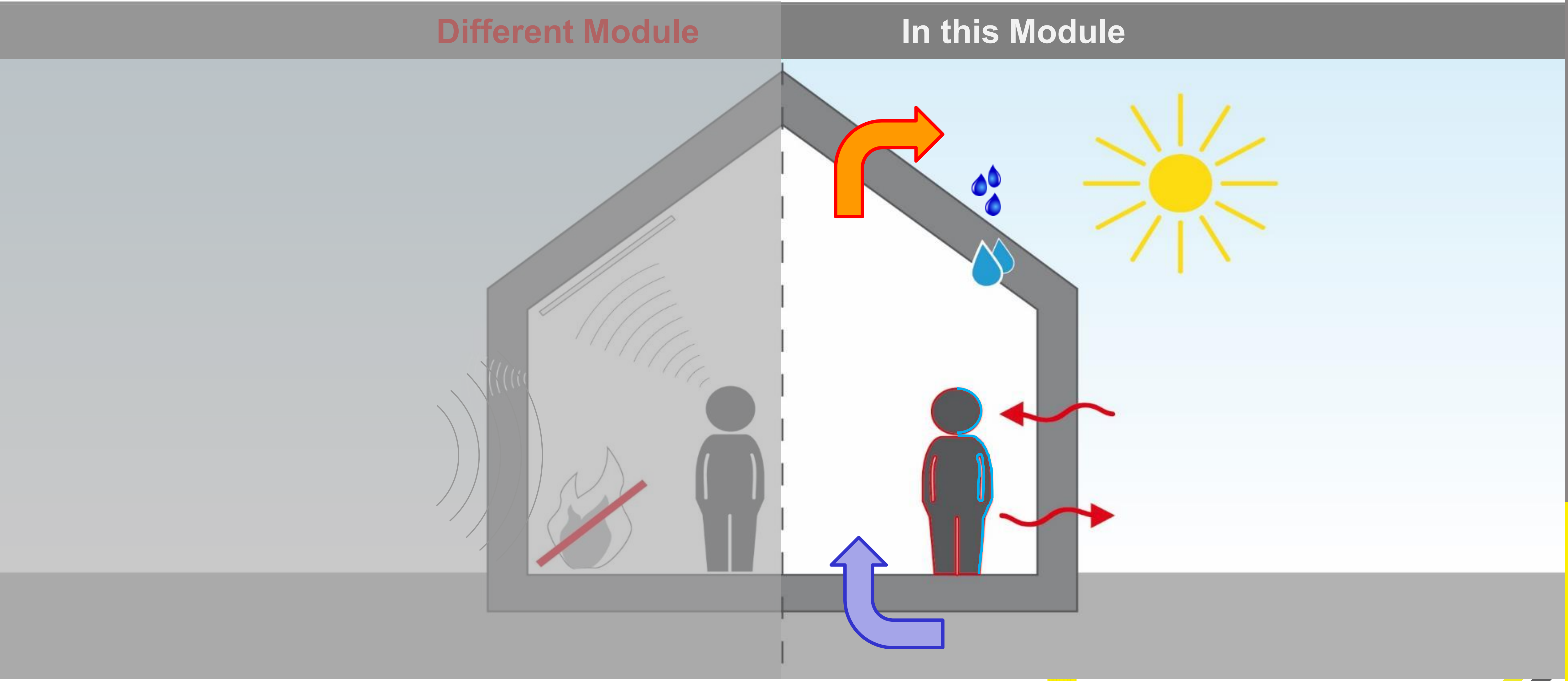
Building Science for Wood Buildings



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Literature suggestion

Building Physics Heat, Air and Moisture

Fundamentals and Engineering Methods with Examples and Exercises

By: Hugo Hens

Publisher: Ernst & Sohn

ISBN: 978-3-433-60127-3

Applied Building Physics

Boundary conditions, building performance and material properties

By: Hugo Hens

Publisher: Ernst & Sohn

ISBN: 978-3-433-02962-6

Building Physics

From physical principles to international standards

By: Marko Pinteric

Publisher: Springer

ISBN: 978-3-319-57483-7

Not mandatory for the course,

but recommended for further study

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Building Science for Wood Buildings

1. Introduction
2. Thermal Performance
3. Thermal Bridging
4. Airtightness Basics and Material
5. Airtightness Details and Test
6. Vapour Diffusion and Moisture Management
7. Developing Durable and High Performing Envelope Assemblies and Details
8. Case Study: Wood Innovation Research Laboratory

Lesson 1: Introduction (45min + 5min Q&A)

- ***Objectives:***
  - Identify the general importance and potential impact of thermodynamics and hydrodynamics on wood buildings
  - Analyze the behavioral differences of wood buildings compared to other materials
  - Differentiate the advantages and disadvantages of wood buildings in terms of building science
  - Explain the principles of highly thermally insulated envelopes, including perception of the thermal insulation qualities
  - Compare general strategies to increase energy efficiency and reduce the environmental impact.

Why do we built with Wood?

- Less Resources needed
- Less Energy Losses
- Less Risk
- Less Cost

What are the Pros and Cons of Wood as Construction Material in regards to Building Science?

- Cons
  - Combustible
  - Can rot
  - Structurally weak
  - Light weight
  - Flexible
  - Nonhomogeneous
  - …
- Pros
  - Predictable fire resistance (charring)
  - Structurally very strong compared to weight
  - Light weight
  - Flexible
  - Low thermal conductivity
  - Environmentally friendly
  - …

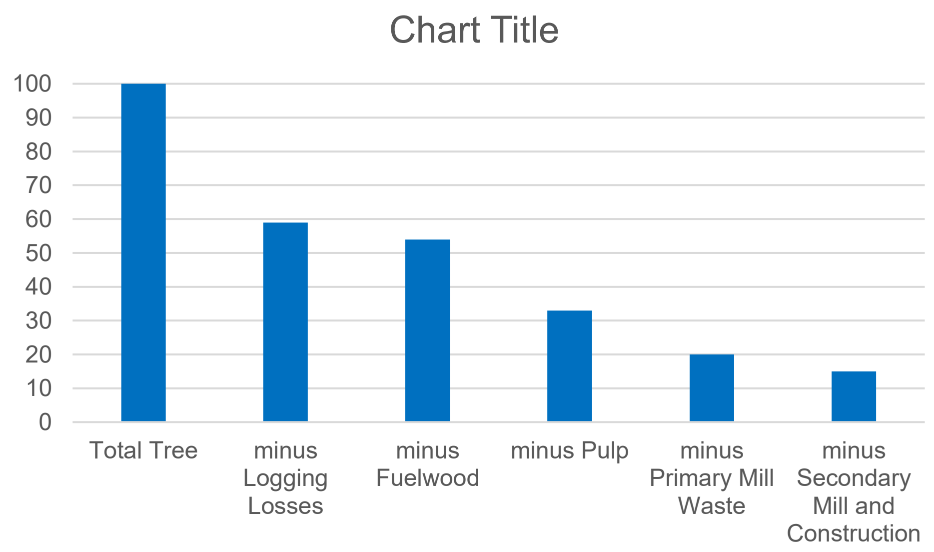
CO_2 Balance of Concrete and Wood in Construction

Author: Wimmers

- Manufacturing of 1 t of cement = 870 kg CO_2 (global average).
- 1 m^3 of wood has filtered about 1 t of CO_2 and stored about 270 kg of carbon in its fibers*.
- 1 kg of carbon = 3.67 kg of CO_2.
- 1 m^3 of wood = 3.67x 270kg = 990kg CO_2**

Yield of Forest Industry

- CO2 storage through the wood product chain.



U.S. Forest Service. 2008. Forest Resources of the United States, 2007. WO-xxx. Washington, D.C.: U.S. Department of Agriculture, Forest Service. https://www.fs.usda.gov/treesearch/pubs/17334

What is Building Science?

- Technical performance of Building
- Environmental performance of Buildings
- Building Materials
- Thermal Performance of Buildings
- Convection and Vapour Diffusion
- Fire Dynamics
- Acoustics
- Light
- EMF

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Why is Building Science important?

- Functionality of a Building
- Performance of a Building
- Well Being
- Durability
- Environmental Impact
- Construction Costs
- Operational Costs
- Satisfaction with the Building

Author: Wimmers

Fields in Building Science

- Heat and Mass Transfer
  - Thermal performance
  - Airtightness
  - Vapour diffusion
- Acoustics
  - Building Acoustics
  - Room Acoustics
- Fire Dynamics
  - Control
  - Suppression
  - Materials
  - Egress

We use Building Science to

- Increase the Energy Efficiency
- Increase durability
- Reduce the environmental impact
- Select best sequence of materials in envelope
- Select best performing materials
- Increase healthy living
- Optimize the long-term structural performance
- Optimize economic performance

Author: Wimmers

Operational Energy vs Embodied Energy

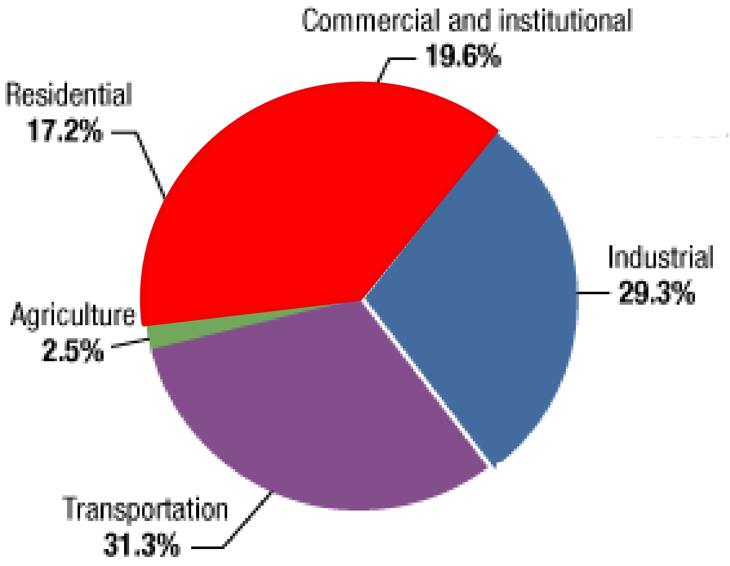
- Traditionally Operational Energy was responsible for 80-90% [1] of the environmental impact of buildings and Embodied Energy played an insignificant role.
- Passive House Standard and similar initiatives radically reduce the Operational Energy Consumption.
- Recent study shows reduction to roughly 60% [2] of the Operational Energy Share of the total lifetime GWP is possible.
- Embodied Energy Consumption gains relative importance, as the Building becomes more energy efficient.

[1] "The energy that buildings use for heating, lighting and cooling is the major component of their environmental impact – approximately 85% of the total life cycle impact for typical office buildings."

[LEED; Cole & Kernan, 1996; Winistorfer and Chen, 2004; Trusty & Meil, 2000; CORRIM, 2004]

[2] "The building materials for the Passive House are in total responsible for approximately 38% of the Global Warming Potential." [A. Wall, G. Wimmers, A comparative LCA of the Wood Innovation Research Laboratory, IPC Munich 2018]

Energy Consumption in Canada



- 36.8 % of Canada's energy consumption in 2009 was for heating and cooling of buildings
- In 2016 this value sank to about 25%
- Average energy density for residential space around 146 kWh/m²
- Average energy density for commercial space around 231 kWh/m²
- Passive House is limited to 15 kWh/m²

Source: NRCAN Energy Use Data Handbook 2010, National Energy Board, 2017

5 Steps to Energy Efficient Buildings

1. compact architecture
2. right orientation
3. excellent insulation
4. no thermal bridges
5. air tightness

Author: Wimmers

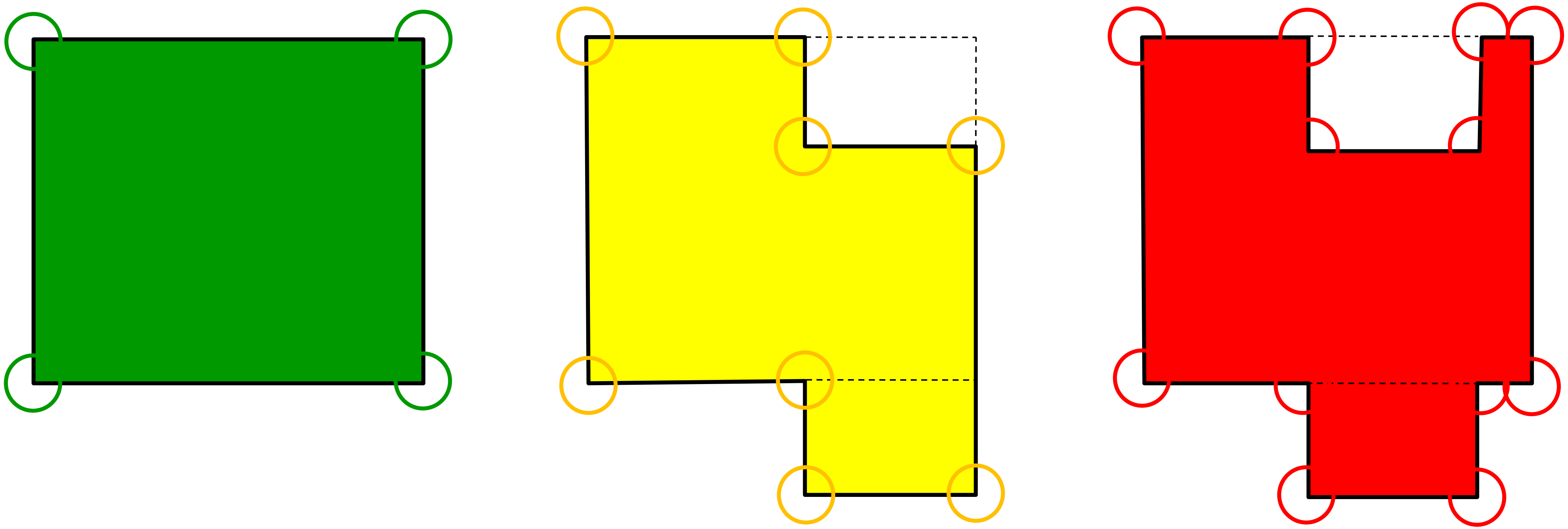
Step 1 for Energy Efficient Construction

- **Compactness** **(Architectural Decision)**
  - **Responsible use of Resources**
  - **Reduction of Energy Losses**
  - **Cost Efficient**

Author: Wimmers

Compact Design

- Influence of an increased perimeter for the same floor area (schematic floor plan)



Compact shape
4 Corners

Increase of wall area 10 %
8 Corners
Insulation $\geq$ 20mm

Increase of wall area 20 %
12 Corners
Insulation $\geq$ 40mm

Source: PHI, Graphic & Author: Wimmers

Non-Optimal Shape Factor

Photo: Habitat 67, Montreal

Optimal Shape Factor

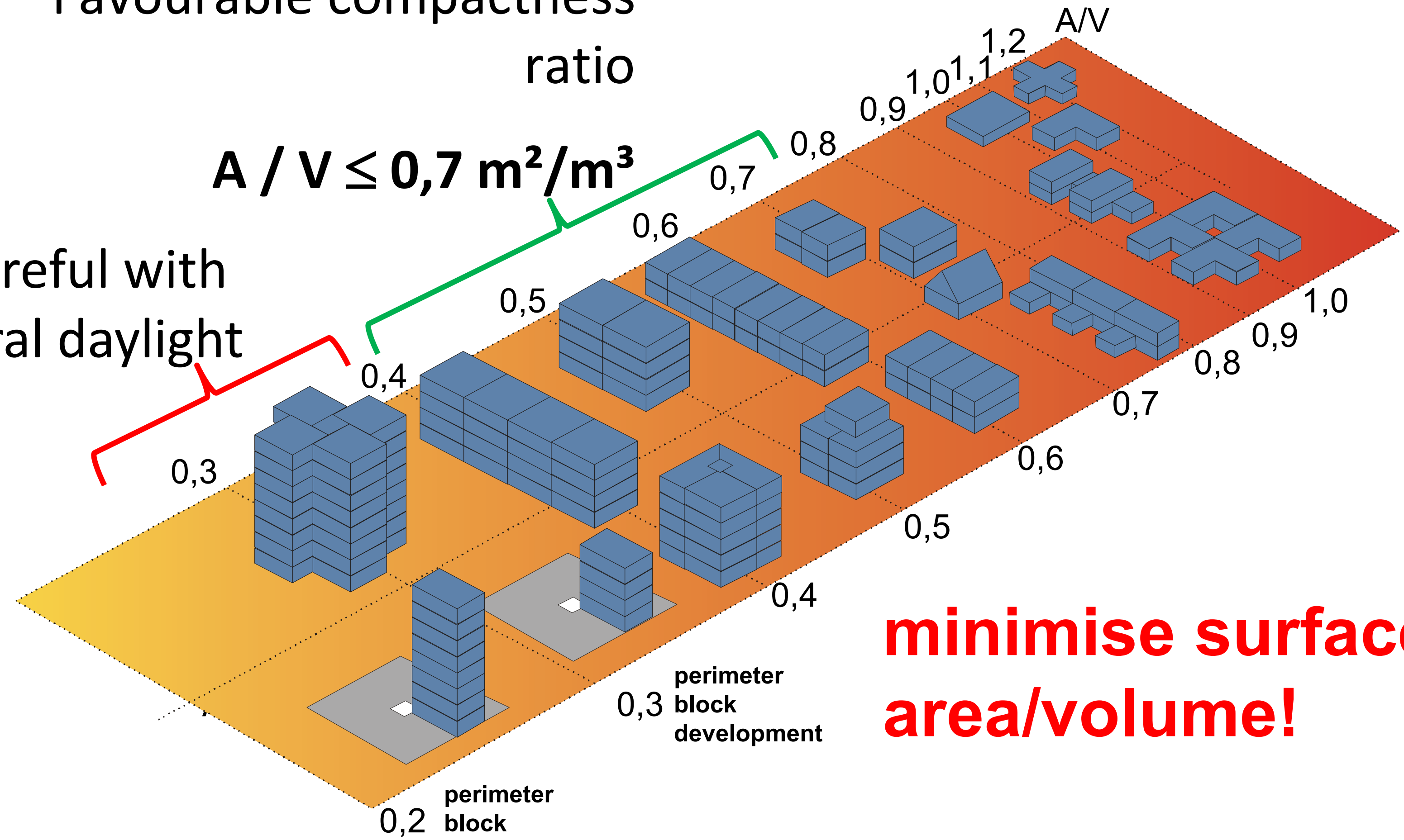
Photo: Jochen Specht

A/V-ratio (thermal envelope area/heated volume)

Favourable compactness ratio

A / V ≤ 0,7 m²/m³

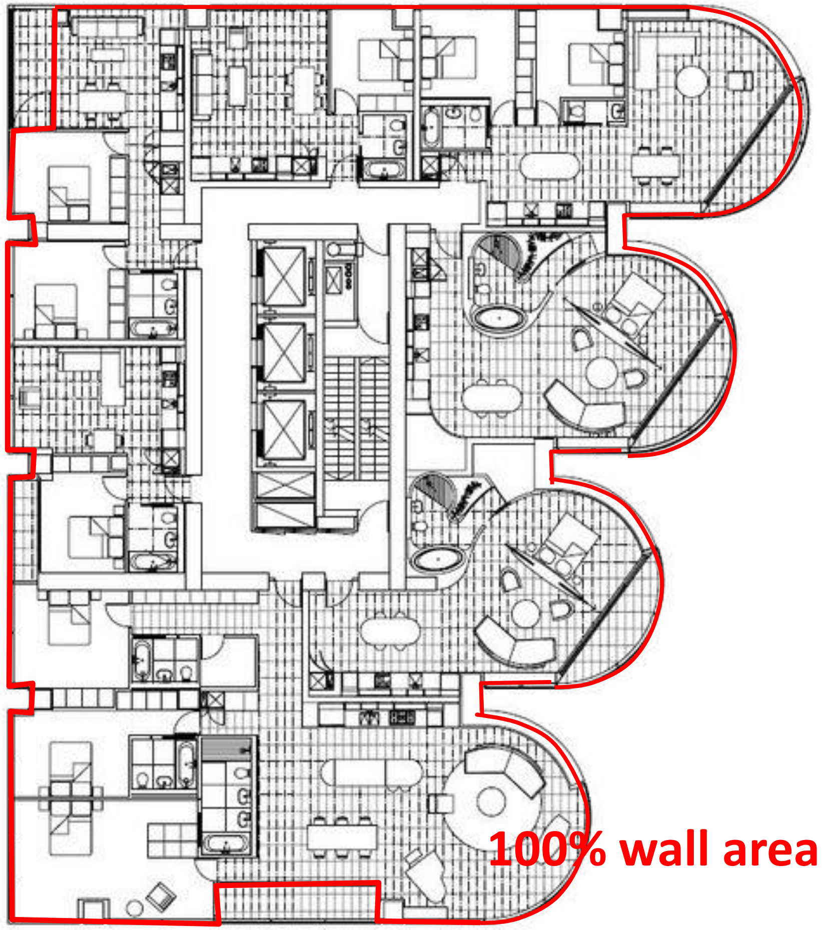
be careful with natural daylight



minimise surface area/volume!

Grafik: PHD, Author: PHI

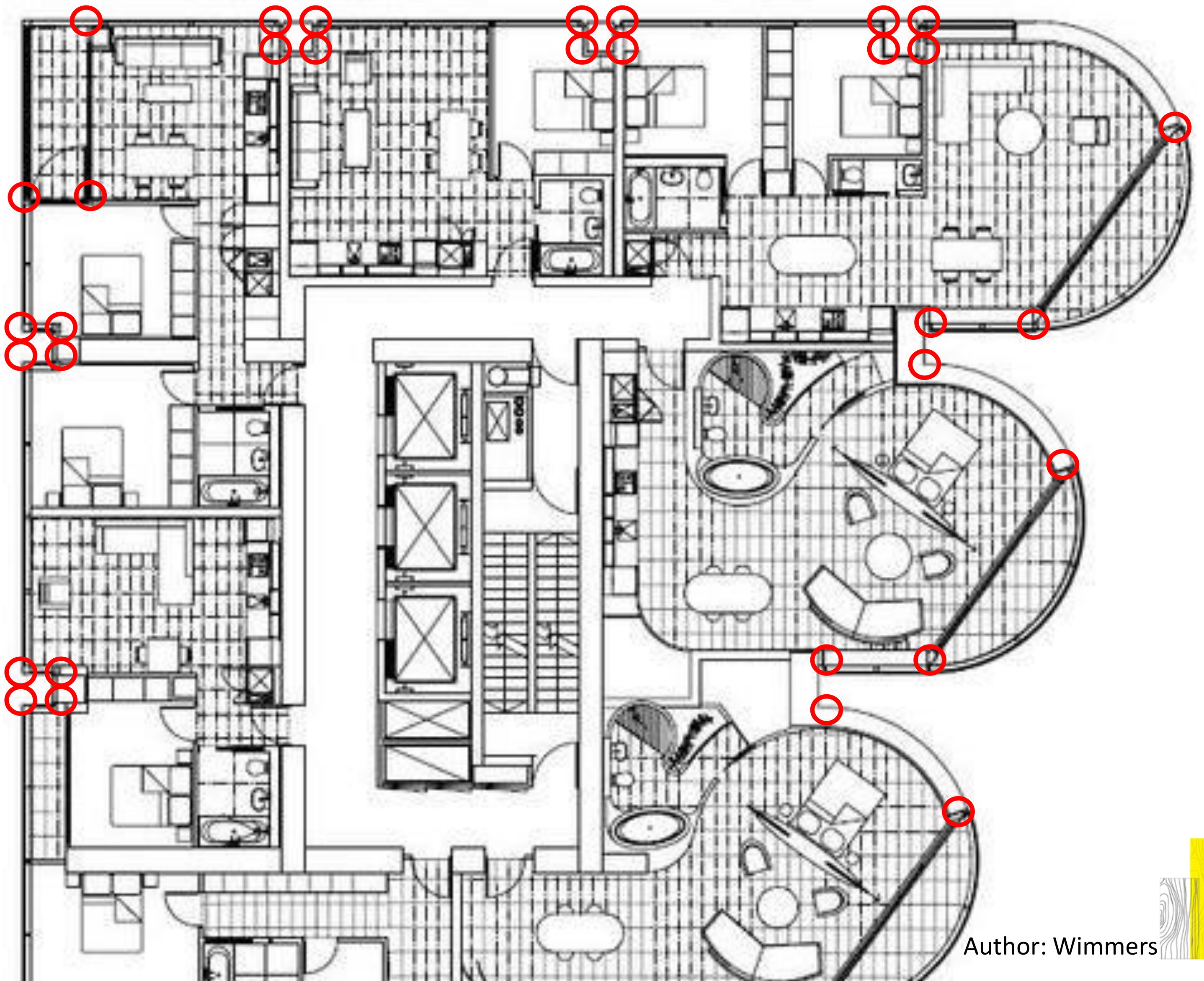
Example



838 W Hastings St. Vancouver, Author: Wim

Author: Wimmers

56 Corners



56 corners in total

Author: Wimmers

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4 Corners

In Total 4 corners possible
28% less wall area

Author: Wimmers

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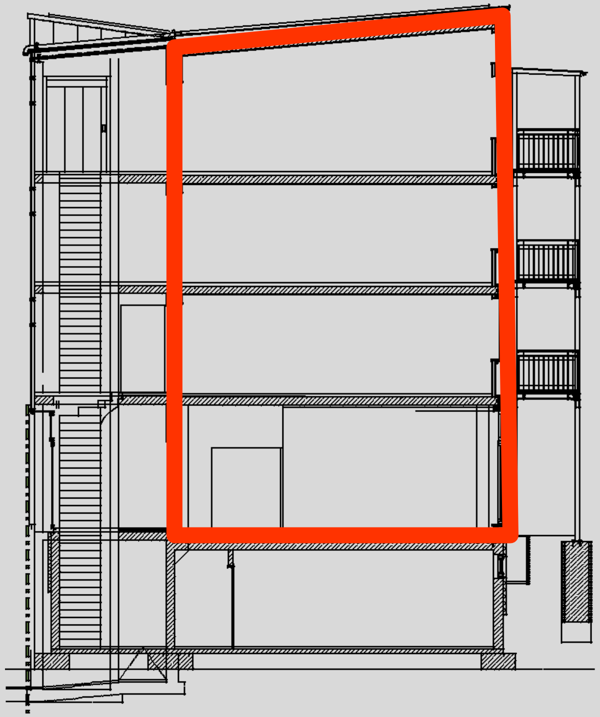
Exercise

- Similar approach can be applied for every section of a building
- Analyze the surface area of this building
- Define the boundary layer



Step 2 for Energy Efficient Construction

Orientation (Architectural Decision)

- **Energy Efficiency strongly influenced by Orientation**
- **Hydrodynamics in Envelope may vary strongly by Orientation**

