into account extra heat loss due to 2-dimensional flow of heat through thermal bridges such as studs . (R-15.5) Follows EN ISO 6946

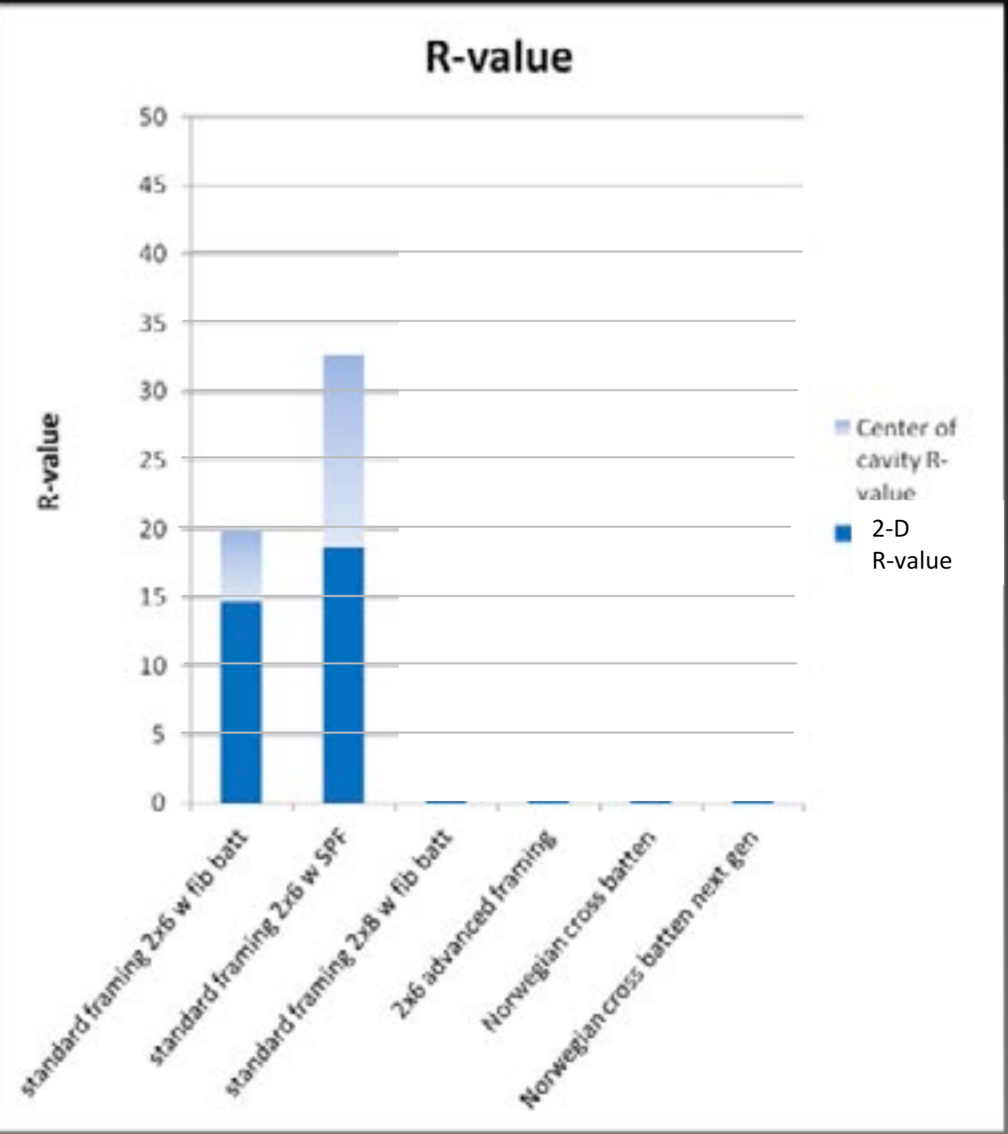
Section 1 – 2-D R-value calculations

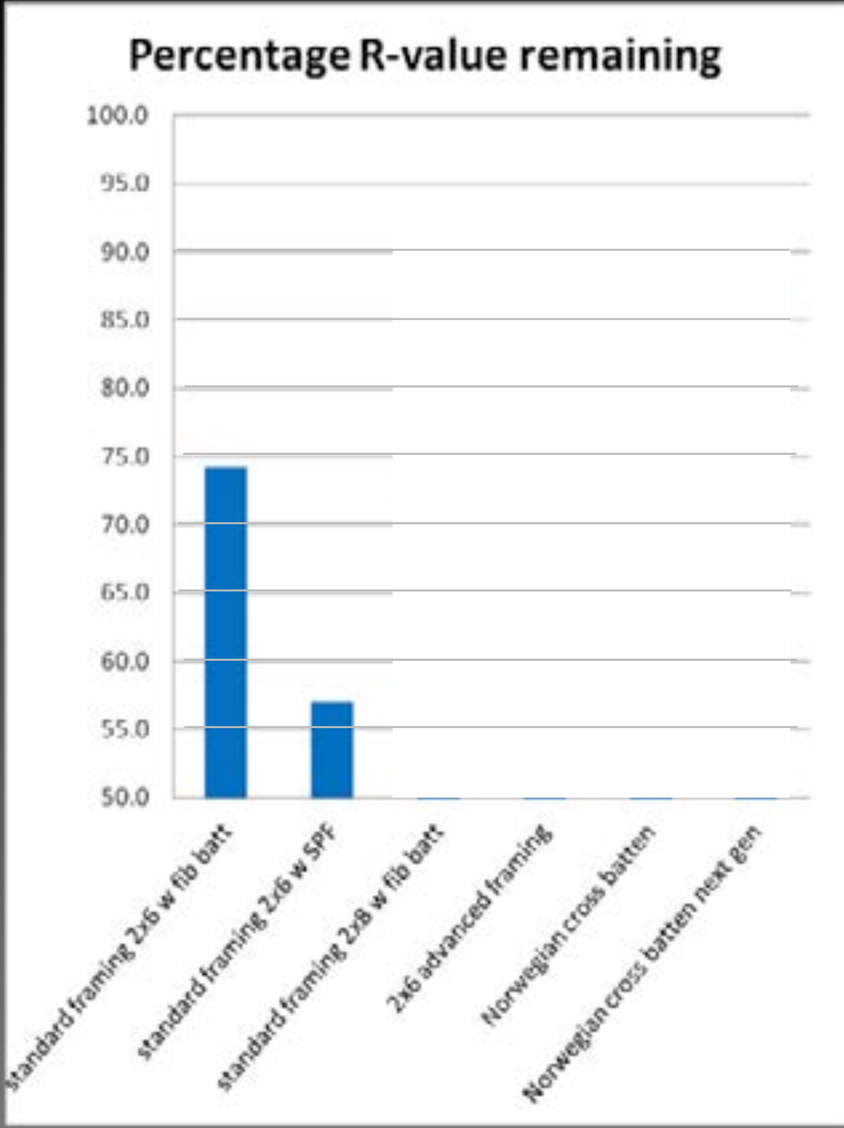




standard framing factor = 25%

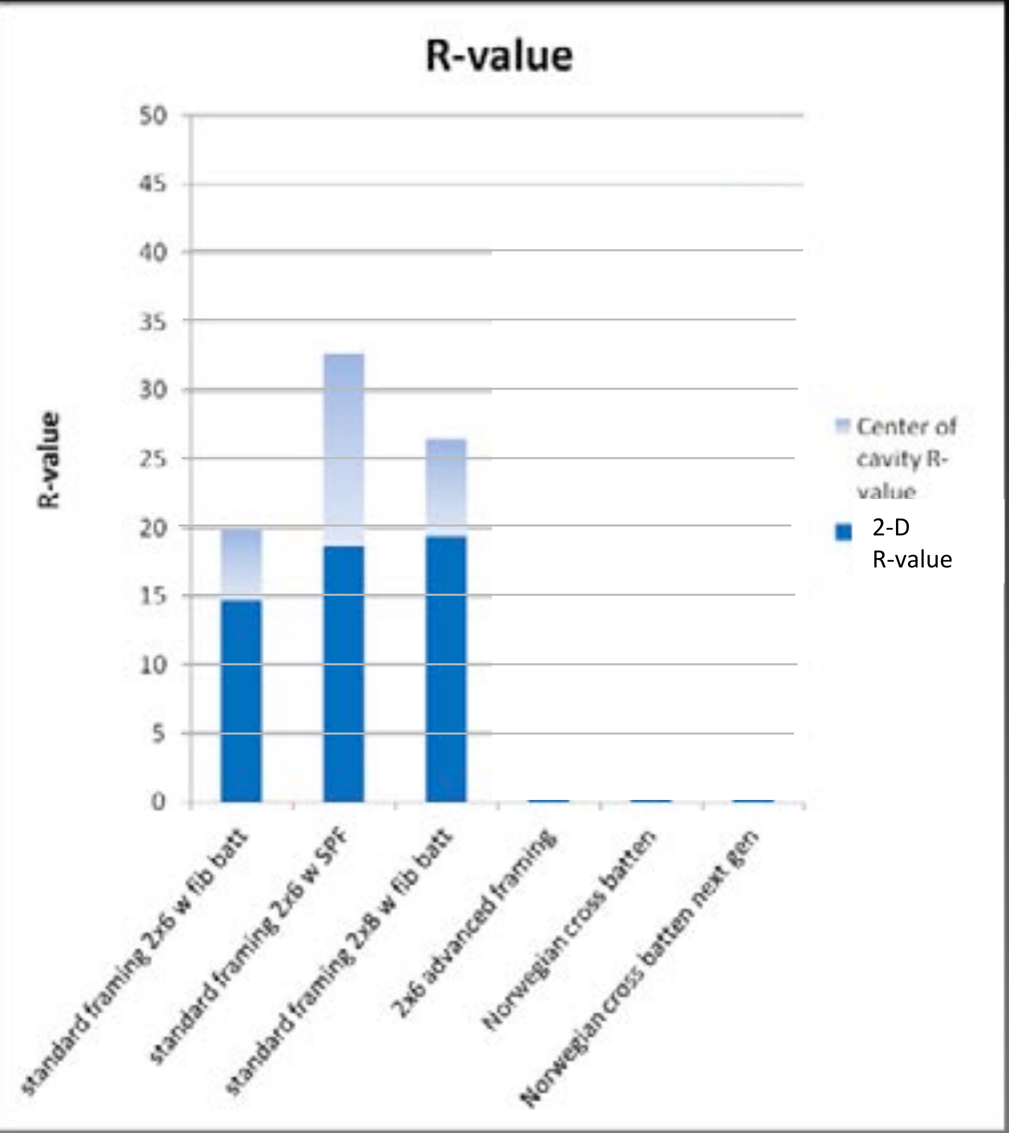
Section 1 – 2-D R-value calculations

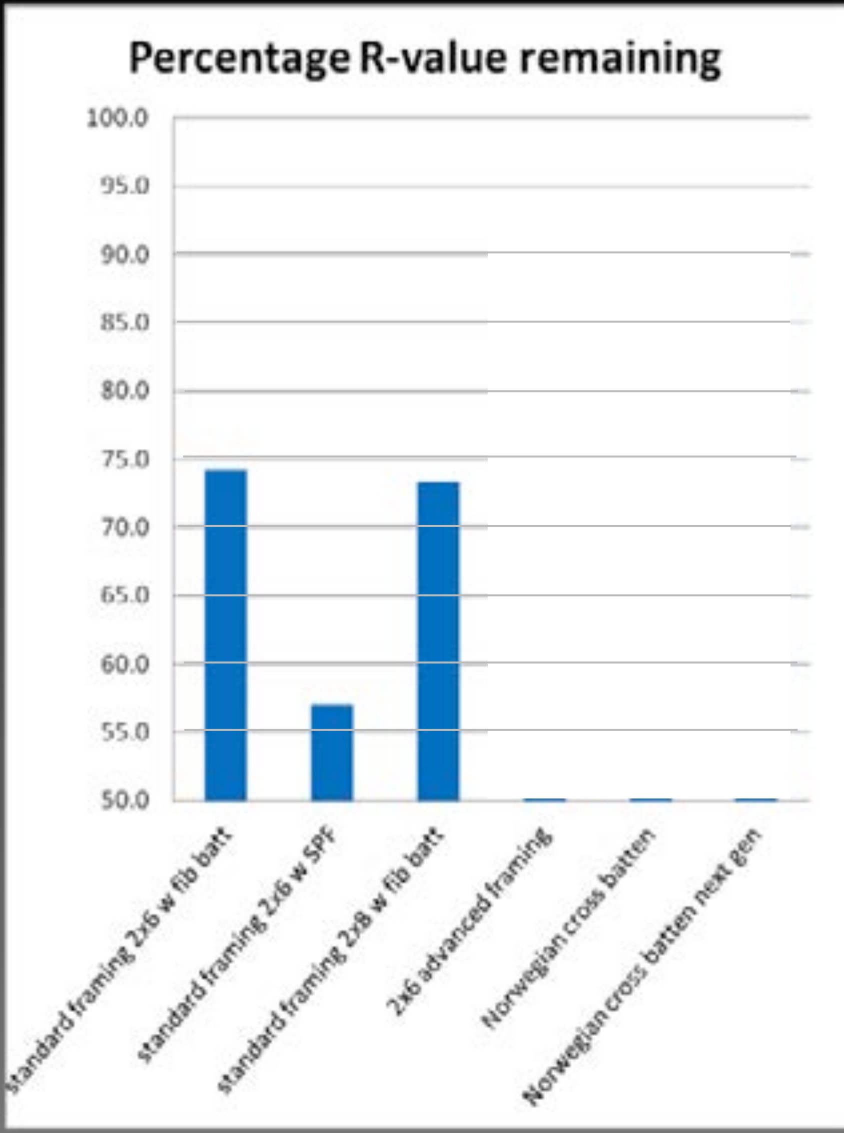

R-value


Percentage R-value remaining

standard framing factor = 25%

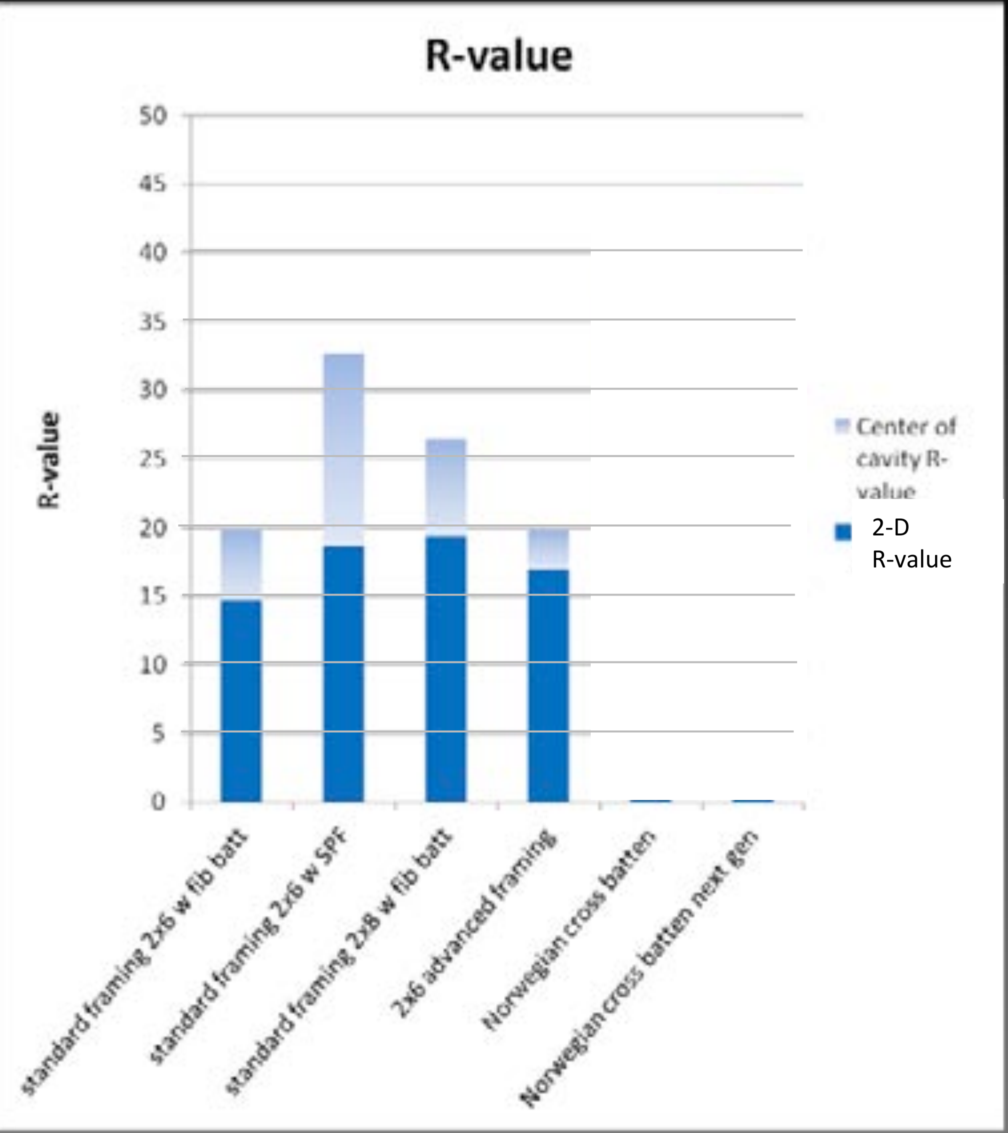
Section 1 – 2-D R-value calculations

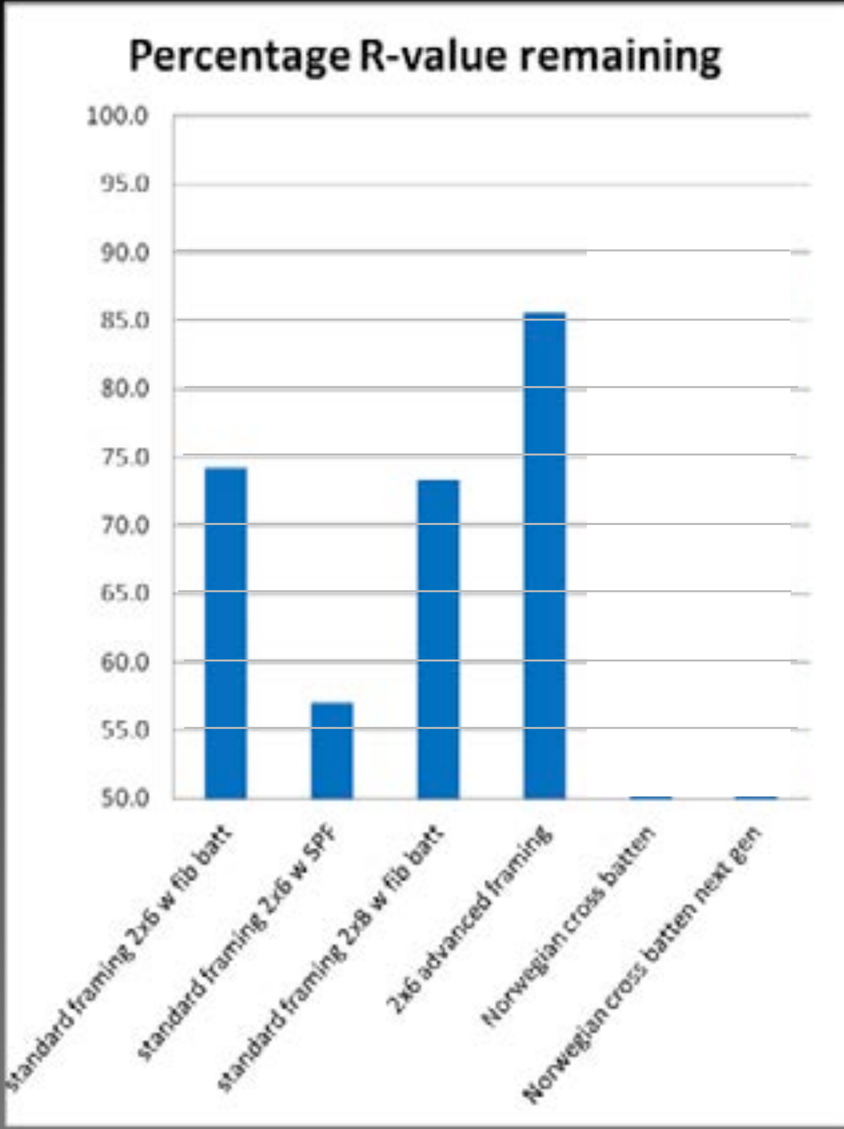




standard framing factor = 25%

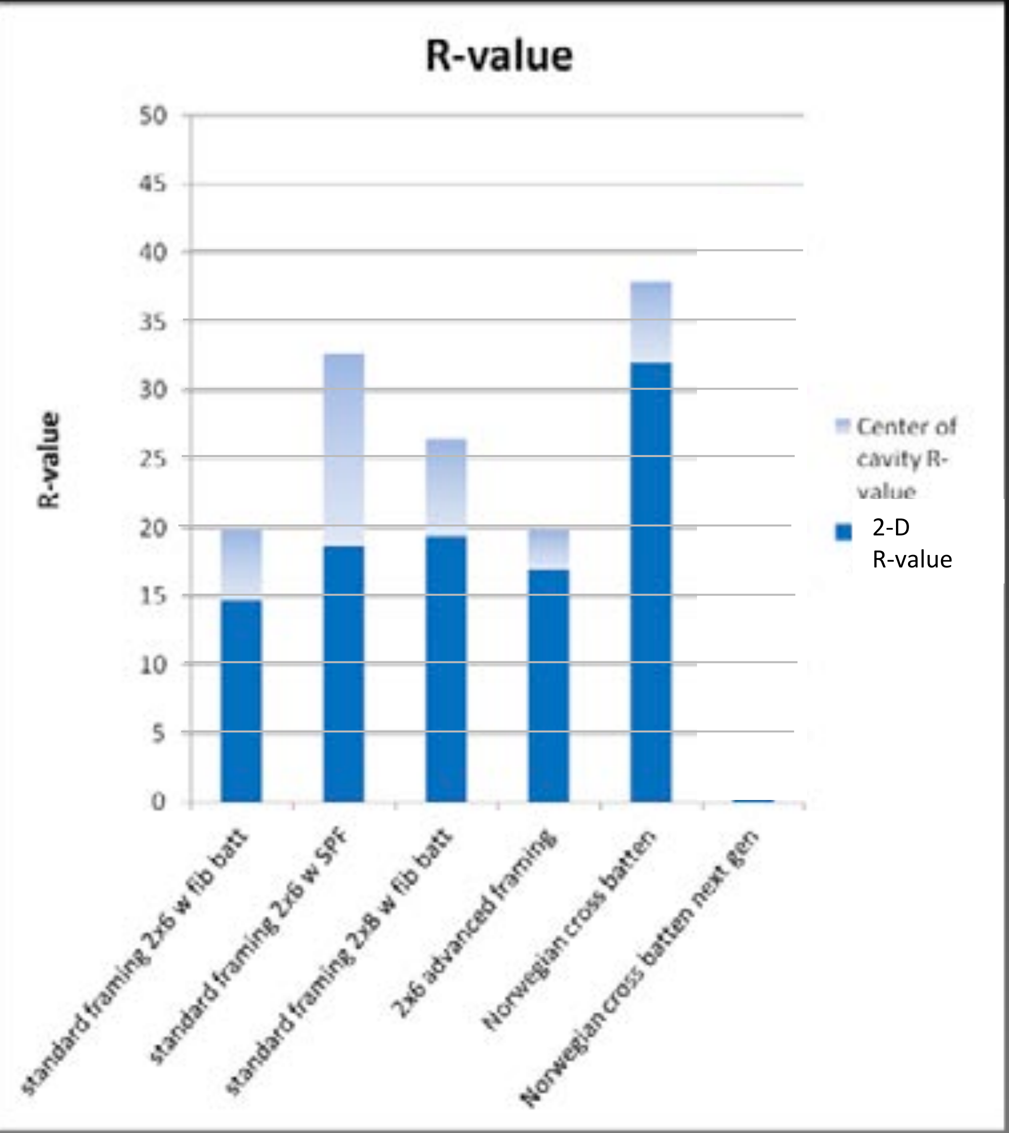
Section 1 – 2-D R-value calculations

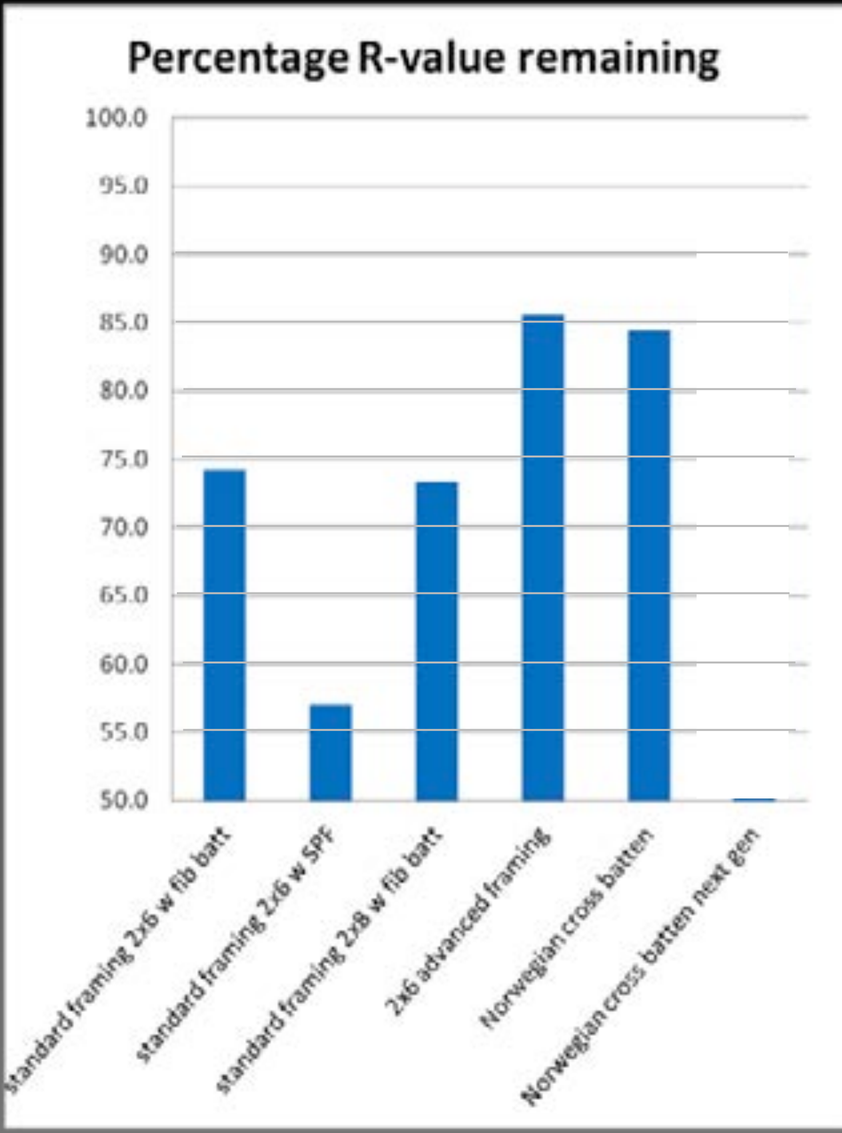




standard framing factor = 25% advanced framing factor = 12%

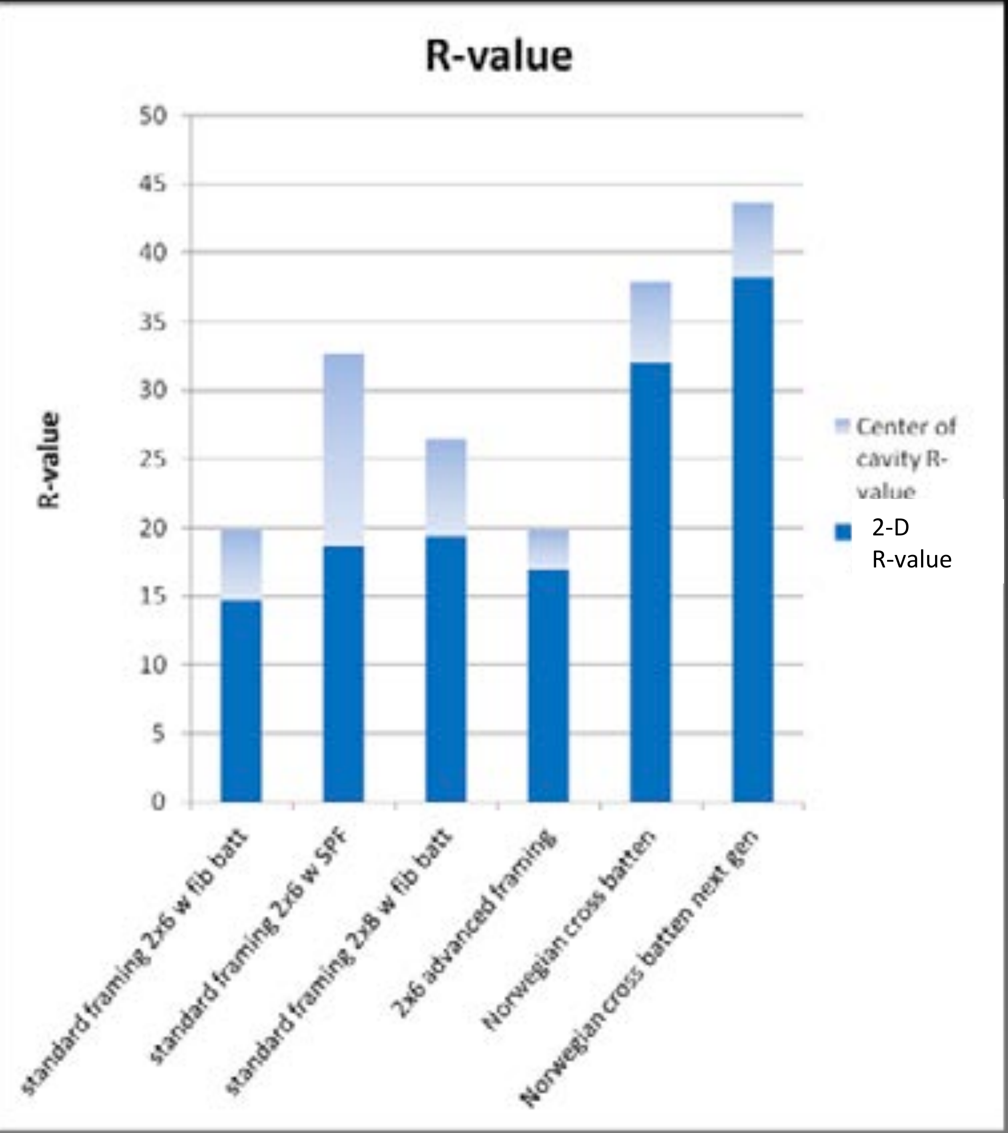
Section 1 – 2-D R-value calculations

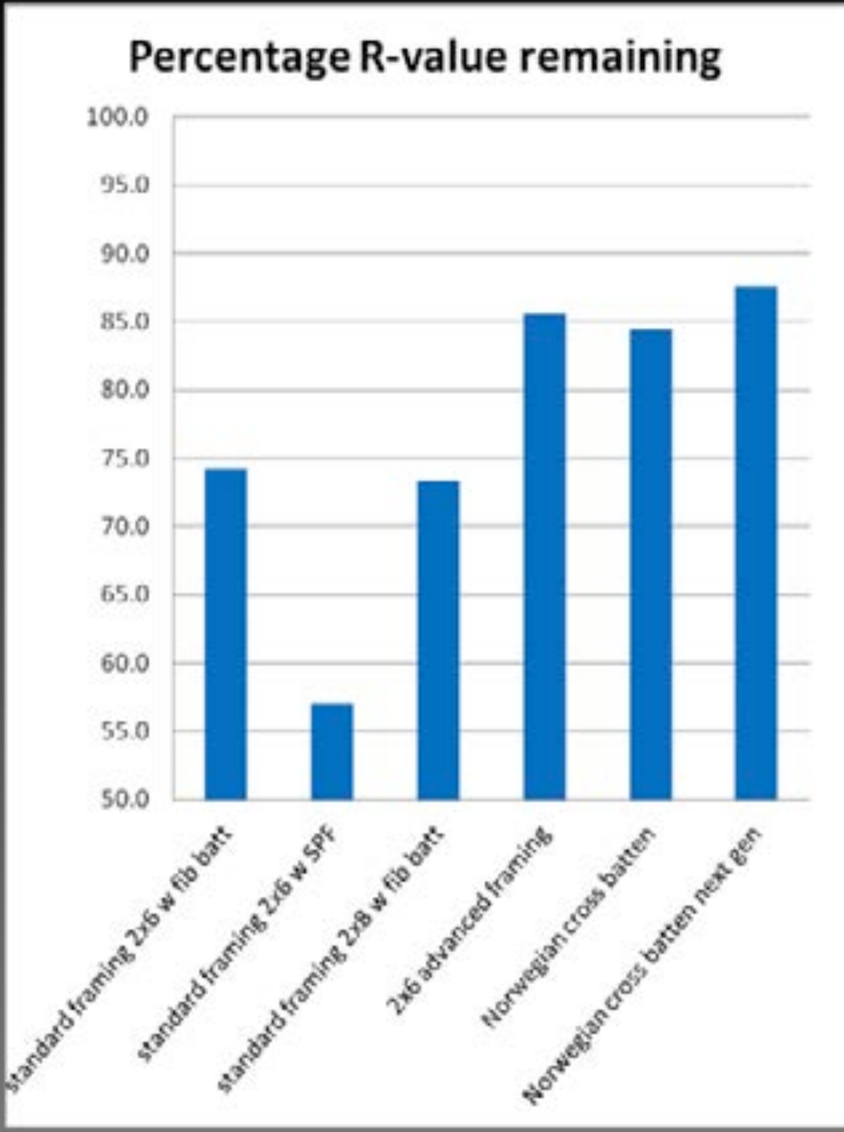




standard framing factor = 25%   Norwegian/advanced framing factor = 12%

Section 1 – 2-D R-value calculations





standard framing factor = 25%   Norwegian/advanced framing factor = 12%

Section 1 – 2-D R-value calculations

Summary

Two common techniques to improve R-value are only marginally effective:

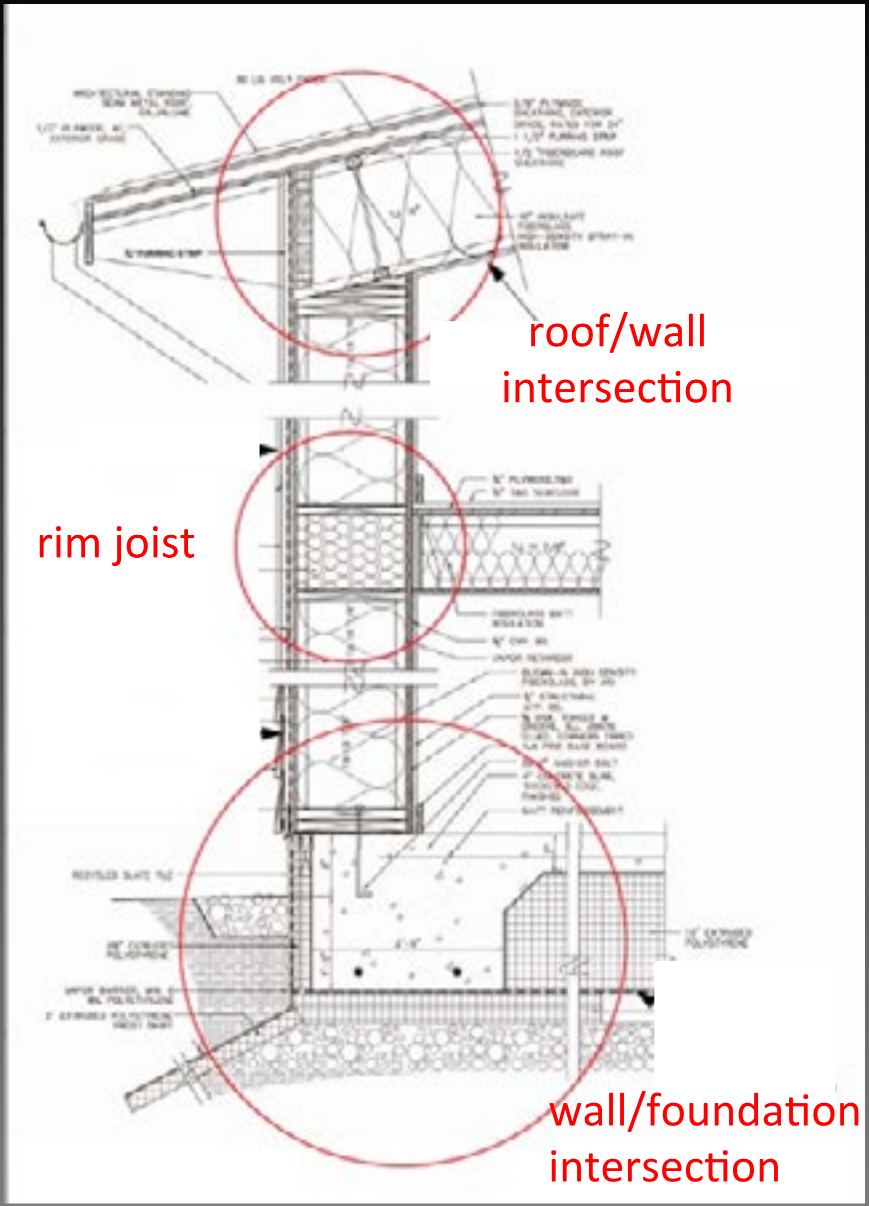
1) With better insulation such as closed cell spray foam (higher R-value/inch), a greater share of heat is lost through studs
2) With thicker stud walls, a greater share of heat is lost through the studs

A better solution is to reduce thermal bridging through the studs first.
Three options to reduce thermal bridging through studs:

1) Reduce amount of framing (advanced framing) – most effective
2) Apply continuous insulation layers – less effective, but still important
3) Use an alternative wall assembly, such as SIPs or ICFs

A common misnomer – cross battens are not as effective at reducing thermal bridging as expected, but they do create a layer behind which the air barrier can be effectively protected.