Author: Wimmers

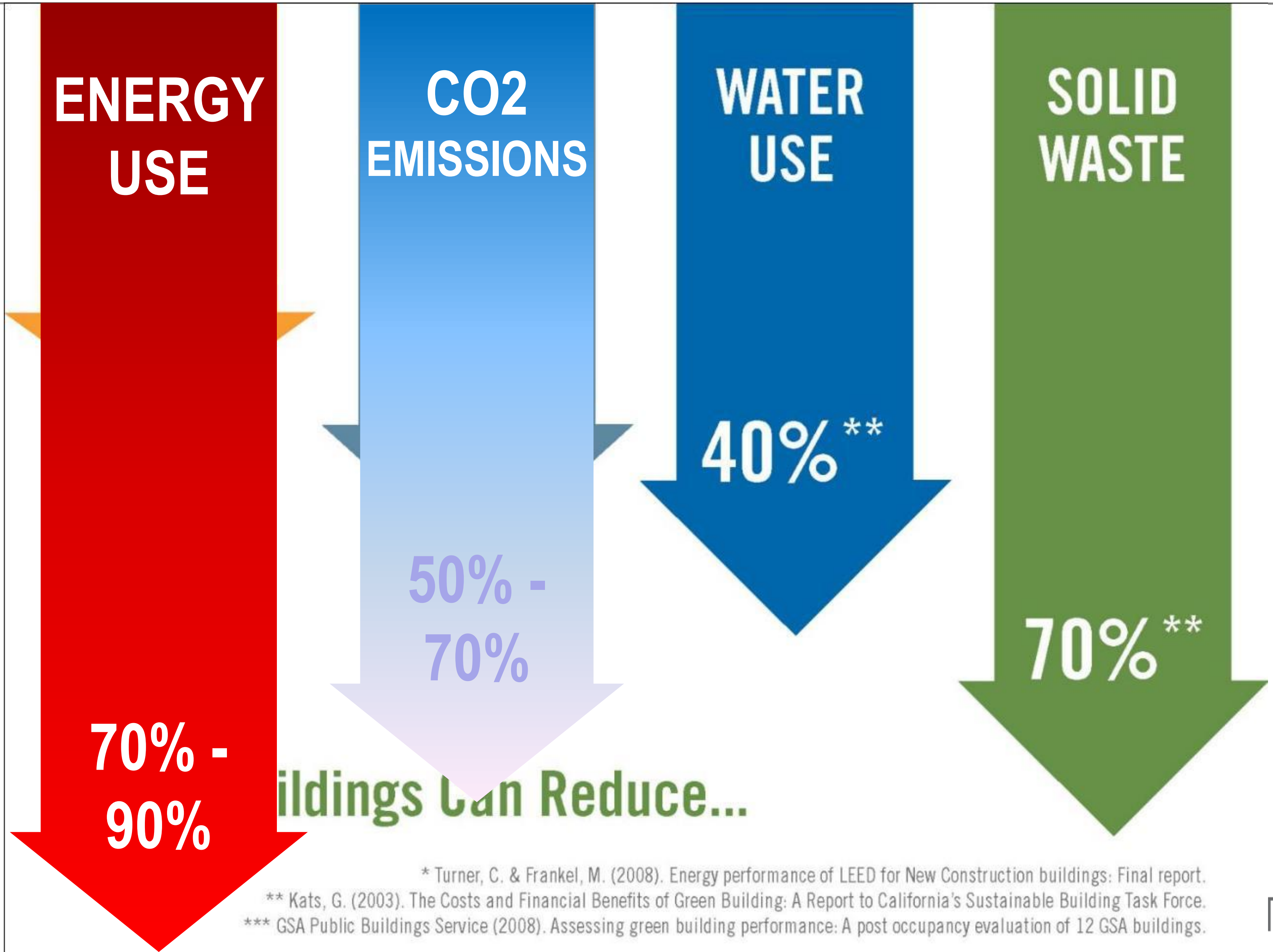
Step 3 for Energy Efficient Construction

Excellent Insulation (Building Science)

- Reduce the Environmental Impact of the Building
- Reduction of heat losses from the building envelope
- Optimize thermal bridges
- Prevention of condensation and mould/rot on the inside
- Safeguarding the performance of the insulation layer
- Insure Thermal Comfort
- Improving the sound insulation of building components
- Improving the fire resistance of the buildings

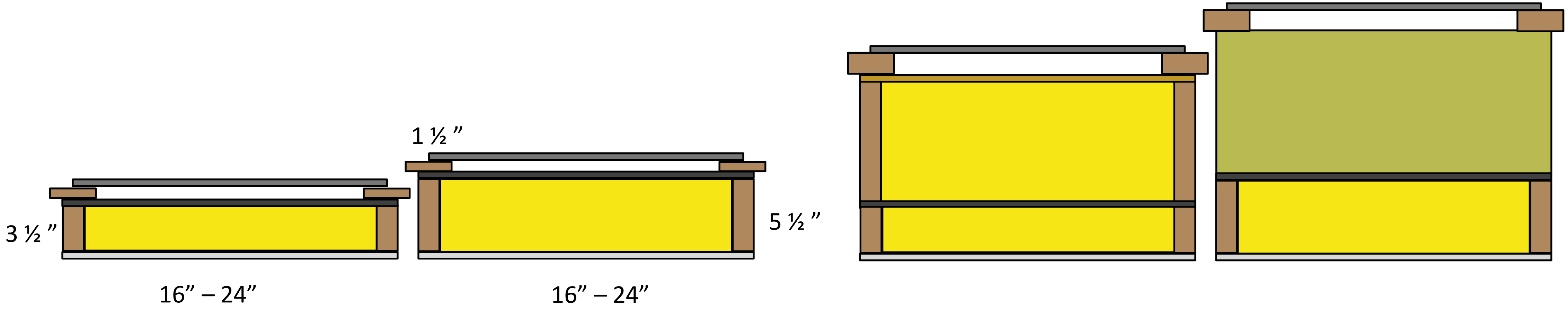
Author: Wimmers

Past, Present and Future



* Turner, C. & Frankel, M. (2008). Energy performance of LEED for New Construction buildings: Final report.
** Kats, G. (2003). The Costs and Financial Benefits of Green Building: A Report to California's Sustainable Building Task Force.
*** GSA Public Buildings Service (2008). Assessing green building performance: A post occupancy evaluation of 12 GSA buildings.

Energy Efficient = Thicker Walls



- Energy efficient does not equal sustainable but without energy efficiency no sustainability!

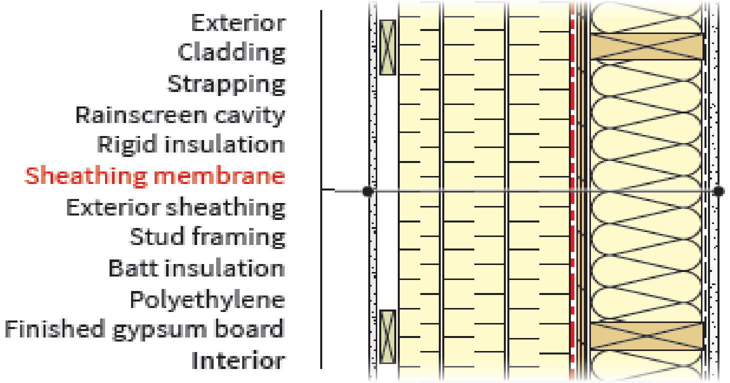
Graphic & Author: Wimmers

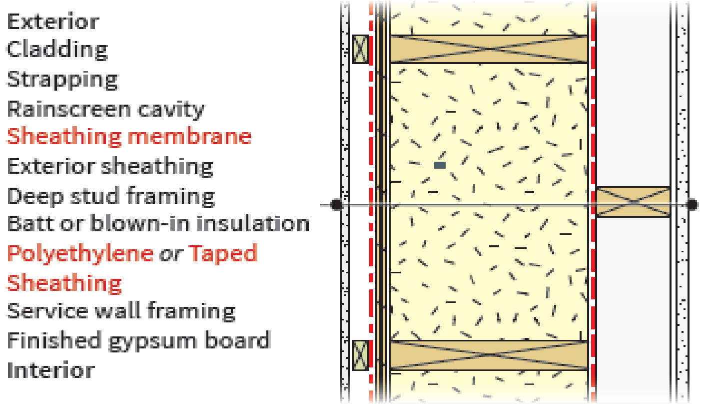
BC Energy Step Code 2017 and new NBC

Author: ENERGY STEPCODE BUILDING BEYOND THE STANDARD

What does this change?

Envelope will get 42 – 77% heavier and will have 87 – 100% more volume! (all numbers are based on the 2017 BCESC)





Source: MOC 2019 Conference Paper: Consequences of the BC Energy Step Code on Offsite Construction

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Step 4 for Energy Efficient Construction

- # Airtightness (Building Science)
  - Reduce Energy Losses
  - Prevention of Condensation (Rot & Mold)
  - Assuring Healthy Living
  - Safeguarding the Performance of Insulation Layers
  - Prevention of Draft
  - Prevention of Cold Floors
  - Preventing Contamination of the Indoor Air
  - Insuring Effectiveness of the Ventilation System
  - Insuring Effectiveness Sound Insulation

Author: Wimmers

Step 5 for Energy Efficient Construction

- # Humidity Management (Building Science)
  - Increase Durability of Envelope
  - Prevention of Condensation (Rot & Mold)
  - Safeguarding the Performance of Insulation Layers
  - Insure Healthy Living Conditions
  - Safeguarding the Structural Performance

Author: Wimmers

Benefit of Energy Efficient Construction

Thermal Comfort (Building Science)

- Optimize Well Being
- Insure Healthy Living Conditions
- Reduce Energy Consumption

Thermal Comfort

Value	Sensation
+3	Hot
+2	Warm
+1	Slightly Warm
0	Neutral
-1	Slightly Cold
-2	Cool
-3	Cold

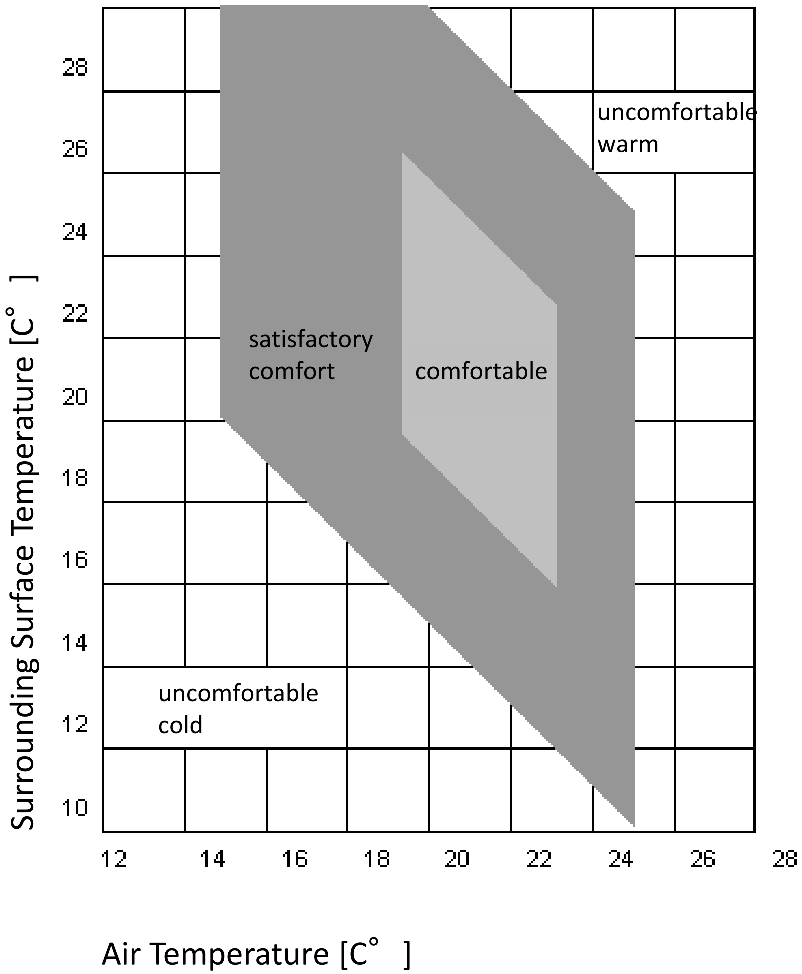
- Thermal comfort is defined in ASHRAE 55 or ISO 7730 or EN 15251 as:

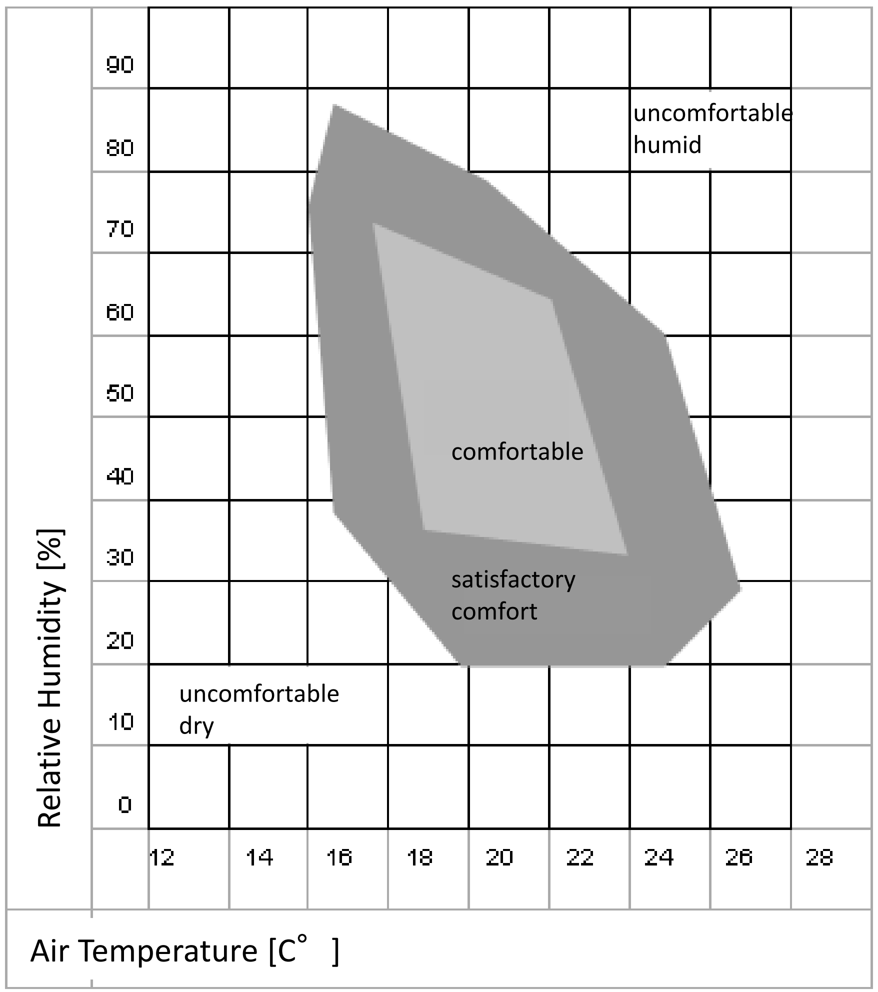
  The condition of mind which expresses satisfaction with the thermal environment.

- Thermal comfort is defined by numerous parameters set by the majority, attempting to convert the condition of mind into physical parameters.

Source: ASHRAE, ISO, Author: Wimmers

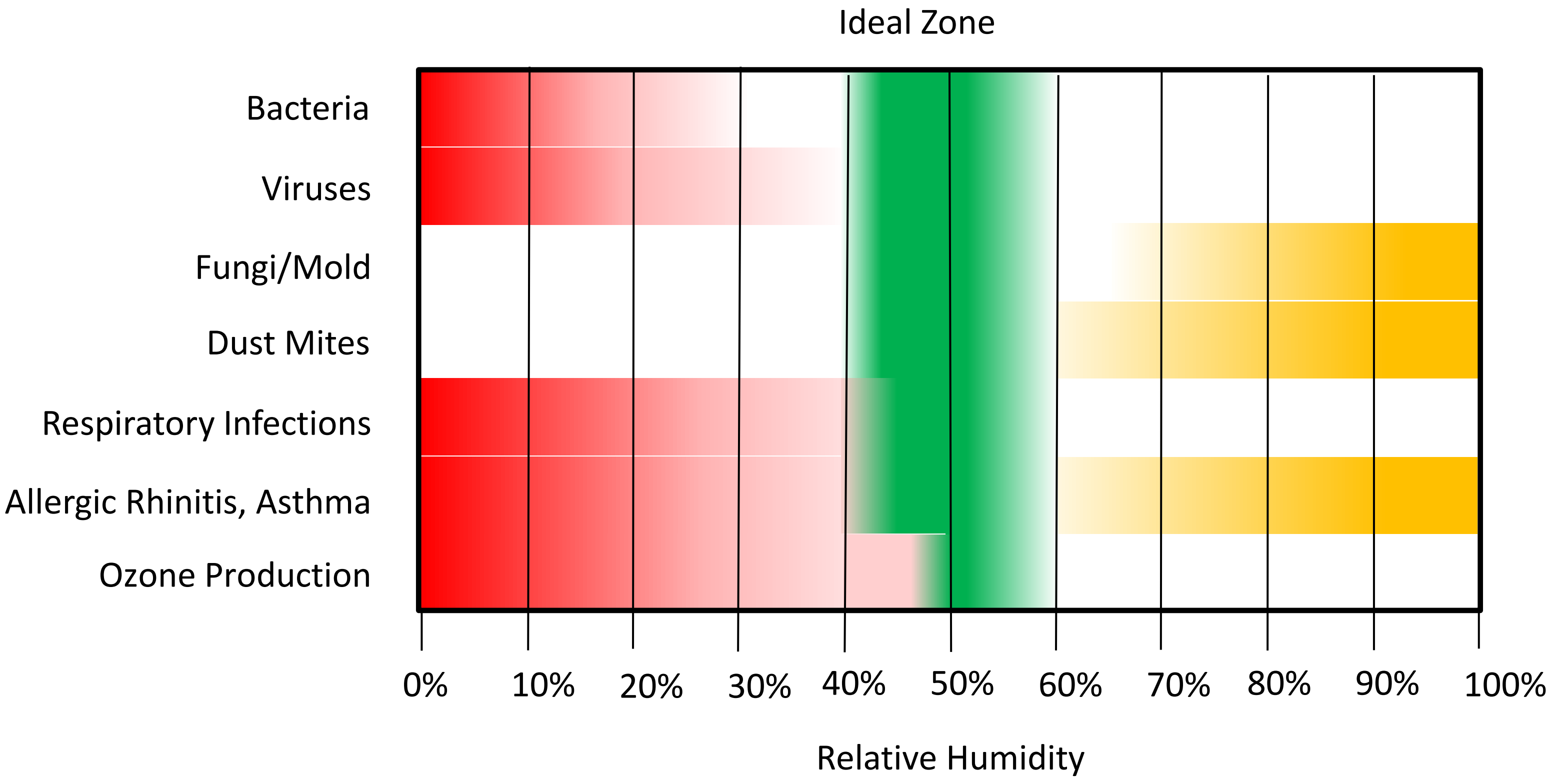
Interior Comfort





Source: O. Fanger, Graphic: Wimmers

Health Benefits depending on Humidity



Source: Building Knowledge, Graphic: Wimmers

Lesson 2: Thermal Performance

(45min + 5min Q&A)

- ***Objectives:***
  - Summarize the basics of thermodynamics
  - Identify all relevant units (thermal conductivity, thermal transmittance, thermal resistance)
  - Classify and ranking thermal conductivity of materials
  - Calculate thermal conductivity of materials.
  - Investigate heat transfer through building envelopes and calculation of heat flow values through simple assemblies (including effects of surface air layers).
  - Differentiate thermally high performing envelope assemblies from low performing assemblies.

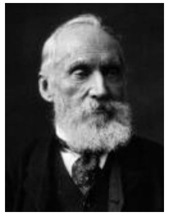
Basics of Thermodynamics in Construction

- Units for Temperature
- 3 Laws of Thermodynamics
- Heat Transfer
- Thermal Energy and Heat Flow
- Thermal Conductivity λ
- R value and U value

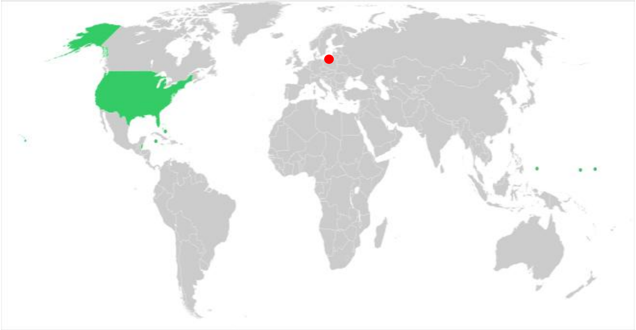
Author: Wimmers

Units for Temperature

- Degree Celsius (℃) by Anders Celsius (1701 – 1744)
  - 0 ℃ triple point of water, 100 ℃ boiling point of water
- Kelvin (K) by Lord Kelvin (1824 – 1907)
  - 0 K is absolute Zero, 273.15 K is the triple point of water
  - Climate in Prince George, BC ~ 243 – 303 K



- USA uses Fahrenheit (℉) by Daniel Gabriel Fahrenheit (1686 – 1736)
  - ratio to Celsius: ℉ = 32 + 9/5℃
  - 0 ℉ was the lowest temperature in Danzig in the winter 1708/09
  - 32 ℉ triple point of water, boiling point of water 212 ℉



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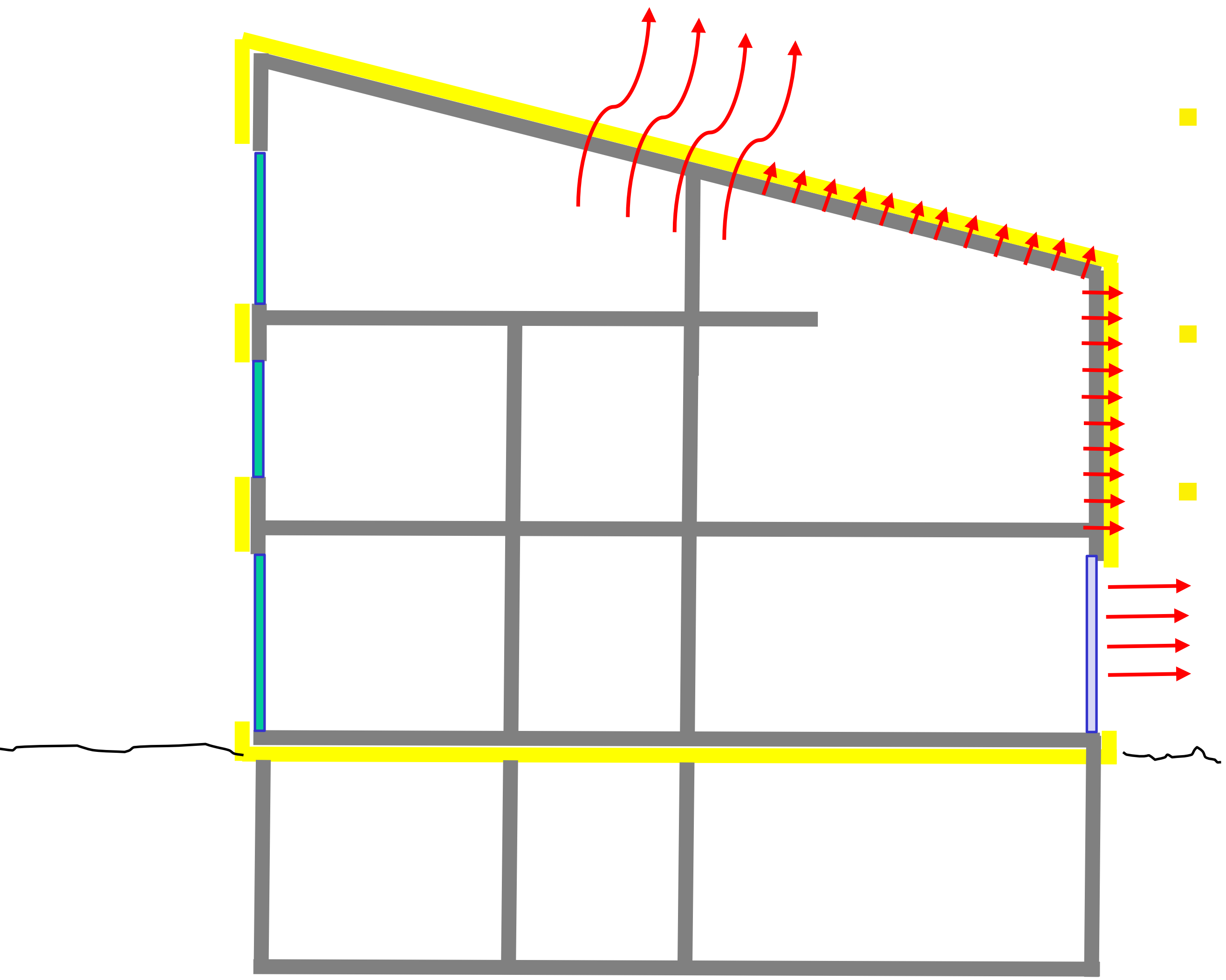
3 Laws of thermodynamics

- 1st law states that energy cannot be created or destroyed in an isolated system
- 2nd law states that the entropy of any isolated system not in equilibrium will tend to increase over time, approaching a maximum value at equilibrium
- 3rd law states that the entropy of a system approaches a constant value as the temperature approaches absolute zero

Entropy = thermodynamic property that is the measure of a systems thermal energy per unit of temperature that is unavailable for doing useful work

3 ways of heat transfer



- Conduction
  - Heat transfer through solids or stationary fluids
- Convection
  - Heat transfer through motion of fluids
- Radiation
  - Heat transfer through electromagnetic radiation

Author: Wimmers

Units for Heat Transfer

Thermal Energy or Heat Transfer (Q)

1 J = 1W/s = 0.0003 Wh = 9.4787 x 10^{-4}Btu

Heat Flow Rate (q)

1j/s = 1W = 3.4123 Btu/h

1 kWh = 3600 J = 3412 BTU

Heat Flux

1W/m² = 0.3171 Btu/h x ft²

1 J = energy to heat 1 g of water by 0.24° Celsius (calorie is 1 g of water by 1° Celsius)

1 Btu = energy to heat 1 pound of water by 1° Fahrenheit

Author: Wimmers

Heat Flow Rate q, R and U

$$q = \frac{\Delta Q}{\Delta t} = \lambda A \frac{\Delta T}{d} = heat\ flow\ rate$$

$\mathrm{Q} = \text{heat transfer}$

$\Delta t = time$

$\lambda\ or\ k = thermal\ conductivity$

$\mathrm{A} = \text{area}$

$\Delta T = temperature\ difference$

$\mathrm{d} = \text{thickness (dimension)}$

$$\mathrm{R} = \frac{d}{\lambda} = Thermal\ Resistance$$

$$\mathrm{U} = \frac{1}{Rt} = \text{Heat Transfer Coefficient}$$

$\mathrm{R}t = Total\ Thermal\ Resistance$

In Canada the letter k is commonly used for thermal conductivity, internationally λ (lambda) is very common. Using k creates the risk of confusion with K (Kelvin), as both are used in the same equation.

$$k(or\ \lambda) = \frac{1W\ x\ 1m}{1m^2\ x\ K}$$

Therefore we continue in this course to use λ (lambda) to avoid any confusion, but you could replace λ with k any time.

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Heat Transfer Coefficient

$$U = \frac{1}{Rt} = \frac{1}{Rse + \frac{d1}{\lambda 1} + \frac{d2}{\lambda 2} + \ldots + Rsi}$$

U = Heat Transfer Coefficient $[W/(m^2K)]$
R = Thermal Resistance $[(m^2K)/W]$
Rt = Thermal Resistance Total
Rse = Resistance Surface Exterior (exterior air film)
Rsi = Resistance Surface Interior (interior air film)
d = thickness (dimension) of material [m]
λ = thermal conductivity [W/mK]
K = Kelvin, 0K = -273° C, 273K = 0° C

If you are only interested in the R value, you just use the denominator of this equation.

Using R or U is both correct as they both describe the same effect, just from the opposite point of view (resistance & conductivity).
Using U has a slight advantage, which will be explained in the following slides.