Section 2 – Thermal Bridge Analysis



Thermal bridges

- repetitive bridges – already accounted for
- point bridges – heat loss too small to consider
- linear bridges – heat loss should be calculated

Circled areas are common linear thermal bridges. Wall corners are also linear thermal bridges.

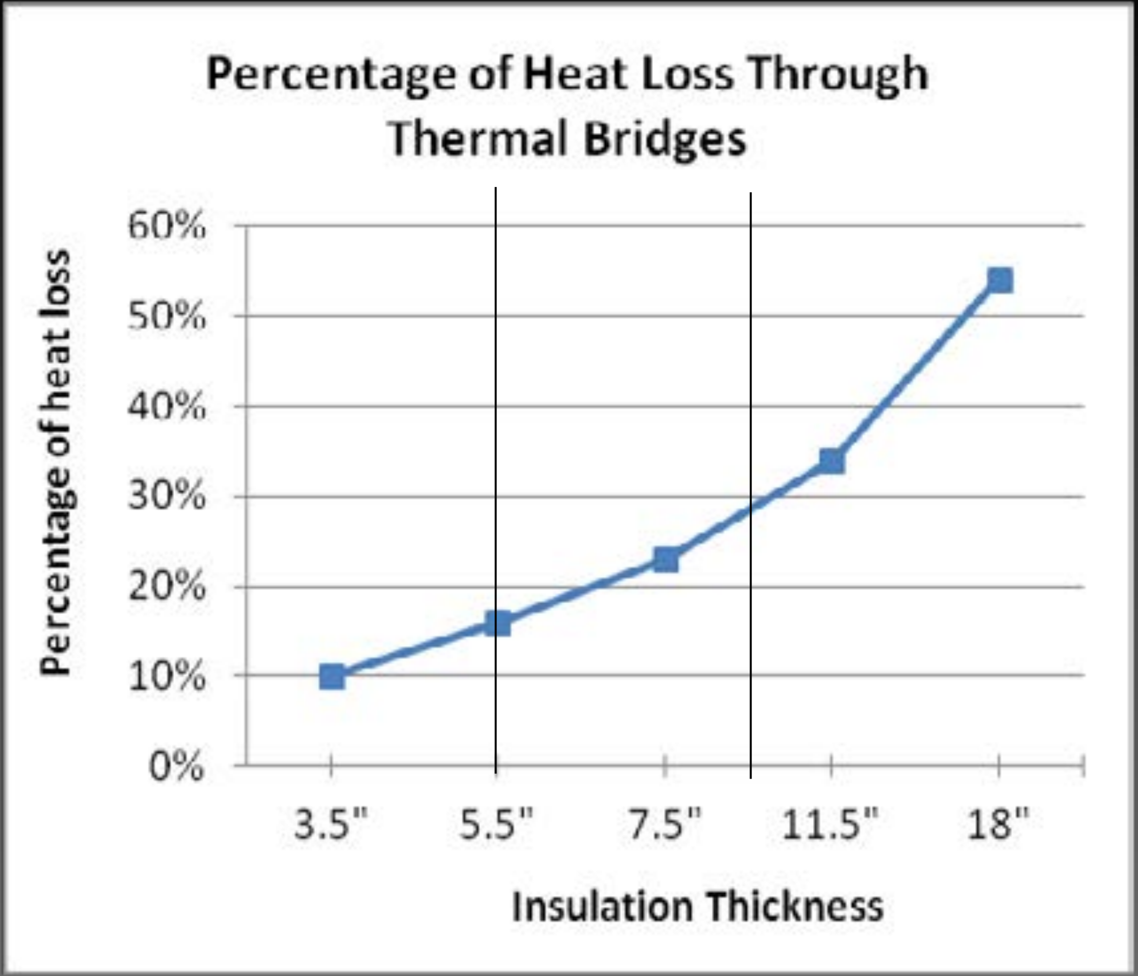
Image from David White, Right Environments, 2010

Section 2 – Thermal Bridge Analysis

Thermal bridges – why do they matter?

- Thermal bridges make up a small portion of heat loss in a poorly insulated envelope - 16% in a typical insulated 2x6 wall.

- If same details from a standard stud wall were used to construct the Norwegian envelope, heat loss through thermal bridges would approach 30%.



extrapolated from Christian, J.E. and J. Kosny. 1996

Conclusion - For highly insulated envelopes, thermal bridges must be considered!

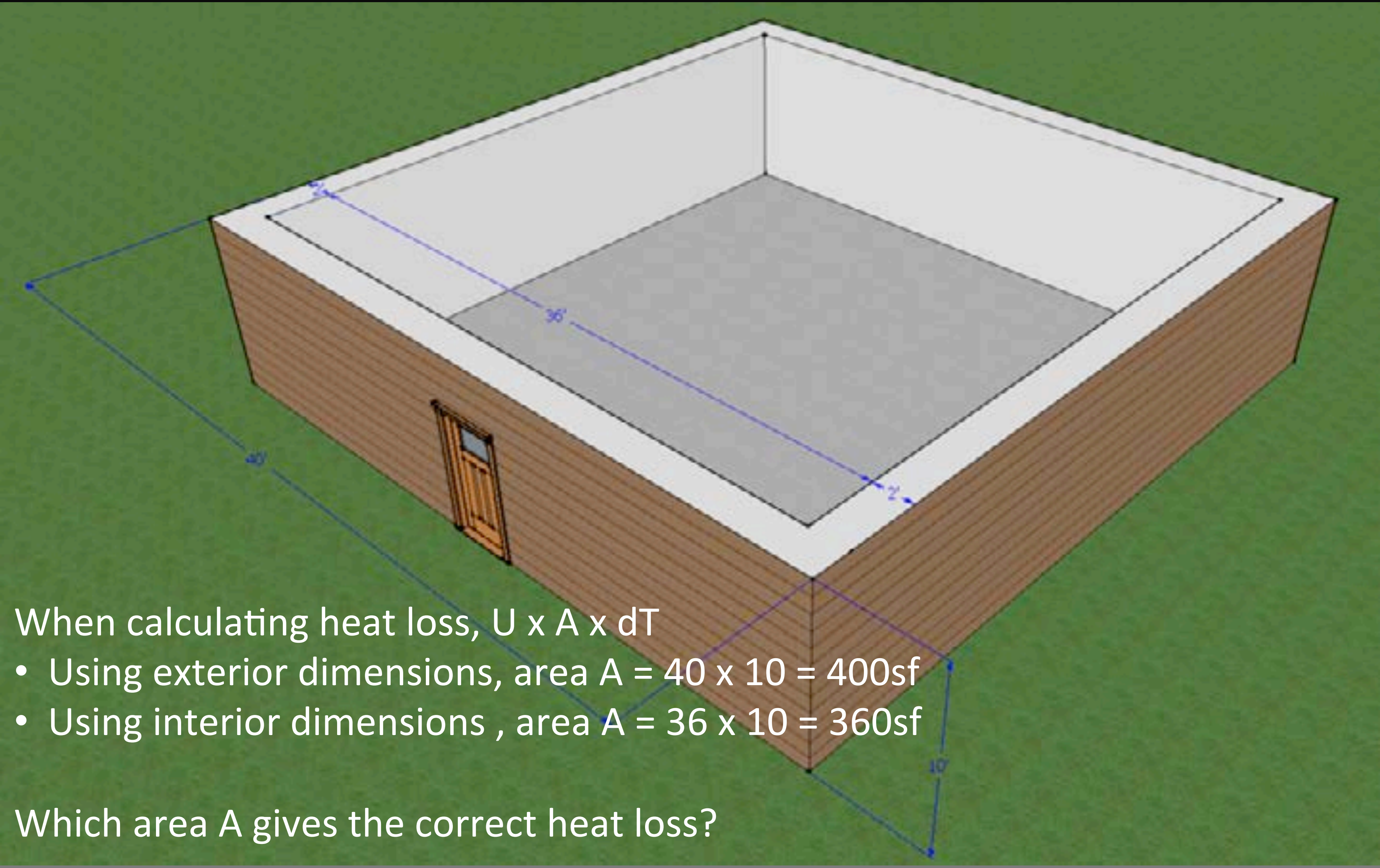
Section 2 – Thermal Bridge Analysis

- Heat loss through a linear thermal bridge is measured with a Ψ value
- A Ψ value is like a U-value for thermal bridges

  U x A x dT = heat loss from a surface, of area A

  Ψ x L x dT = heat loss from a linear thermal bridge, of length L
- Ψ values </= 0.01 W/mK qualify as “thermal bridge free” according to Passive House
- To calculate Ψ values, a 2-D heat flow simulation model (such as THERM) is used.

Section 2 – Thermal Bridge Analysis

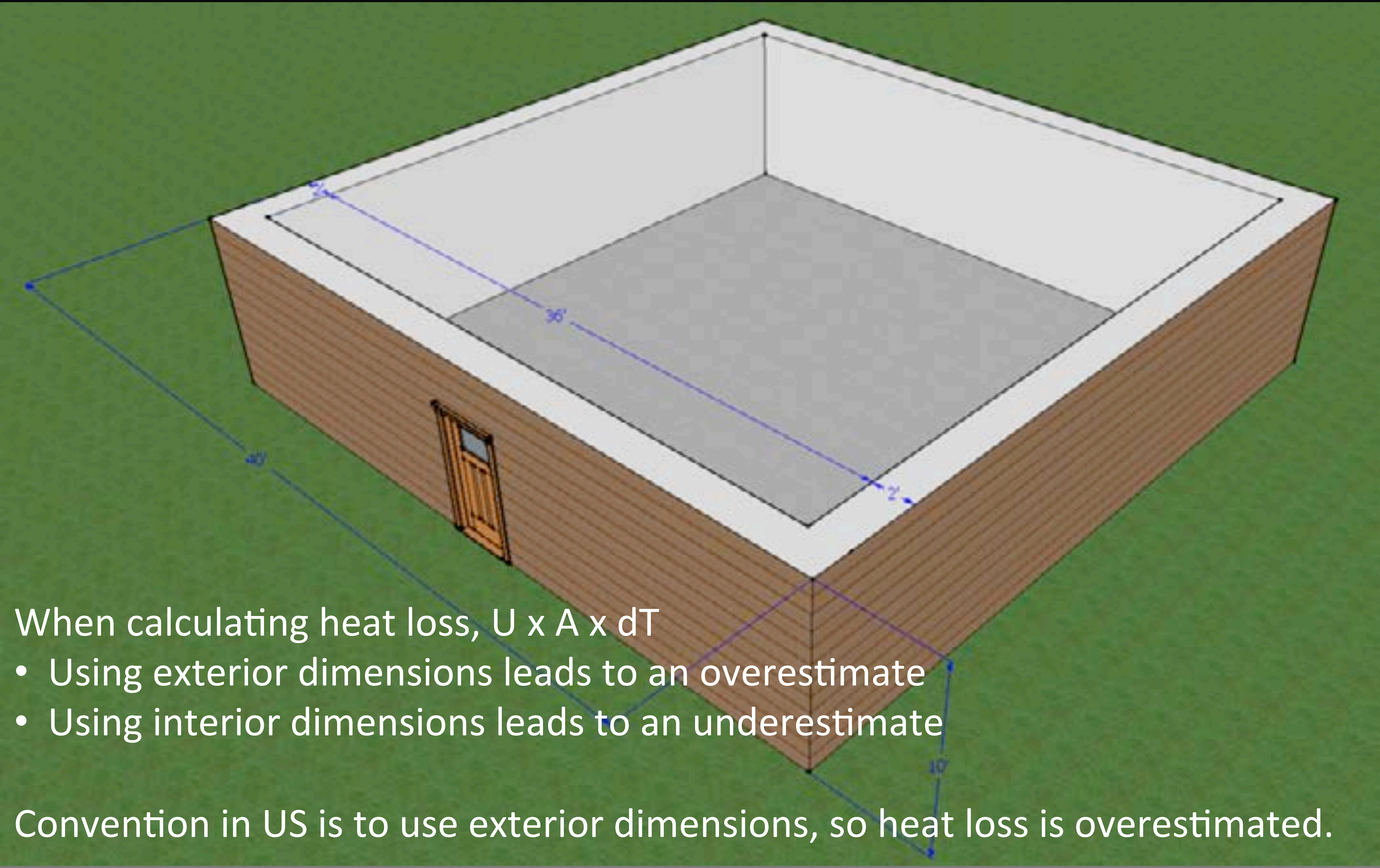


When calculating heat loss, U x A x dT

- Using exterior dimensions, area A = 40 x 10 = 400sf
- Using interior dimensions , area A = 36 x 10 = 360sf

Which area A gives the correct heat loss?

Section 2 – Thermal Bridge Analysis

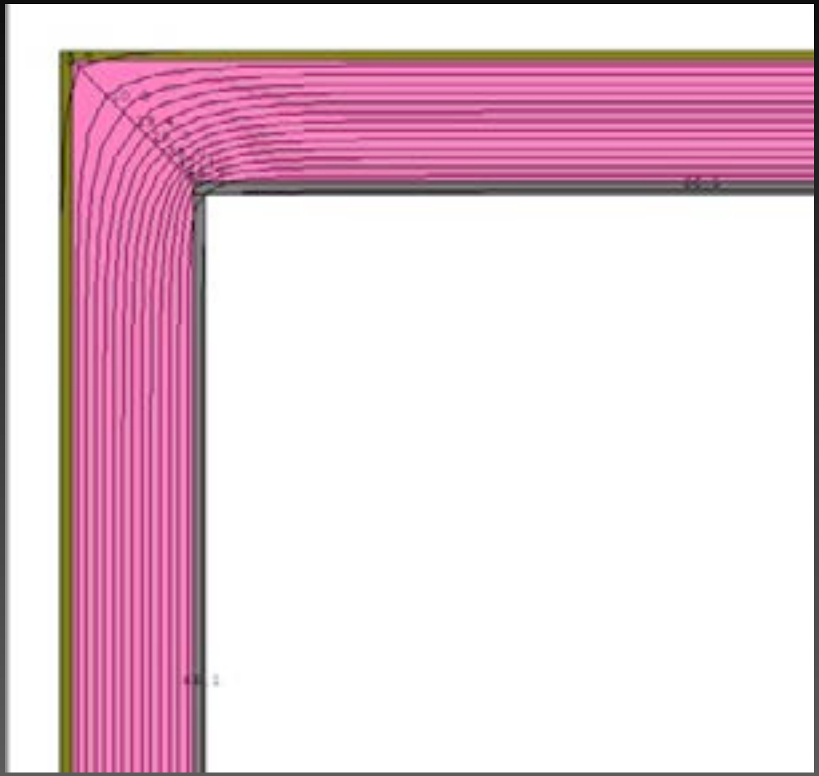


When calculating heat loss, U x A x dT

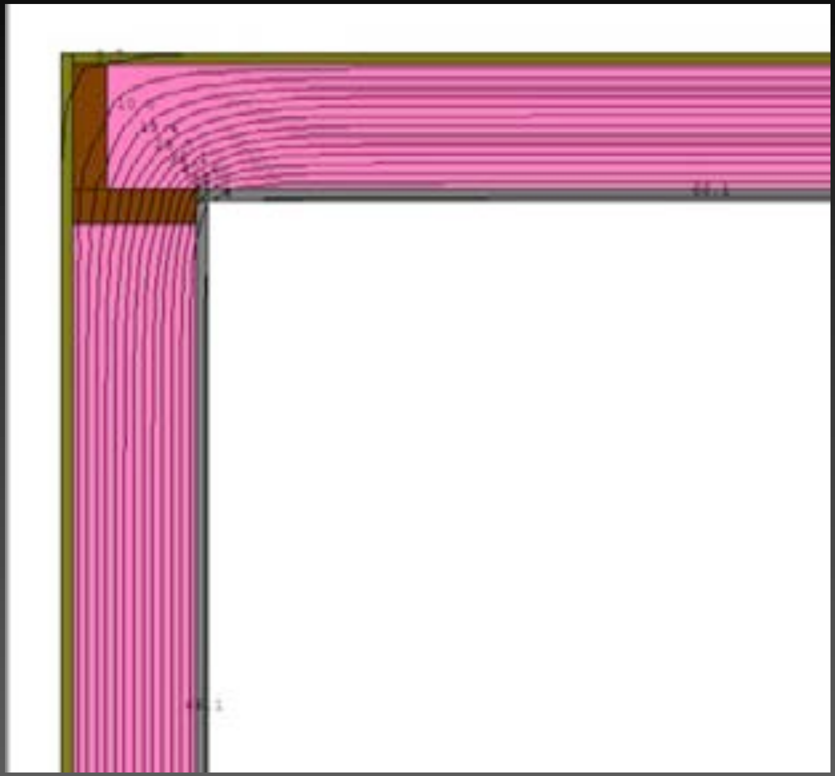
- Using exterior dimensions leads to an overestimate
- Using interior dimensions leads to an underestimate

Convention in US is to use exterior dimensions, so heat loss is overestimated.

Section 2 – Thermal Bridge Analysis



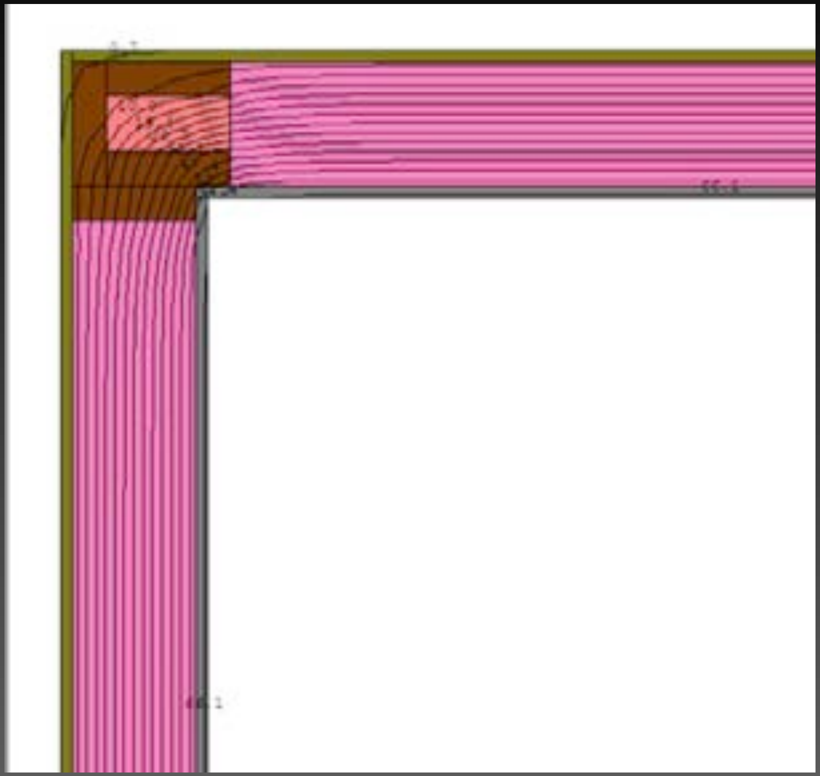
2x6 wall, no studs: Ψ = - 0.092 W/mK



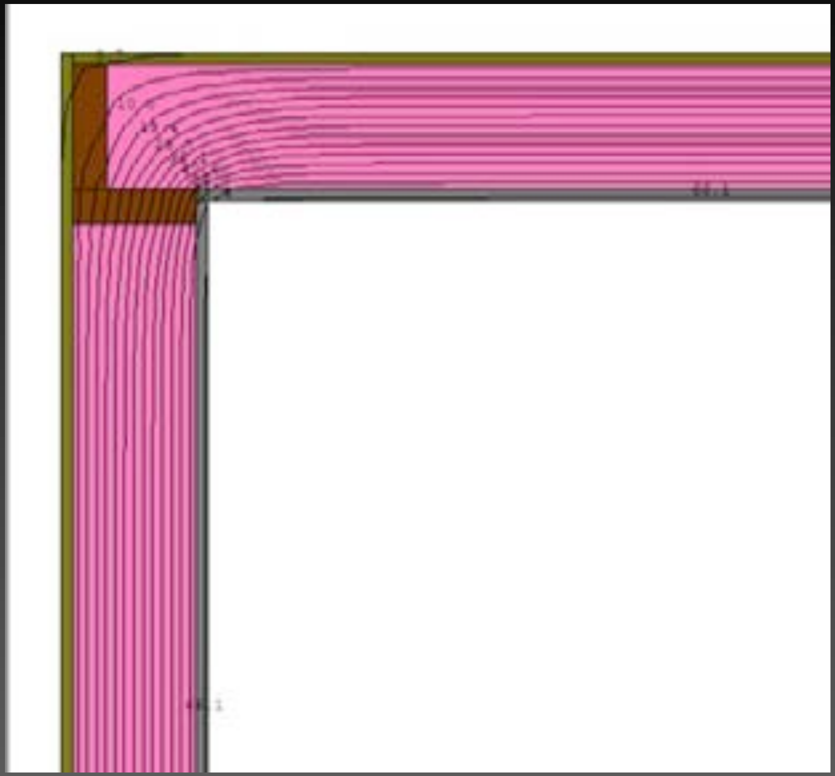
2x6 wall, 2-stud: Ψ = - 0.081 W/mK

- By subtraction, negative psi values correct for overestimate of heat loss at corners.
- The lower (more negative), the better. Higher psi values indicate increasing heat loss.
- Positive psi values above 0.01 W/mK indicate net heat loss that should be accounted for.

Section 2 – Thermal Bridge Analysis



2x6 wall, C-corner: Ψ = - 0.073 W/mK

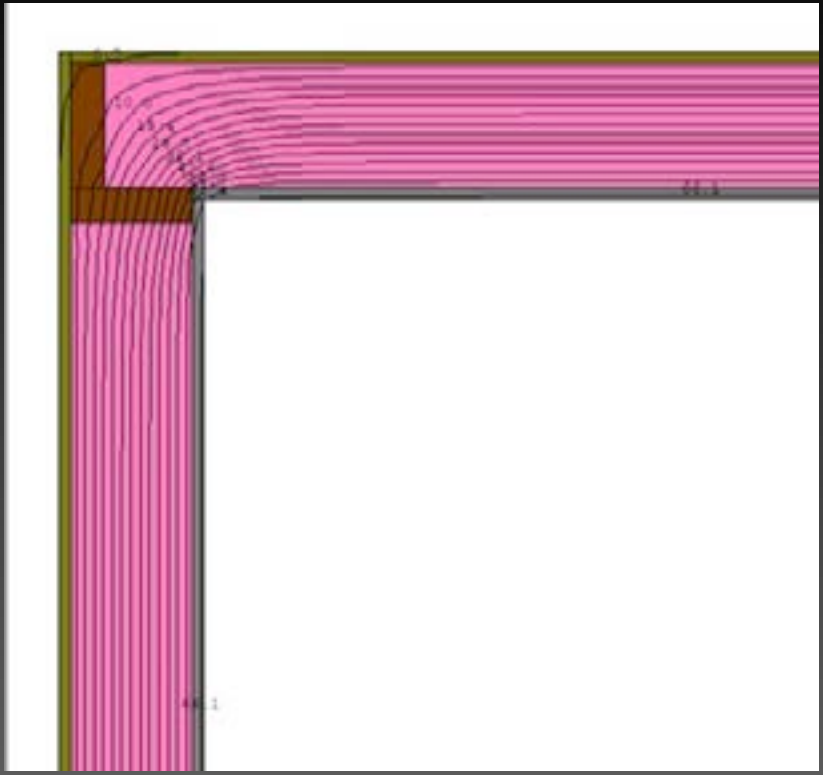


2x6 wall, 2-stud: Ψ = - 0.081 W/mK

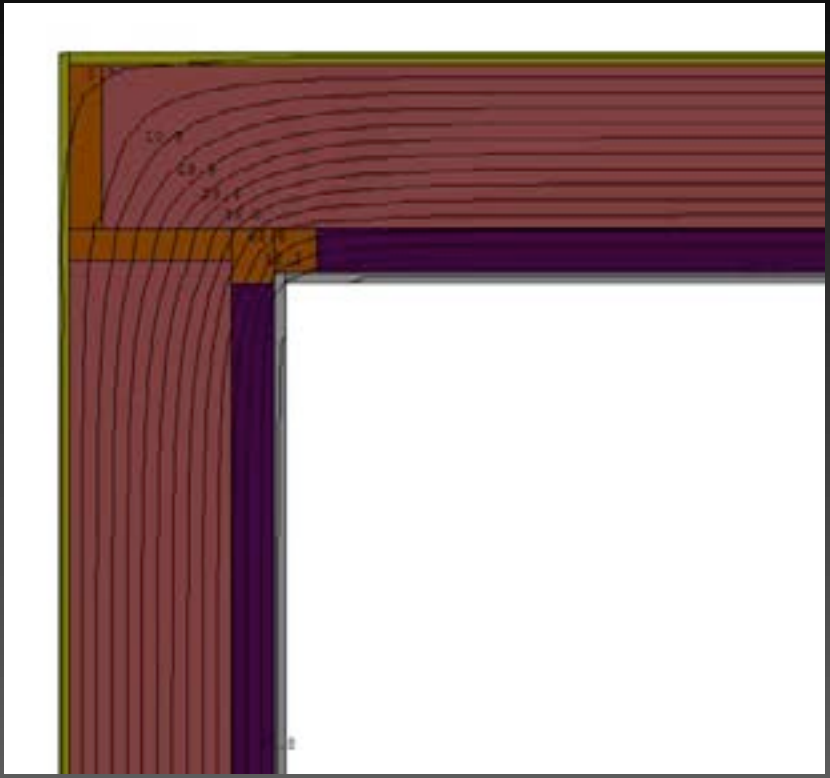
- As number of corner studs increase, the psi value increases, indicating increased heat loss
- The magnitude of additional heat loss going from a 2-stud to a C-corner = 0.01W/mK

STEP 1 – Avoid elements that bridge from interior to exterior

Section 2 – Thermal Bridge Analysis



2x6 wall, 2-stud: Ψ = - 0.081 W/mK

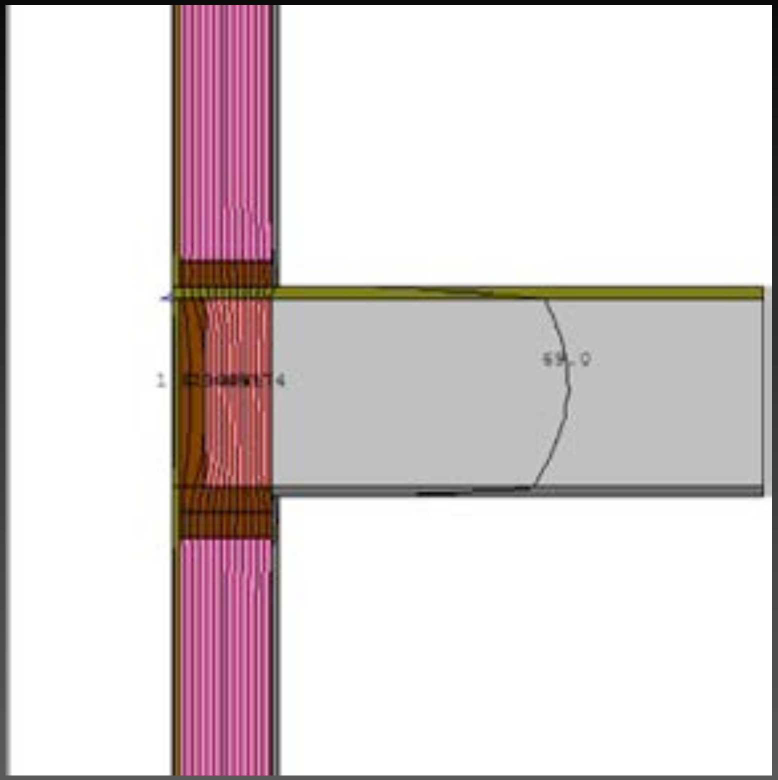


Norwegian wall: Ψ = - 0.056 W/mK

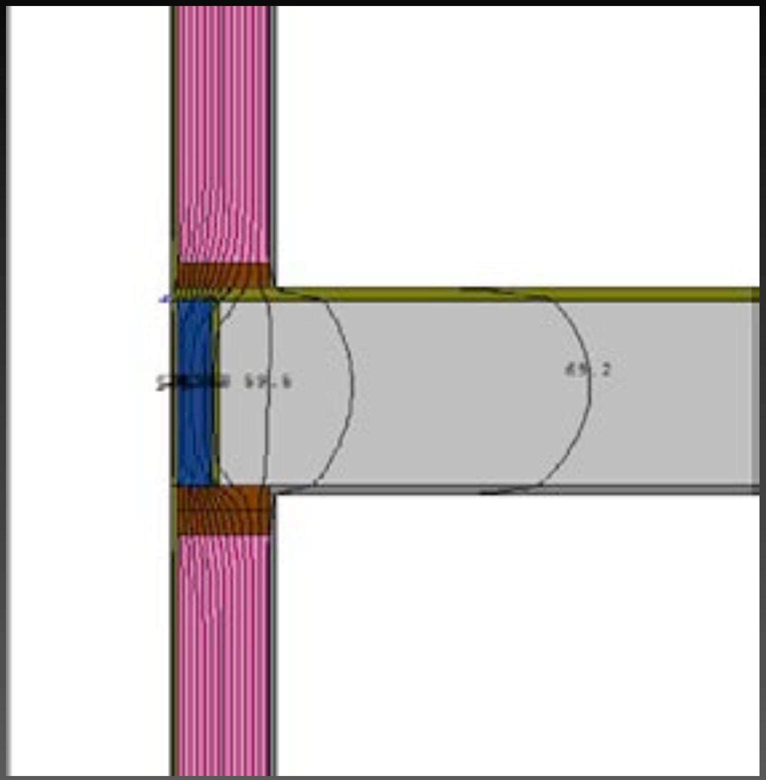
Essentially the same detail is used for the Norwegian wall, but mineral wool is thicker and provides more resistance to heat flow. Just like the 2-D R-values, this accentuates the effect of heat loss through the studs and leads to a higher psi value.

Confirms the importance of managing thermal bridge details for highly-insulated envelopes

Section 2 – Thermal Bridge Analysis



rim joist, fib. batt (R-15.5) : Ψ = 0.032 W/mK

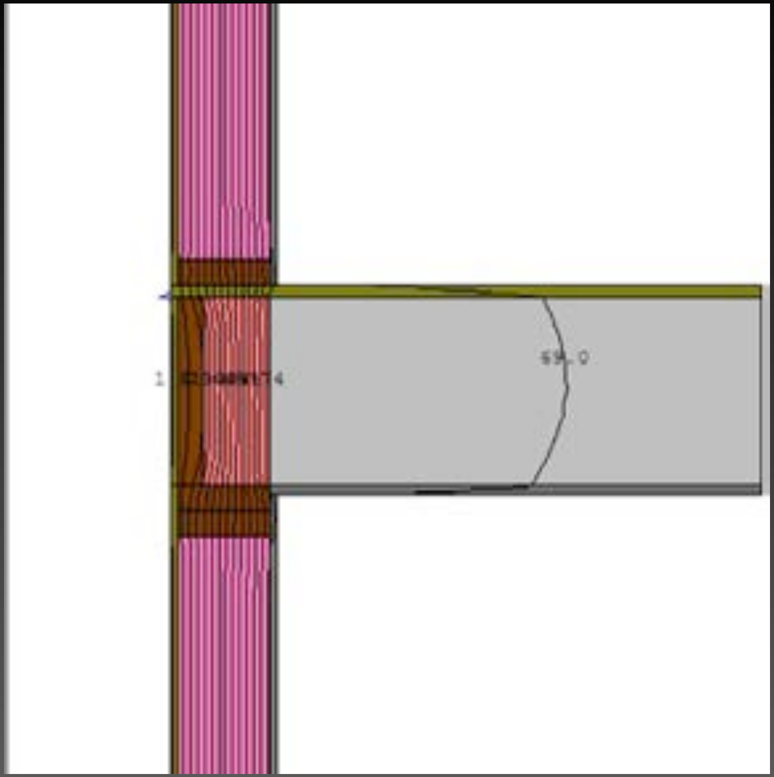


rim joist, rim board (R-12): Ψ = 0.086 W/mK

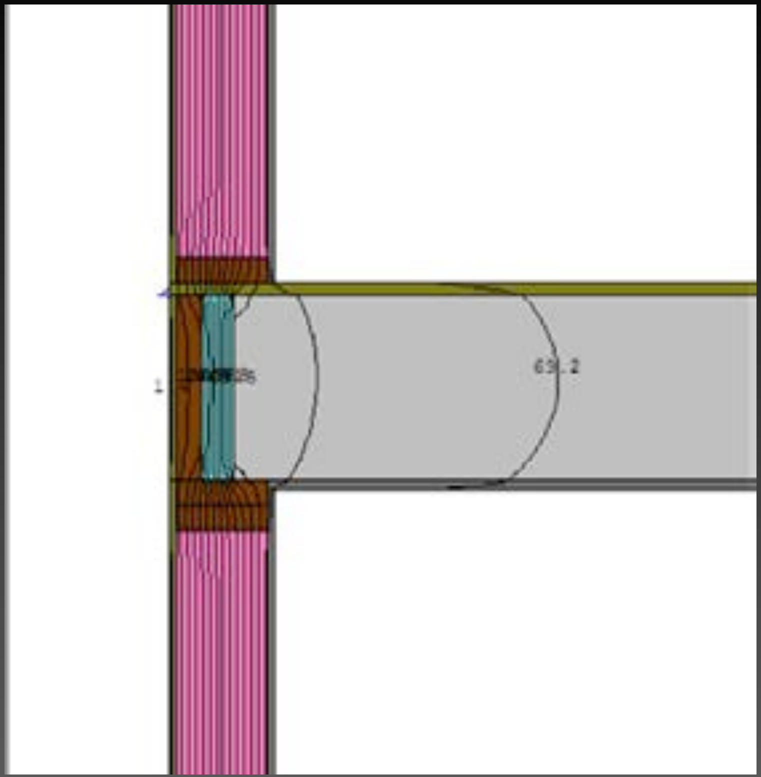
- Rim joist thermal bridge - challenging to achieve the Ψ = 0.01 W/mK target.
- Maintaining continuity and alignment of insulation layers is a good first step.