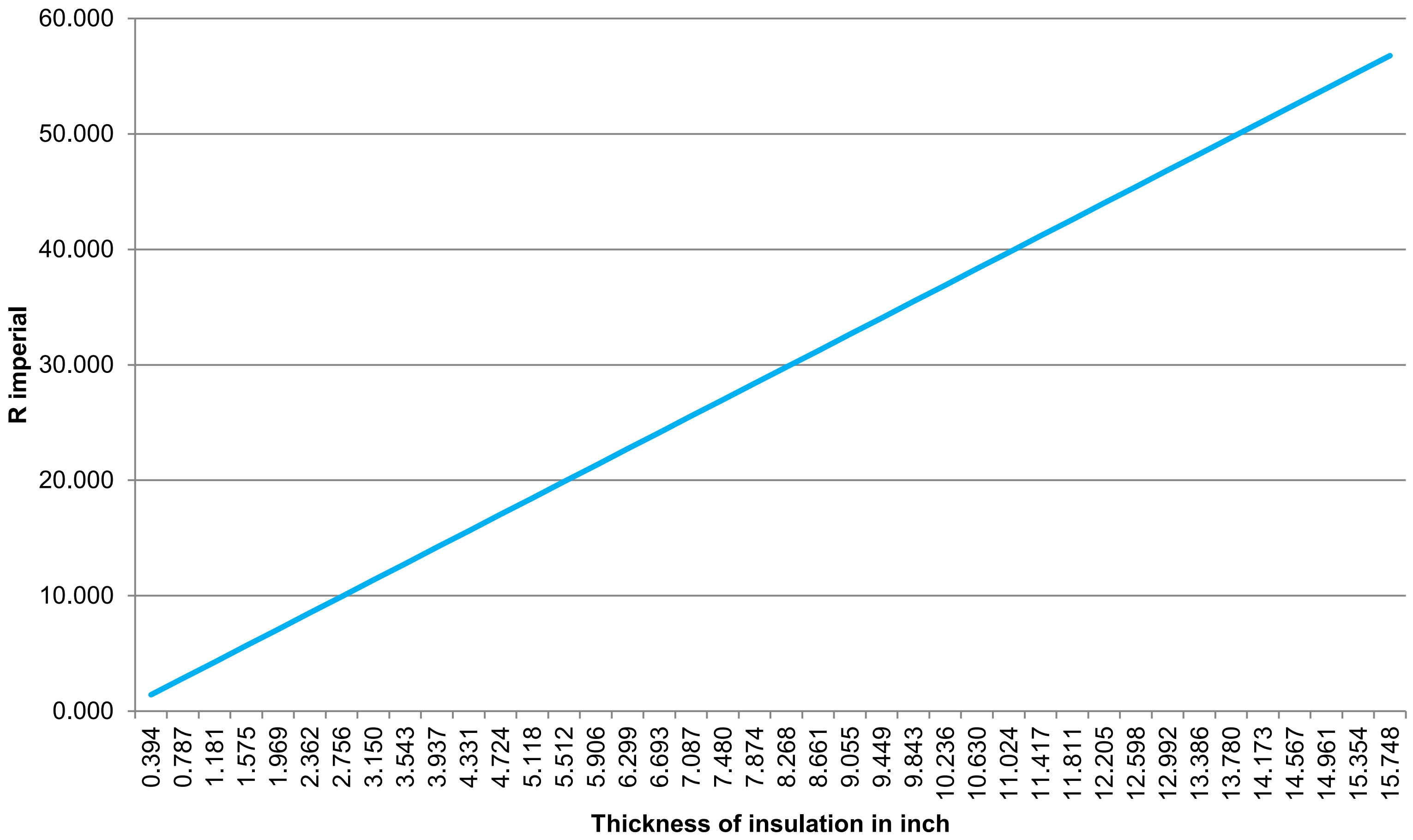
In Canada the total R value is commonly referred to as RSI (R Standard International) to emphasize that this is the metric R value. This triggers confusion with Rsi, the Interior Surface Resistance, called in Canada interior air film.

Author: Wimmers

Practical differences between U and R

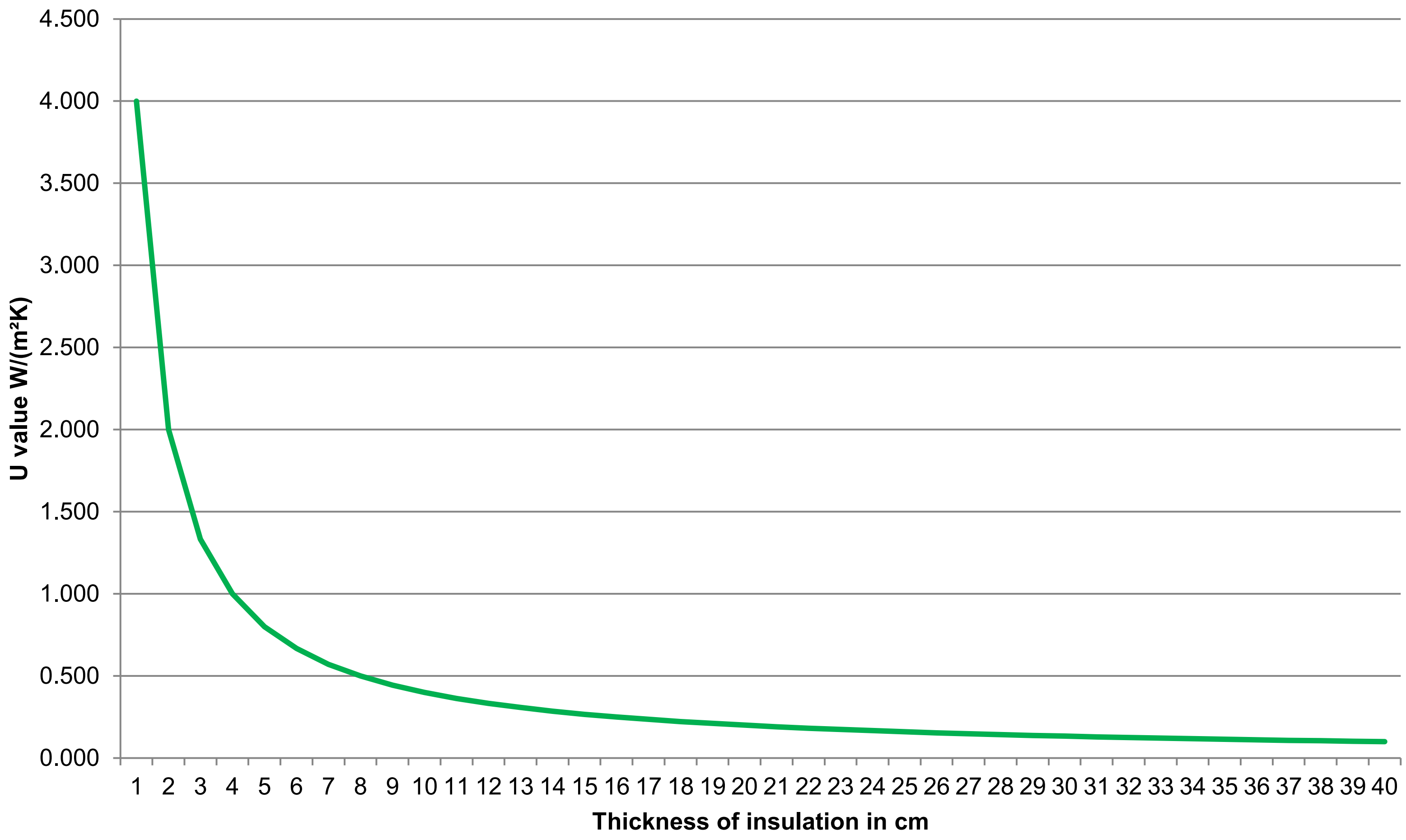
Which R value is shown?

Thermal Resistance R imperial



Graphic & Author: Wimmers

Heat Transfer Coefficient U metric



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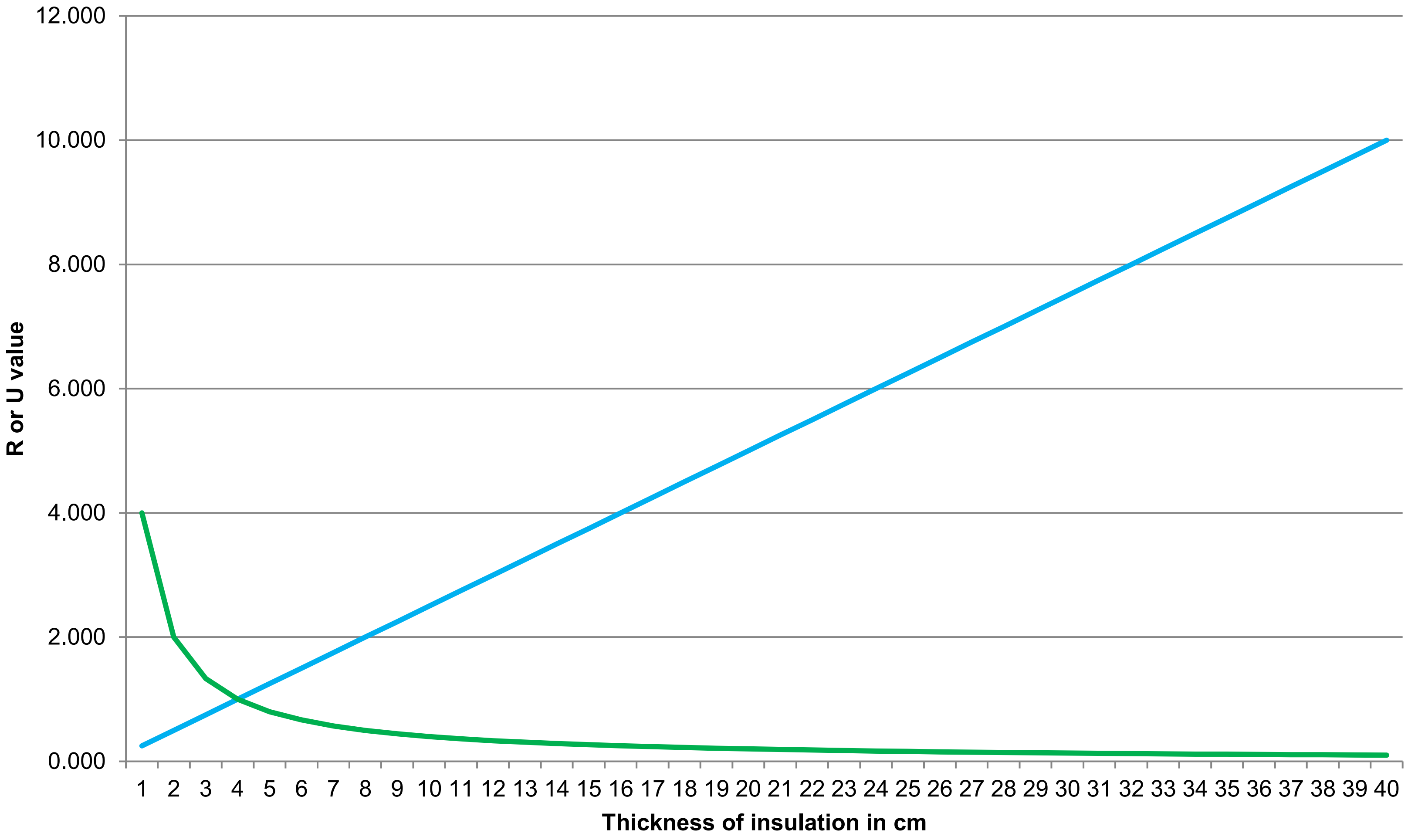
U & RSI



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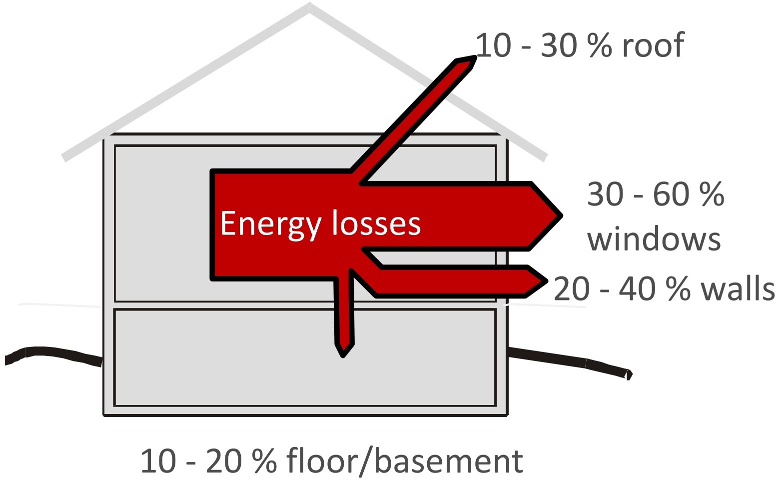
Economic and Ecological Balance

- Economical sweet spot for the amount of insulation installed
  - ratio of additional initial investment compared to operational costs = “Monthly Costs of Ownership”
- Ecological sweet spot for the amount of insulation installed.
  - Both are depending on several variables such as: location, climate,, insulation material, availability of materials and shipping, type of heating fuel…



Graphic & Author: Wimmers

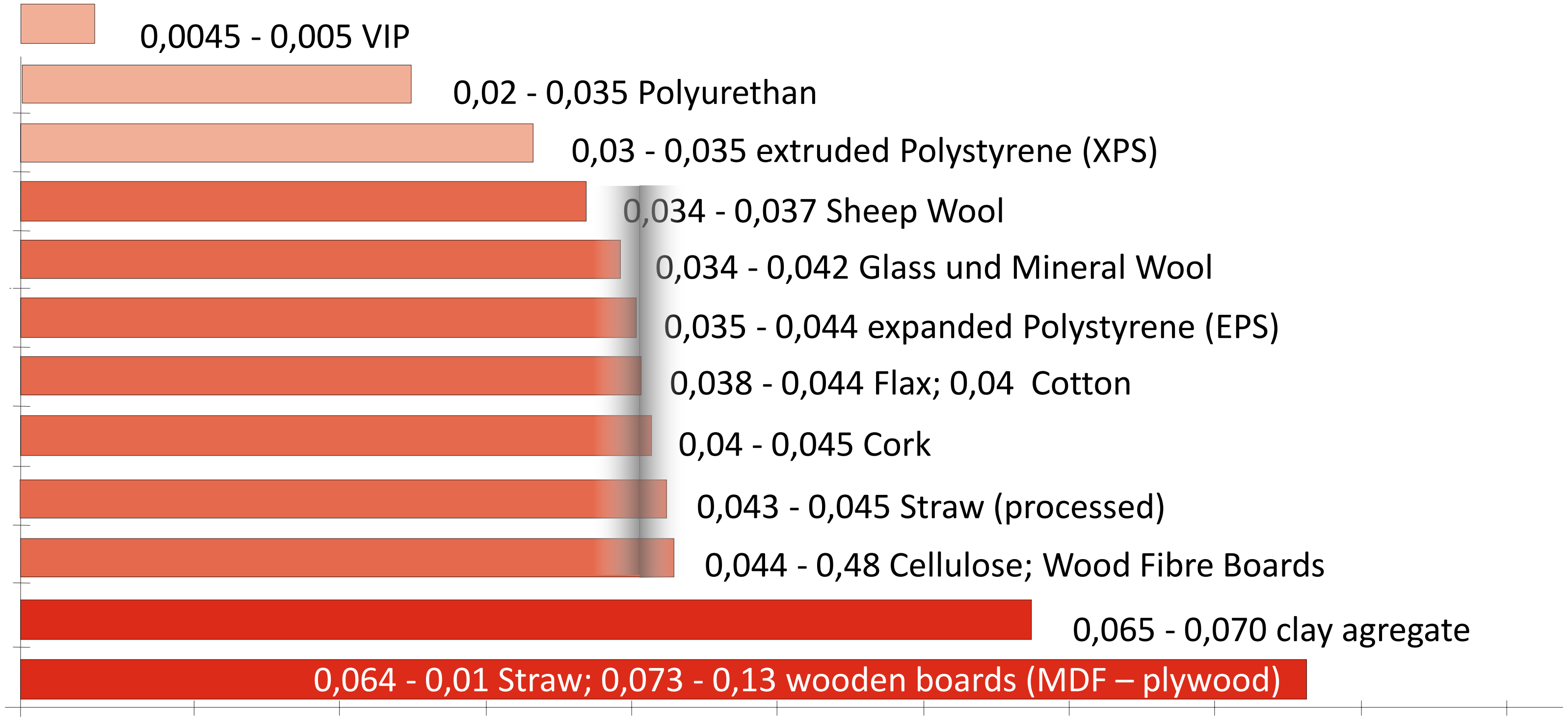
Conversion

Conversion Factor between RSI and R imp = 5.678

	metric		imperial	
	U-value [W/m²K] U=1/R	**RSI** [m²K/W]	U-value [BTU/ft²Fh] U=1/R	R-value [ft²Fh/BTU]
Opake Envelope	**0.08**	**12.50**	0.014	70.98
	0.09	**11.11**	0.016	63.09
	0.10	**10.00**	0.018	56.78
	0.11	**9.09**	0.019	51.62
	0.12	**8.33**	0.021	47.32
	0.13	**7.69**	0.023	43.68
	0.14	**7.14**	0.025	40.56
	0.15	**6.67**	0.026	37.86
	0.20	**5.00**	0.035	28.39
	0.25	**4.00**	0.044	22.71
	0.30	**3.33**	0.053	18.93
	0.35	**2.86**	0.062	16.22
	0.40	**2.50**	0.070	14.20
	0.45	**2.22**	0.079	12.62
	0.50	**2.00**	0.088	11.36
	0.55	**1.82**	0.097	10.32
	0.60	**1.67**	0.106	9.46
Windows	**0.65**	**1.54**	0.114	8.74
	0.70	**1.43**	0.123	8.11
	0.75	**1.33**	0.132	7.57
	0.80	**1.25**	0.141	7.10

Author: Wimmers

Thermal conductivity: λ-value [W/mK] (or k-value)



The lower the λ- value, the less the conductivity.

Graphic & Author: Wimmers

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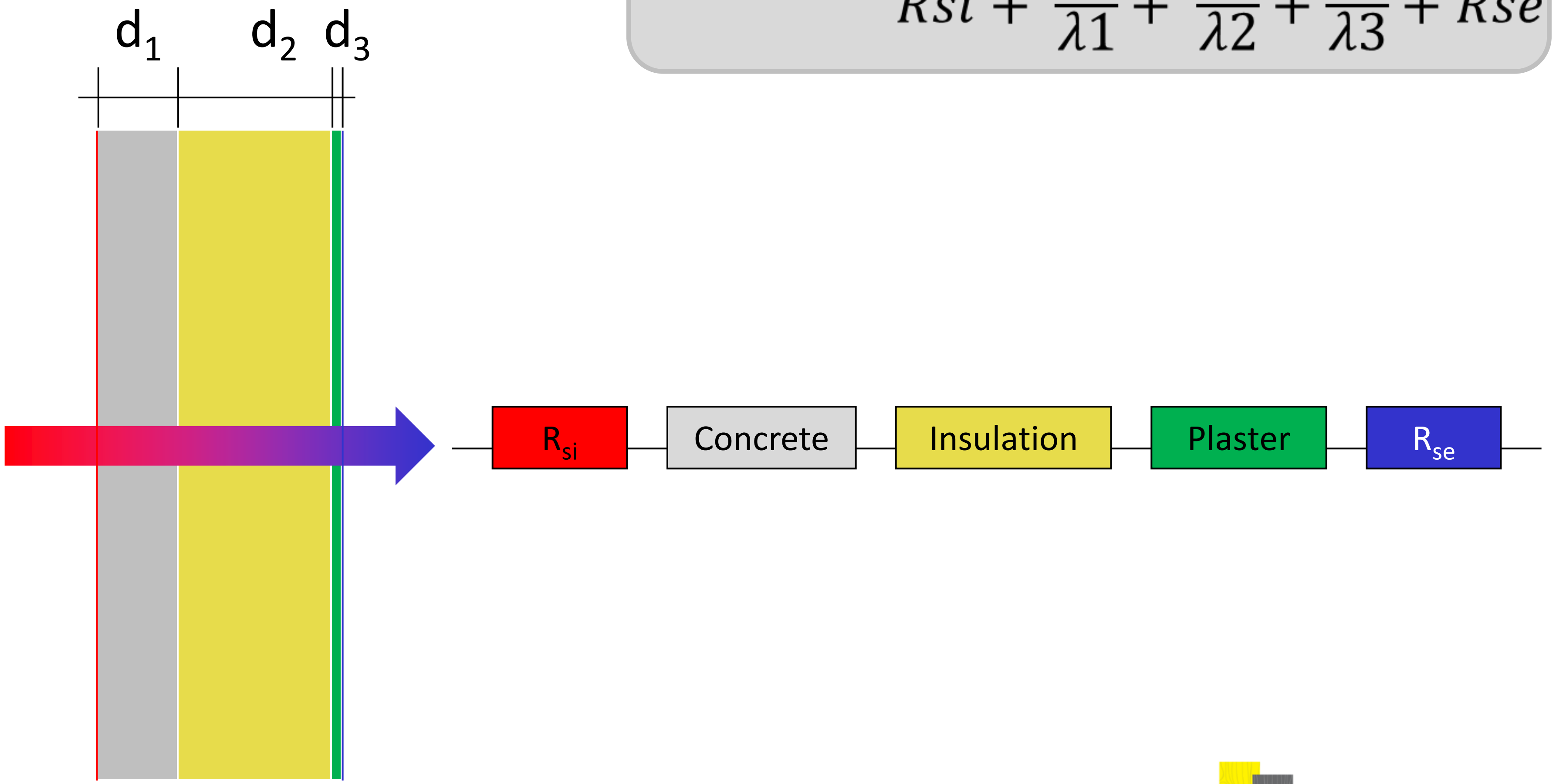
U-value calculation (ISO 6946)

$$U = \frac{1}{Rt} = \frac{1}{Rsi + \frac{d1}{\lambda 1} + \frac{d2}{\lambda 2} + \frac{d3}{\lambda 3} + Rse}$$



Source: PHI, Author: Wimmers

Exercise

U-values of homogeneous building elements (EN ISO 6946)

Exercise 1

Calculate the U-value of the following wall construction

d1 = 0.2 m, λ = 2.3 W/mK

d2 = 0.30 m, λ = 0.38 W/mK

d3 = 0.015 m, λ = 0.70 W/mK

R_T = Total thermal resistance (m²K/W)

R_{si} = Thermal resistance of inner surface = 0.13 m²K/W

R_{se} = Thermal resistance of outer surface = 0.04 m²K/W

U = Heat transfer coefficient (W/m²K)

Exercise

$$U = \frac{1}{R_T} = \frac{1}{Rsi + d1/l1 + d2/l2 + d3/l3 + Rsa}$$

$$U = \frac{1}{R_T} = \frac{1}{0.13\ m^2K/W + 0.20\ m/2.3\ W/mK + 0.30\ m/0.038\ W/mK + 0.015\ m/0.70\ W/mK + 0.04\ m^2K/W}$$

$$U = \frac{1}{R_T} = \frac{1}{0.13\ m^2K/W + 0.087\ m^2K/W + 7.895\ m^2K/W + 0.021\ m^2K/W + 0.04\ m^2K/W}$$

$$U = \frac{1}{R_T} = \frac{1}{0.13\ m^2K/W + 8.00\ m^2K/W + 0.04\ m^2K/W}$$

$$U = \frac{1}{R_T} = \frac{1}{8.\ 17\ m^2K/W} = 0.122\ W/m^2K$$

Author: Wimmers

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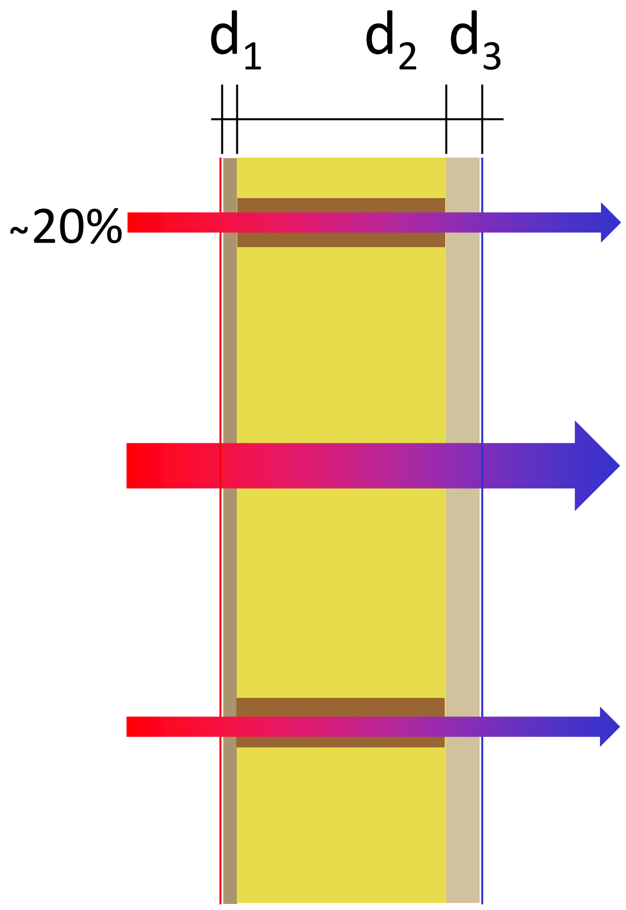
U-value calculation non homogenous components (ISO 6946)

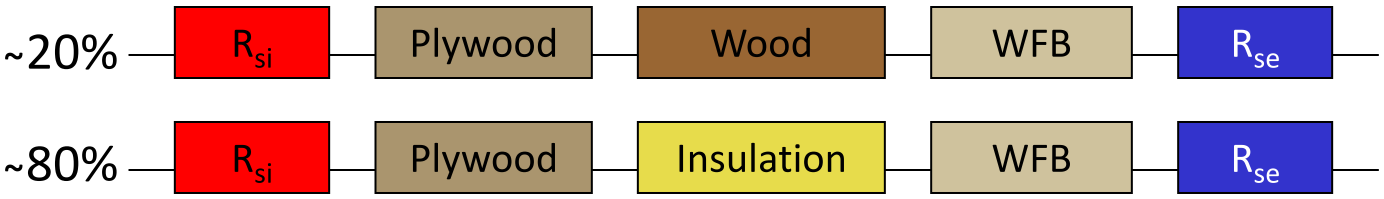


Cross Section of Stud Wall

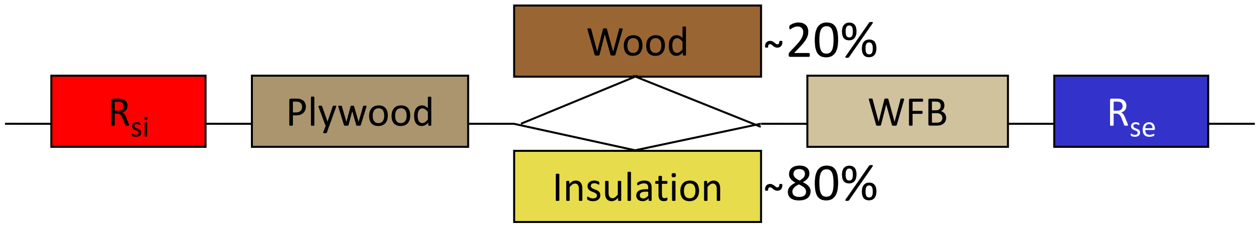
Graphic & Author: Wimmers

$$U = \frac{1}{Rt} = \frac{1}{(R't + R''t)/2}$$

Upper Estimated R't



Lower Estimated R''t



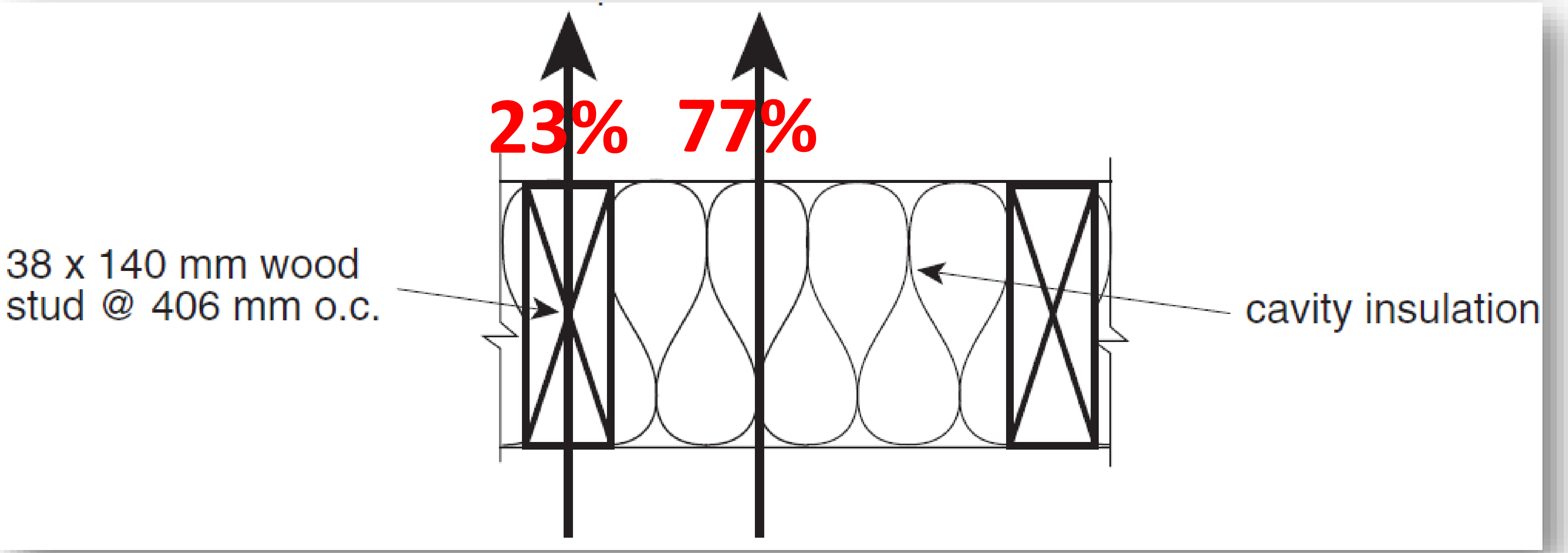
wood SMART

Canadian Wood Council

Conseil canadien du bois

Effective R-value calculation for 2x6 wood studs and cavity insulation:

$$R_{eff} = \frac{100}{\frac{\overset{23\%}{\%\ \text{area framing}}}{R_F} + \frac{\overset{77\%}{\%\ \text{area cavity insulation}}}{R_C}}$$