STEP 2 – Align insulation layers

Section 2 – Thermal Bridge Analysis



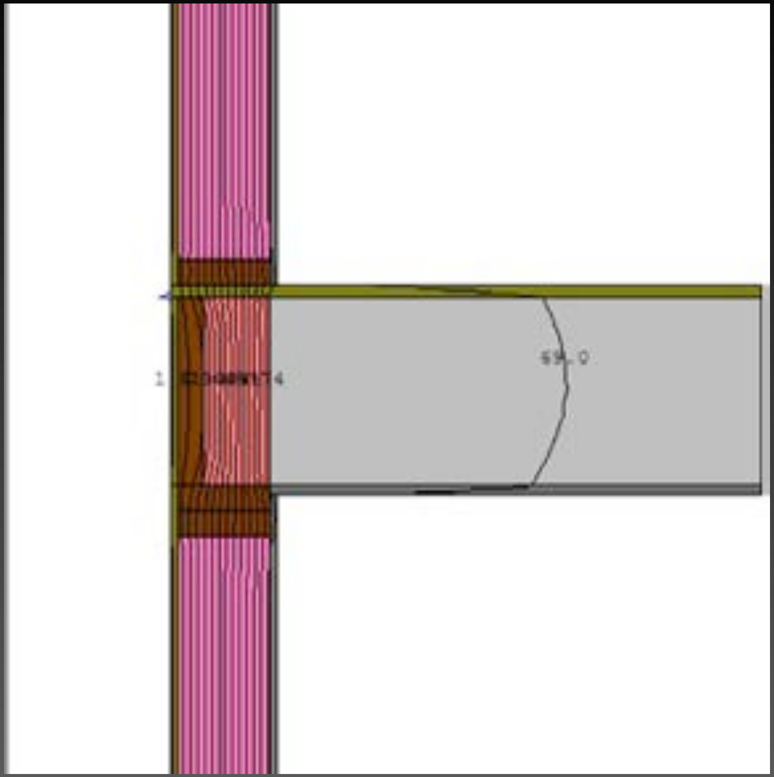
rim joist, fib. batt (R-15.5) : Ψ = 0.032 W/mK



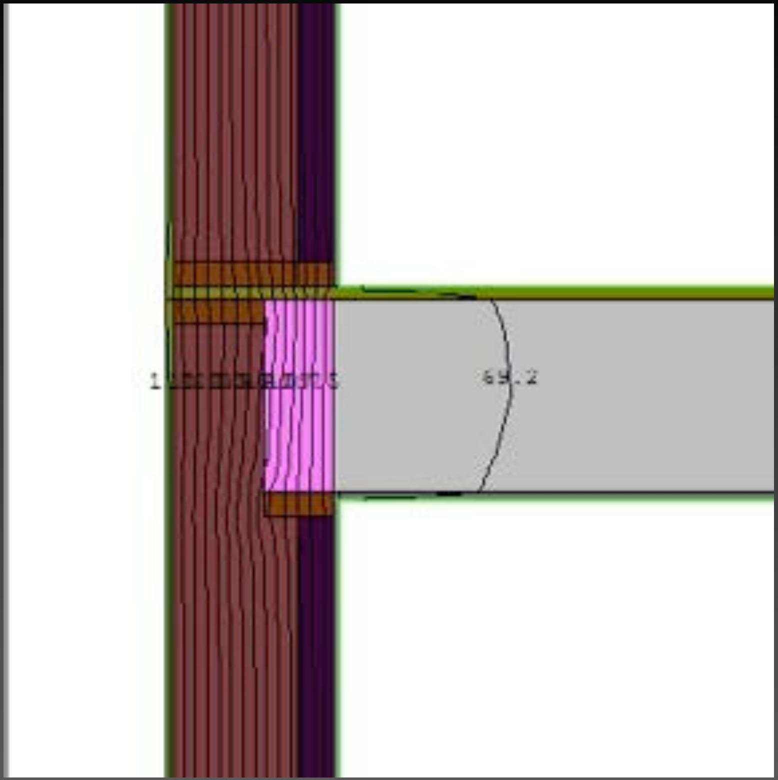
rim joist, 2” SPF (R-14.5): Ψ = 0.043 W/mK

- If alignment cannot be maintained, try to center the compression zone in the middle of the wall (goes for windows as well).
- Spray foam also provides important benefits such as air sealing and vapor control at the rim joist. Remember to consider other factors!

Section 2 – Thermal Bridge Analysis



rim joist, fib. batt (R-15.5) : Ψ = 0.032 W/mK

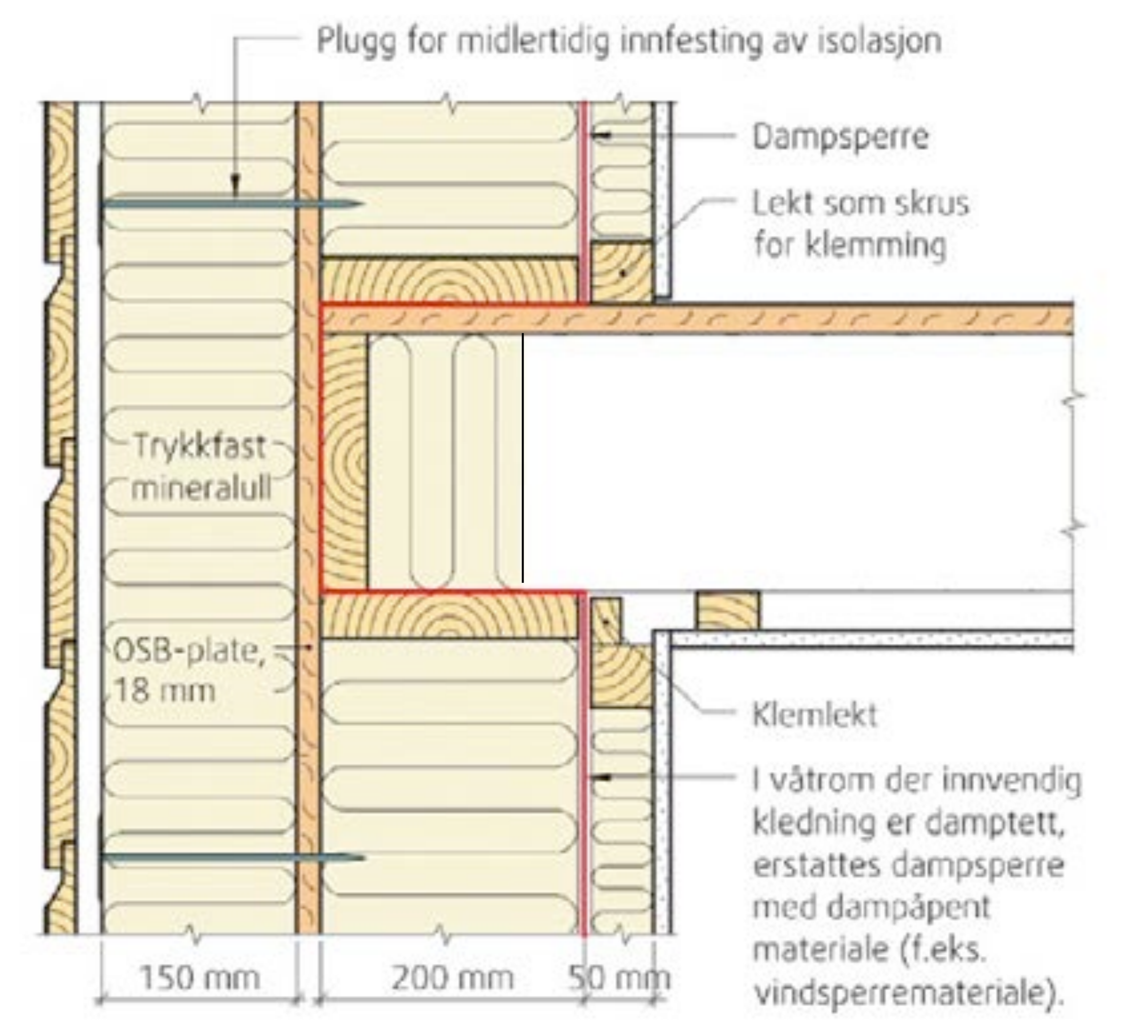


rim joist, Norwegian (R-30): Ψ = 0.021 W/mK

- Norwegian rim joist reduces number of bridging elements.
- Ψ = 0.01 W/mK target still not achieved – would require continuous exterior insulation covering the top and bottom plates.

STEP 3 – Use continuous exterior insulation to isolate bridging elements like plates and stud

Section 2 – Thermal Bridge Analysis



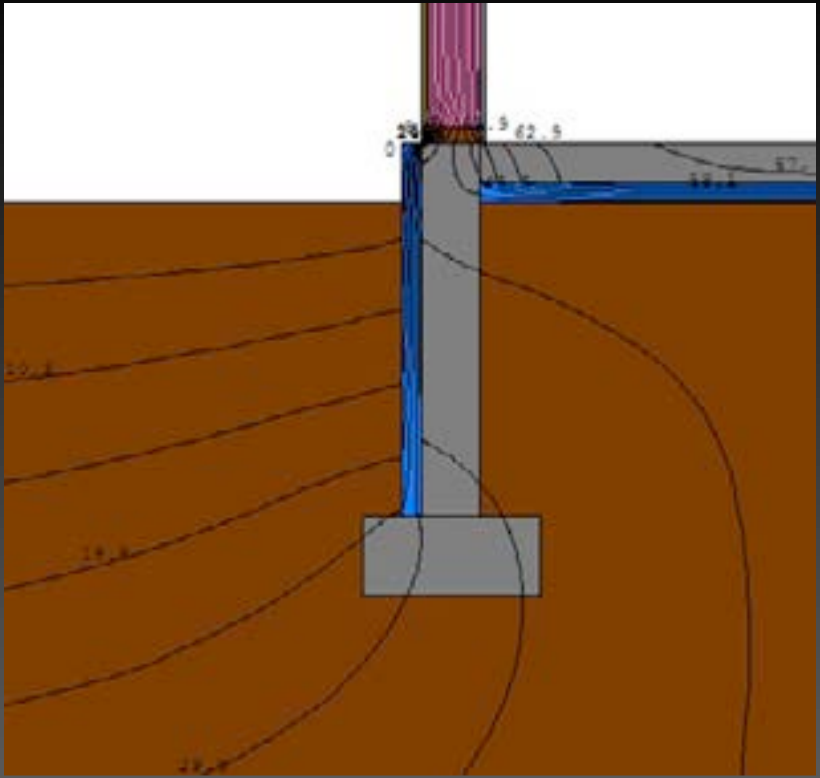
Next generation Norwegian rim joist detail

Adds rigid exterior mineral wool, 3 to 6 inches

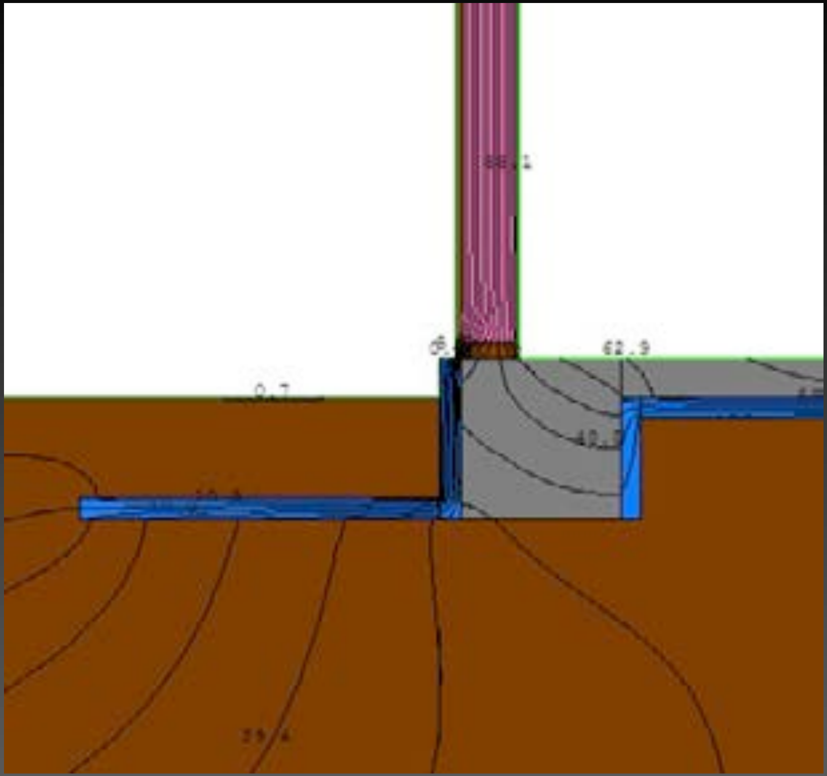
Provides thermal break for studs and plates

Image from Byggdetaljer 2012

Section 2 – Thermal Bridge Analysis



stem wall: $\Psi = 0.198$ W/mK

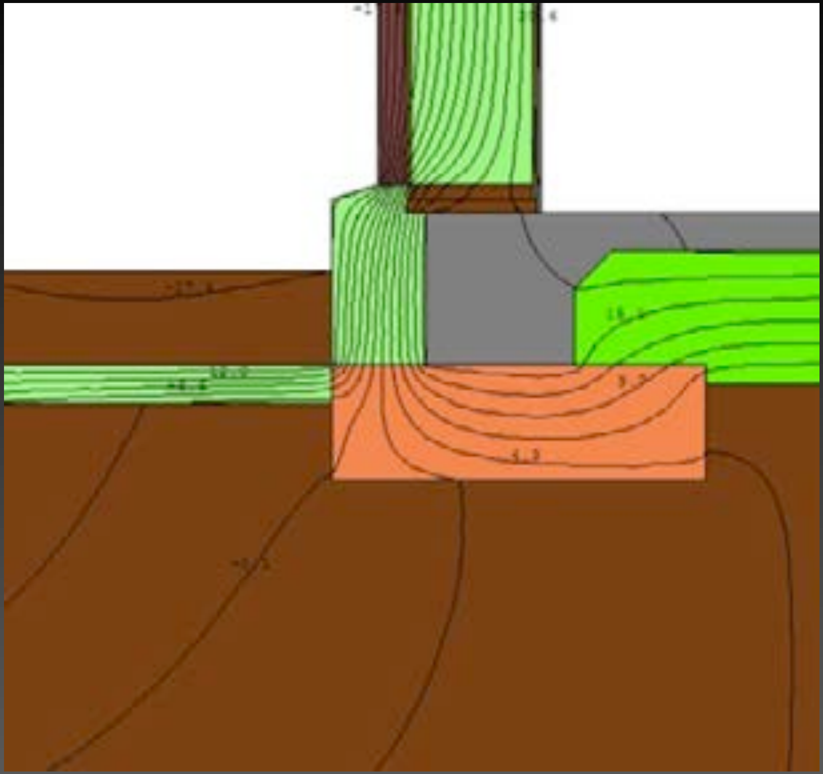


FPSF: $\Psi = 0.374$ W/mK

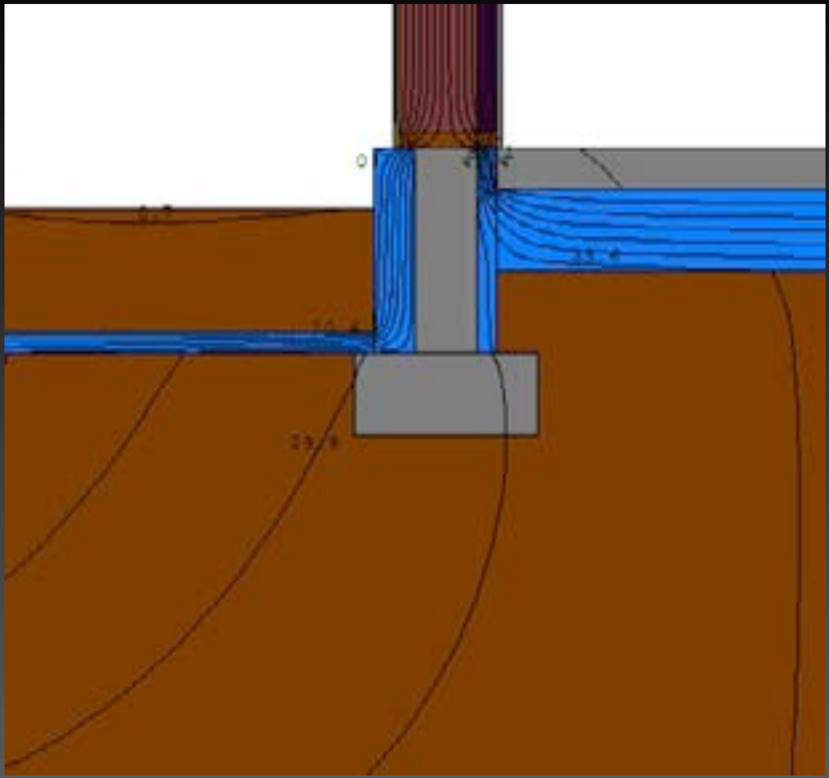
- Thermal bridge at the foundation is typically the largest and most challenging to address.
- The concrete stem wall and footing acts as a radiation fin.

STEP 4 – Avoid accidental "radiation fins", even well-insulated ones.

Section 2 – Thermal Bridge Analysis



FPSF (well insulated): Ψ = 0.052 W/mK



Norwegian footing: Ψ = -0.007 W/mK

Norwegian frost-protected shallow foundation provides an insulated break between the stem wall and the floor slab, effectively cutting off the “radiation fin”.

Also does better at aligning insulation layers at junction of stem wall and above grade wall.

STEP 5 – An insulated break between the exterior wall and floor slab is necessary.