Source: NBC A9.36.2.4

Author: Jonkman

Wood Percentage in Framing

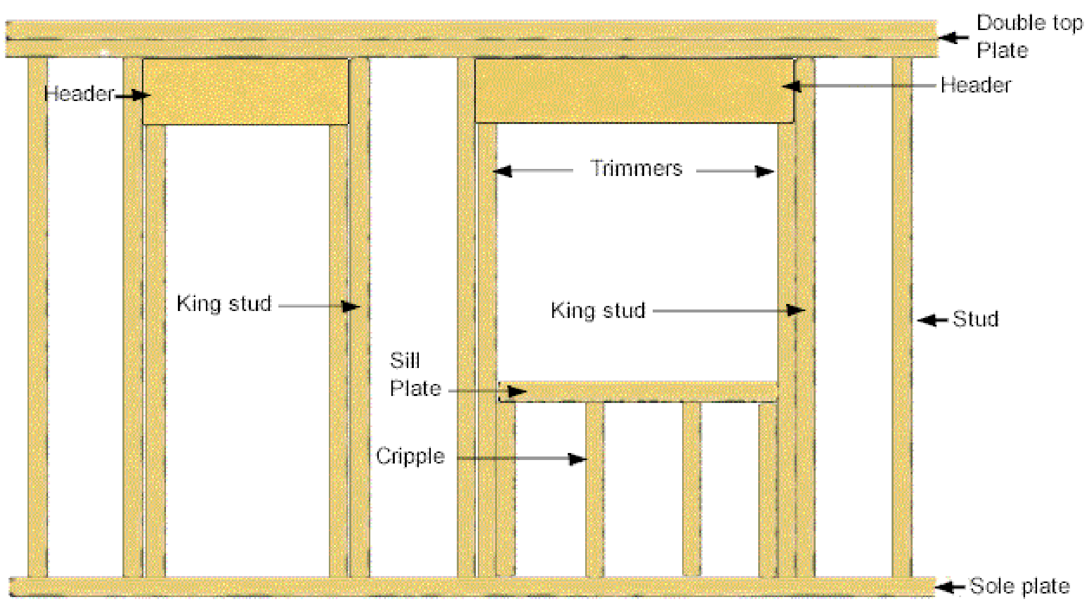


Table A-9.36.2.4.(1)A
Framing and Cavity Percentages for Typical Wo

Wood-frame Assemblies		Fra			
		304		406	
		% Area Framing	% Area Cavity	% Area Framing	% Area Cavity
Walls	typical wood-frame	24.5	75.5	23	77
	advanced wood-frame with double top plate(2)	–	–	19	81

Graphic: NBC

wood SMART
Canadian Wood Council
Conseil canadien du bois

Lesson 3: Thermal Bridging

(5min summary + 40min + 5min Q&A)

Objectives:

- Describe types of thermal bridges
- Outline the principle of thermal-bridge-optimized construction, and appraise the impact thermal bridges play in overall building performance.
- Qualitatively analyze a building envelope in terms of potential thermal bridges, and identifying which areas and details are most important.
- Demonstrate calculation method for thermal bridges using heat loss programs (e.g. FLIXO)
- Design details and compare to representative values via examples

Thermal Bridging

- Definition of Thermal Bridges
- Types of Thermal Bridges
- Avoidance and Optimization
- Calculation of Thermal Bridge Coefficient Ψ

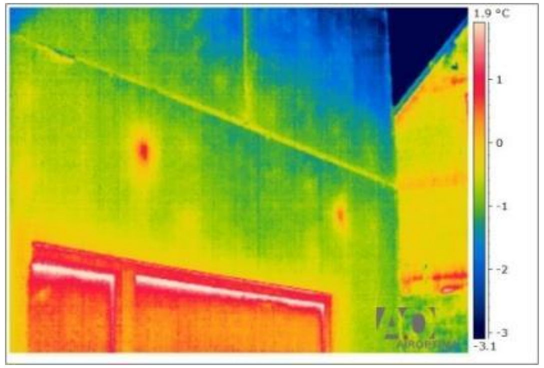
Author: Wimmers

Canadian Wood Council
Conseil canadien du bois

Thermal Bridge

- A thermal bridge occurs if Isotherms are bend
- There are Linear Thermal Bridges Ψ (psi) and Point Loads χ (chi)

- Weakening of thermal properties of the envelope caused by:
  - Planning and design
  - Workmanship
  - Geometrical

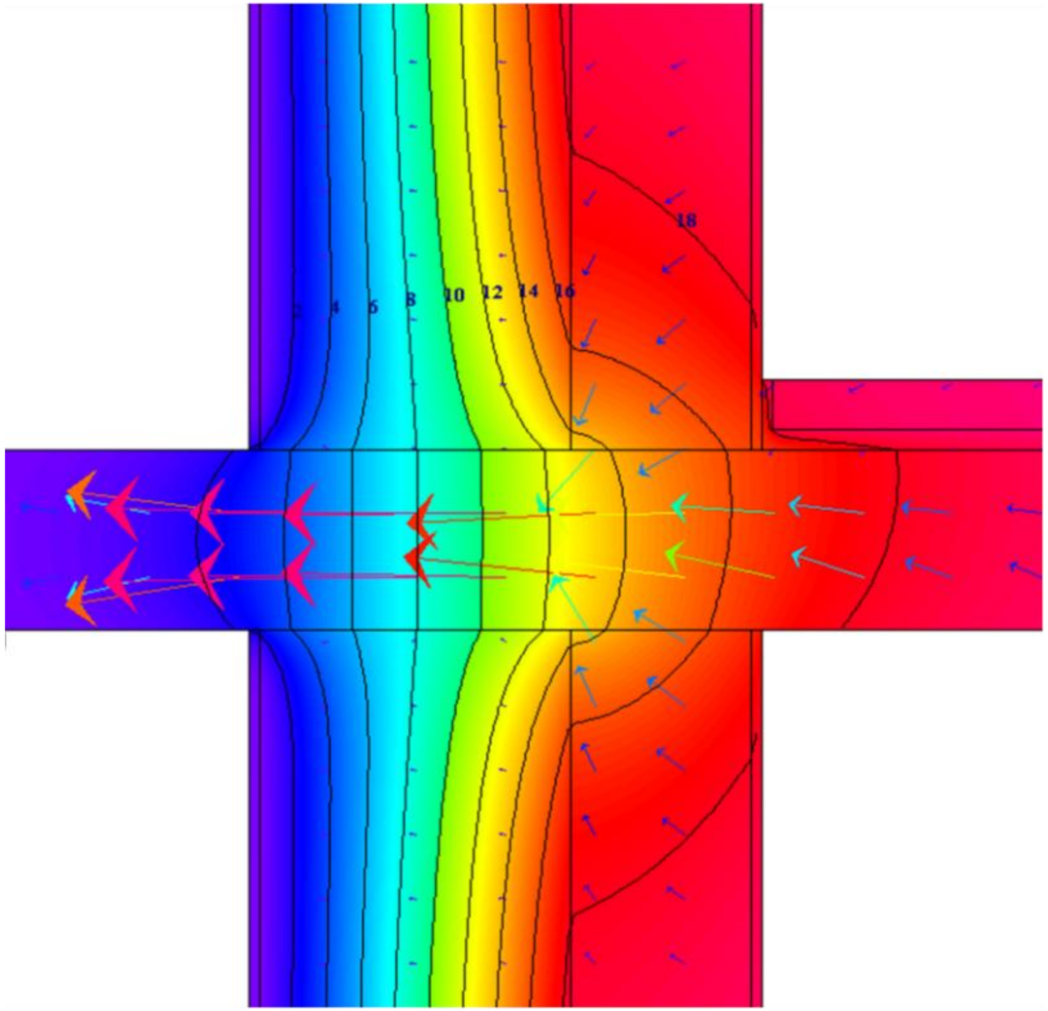


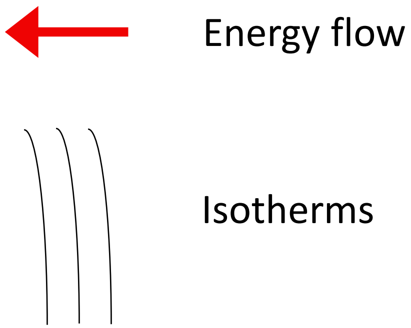
Author: Wimmers, Photo: PHI

“Typical” Thermal Bridge

Photos: Harley Davidson, Wimmers

Isotherms





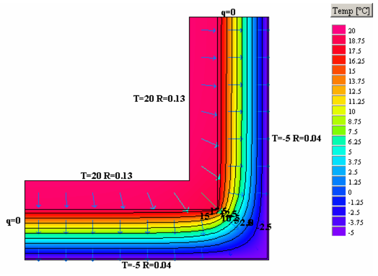
Source: PHI, Author: Wimmers

Avoid and Optimize

- Avoid penetration of insulation with high thermally conductive materials.

- If penetrations are necessary, optimize detail and select suitable materials to minimize thermal losses.

- Optimize the geometry of the building (see compactness) by design less corners and ideally no corners <90˚



Author: Wimmers

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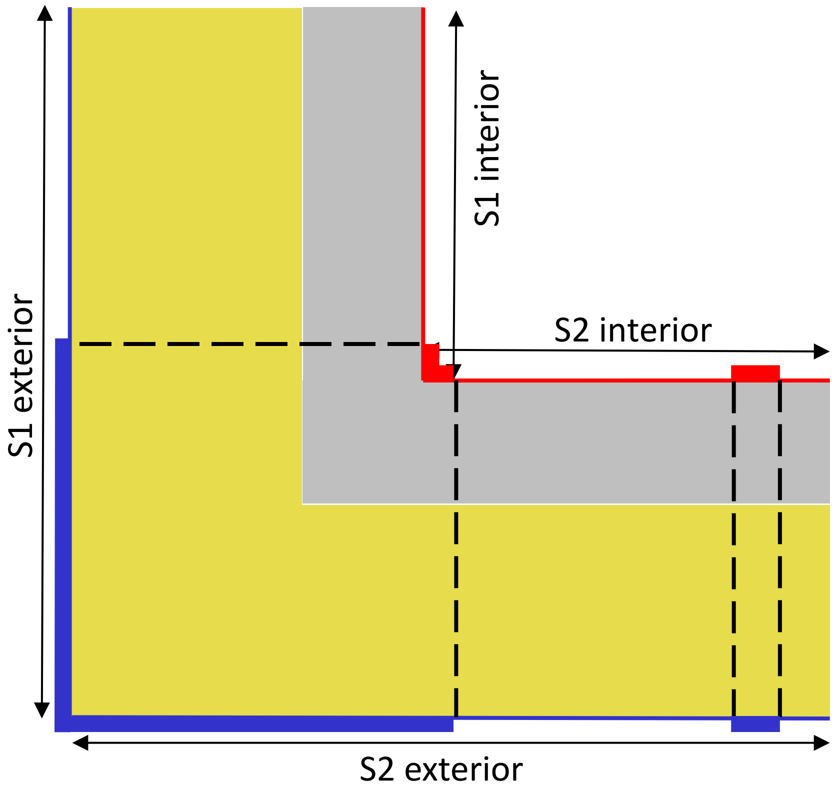
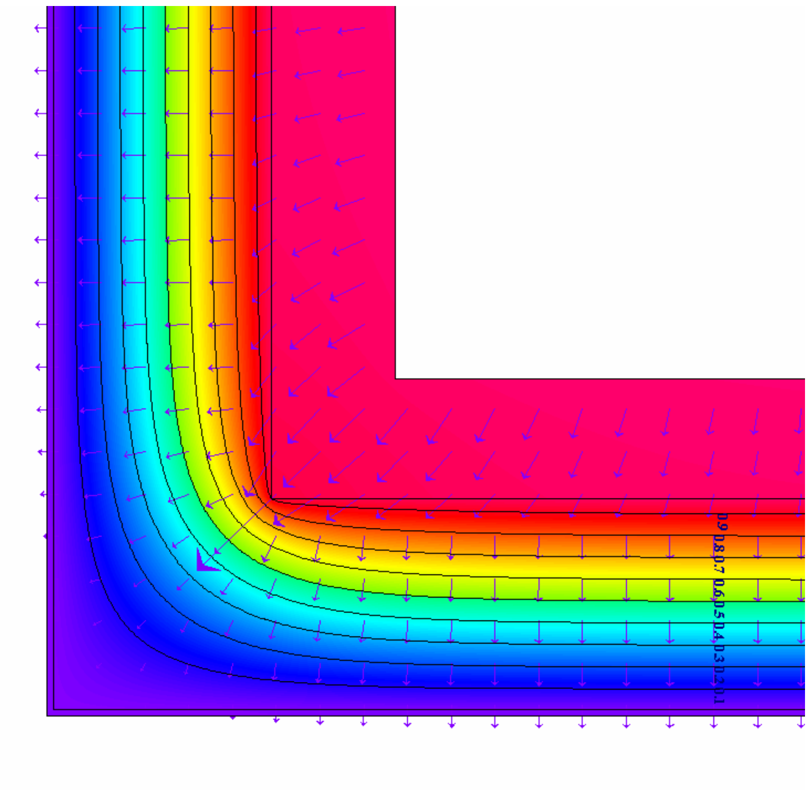
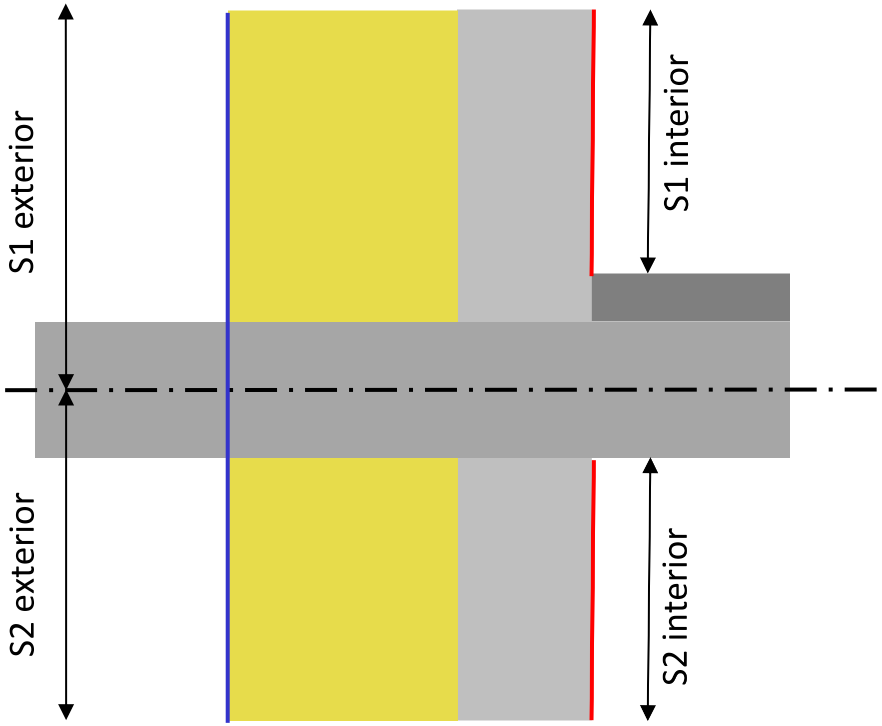
Geometry

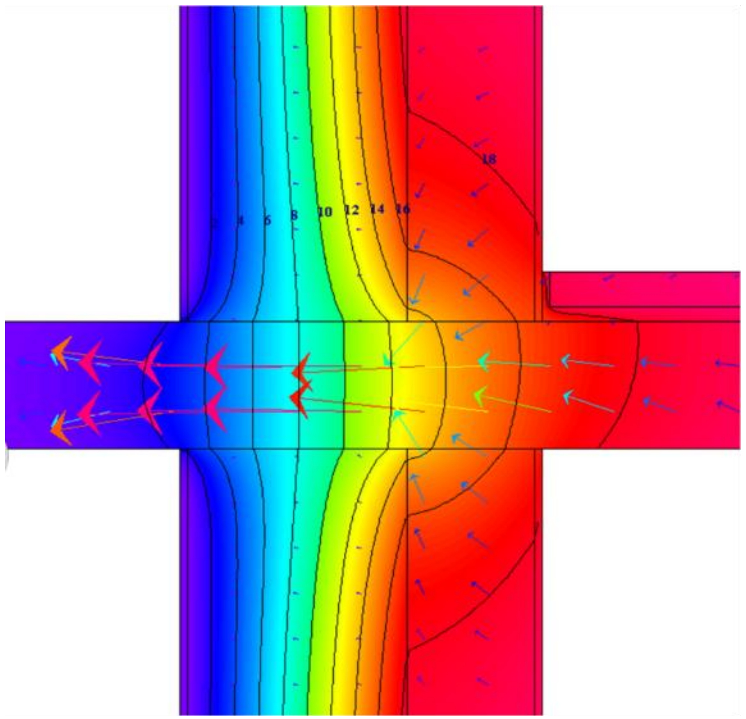




Author & Graphic: Wimmers

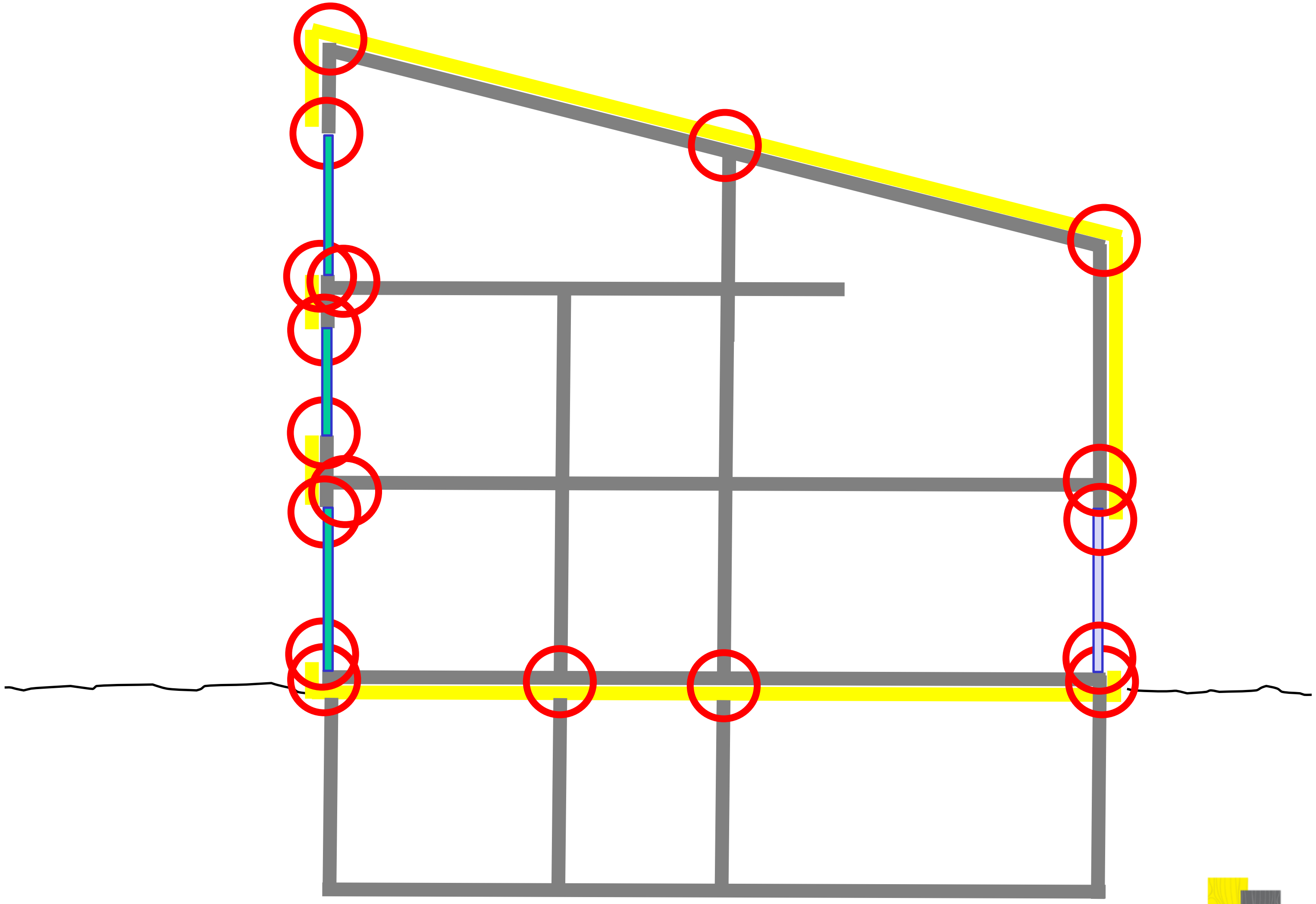
Penetration





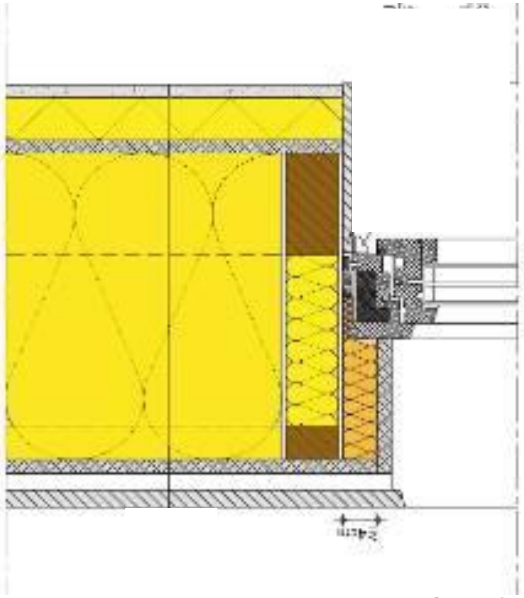
Author & Graphic: Wimmers

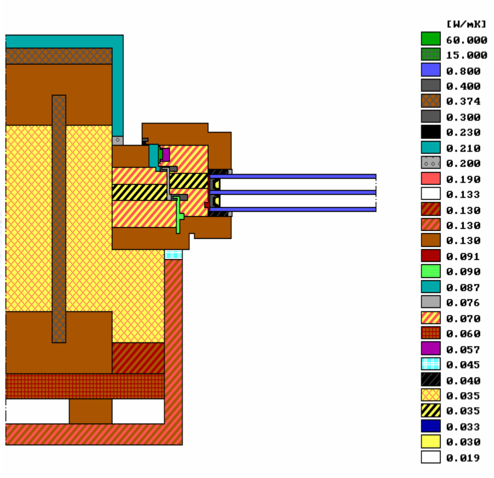
Where are Thermal Bridges?

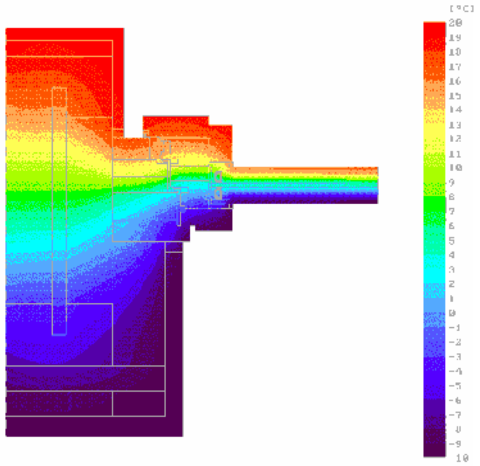


Author & Graphic: Wimmers

Thermal Bridges are a Design Exercise







Detailed Design, Thermal Bridge Calculation and Optimization, Installation and Site Supervision

Graphic: PHI, Wimmers, Photo: Wimmers

wood SMART

Canadian Wood Council

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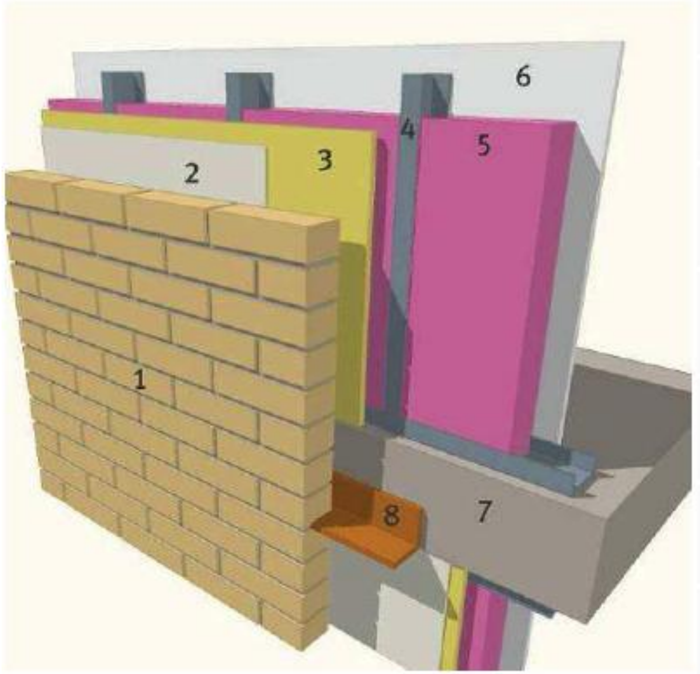
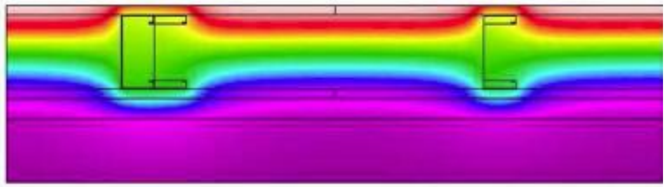
Steel Stud Wall Assemblies

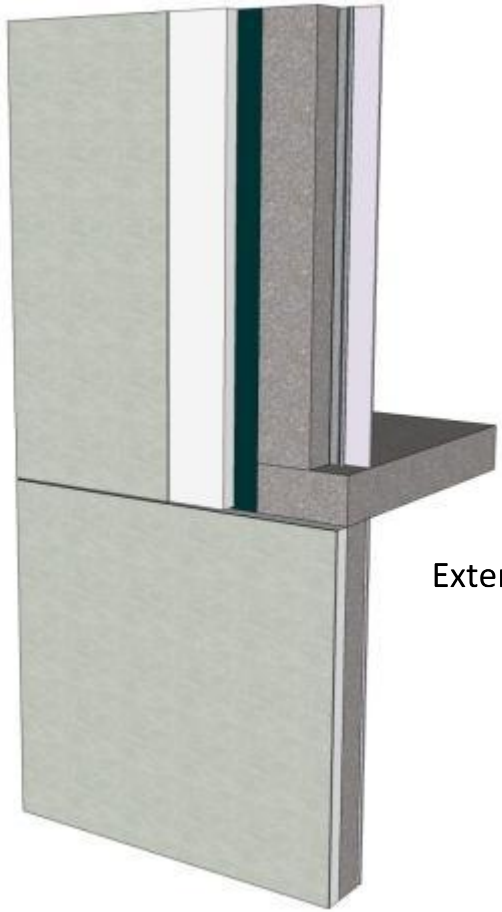
- Thermal Bridge of Steel Studs reduces effective R value by 50-60%
- Additional 30-40% reduction through thermal bridge of slab
- Nominal R-12 wall results in effective R-3 to R-4
- Same wall without any insulation would be R-2





Source: Energy Consumption Trends and Considerations for Deep Energy Retrofits, 2009, G. Finch, W. Knowles

Impact of Exposed Slabs & Balconies a)



Exterior insulation over concrete wall

R-values for 8'8" High Wall - No Balcony or Eyebrow (Center of Wall)

Insulation Strategy	Effective R-value
3" EPS (R-12), Exterior Insulation	**R-13.9**
4" EPS (R-16), Exterior Insulation	**R-18.0**
6" EPS (R-24), Exterior Insulation	**R-25.8**

Results from thermal modeling using calibrated finite element 3-dimensional software

Source: RDH, G. Finch

wood SMART

Canadian Wood Council

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Impact of Exposed Slabs & Balconies b)

R-values for 8'8" High Wall - No Balcony or Eyebrow (Center of Wall)

Insulation Strategy	Effective R-value
3" EPS (R-12), Exterior Insulation	**R-13.9**
4" EPS (R-16), Exterior Insulation	**R-18.0**
6" EPS (R-24), Exterior Insulation	**R-25.8**

R-values for 8'8" High Wall with Balcony or Eyebrow (Overall)

Insulation Strategy	Effective R-value
3" EPS (R-12), Exterior Insulation	**R-7.4** ***(-47%)***
4" EPS (R-16), Exterior Insulation	**R-8.6** ***(-52%)***
6" EPS (R-24), Exterior Insulation	**R-10.6** ***(-59%)***

Source: RDH, G. Finch

Is this a Thermal Bridge?

Point load thermal bridges at Prince George Airport

Visualization of linear thermal bridge and installation of Isokorb.

This can reduce the thermal bridge by about 80%, but it is still worse than a continuous penetration with Wood.

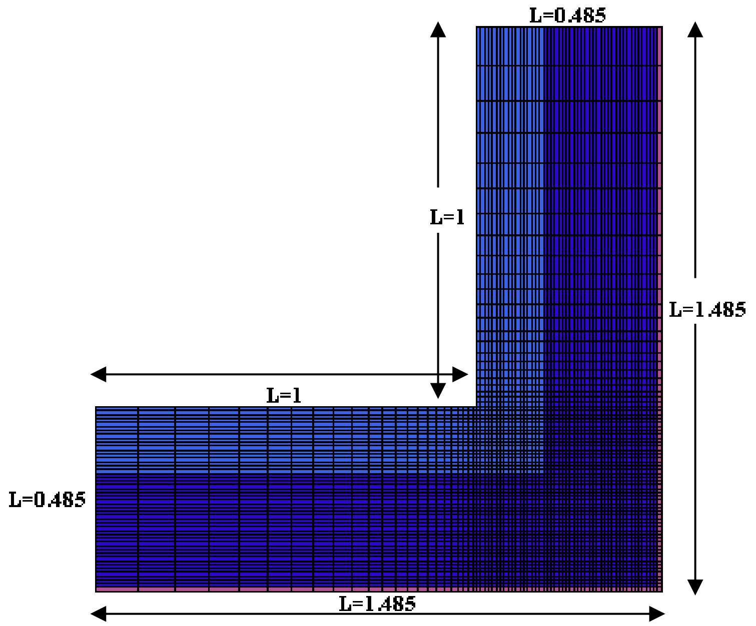
Photos: Wimmers, Schock Isokorb

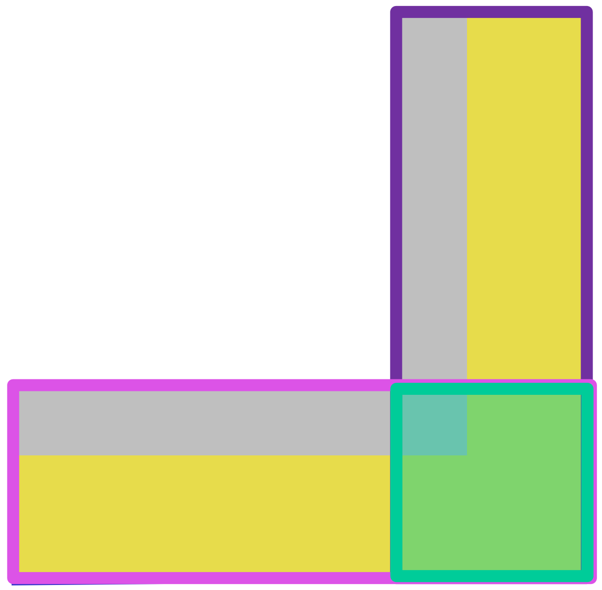
Compare λ or k values

- Thermal condustivity λ of...
  - Steel:
  - Concrete:
  - Wood:
  - Insulation:

Finite Element Calculation of Thermal Bridges a) (as per DIN EN ISO 10211)

Example: Exterior Corner





Source: PHI/PHD Author & Graphic: Wimmers

Finite Element Calculation of Thermal Bridges b) (as per DIN EN ISO 10211)

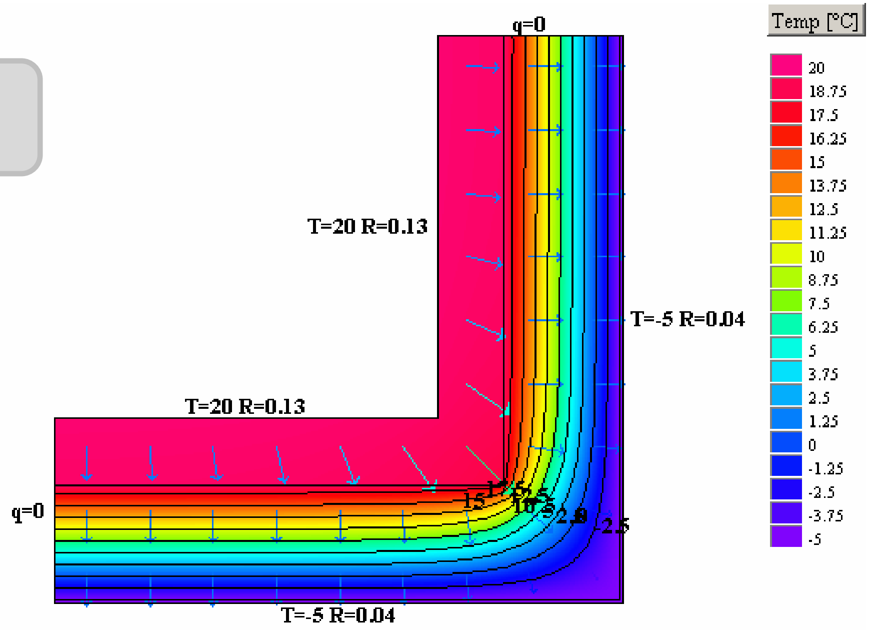
$$Q_{1D} = A_1 * U_1 * \Delta T_1 + A_2 * U_2 * \Delta T_2$$

Example: $U_1 = U_2 = 1/(0.13+0.175/2.3+0.3/0.04+0.01/1+0.04) = 0.129\ W/(m^2K)$

$$1/(R_{si} + d_1/\lambda_1 + d_2/\lambda_2 + d_3/\lambda_3 + R_{se})$$

$$Q_{2D} = A_1 * U_1 * \Delta T_1 + A_2 * U_2 * \Delta T_2 + \Psi * l * \Delta T_{max(1.2)}$$

Example : Q_{2D} = 8.0275 W/m as per HEAT2-6.0



Author & Graphic: PHI, Wimmers

Finite Element Calculation of Thermal Bridges c) (as per DIN EN ISO 10211)

$$\Psi = (Q_{2D} - A_1 * U_1 * \Delta T - A_2 * U_2 * \Delta T) \ / \ l \ / \ \Delta T_{max(1.2)}$$

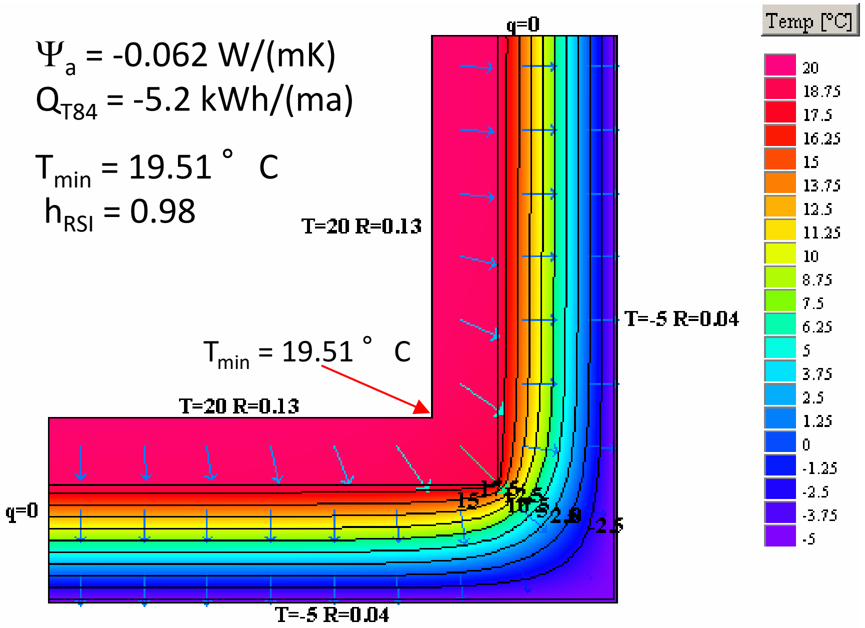
Example : Ψ_a = (8.0275 – 0.129*1.485*2*25)W/K / 1 m / 25 K = -0.062 W/(mK)

Ψ_a = -0.062 W/(mK)
Q_{T84} = -5.2 kWh/(ma)

Example assumes 20m (4 corners, 5m high)

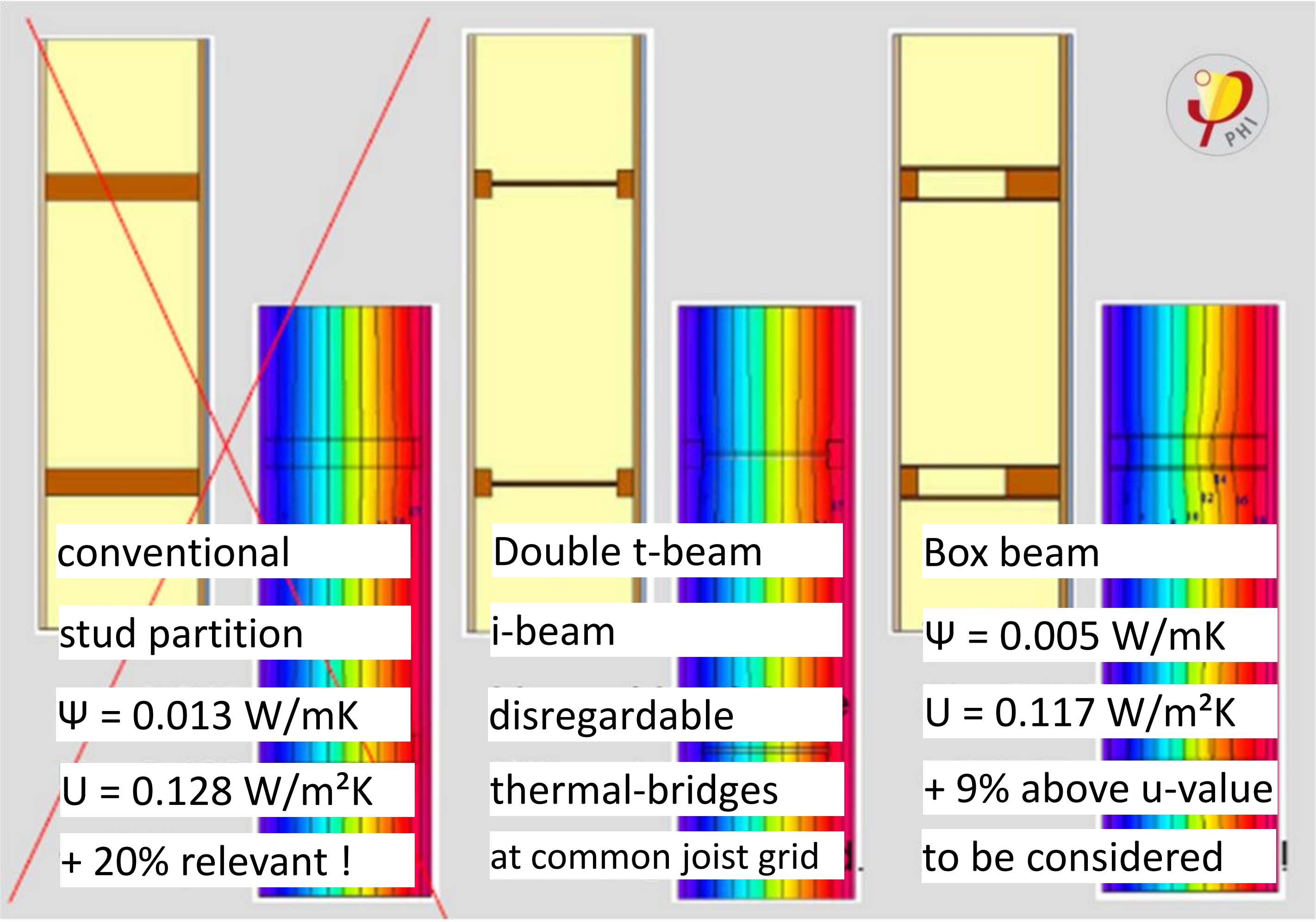
Resulting in 104 KWH/a “credit“

At a 200m² building the optimized thermal bridge has a positive impact on the energy density of 0.52kWh/(m²a).



Author & Graphic: PHI, Wimmers

Thermal Bridges of Studs and Posts



Source: PHI. Sariri, Author: Schnieders

Thermally Optimized Rafters, Beams and Posts




Photos: M. Ploss, lignotrend, Wimmers

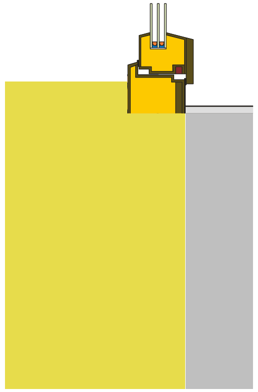
Effective R or U value or Thermal Bridge Calculation

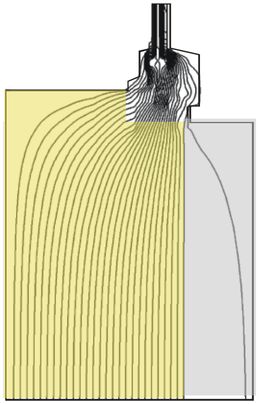
- PHPP or equivalent tools for accurate U-value calculation for non-homogenous multilayer envelope assemblies
- Flixo, Heat or equivalent tools for wood construction detail
- Resulting Ψ values have to be included in energy balance as relative impact increases with energy efficiency of building

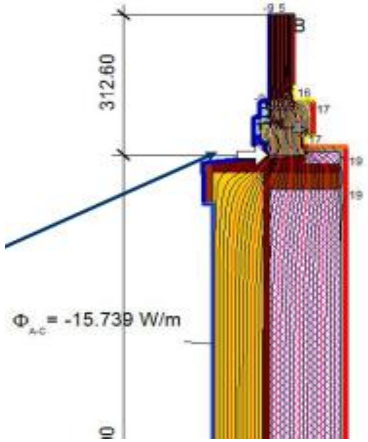
Author: G. Wimmers

Typically the largest Thermal Bridge

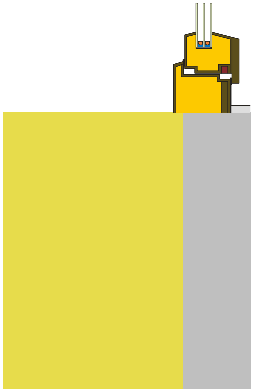
Uw = 0.8 W/(m²K)
recommended installation
Ψinstall = 0.005 W/(mK)
Uw,eff = 0.78 W/(m²K)

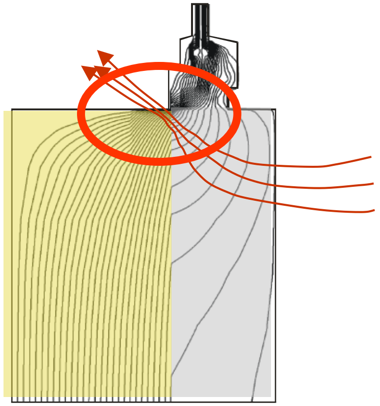






extremly bad installation
Ψinstall = 0.015 W/(mK)
Uw,eff = 1.19 W/(m²K)
Resulting in 50% higher energy losses with equal components!!!

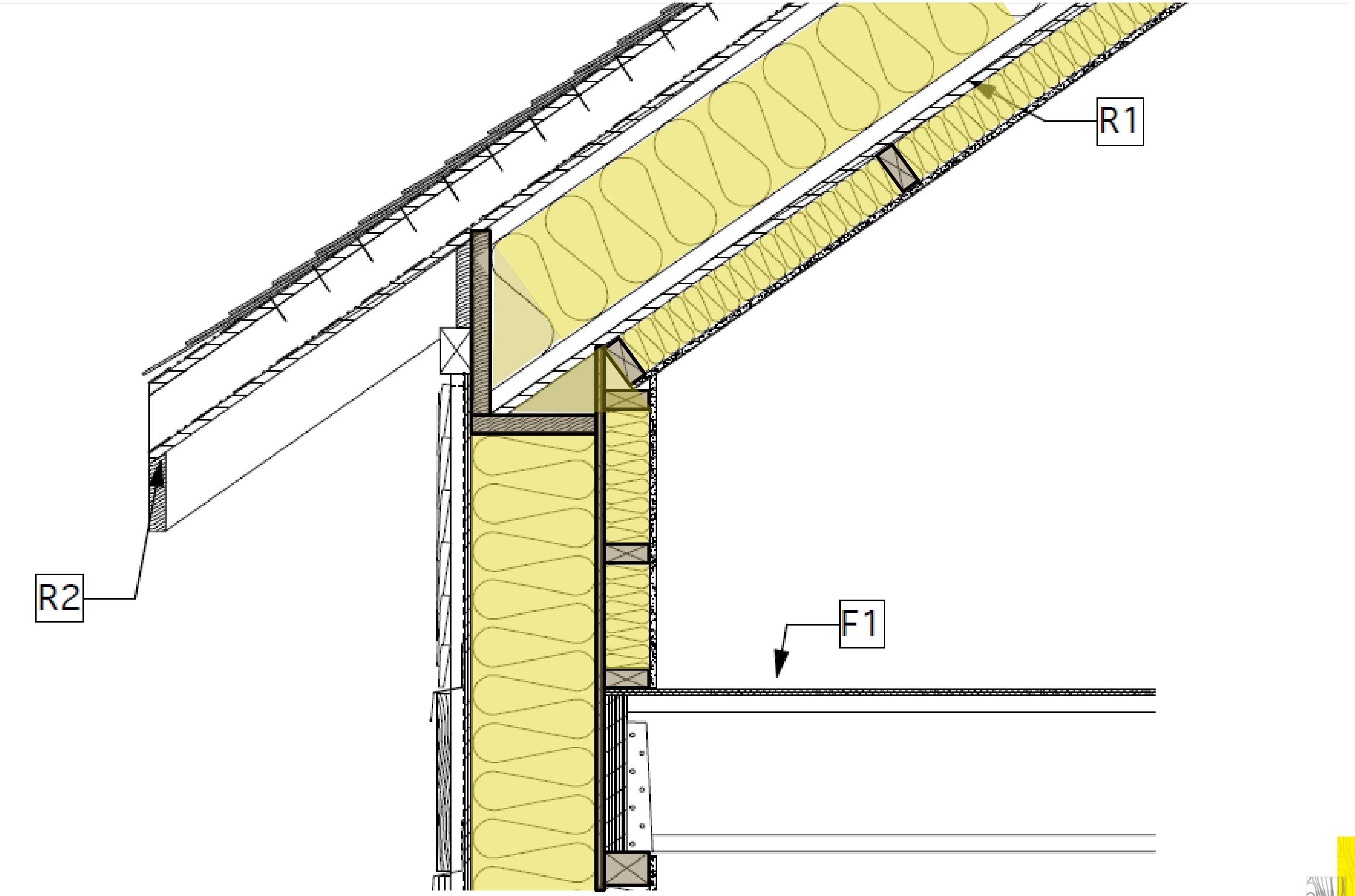




Insulation
Concrete

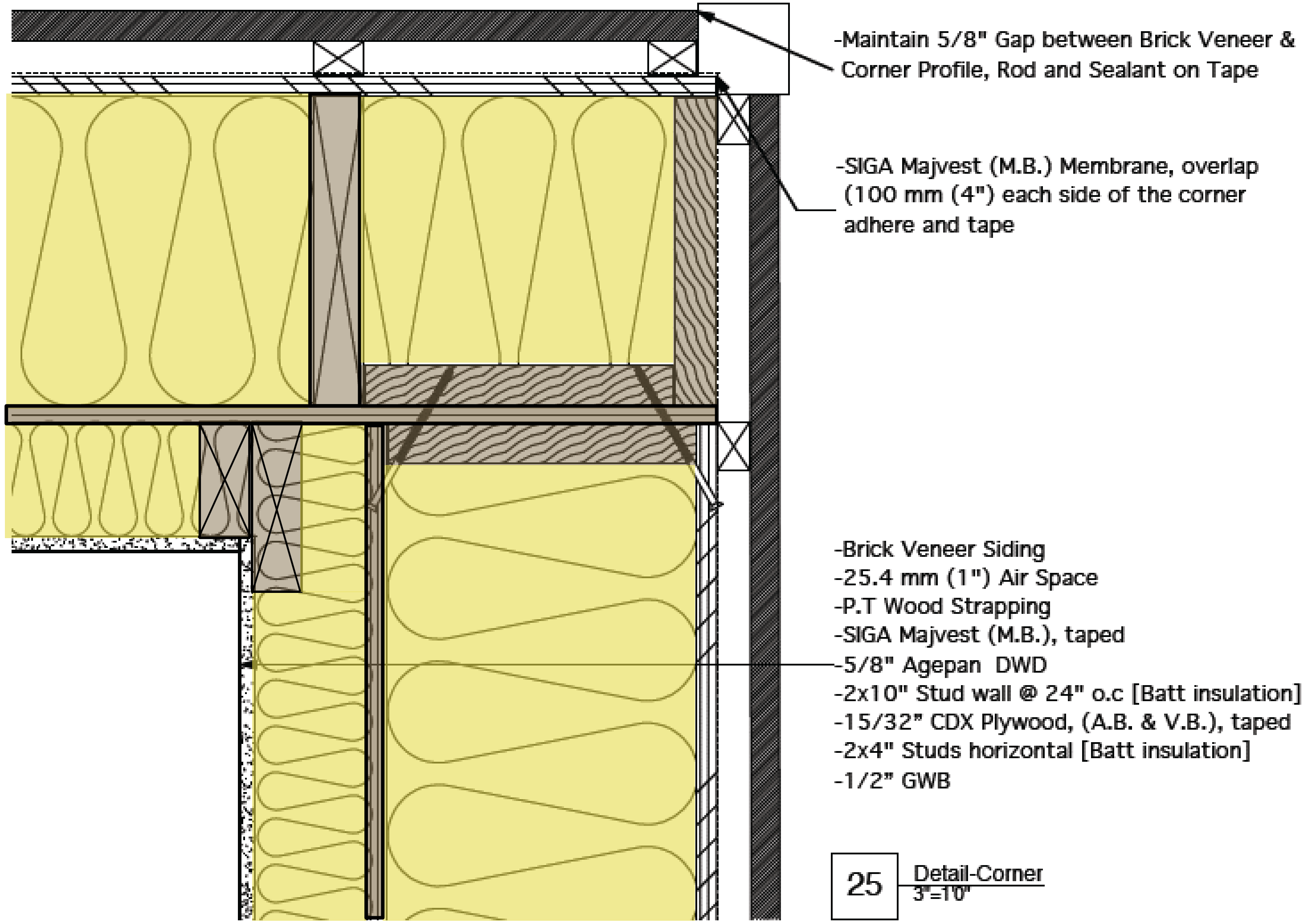
Source: W. Feist, F. Freundorfer, Volume 14 of Research group cost-effective Passive Houses: Passive House windows. Passivhaus Institut, Darmstadt 1998 (currently only available in German)
Graphic: G. Wimmers, CertiPHIers Cooperative

Thermally Optimized Eaves, Wall to Roof (Prefab)



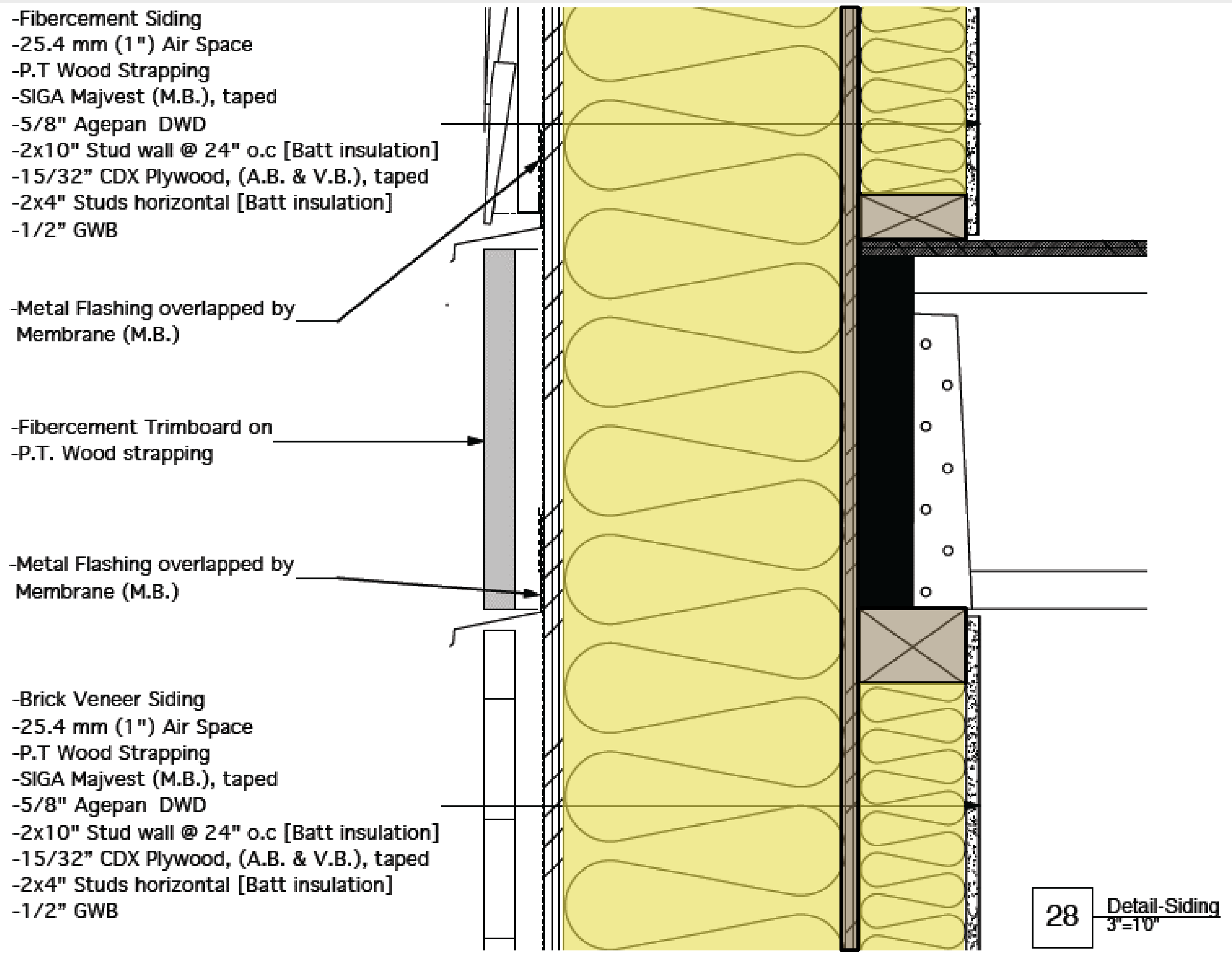
Graphic: Wimmers

Thermally Optimized Corner (Prefab)