Section 2 – Thermal Bridge Analysis

Summary

- Avoid elements that bridge from interior to exterior.
- Align insulation layers.
- Use continuous exterior insulation to isolate bridging elements like plates and studs.
- Avoid accidental "radiation fins", even well-insulated ones.
- An insulated break between the exterior wall and floor slab is necessary.

Section 3 – Moisture and Air Leakage

Moisture safety = balance between wetting, drying,
and safe moisture storage

In general, drying potential of an envelope must be greater than its wetting potential over the course of a year.

Wetting may overcome drying at times, if there is storage capacity to hold the moisture until drying conditions return.

Section 3 – Moisture and Air Leakage

Wetting pathways – arranged in rough order of significance

1. Bulk water leakage
2. Capillary movement
3. Air leakage
4. Diffusion
5. Moisture from construction

Drying pathways

1. Shedding/drainage (bulk water)
2. Wicking (capillary movement)
3. Evaporation (air movement)
4. Diffusion

The wetting pathways are essentially the same as the drying pathways. Make the pathways work for you rather than against you.

Section 3 – Moisture and Air Leakage

Wetting pathways

1. Bulk water leakage – rain leaking or blowing in through cladding, roofing
2. Capillary movement – wet cladding and roofing in direct contact with sheathing also, wood in contact with ground or concrete
3. Air leakage
4. Diffusion
5. Moisture from construction

Best way to deal with bulk water leakage and capillary movement is the vented rainscreen and back-ventilated roofing.

"Every cladding should be back-ventilated and drained everywhere all the time no matter what."
- Joe Lstiburek, 2010 **BSI-039: Five Things**

Section 3 – Moisture and Air Leakage

Back-ventilation - used 100% of the time in Norway for roofing and cladding

Air gap has five-fold functionality:

- allows drainage of bulk water that penetrates cladding or roofing
- reduces pressure of wind driven rain
- prevents wet siding and roofing from contacting the sheathing (capillary action)
- assists evaporative drying of both siding and sheathing
- reduces penetrations through the weather barrier

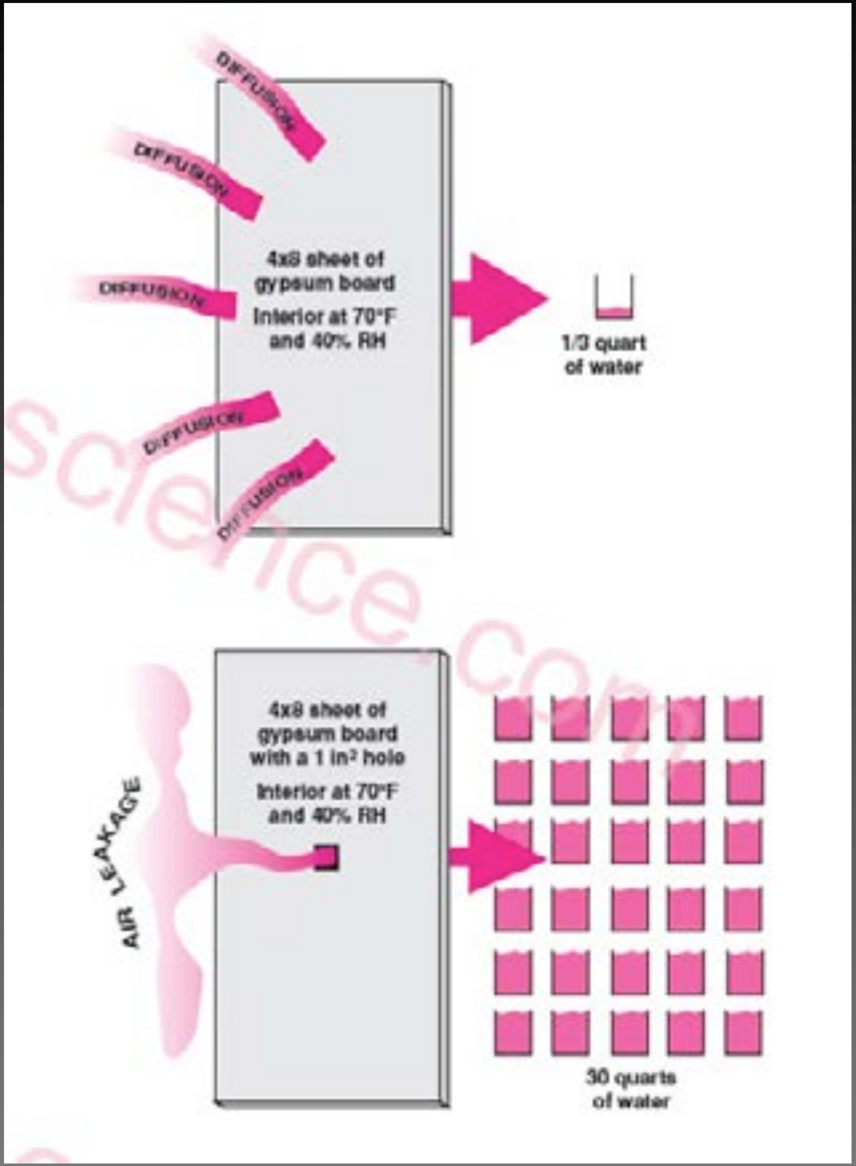
Section 3 – Moisture and Air Leakage

Wetting pathways

1. Bulk water leakage
2. Capillary movement
3. Air leakage – humid indoor air condensing on cold surfaces such as sheathing
4. Diffusion - water vapor molecules driven through materials by vapor pressure and heat
5. Moisture from construction

In Norway, air leakage and diffusion are often both controlled with a single layer – 6 mil or thicker polyethylene. Not necessarily the best strategy. Controlling air leakage is by far the most important of the two functions and requires an un-punctured sheet.

Section 3 – Moisture and Air Leakage



Air leakage has the potential to introduce many times more water into a wall than diffusion.

Controlling air leakage is important not just for energy savings, but for the long term moisture durability of highly-insulated envelopes.

Remember:
MORE insulation = less heat = LESS drying. As R-values go up, air leakage must go down. That is moisture balance.

Section 3 – Moisture and Air Leakage

Several important steps are taken in Norway to better control air leakage:

- 6mil poly is protected from puncture by placement behind cross batten layer, which creates a chase for utilities. Wiring can be run w/out punching holes in poly.
- Exterior wind barrier (house wrap) is also detailed as a second air barrier.
- A specific air tightness target of 2.5 ACH@50Pa has been set in the code, though it is not yet enforced with mandatory blower door tests.

Section 3 – Moisture and Air Leakage

Wetting pathways

1. Bulk water leakage
2. Capillary movement
3. Air leakage
4. Diffusion - water vapor molecules driven through materials by vapor pressure and heat
5. Moisture from construction

Assuming bulk water leakage, capillary movement and air leakage are under control, diffusion wetting and drying should be considered. Norwegian code requires exterior layers of sheathing and insulation to be 10x more vapor permeable than the warm side vapor retarder. This ensures a strong drying potential to the exterior.

Section 3 – Moisture and Air Leakage

Testing the 10x guideline…

If 6 mil poly (0.1 perms) is used as the warm side vapor retarder, can 1 inch of exterior XPS (pink or blue foam) be applied?

Section 3 – Moisture and Air Leakage

Testing the 10x guideline…

If 6 mil poly (0.1 perms) is used as the warm side vapor retarder, can 1 inch of exterior XPS (pink or blue foam) be applied?

- 1 inch of exterior XPS (0.75 perms) is 7.5x more vapor open - FAILS

Section 3 – Moisture and Air Leakage

Testing the 10x guideline…

If 6 mil poly (0.1 perms) is used as the warm side vapor retarder, can 1 inch of exterior EPS (crumbly white foam) be applied?

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- 1 inch of exterior XPS (0.75 perms) is 7.5x more vapor open - FAILS
- 1 inch of exterior EPS (3.0 perms) is 30x more vapor open - PASSES

Section 3 – Moisture and Air Leakage

Testing the 10x guideline…

If 6 mil poly (0.1 perms) is used as the warm side vapor retarder, can 1 inch of exterior foil-faced polyiso be applied?

Section 3 – Moisture and Air Leakage

Testing the 10x guideline…

If 6 mil poly (0.1 perms) is used as the warm side vapor retarder, can 1 inch of exterior foil-faced polyiso be applied?

- 1 inch of exterior XPS (0.75 perms) is 7.5x more vapor open - FAILS
- 1 inch of exterior EPS (3.0 perms) is 30x more vapor open - PASSES
- 1 inch of foil faced polyiso (0.05 perms) is less permeable than the poly - FAILS!!!

Section 3 – Moisture and Air Leakage

Testing the 10x guideline…

If 6 mil poly (0.1 perms) is used as the warm side vapor retarder, can 1 inch of exterior mineral wool be applied?

- 1 inch of exterior XPS (0.75 perms) is 7.5x more vapor open - FAILS
- 1 inch of exterior EPS (3.0 perms) is 30x more vapor open - PASSES
- 1 inch of foil faced polyiso (0.05 perms) is less permeable than the poly - FAILS
- 1 inch of mineral wool (100 perms) is 1000x more vapor open- PASSES (easily)

Section 3 – Moisture and Air Leakage

Testing the 10x guideline…

If 6 mil poly (0.1 perms) is used as the warm side vapor retarder, can OSB be used as the exterior sheathing?

- 1 inch of exterior XPS (0.75 perms) is 7.5x more vapor open - FAILS
- 1 inch of exterior EPS (3.0 perms) is 30x more vapor open - PASSES
- 1 inch of foil faced polyiso (0.05 perms) is less permeable than the poly - FAILS
- 1 inch of mineral wool (100 perms) is 1000x more vapor open- PASSES

- OSB sheathing (1.0 perms) is exactly 10x more vapor open – PASSES

Section 3 – Moisture and Air Leakage

Testing the 10x guideline…

If 6 mil poly (0.1 perms) is used as the warm side vapor retarder, can fiberboard (like Bildrite) sheathing be used?

- 1 inch of exterior XPS (0.75 perms) is 7.5x more vapor open - FAILS
- 1 inch of exterior EPS (3.0 perms) is 30x more vapor open - PASSES
- 1 inch of foil faced polyiso (0.05 perms) is less permeable than the poly - FAILS
- 1 inch of mineral wool (100 perms) is 1000x more vapor open- PASSES

- OSB sheathing (1.0 perms) is exactly 10x more vapor open – PASSES
- Coated fiberboard sheathing (15.5 perms) is 155x more vapor open – PASSES

Section 3 – Moisture and Air Leakage

Testing the 10x guideline…

If 6 mil poly (0.1 perms) is used as the warm side vapor retarder, can OSB + exterior EPS be used together?

- 1 inch of exterior XPS (0.75 perms) is 7.5x more vapor open - FAILS
- 1 inch of exterior EPS (3.0 perms) is 30x more vapor open - PASSES
- 1 inch of foil faced polyiso (0.05 perms) is less permeable than the poly - FAILS
- 1 inch of mineral wool (100 perms) is 100x more vapor open- PASSES

- OSB sheathing (1.0 perms) is exactly 10x more vapor open – PASSES
- Coated fiberboard sheathing (15.5 perms) is 155x more vapor open – PASSES
- OSB sheathing + 1 inch of EPS (0.75 perms total) is 7.5x more vapor open - FAILS, but…

The addition of exterior rigid foam over sheathing is often a gray area that requires more analysis.

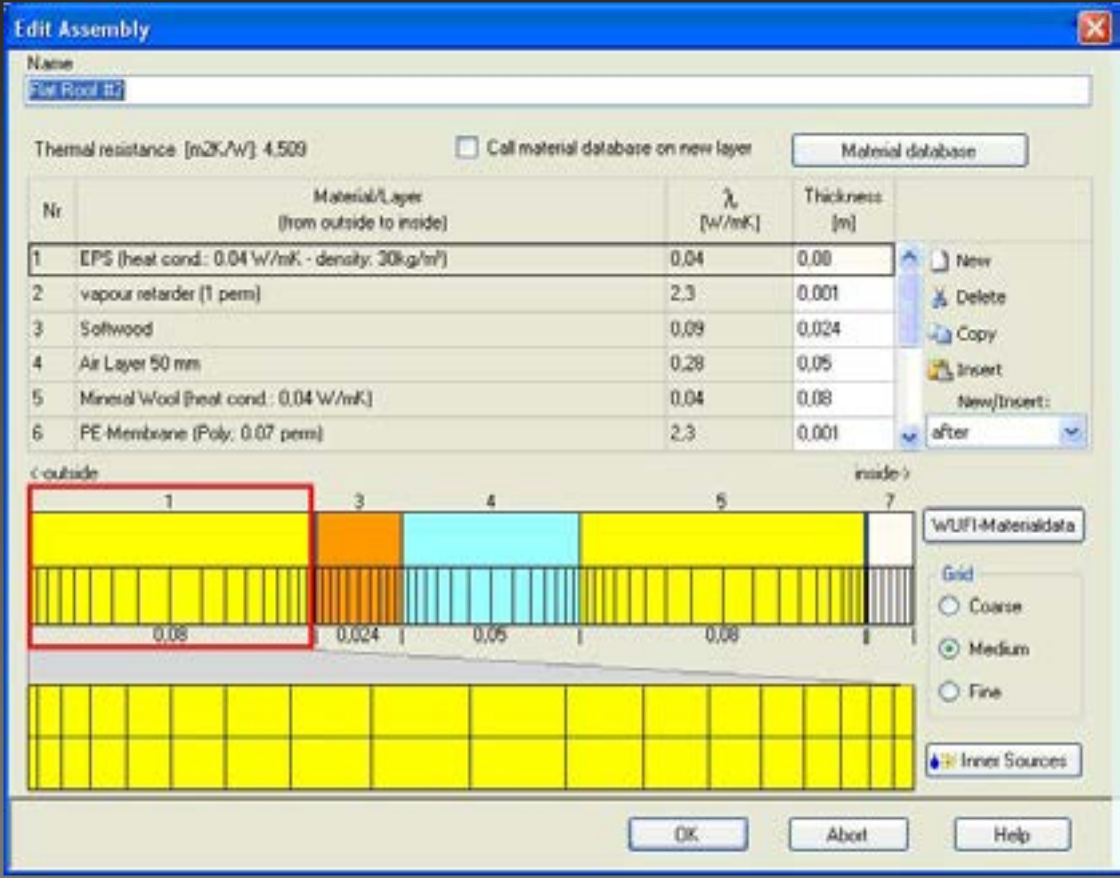
Section 3 – Moisture and Air Leakage

WUFI works well to see what happens with diffusion drying/wetting.

- Can also model capillary movement and water "events" due to bulk water leakage or periodic air leakage.

- Moisture content and relative humidity can be tracked over multiple years for any layer in the envelope assembly.

- Generally, the layer at greatest risk for moisture damage/mold growth is called the critical layer. Most often, this is the sheathing in wood-framed envelopes.



Edit Assembly

Name: Flat Roof #7

Thermal resistance [m2K/W]: 4.509

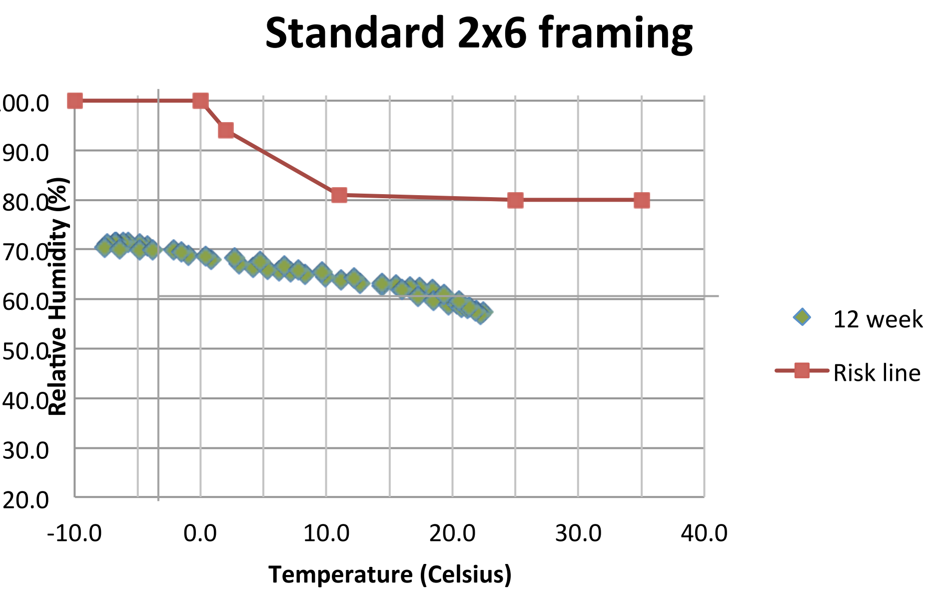
☐ Call material database on new layer

Nr	Material/Layer (from outside to inside)	λ [W/mK]	Thickness [m]
1	EPS (heat cond.: 0.04 W/mK - density: 30kg/m³)	0,04	0.08
2	vapour retarder (1 perm)	2,3	0.001
3	Softwood	0,09	0.024
4	Air Layer 50 mm	0,28	0.05
5	Mineral Wool (heat cond.: 0.04 W/mK)	0,04	0.08
6	PE-Membrane (Poly; 0.07 perm)	2,3	0.001

New/Insert: after

Grid: ○ Coarse ● Medium ○ Fine

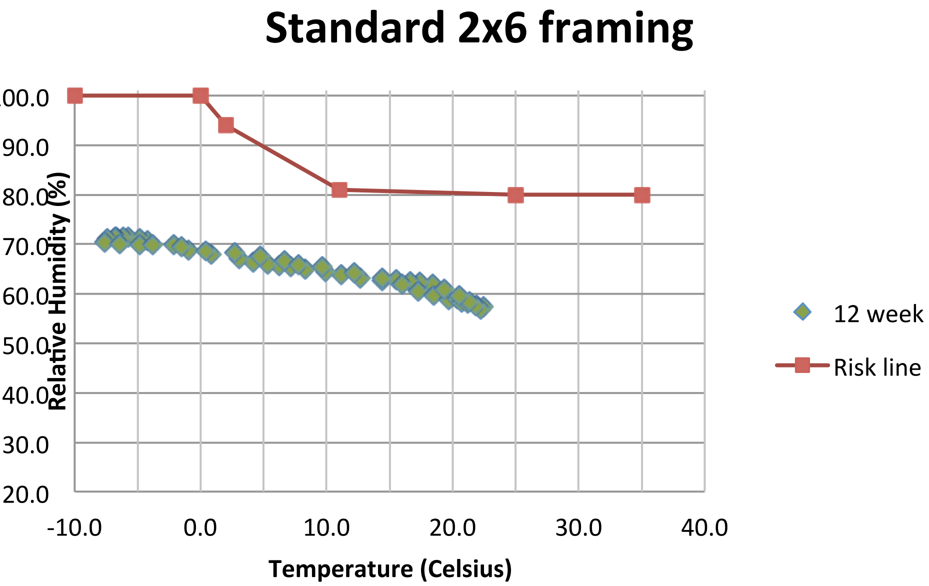
Section 3 – Moisture and Air Leakage

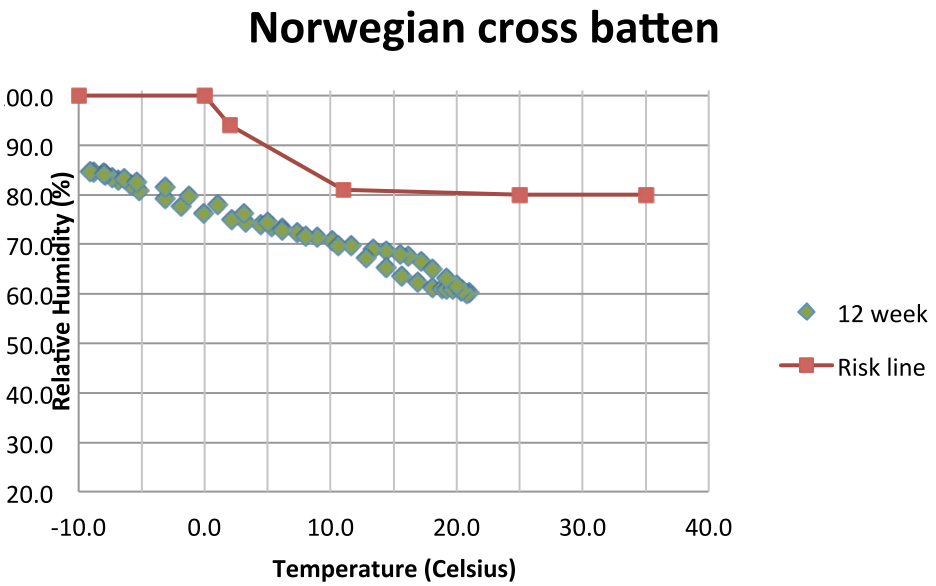


Standard 2x6 framing, 5.5” fiberglass batts,
6mil poly, R-14.75
Critical layer = OSB sheathing

What happens when we take away heat by adding insulation to the stud cavity?

Section 3 – Moisture and Air Leakage


Standard 2x6 framing

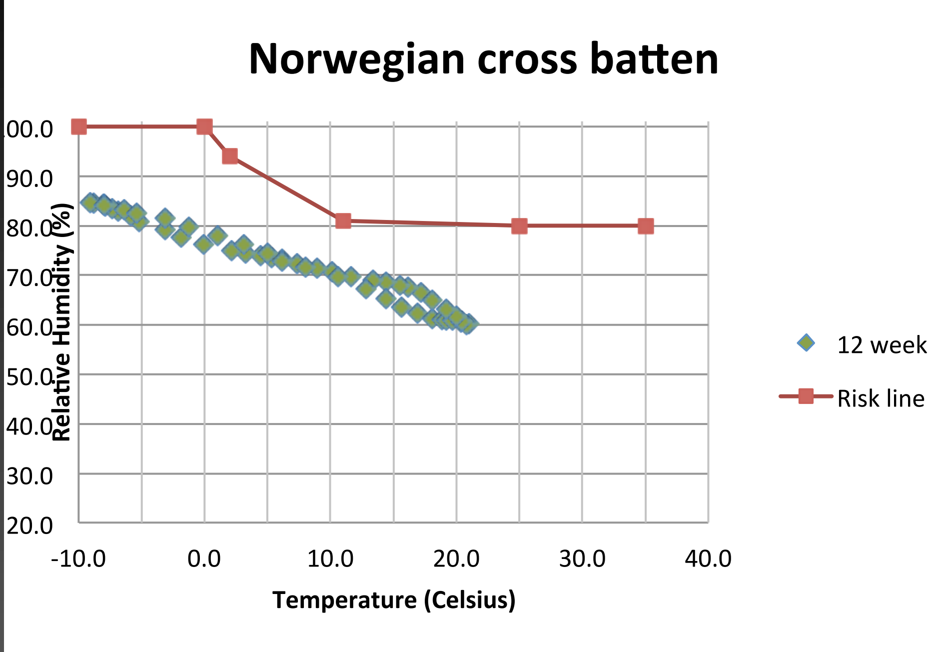

Norwegian cross batten

Standard 2x6 framing, 5.5” fiberglass batts, 6mil poly, R-14.75
Critical layer = OSB sheathing

Norwegian cross batten, 2x8 with interior cross battens, 9.5” mineral wool total, 6mil poly, R-32
Critical layer = OSB sheathing

Relative humidity levels in the critical layer rise above 80% in the winter and the ability of the sheathing to dry quickly in the spring becomes imperative.

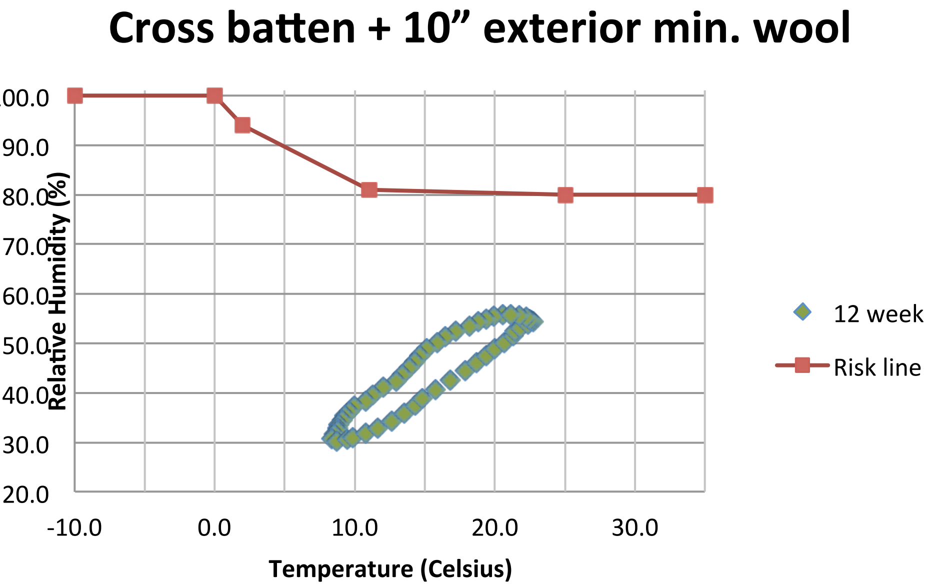
Section 3 – Moisture and Air Leakage

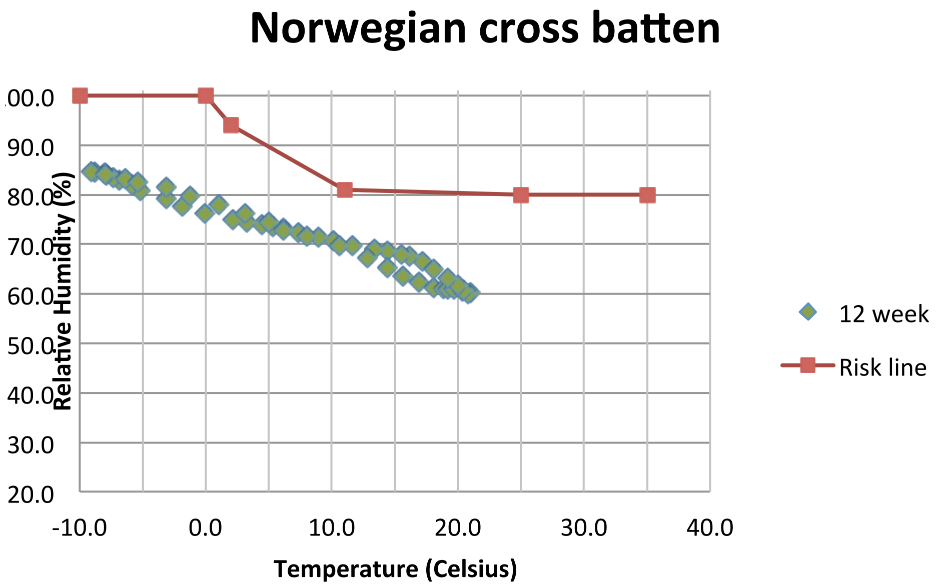


Norwegian cross batten, 2x8 with interior cross battens, 9.5” mineral wool total, 6mil poly, R-32
Critical layer = OSB sheathing

What happens when <u>permeable</u> exterior insulation is applied over the sheathing?

Section 3 – Moisture and Air Leakage


Cross batten + 10” exterior min. wool


Norwegian cross batten

Norwegian cross batten, 2x8 with interior cross battens and 10” exterior insulation, 19.5” mineral wool total, 6mil poly, R-60
Critical layer = OSB sheathing beneath exterior insul.

Norwegian cross batten, 2x8 with interior cross battens, 9.5” mineral wool total, 6mil poly, R-32
Critical layer = OSB sheathing

Sheathing is warmed, additional heat drives out moisture, and relative humidity levels drop.

Section 3 – Moisture and Air Leakage

Wetting pathways

1. Bulk water leakage
2. Capillary movement
3. Air leakage
4. Diffusion
5. Moisture from construction

Moisture from rain events during construction can be considerable, especially in coastal areas of Norway. Several innovative techniques to deal with this issue are growing more popular – prefabrication and shelter scaffolding.

Section 3 – Moisture and Air Leakage

Prefabricated wall panels assembled at Skanska Husfabriken

Site construction under temporary shelter scaffolding

Section 3 – Moisture and Air Leakage

Summary

- Know the vapor permeance of the materials in your envelope. Ensure that the exterior sheathing and insulation is 10x more permeable than the warm side vapor retarder.

- Several inches of permeable exterior insulation (such as mineral wool, EPS, or fiberglass faced-polyiso) is a good idea to warm the critical layer and reduce mold growth risks.

- Achieve an airtight envelope (better than 2.5 ACH@50Pa).

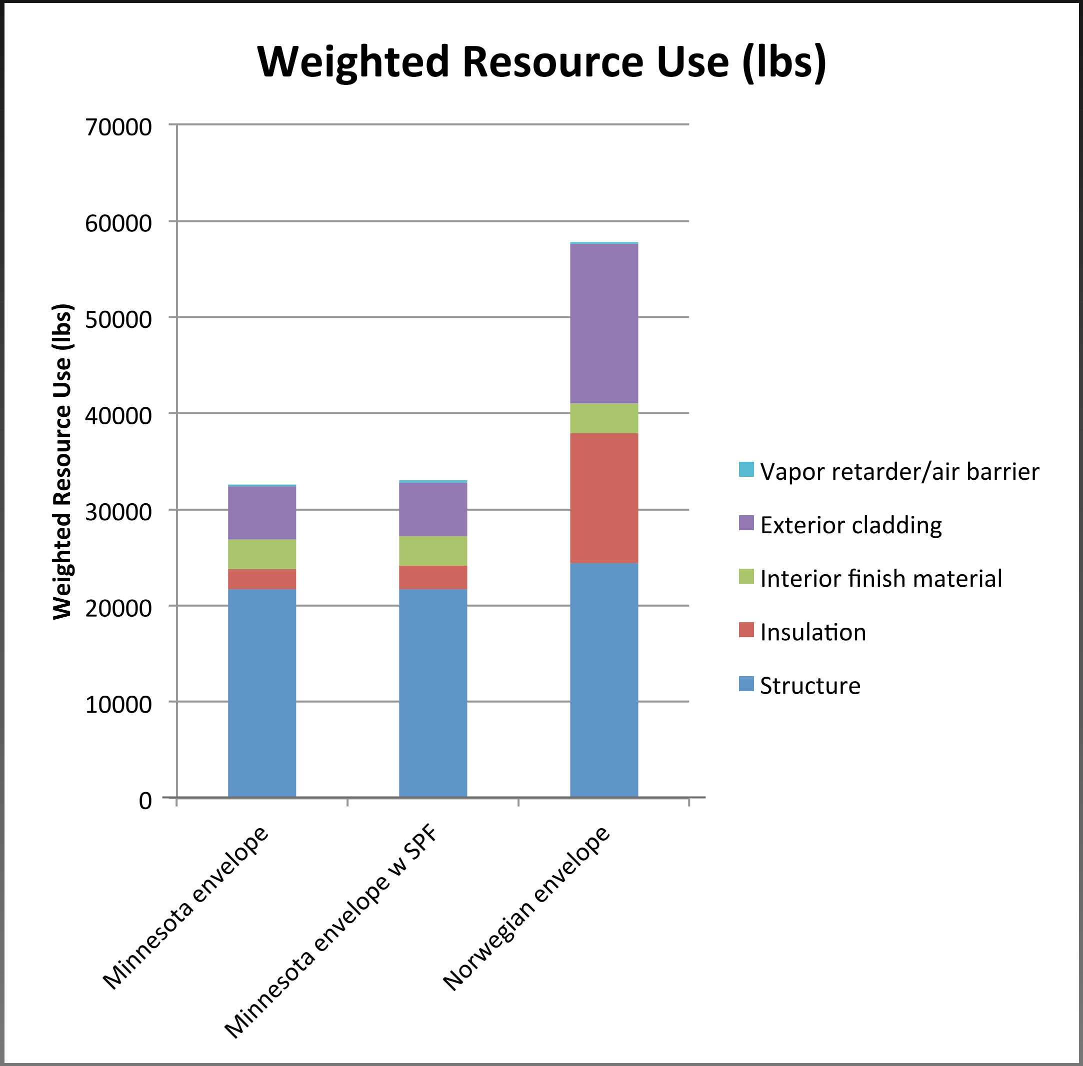
- Take advantage of the 5-fold functionality of back-ventilated cladding and roofing to control bulk water, capillary movement, and improve evaporation for the cladding and sheathing.

Section 4 – Life Cycle Env. Impacts

Life cycle environmental impacts of the envelope materials:

- Measured using Athena Environmental Impact Estimator
- Athena's "life cycle" includes raw material extraction/mining, transportation, processing, product fabrication, distribution, maintenance, and disposal
- Results measured in terms of 8 environmental indicators such as embodied energy, global warming potential, weighted resource use, eutrophication, etc. These indicators represent a comprehensive view of the impact on the environment. We will only look at the first three indicators.

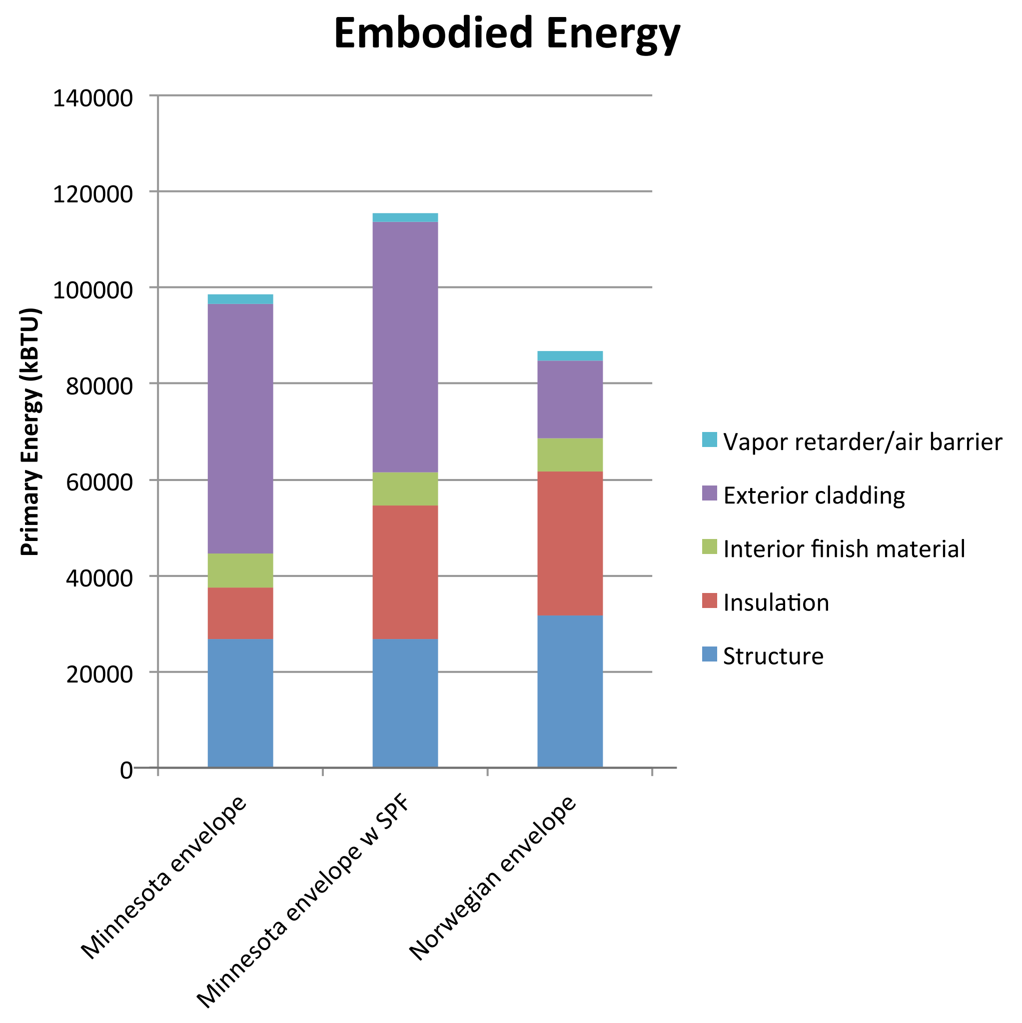
Section 4 – Life Cycle Env. Impacts



Life cycle weighted resource use of above grade walls by building element

- most insulation types (except mineral wool) have very low resource use since they're mostly air
- increase in structural wood is not as great as expected in Norwegian envelope since advanced framing reduces number of studs and plates