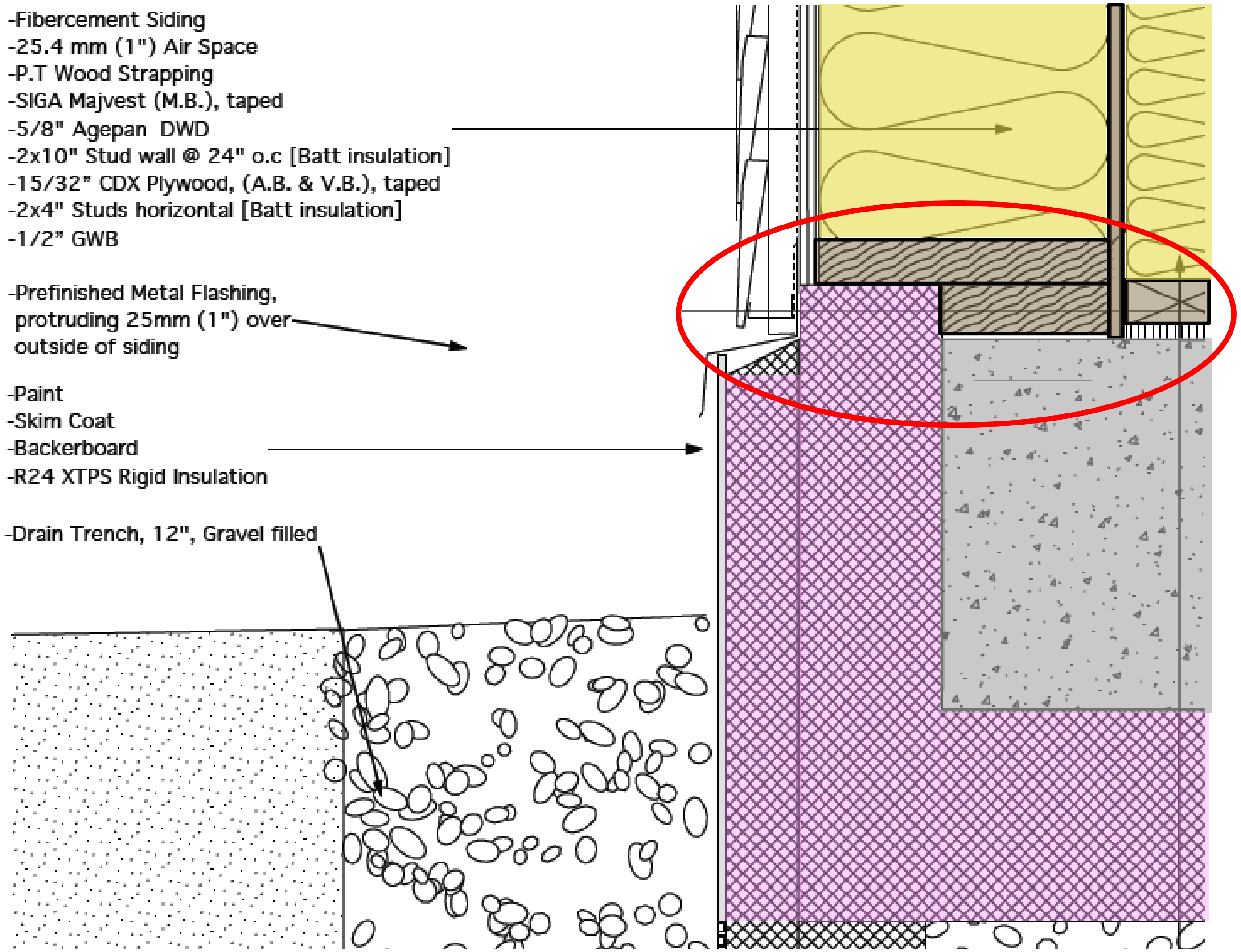
Graphic: Wimmers

Thermally Optimized Floor Connection (Prefab)



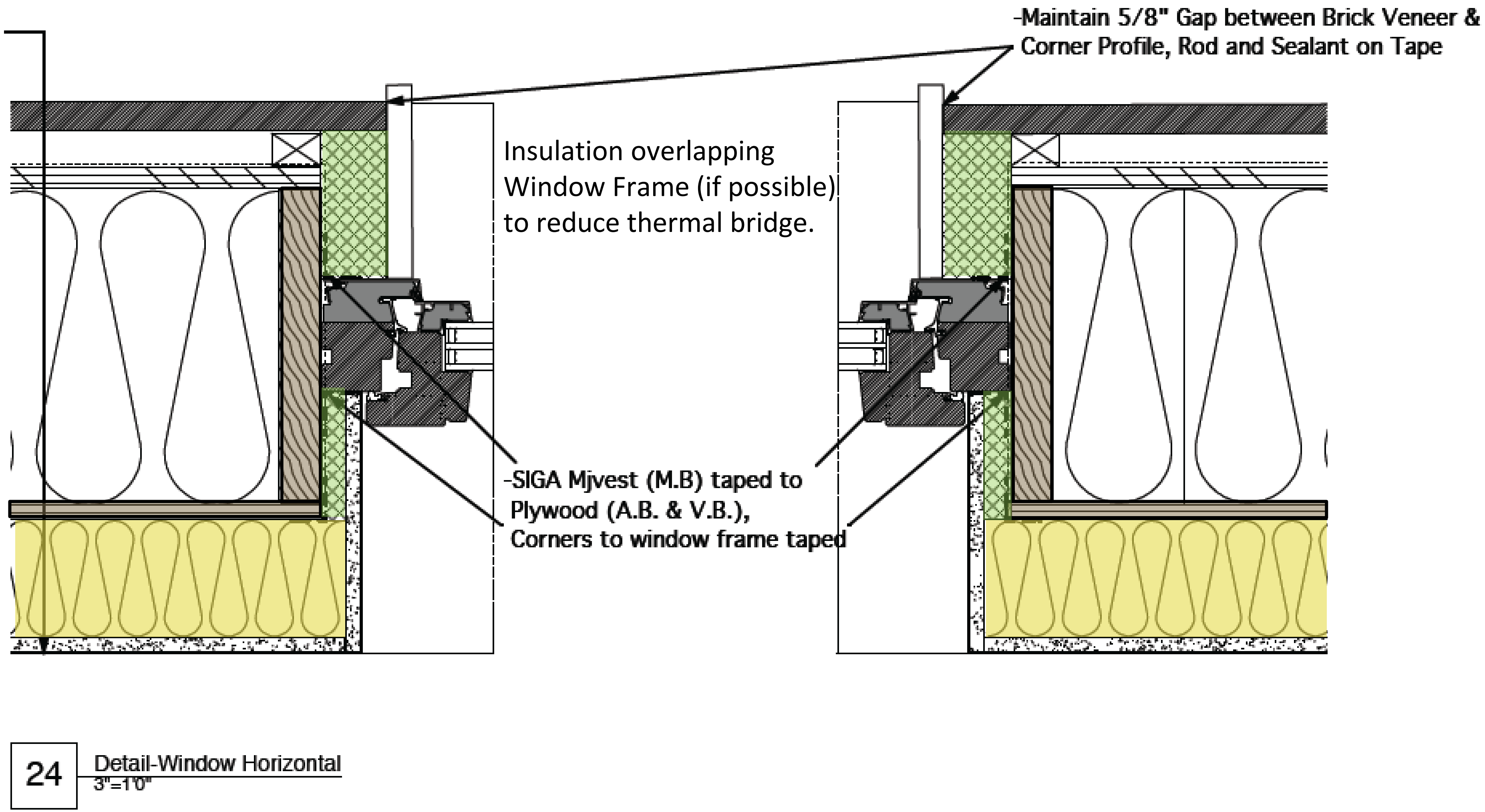
Graphic: Wimmers

Thermally Optimized Footing Detail, no Basement (Prefab)



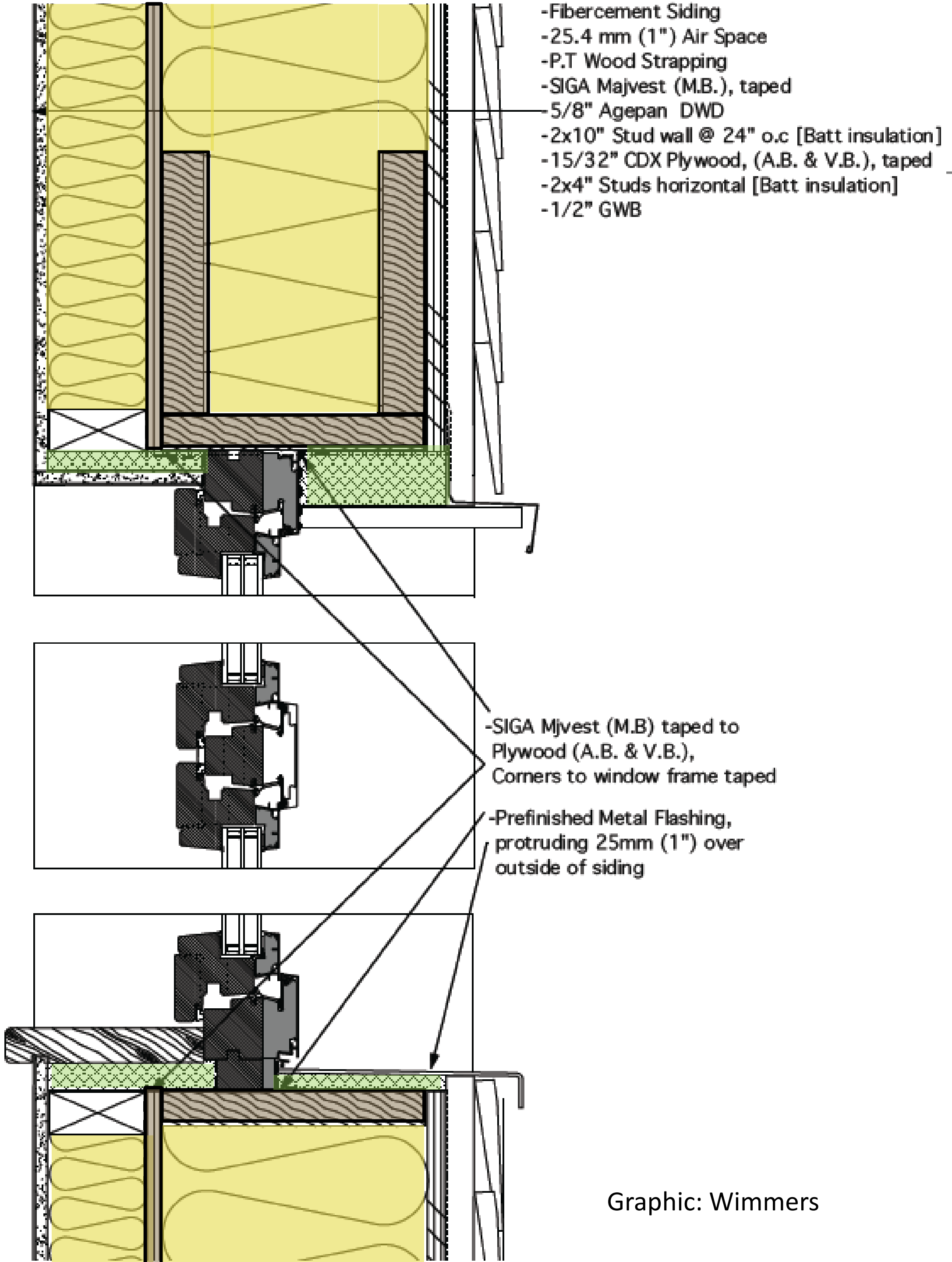
Author & Graphic: Wimmers

Thermally Optimized Window Installation



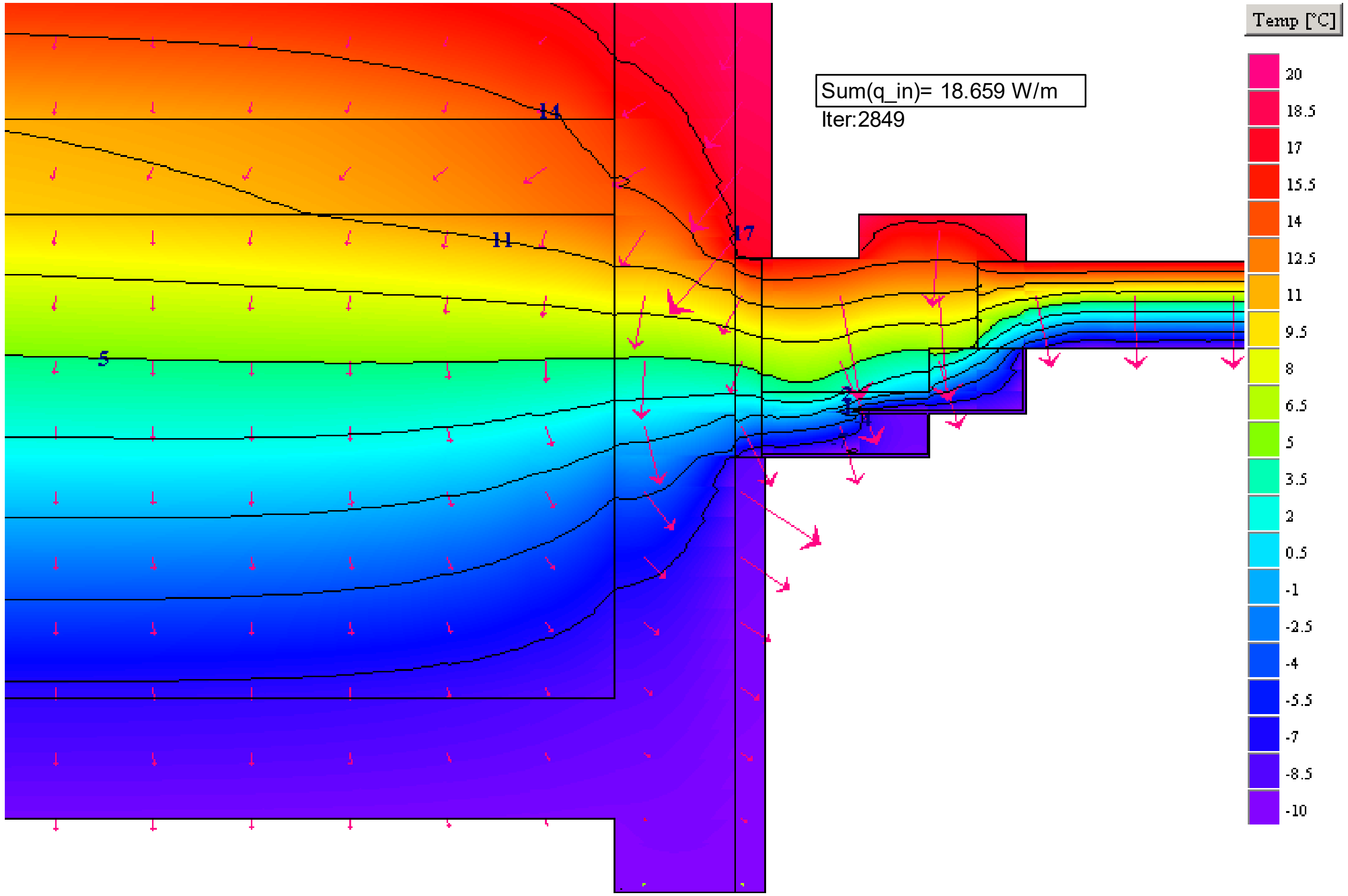
Graphic: Wimmers

Window Installation



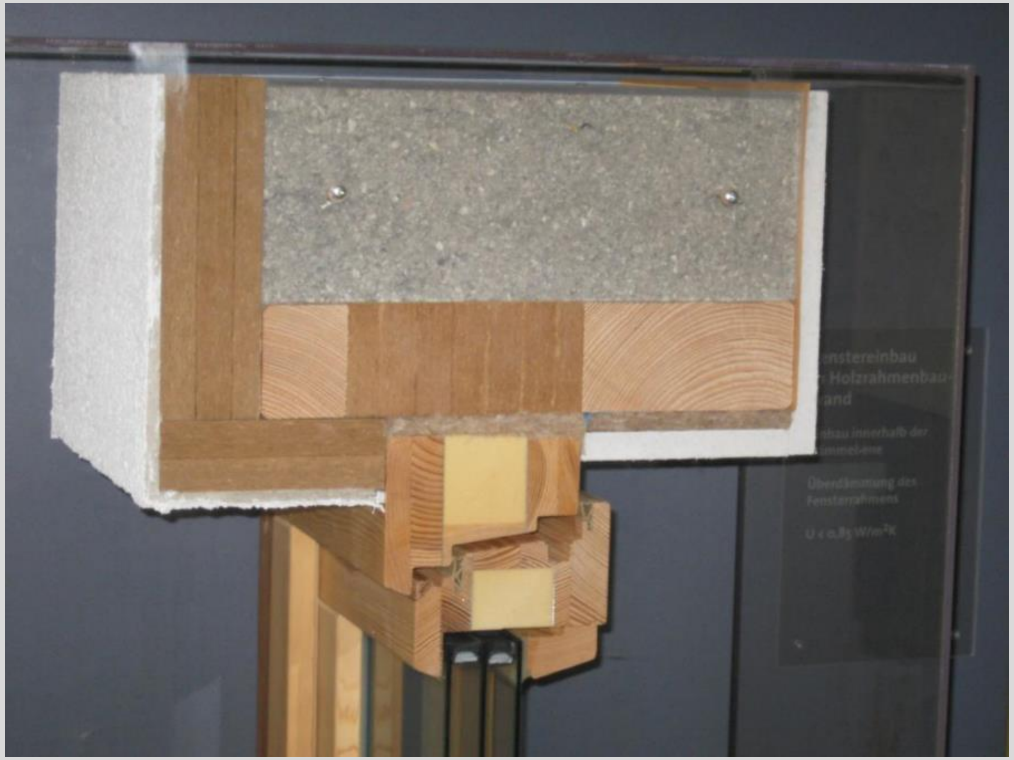
Graphic: Wimmers

Detail optimization with FEM tool



Graphic: Wimmers

Analyze Window Details



Photos: Wimmers

Lesson 4: Airtightness Basics and Materials

(45min + 5min Q&A)

- ***Objectives:***
  - Contrast all relevant units (vapour diffusion resistance factor, vapour diffusion thickness, permeance)
  - Differentiate the different forms of moisture transport through a building envelope
  - Estimate the impact of different methods of vapour transportation
  - Evaluate available materials
  - Assess the consequences of underperforming or misplacement of the air barrier
  - Develop strategies for airtight building envelop assemblies

Airtightness Basics

- Importance of Airtightness
- Air Flow through Envelope
- Moisture Loads
- Wind and Stack Effect
- Airtightness as Design Task

The Importance of Airtightness

- Generally
  - Prevention of condensation and mould/rot in the construction
  - Safeguarding the performance of the insulation layer
  - Prevention of rafts
  - Prevention of cold floors in the ground floor
  - Preventing contamination of the room air
  - Reduction of heat losses from the building envelope
  - Securing the effectiveness of the ventilation system
  - Securing the sound insulation of building components

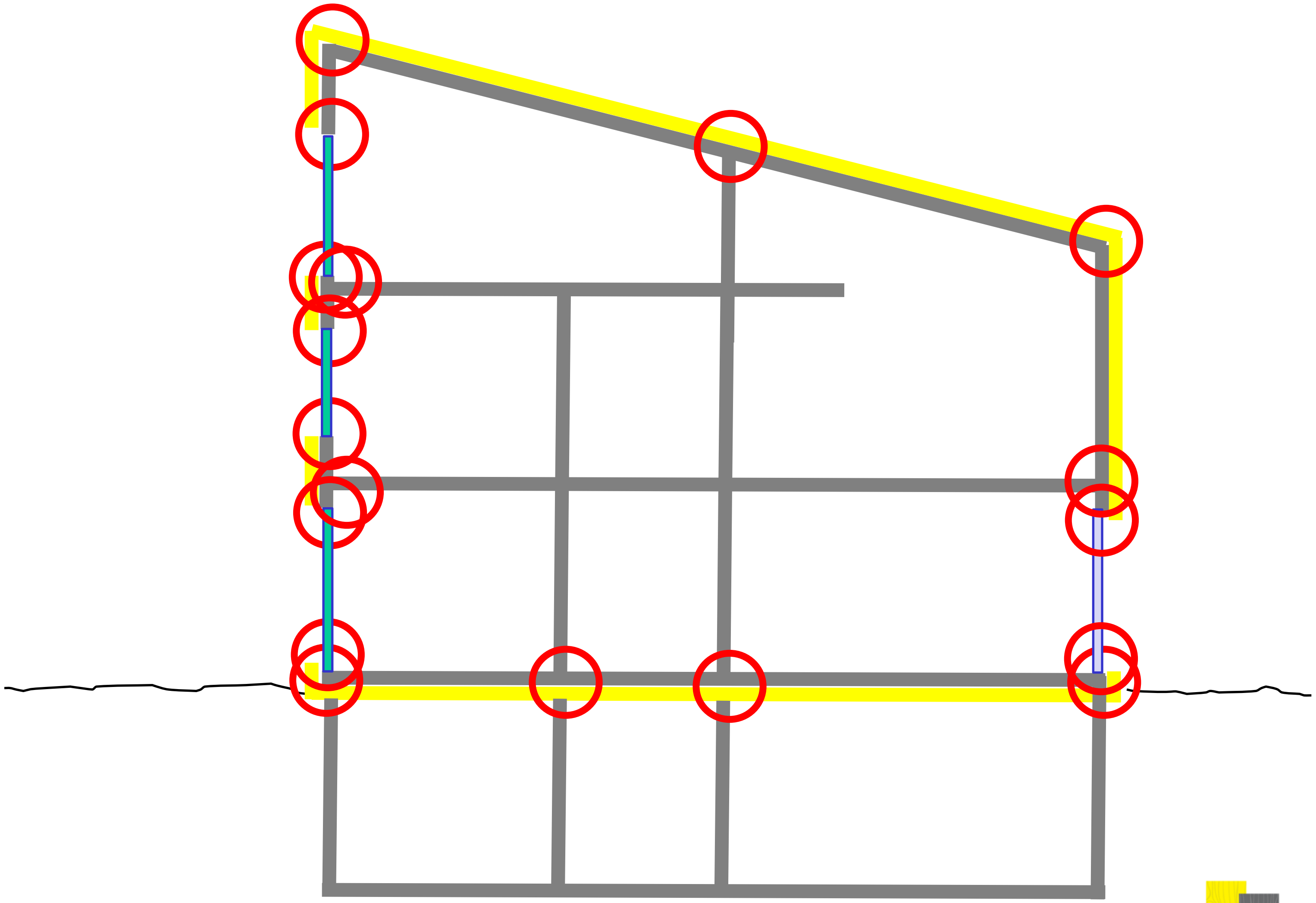
- Wood reacts very sensitive to moisture

Author: Wimmers

Clarification

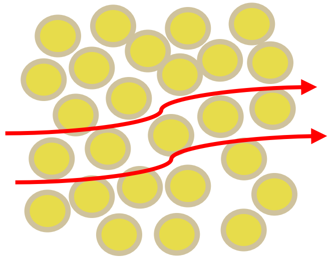
- Airtightness (on the inside)
  - Layer to stop airflow from inside to outside
- Vapour retarder (on the inside)
  - Layer to reduce vapour diffusion from the inside into the insulation
- Wind tightness (on the outside)
  - Layer to stop wind flow from outside to inside
- WRB =
  - Weather Resistant Barrier or
  - Water Resistant Barrier or
  - Wind Resistant Barrier

Where are the crucial details for Airtightness?