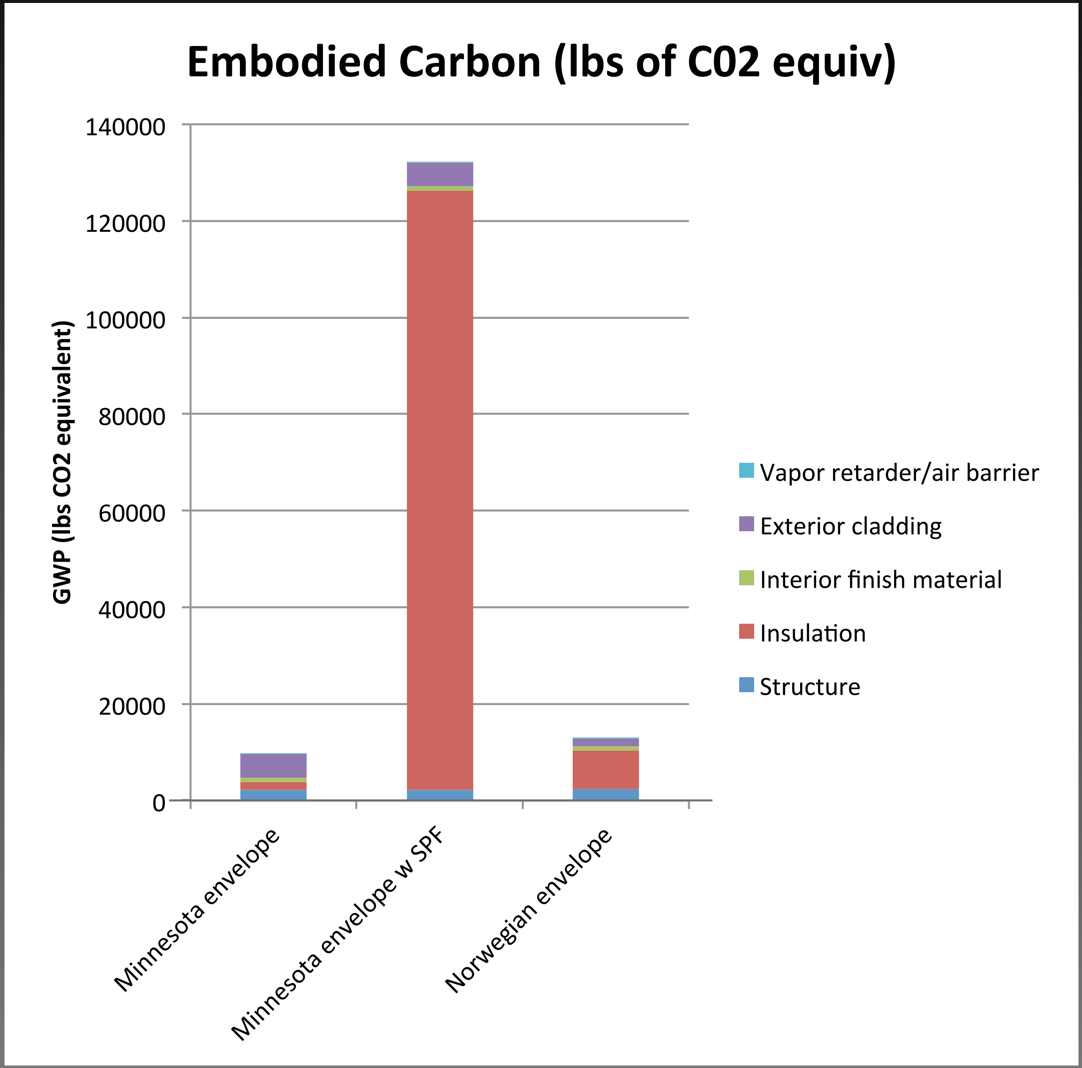
Section 4 – Life Cycle Env. Impacts



Life cycle embodied energy of above grade walls by building element

- mineral wool and spray foam insulation have quite a bit of embodied energy
- fiberglass is better, but cellulose is best
- Vinyl siding also has a large embodied energy

Section 4 – Life Cycle Env. Impacts

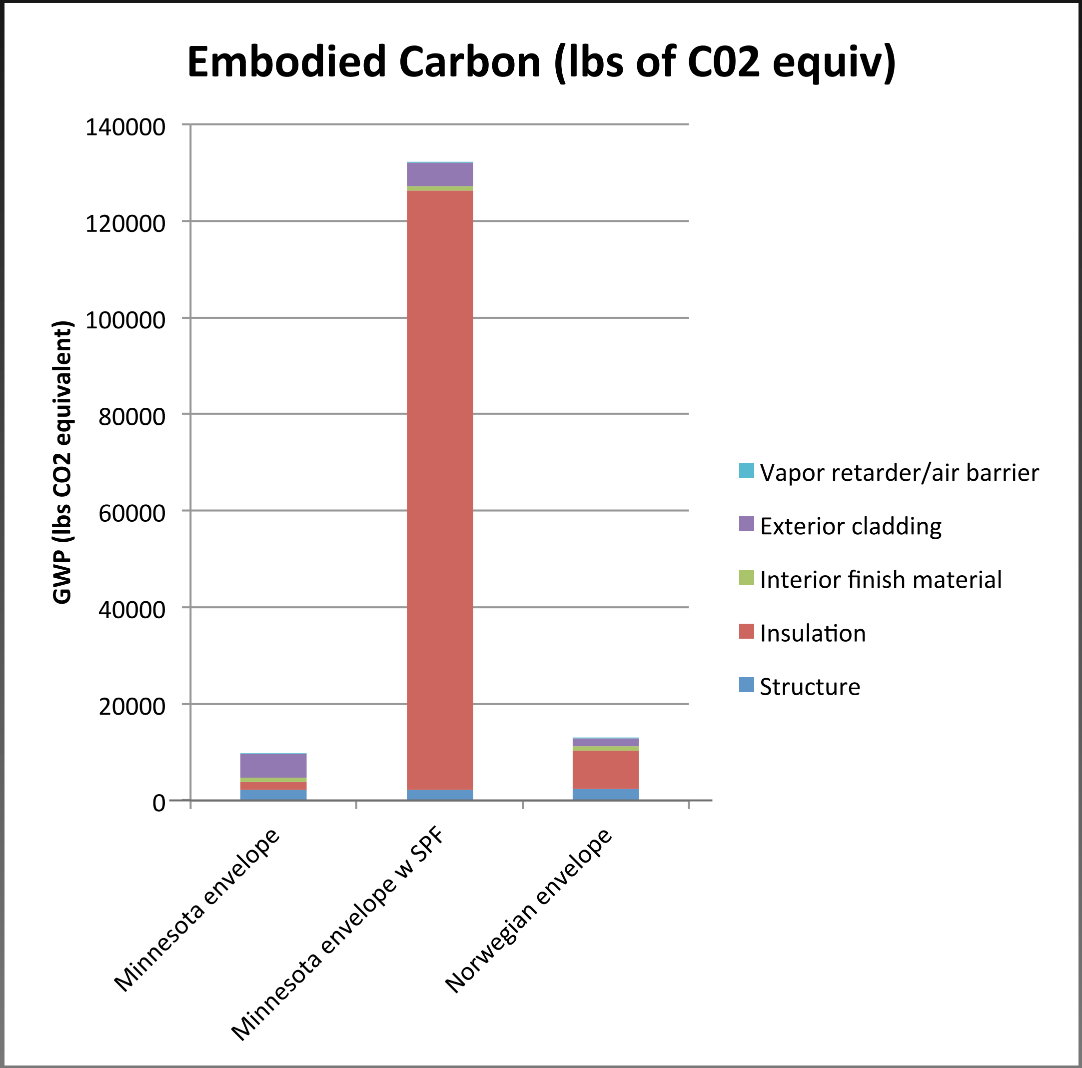


Life cycle global warming potential of the envelope materials:

- vinyl siding and mineral wool have high GWP, but…
- spray polyurethane foam blown with HFC blowing agents has almost 100x greater GWP than fiberglass per unit area per R-value

Similar effects are seen with XPS!

Section 4 – Life Cycle Env. Impacts



Incredibly high GWP of closed cell SPF and XPS are reported in Environmental Building News article by Alex Wilson in 2010.

XPS can be replaced by EPS or foamglass below grade. Above grade, a good replacement might be fiberglass-face polyiso.

ccSPF can be replaced with spray foam that does not use HFC blowing agents (icynene, for example).

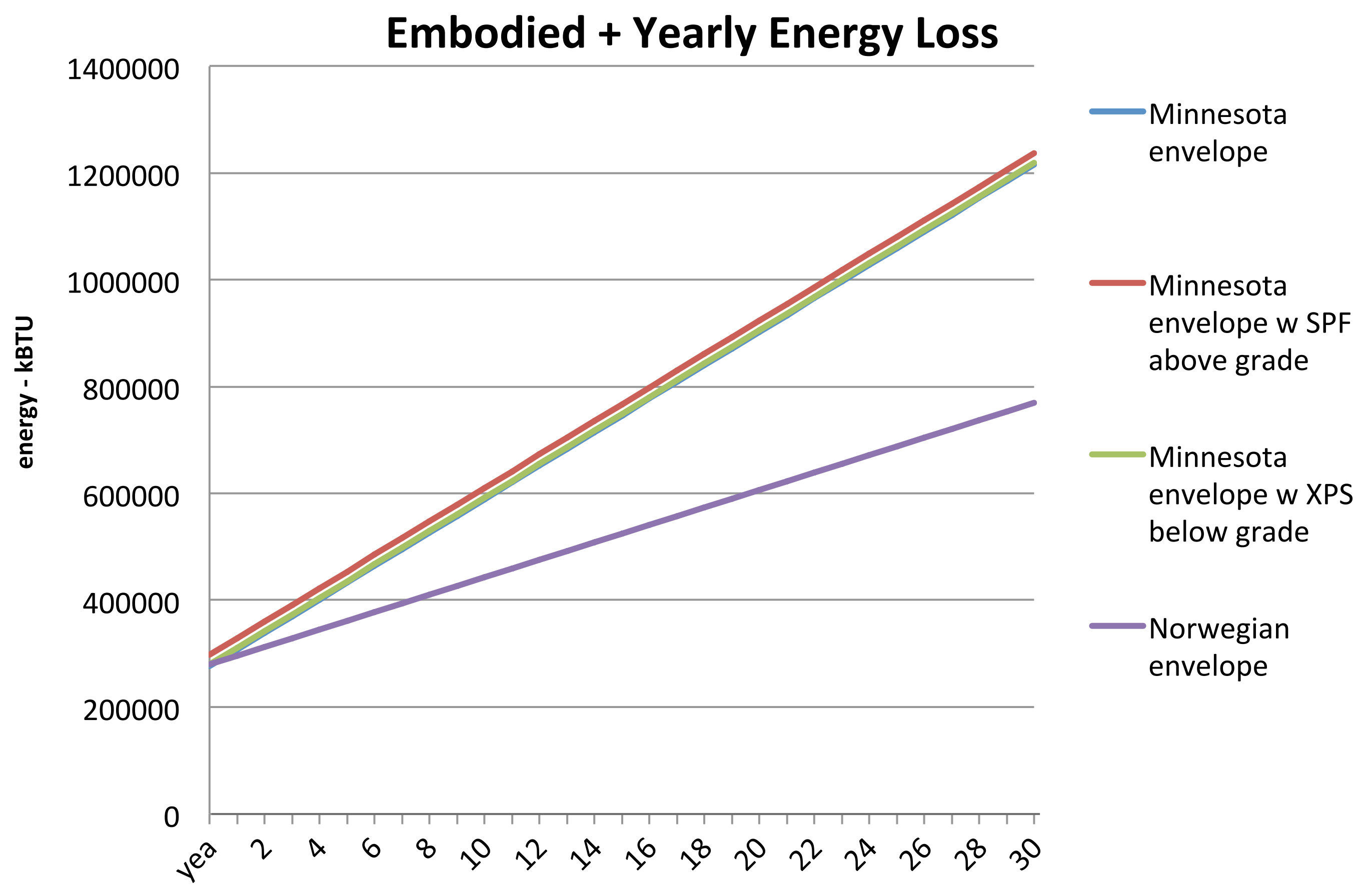
New blowing agent formulations for closed cell SPF are expected starting in late 2013.

Section 4 – Life Cycle Env. Impacts

The big question – does a Norwegian envelope save energy and carbon emissions in the long run?

- We know the embodied energy and carbon of a Norwegian envelope can be higher than a Minnesota envelope (that avoids XPS and ccSPF)
- Add in the yearly energy use and associated carbon emissions due to heat loss through the envelope
- Compare to a base case house with a standard envelope to see if there are any paybacks
- Results are based on a 1728sf house including basement, heated with 90AFUE furnace.

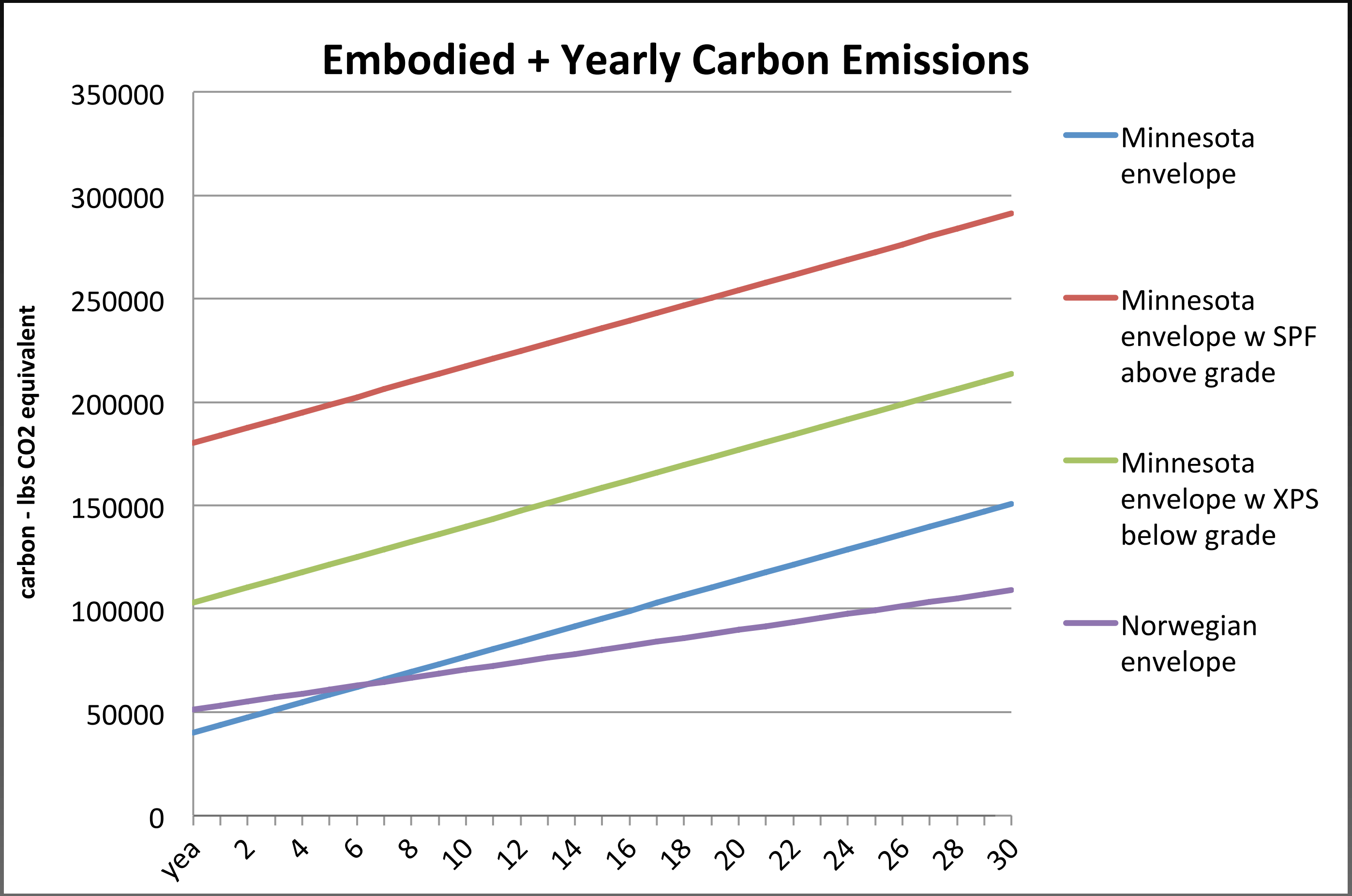
Section 4 – Life Cycle Env. Impacts



Life cycle embodied energy of above and below grade envelope, plus yearly energy loss through envelope over 30 years.

Energy payback: < 1 year. Despite use of mineral wool, concrete roof tiles, and much thicker rigid insulation below grade, Norwegian envelope has very similar embodied energy to standard Minnesota envelopes. Why? Vinyl siding and asphalt shingles for MN envelopes.

Section 4 – Life Cycle Env. Impacts



Life cycle embodied carbon of above grade and below grade envelope plus carbon emissions from energy use over 30 years.

Carbon payback: 7 years compared to Minnesota envelope that avoids XPS and ccSPF.
Immediate compared to Minnesota envelope that uses either XPS or ccSPF

Section 4 – Life Cycle Env. Impacts

Summary

- Reduce material use with advanced framing.
- Think about using recyclable or natural alternatives to asphalt shingles and vinyl siding to reduce embodied energy. Or at least consider more durable, longer-lasting products such as fiber cement.
- To avoid extremely high global warming impacts, avoid using XPS and ccSPF until blowing agents are reformulated. EPS is used extensively for below grade applications in Norway.
- The increased embodied energy and GWP of well-insulated envelopes can easily be recouped by energy savings (as long as extra XPS and ccSPF are avoided).