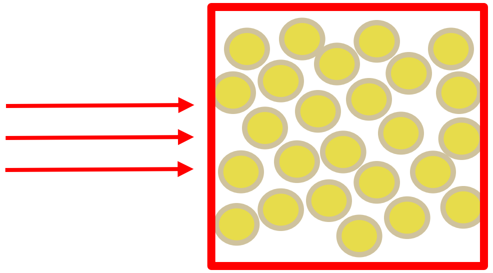


Author & Graphic: Wimmers

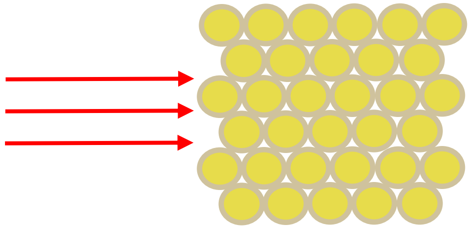
Principle of Thermal Insulation



Loose Insulation without Air or Wind Barrier



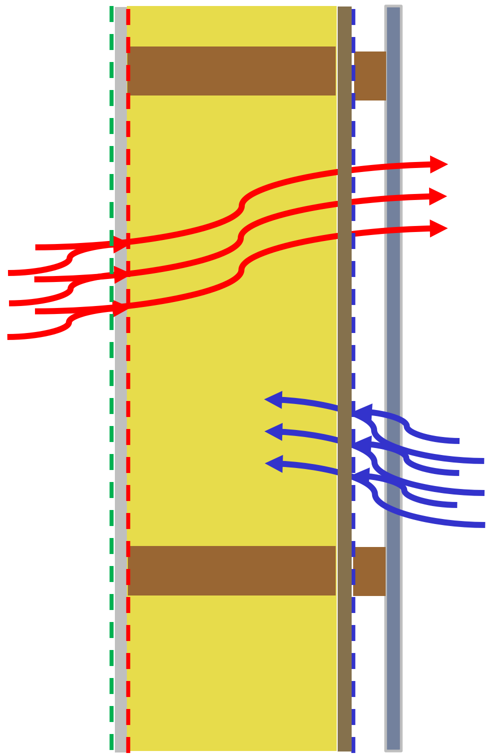
Loose Insulation with Air or Wind Barrier



Insulation with consistency to sufficiently block airflow

Author & Graphic: Wimmers

Air Flow



Wood (studs and strapping)

Insulation

Drywall

Plywood or OSB

Cladding

Warm Air (interior, humid)

Cold Air (exterior)

Air Barrier

Wind Barrier

Vapor Diffusion Resistance Layer

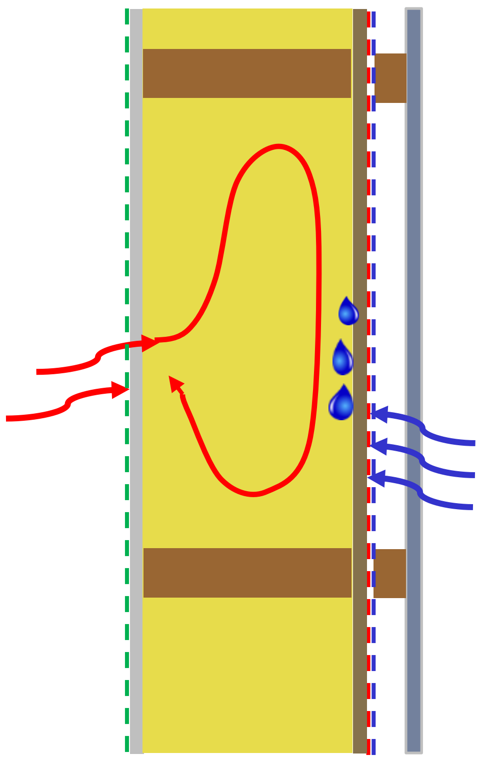
Author & Graphic: Wimmers

wood SMART

Canadian Wood Council

Conseil canadien du bois

Convective Looping



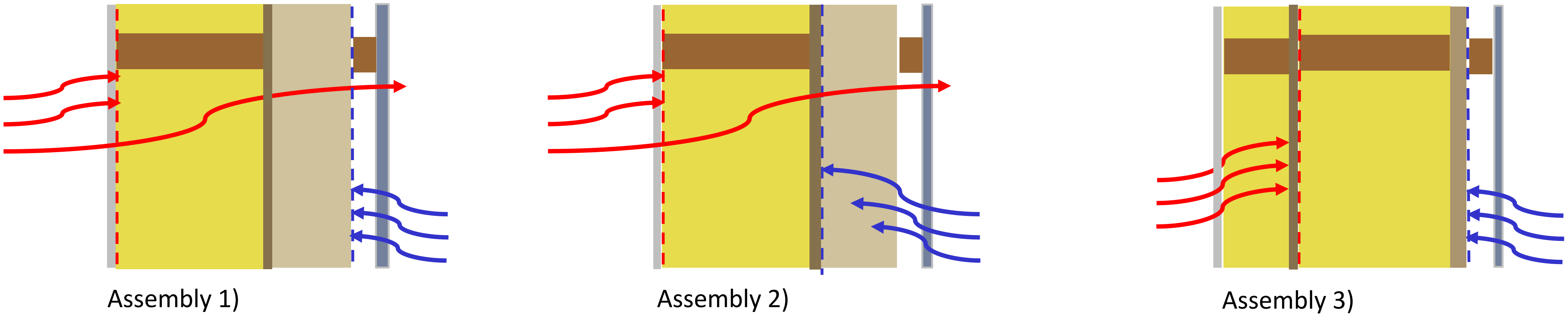
- If there is no interior air barrier, the wind barrier takes over partially the purpose of an air barrier as well and only a vapour diffusion resistant layer (e.g. “airtight drywall”) on the inside is used, convective looping can occur and trigger moisture accumulation in the cavity.

Vapor Diffusion Resistance Layer

Potential Condensation

Author & Graphic: Wimmers

Possible Locations of Air Barrier and Wind Barrier a)



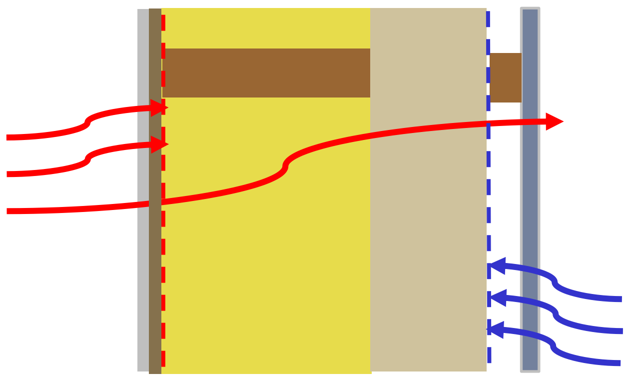
Exterior Insulation Board (Mineral or Wood Fiber)

Exterior Structural Wood Fiber Board

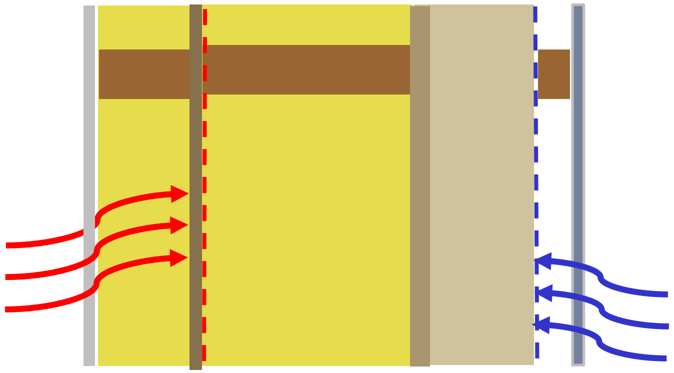
Plywood or OSB

Author & Graphic: Wimmers

Possible Locations of Air Barrier and Wind Barrier b)



Assembly 4)



Assembly 5)

Exterior Insulation Board (Mineral or Wood Fiber)

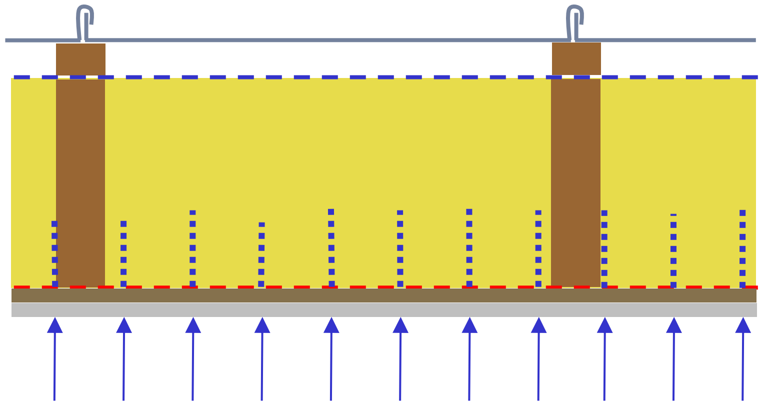
Exterior Structural Wood Fiber Board

Plywood or OSB

Author & Graphic: Wimmers

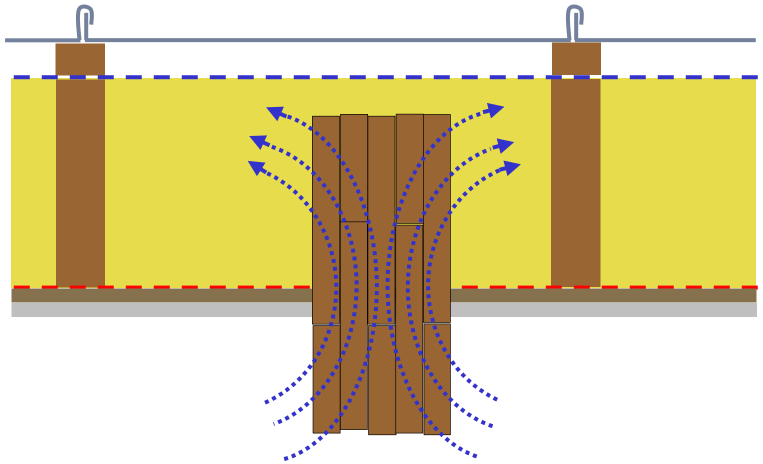
Possible Moisture Loads in Construction Assemblies a)

Scenario 1)



Diffusion $\approx 3 \frac{g}{m^2 day}$

Scenario 2)

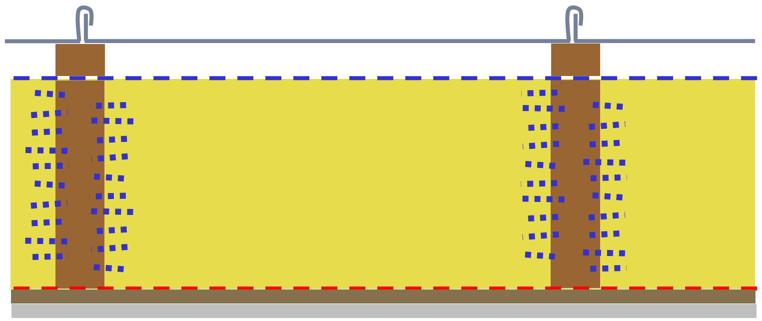


Flank Diffusion $\approx 30 \frac{g}{m^2 day}$

Source: S. Peper, W. Feist, V. Sariri: Luftdichte Projektierung von Passivhäusern – eine Planungshilfe. Fachinformation PHI 1999/6, Passivhaus Institut, Darmstadt 1999/ 9. Auflage 2008, Graphic: Wimmers

Possible Moisture Loads in Construction Assemblies b)

Scenario 3)

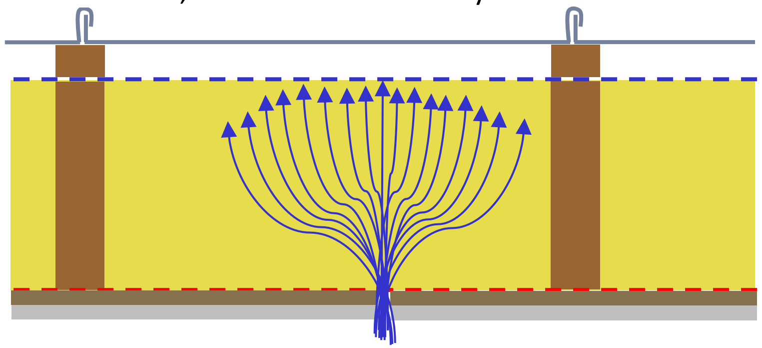


Drying of Wood $\approx 50 \frac{g}{m^2 day}$

(only short term)

Scenario 4)

Outside 0° C; 80% relative humidity

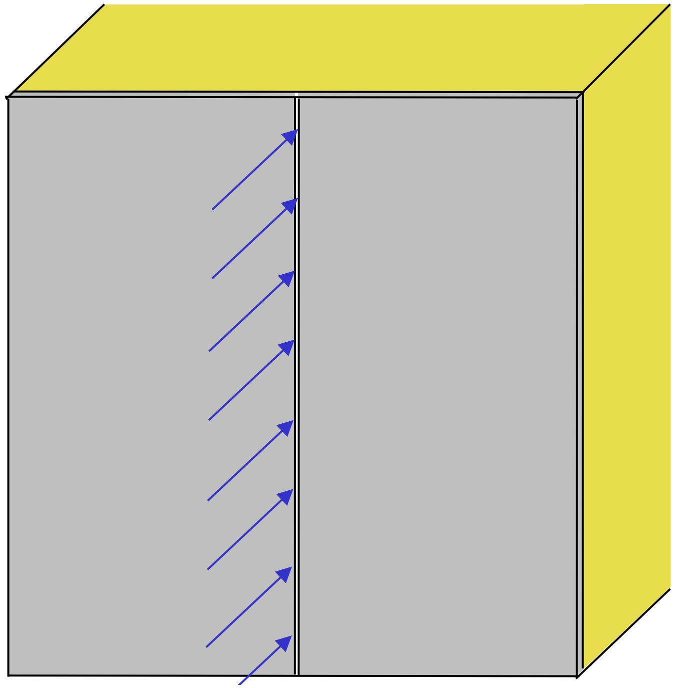


Inside 20° C; 50% relative humidity

Convection 1mm gap $> 300 \frac{g}{m^2 day}$

Source: S. Peper, W. Feist, V. Sariri: Luftdichte Projektierung von Passivhäusern – eine Planungshilfe. Fachinformation PHI 1999/6, Passivhaus Institut, Darmstadt 1999/ 9. Auflage 2008, Graphic: Wimmers

Experiment



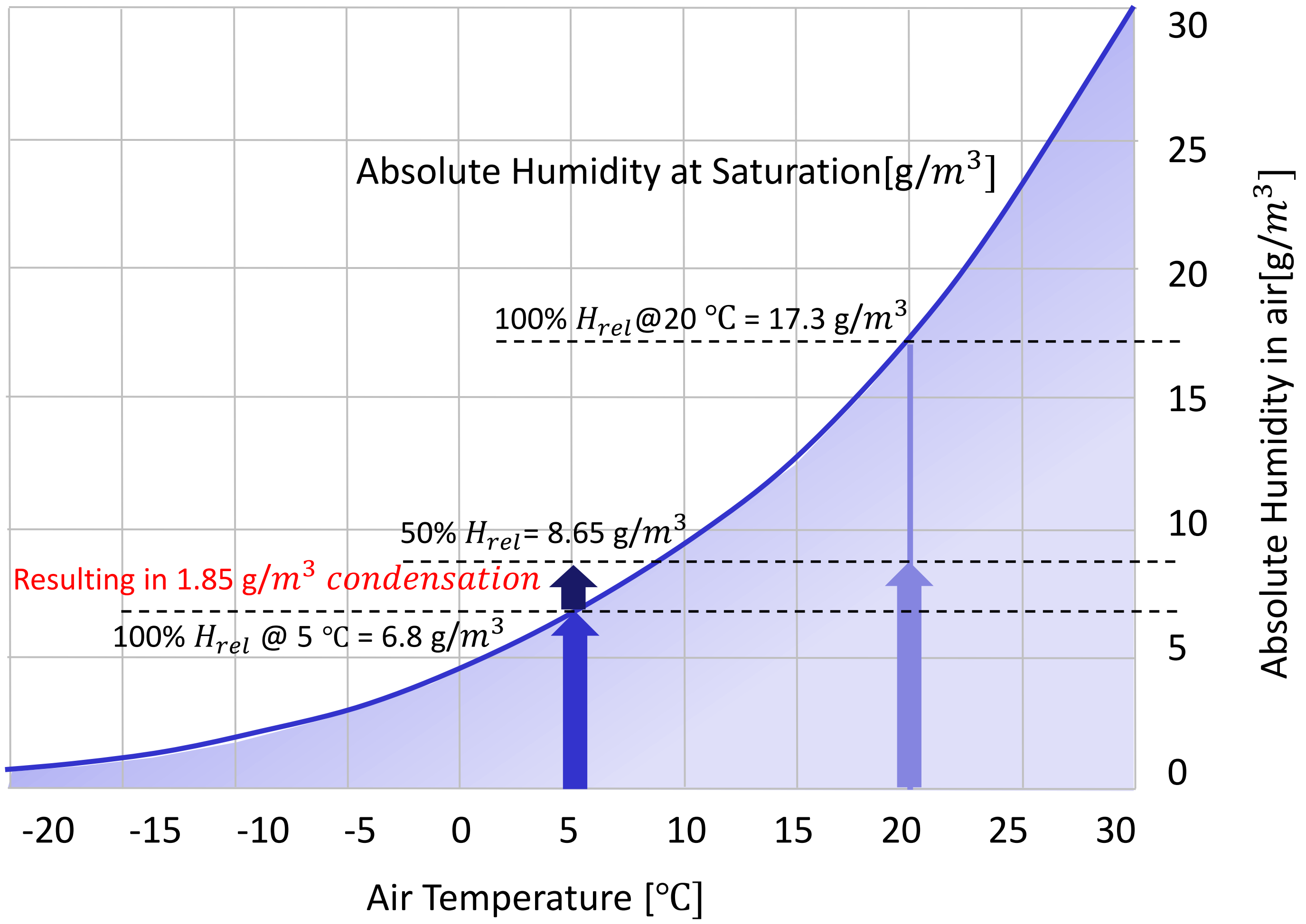
Experimental Setup
Interior Temperature 20° C
Exterior Temperature -10° C
Pressure Difference 20 Pa,
2-3 Beaufort
Vapour Diffusion Resistance Sd 30m
Mineral Fiber Insulation 140mm

Without Gap
U = 0.3 W/mK
Water Transport via Diffusion = $0.5 \frac{g}{m^2 day}$

With Gap
U = 1.44 W/mK
Water Transport via Convection = $\mathbf{800 \frac{g}{m^2 day}}$ $per\ 1m\ length\ of\ 1mm\ gap$

Source: Institute of Building Physics, Stuttgart, DBZ 12/89, page 1639ff, Graphic: Wimmers

Vapour to liquid Water



Author & Graphic: Wimmers

wood SMART

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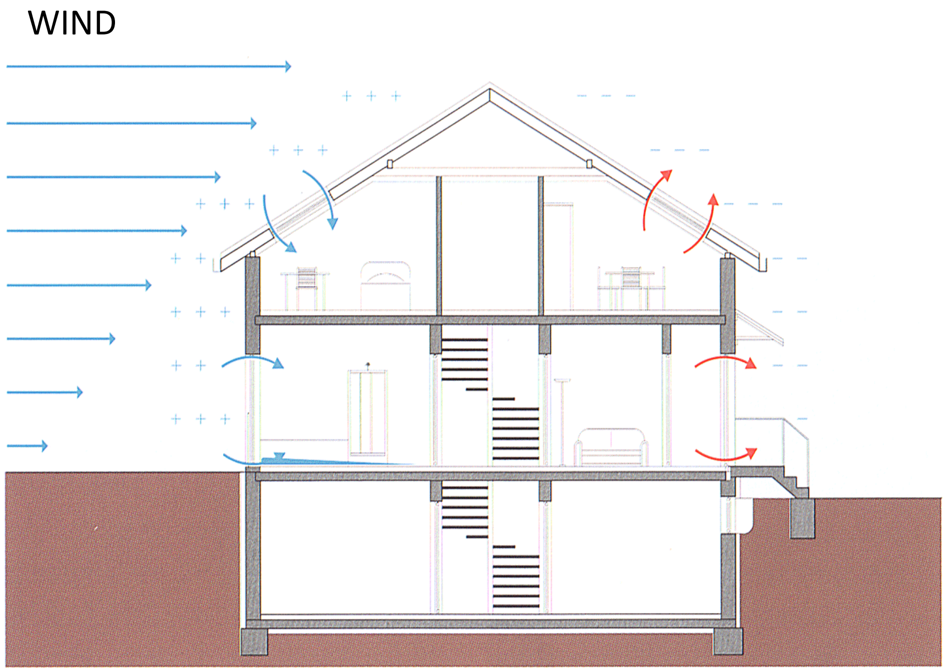
Conseil canadien du bois

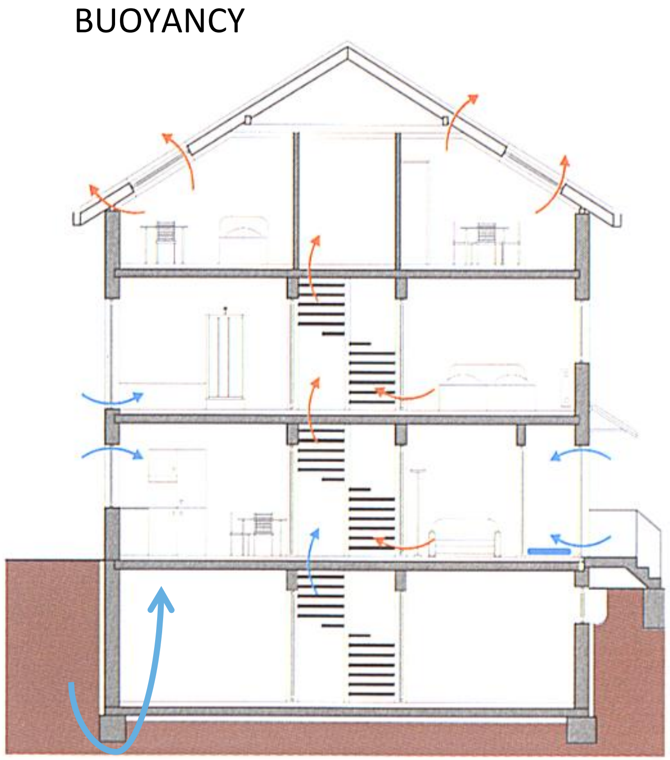
Conclusions

1. There is no absolute protection against moisture
2. Air tightness is of high importance to reduce moisture load
3. For remaining moisture load, low vapour diffusion resistance towards the outside important to allow for drying out.

Author: Wimmers

Driving Forces for Air Movement





- The volume of infiltration and exfiltration due to leakages in the building envelope is identical

Author & Graphic: Schnieders, Wimmers

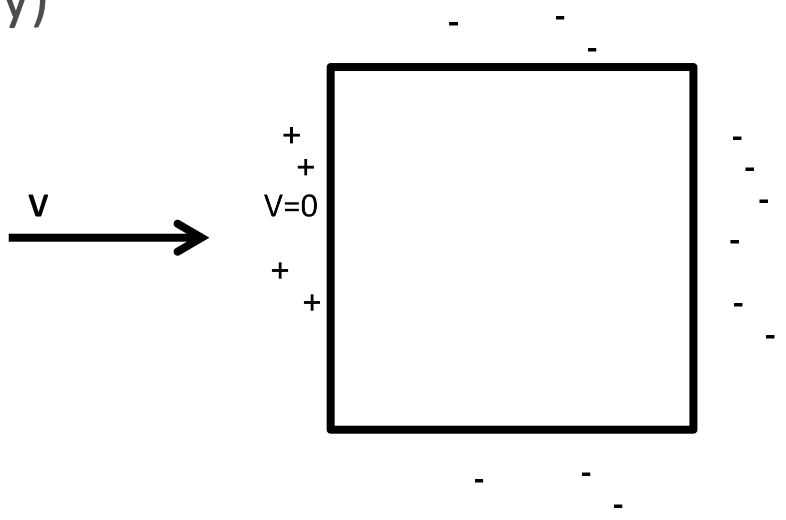
Wind

Velocity of Wind reduced to theoretically 0

After colliding with infinite Obstacle

(conversion from kinetic to potential energy)

$$p_w \approx 0.6 C_p v^2$$



C_p= pressure coefficient (negative means depressurized and 0 equals free stream

Please see also 4.1.7.4 and following in NBC

Source: Applied Building Physics, Boundary conditions, building performance and material properties

Author: Hugo Hens

Buoyancy

$$p_{T_{1-2}} \approx \; p_a * g * \beta * \theta_1 - \theta_2 * h$$

$p_{T_{1-2}} \; = pressure\ driven\ by\ temperature\ difference$

$p_a \quad = 1.2\ kg/m^2$

$g \quad = 9.81 m/s^2$

$\beta \quad = 1/273 K^{-1}$

$\theta_1 - \theta_2 = temperature\ difference\ inside/outside$

$h \quad = hight\ difference\ of\ two\ openings$

Source: Applied Building Physics, Boundary conditions, building performance and material properties
Author: Hugo Hens

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Exercise

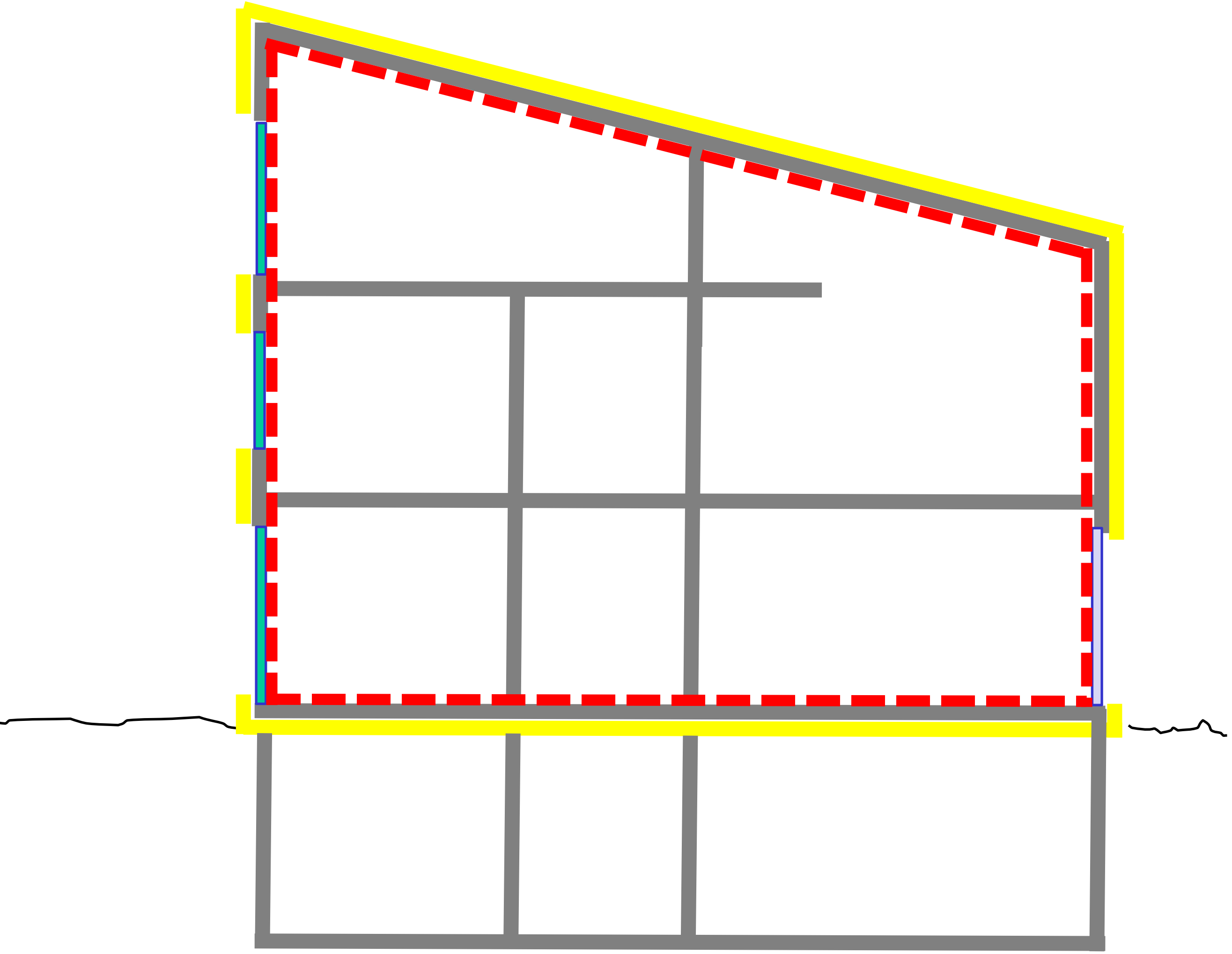
$$p_{T_{1-2}} \approx \ p_a * g * \beta * \theta_1 - \theta_2 * h$$

What is the pressure difference?

a) Assumption 20°C inside and 0°C
   Height difference of openings 2.5m

b) Assumption 20°C inside and -20°C
   Height difference of openings 10m

Airtightness as a Design Task



Author & Graphic: Wimmers

- Decide where the airtight layer should be
- Avoid penetrations
- Define materials and connections
- Draw out details on plans
- Consider the durability of materials and connections
- Check construction drawings (continuous airtight envelope)
- Communicate the deails and give instructions

Airtight Materials

- Membranes
- Tapes
- Gaskets

Airtight Materials

- Concrete*
- Plywood and OSB**
- Airtight membranes
- Airtightness Tapes

*Concrete has to be free of air pockets
**B Grade plywood according to CSA O121 and CSA O151, grade C has often small air pockets in low grade veneer layers and is less airtight; OSB is also not 100% airtight but leakage is extremely small and <0.6 ach@50Pa will not be a problem.
Plywood and OSB have to be taped with appropriate material.

Source: PHI/ Kaufmann, Author: Schnieders, Wimmers

Non Durable Materials for Airtightness

- Masking Tape, Duct Tape, Tuck Tape
- Adhesion to Concrete without Primer
- Application on Humid Surfaces
- Polyurethane Foam*
- Caulking and Jointing with Silicone or Acrylic
- Polyethylene (Poly-mil) plastic foil**

*there are exemption: specialty foams with improved elasticity, such as Rothoblaas Sealing Foam
** the connections are the problem, not the foil itself

Source: PHI/ Kaufmann, Author: J. Schnieders, G. Wimmers

Leaky Materials for Airtightness

- “Airtight Drywall” Approach
- Spray Foam Insulation
- Perforated Membranes (staples)
- EPS or XPS Foam Boards
- Brick Walls (Plaster is airtight layer)

Source: PHI/ Kaufmann, Author: J. Schnieders, G. Wimmers

Specialty Membranes

Wide range of Membranes available for interior use, from very high vapour diffusion resistance to relative low resistance.

Author & Photo: Wimmers

Specialty Tapes

Wide range of Tapes available, tailored to very specific tasks and to adhere to different surfaces.

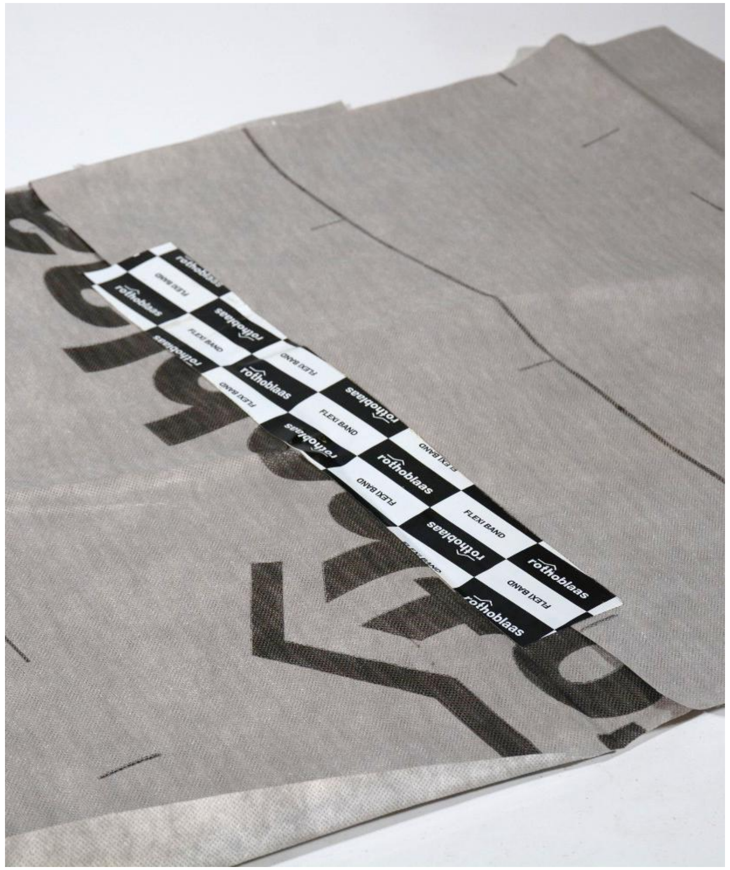
Author & Photo: Wimmers

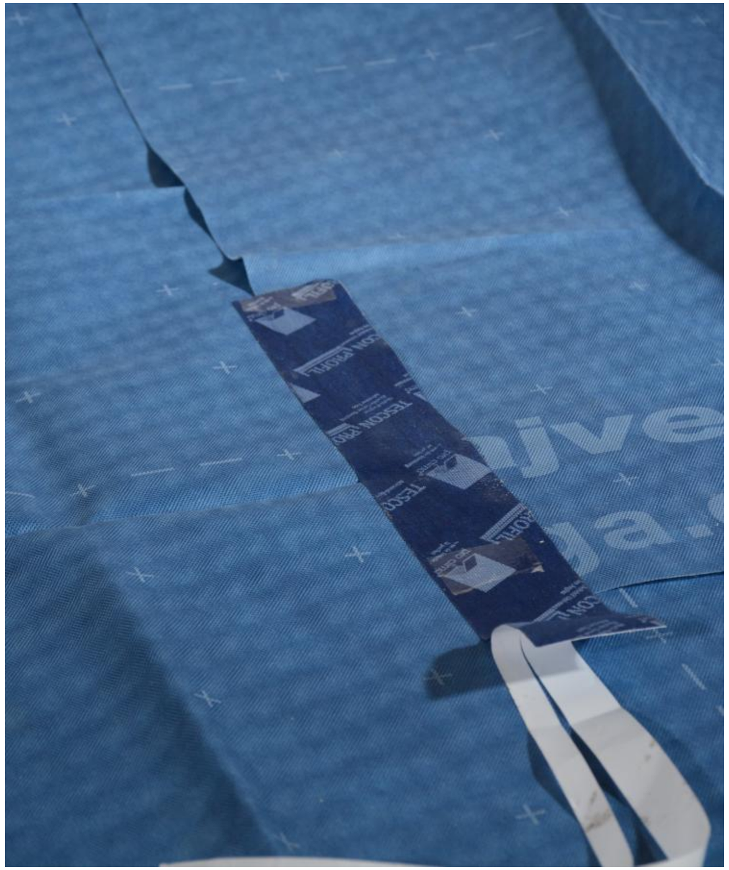
Corner Tapes

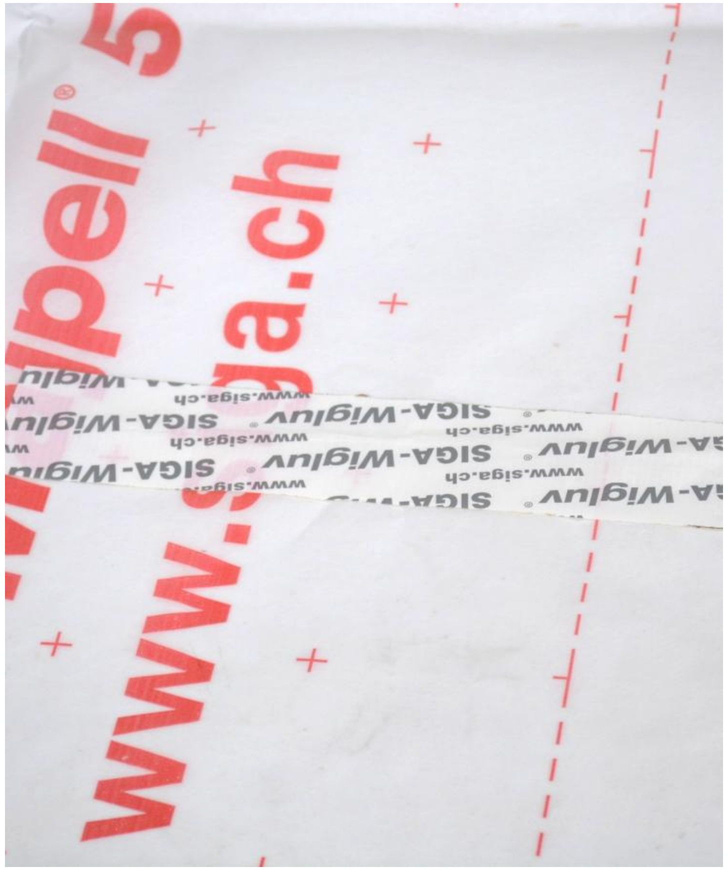
Corner tapes have two strip backing, so that one can be pulled of and glued down and then the second backing can be removed to finish the seal.

Author & Photo: Wimmers

Combine the right Membranes and Tapes







Spot the mistake

Author & Photo: Wimmers

Specialty OSB Tape

OSP has a relatively rough surface and need specific tapes with a relatively thick adhesive layer and flexible consistency to properly seal all micro gaps

Author & Photo: Wimmers

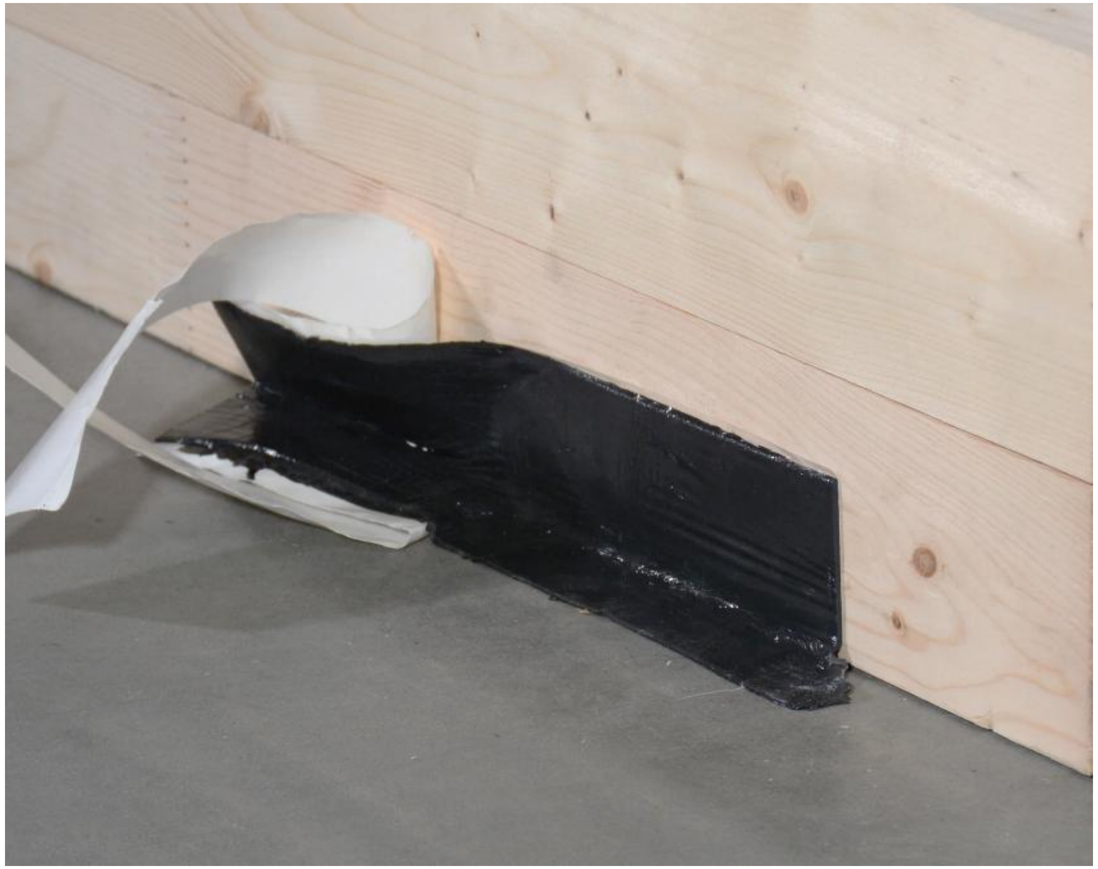
Specialty Foundation Tape

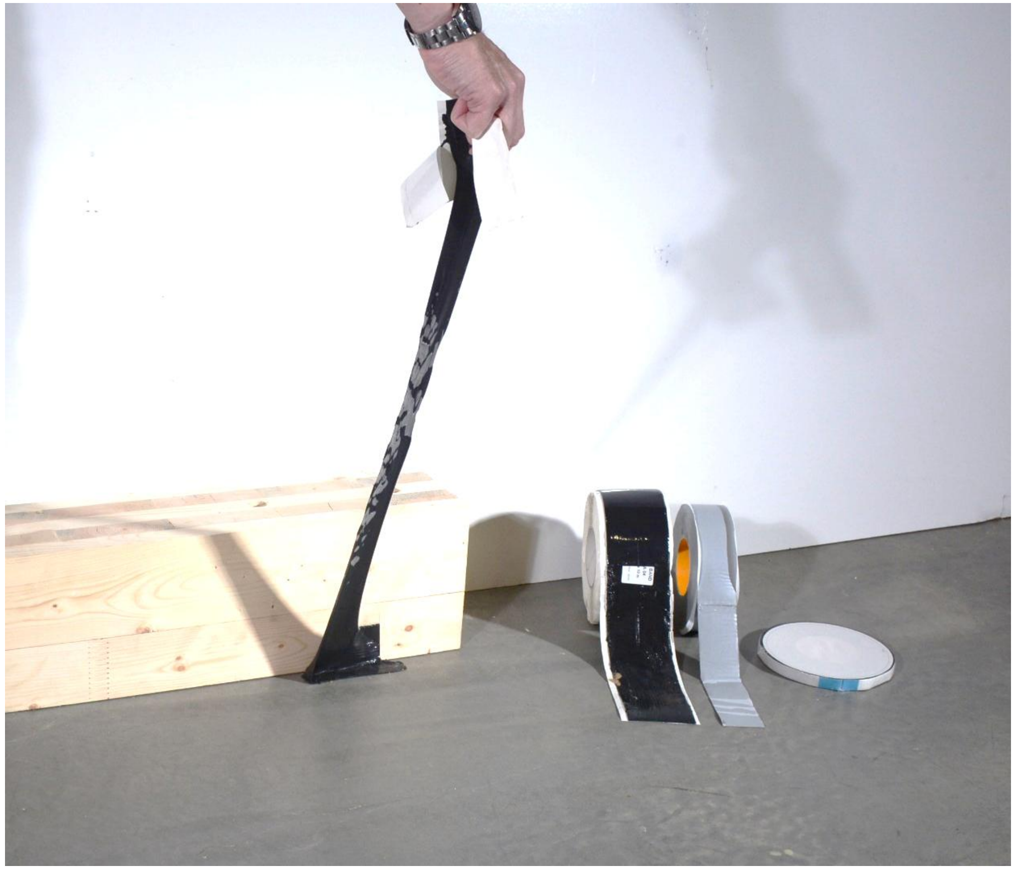
Tape to block moisture from below (typically concrete) and two expanding polyurethane foams to achieve airtightness on uneven ground.

Tape with two hollow rubber hoses to seal gap between floor and walls, staples on wood to achieve airtightness.

Author & Photo: Wimmers

Butyl Tapes

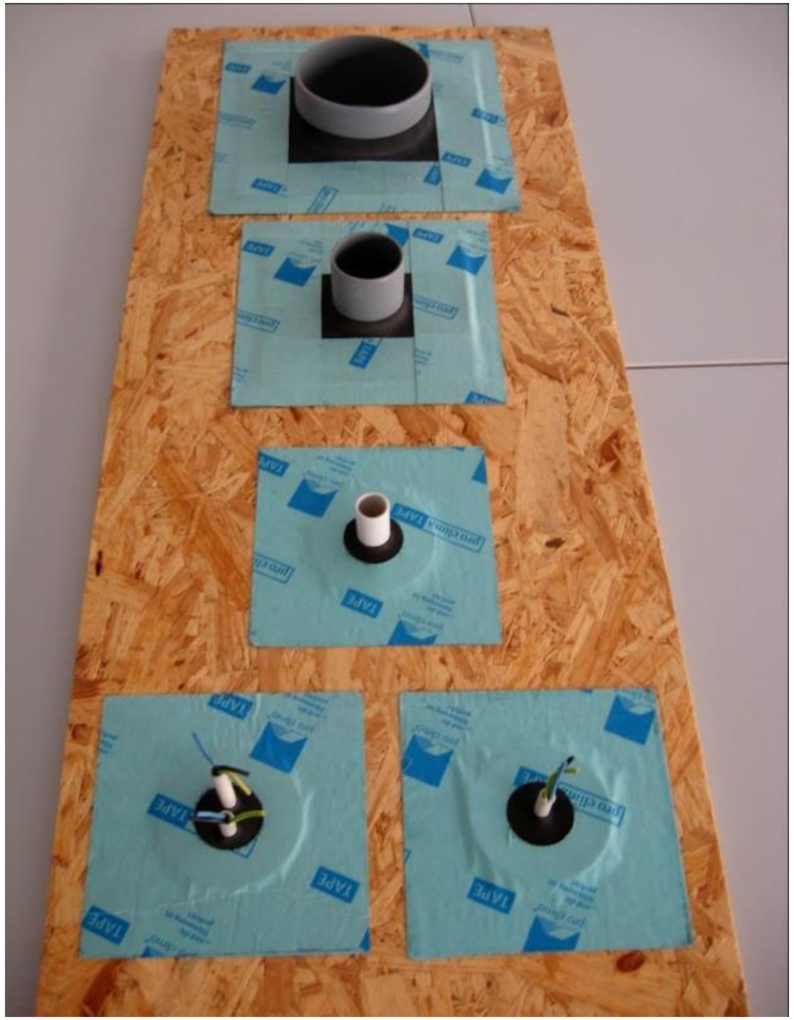


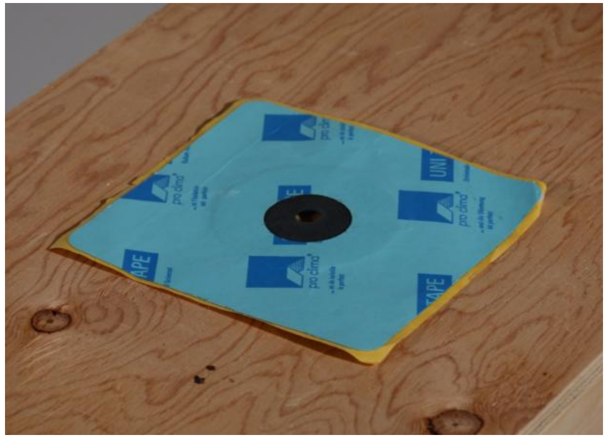


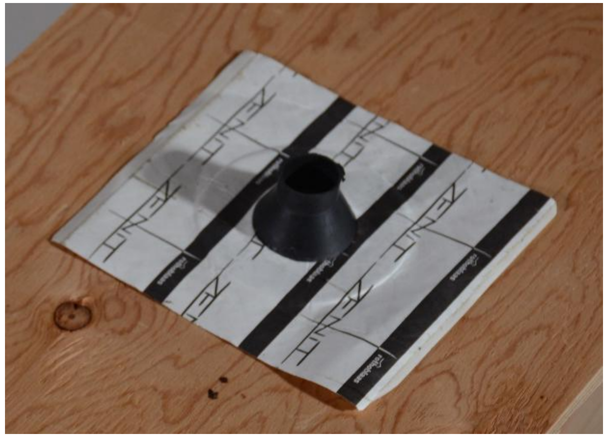
Butyl tapes are used to adhere to concrete or other porous materials (primer might be needed) and if movement is to be expected. Careful: Very Sticky!

Author & Photo: Wimmers

Grummets, Collars, Gaskets…







Various Sizes for Cables, Conduit and Plumbing Lines

Author & Photo: Wimmers

Sealing without gaskets

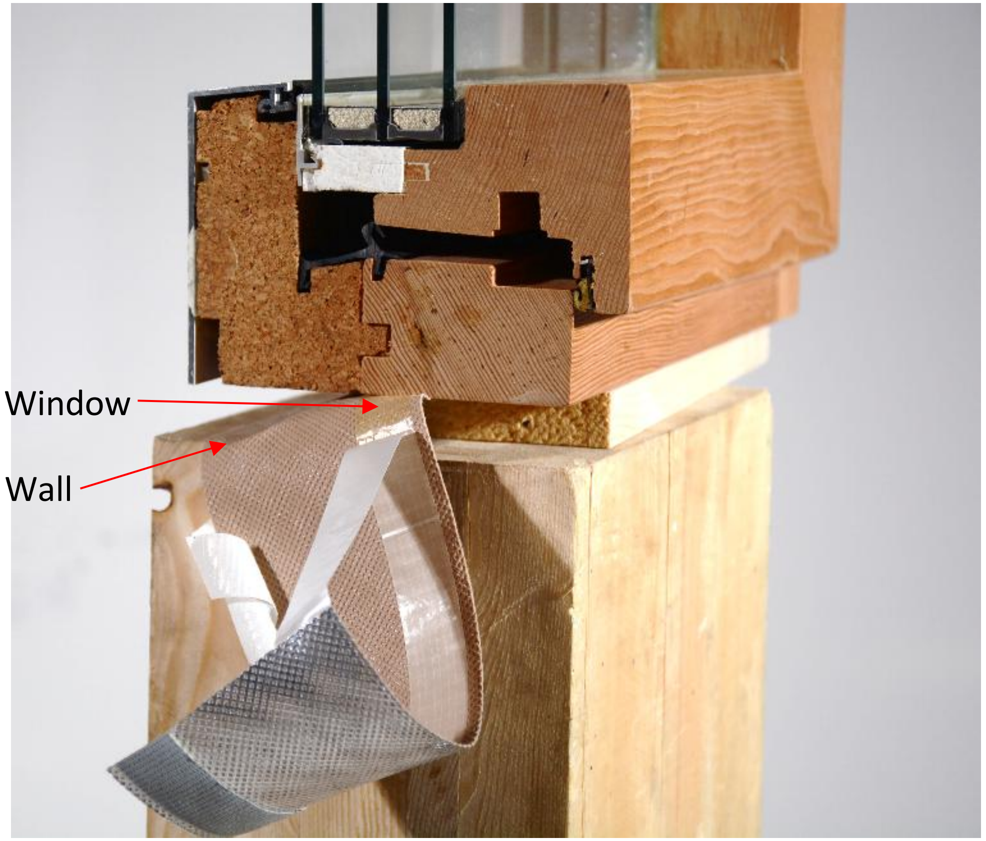
The material costs for appropriate Gaskets might be higher than for the tape but if possible, proper Gaskets should be used.

Source: PHI, Author: G.Wimmers

Specialty Window Tapes, double sided or expanding Foam

Adhesive to Window

Adhesive to Wall



Double sides tape with butyl layer for wall (wood, concrete etc) and adhesive layer for wood or PVC windows. This tape allows to be “S” shapes to overcome the distance between wall and frame (rough opening) of 10-12mm.

Compressed Foam tape self expands after installation (30-90min, depending on temperature), achieving airtightness with defined vapour diffusion resistance.

Author & Photo: Wimmers

Lesson 5: Airtightness Details and Test

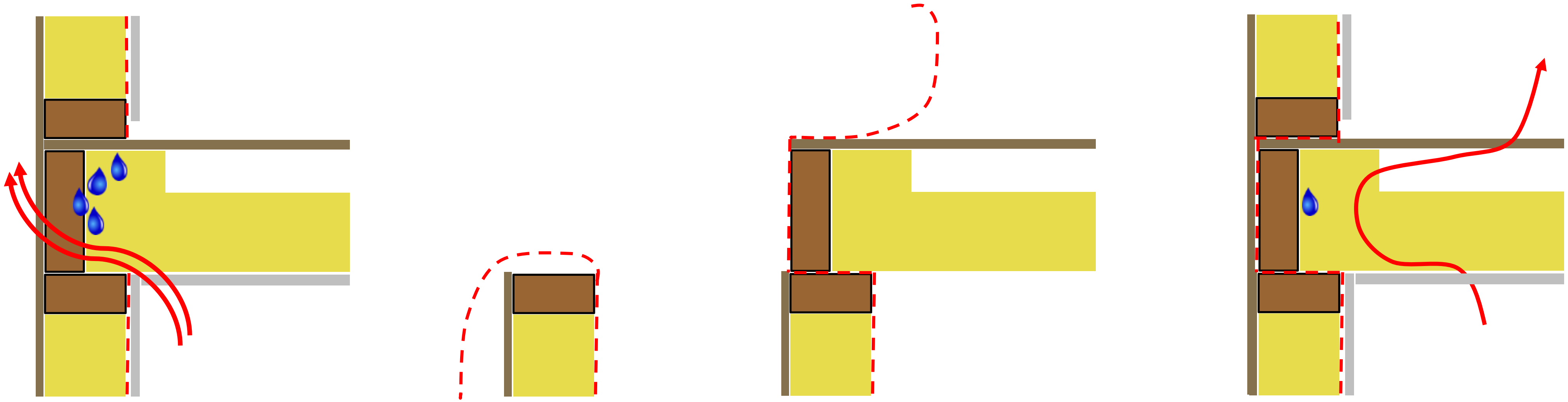
(5min summary + 40min + 5min Q&A)

- ***Objectives:***
  - Analyze the principle challenges of airtightness in detail
  - Develop potential methods and solutions
  - Investigate the basics of the airtightness test (Blower Door Test)

Airtightness Details

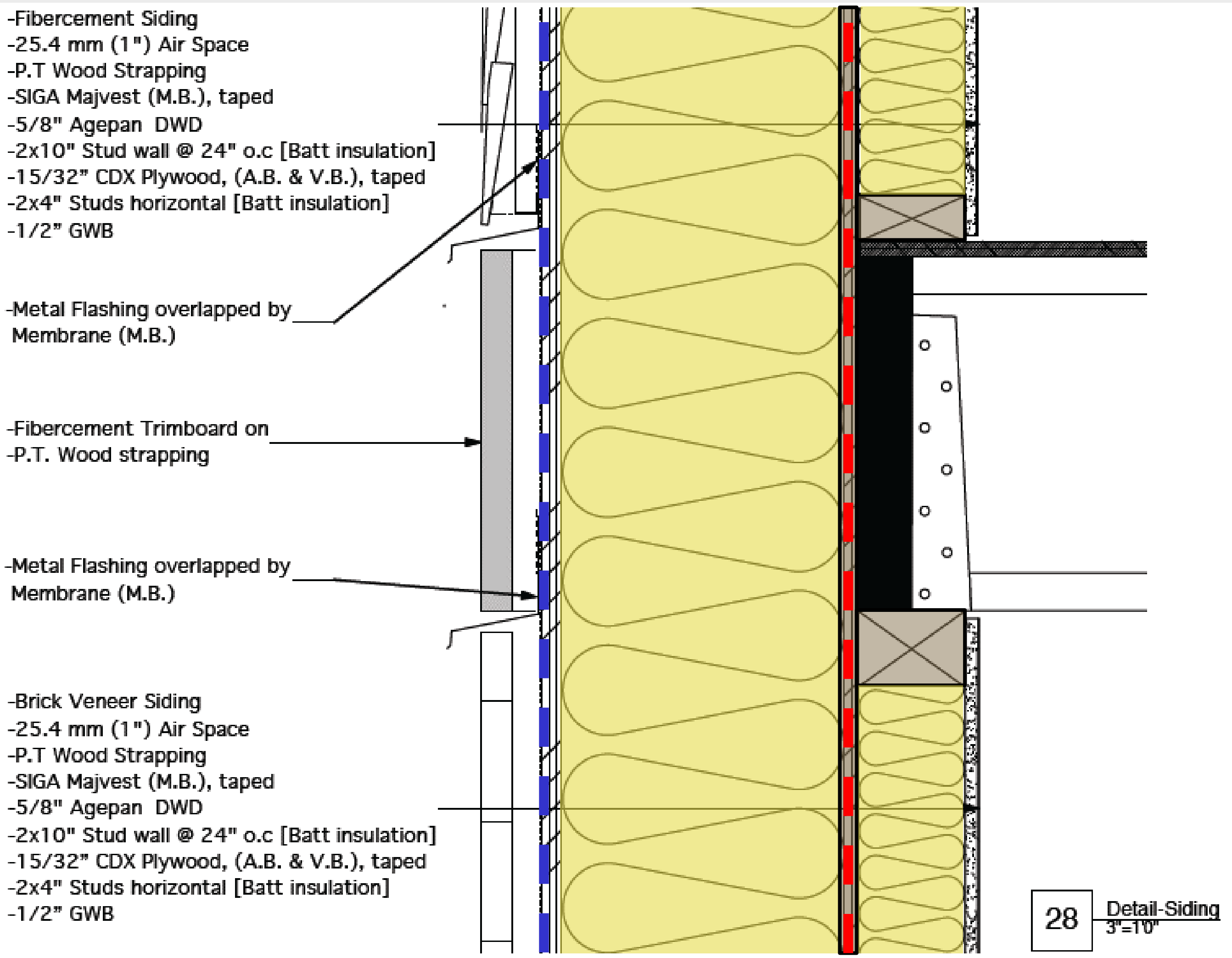
- Various Details to improve Airtightness

Basic Problem with Airtightness in Platform Framing



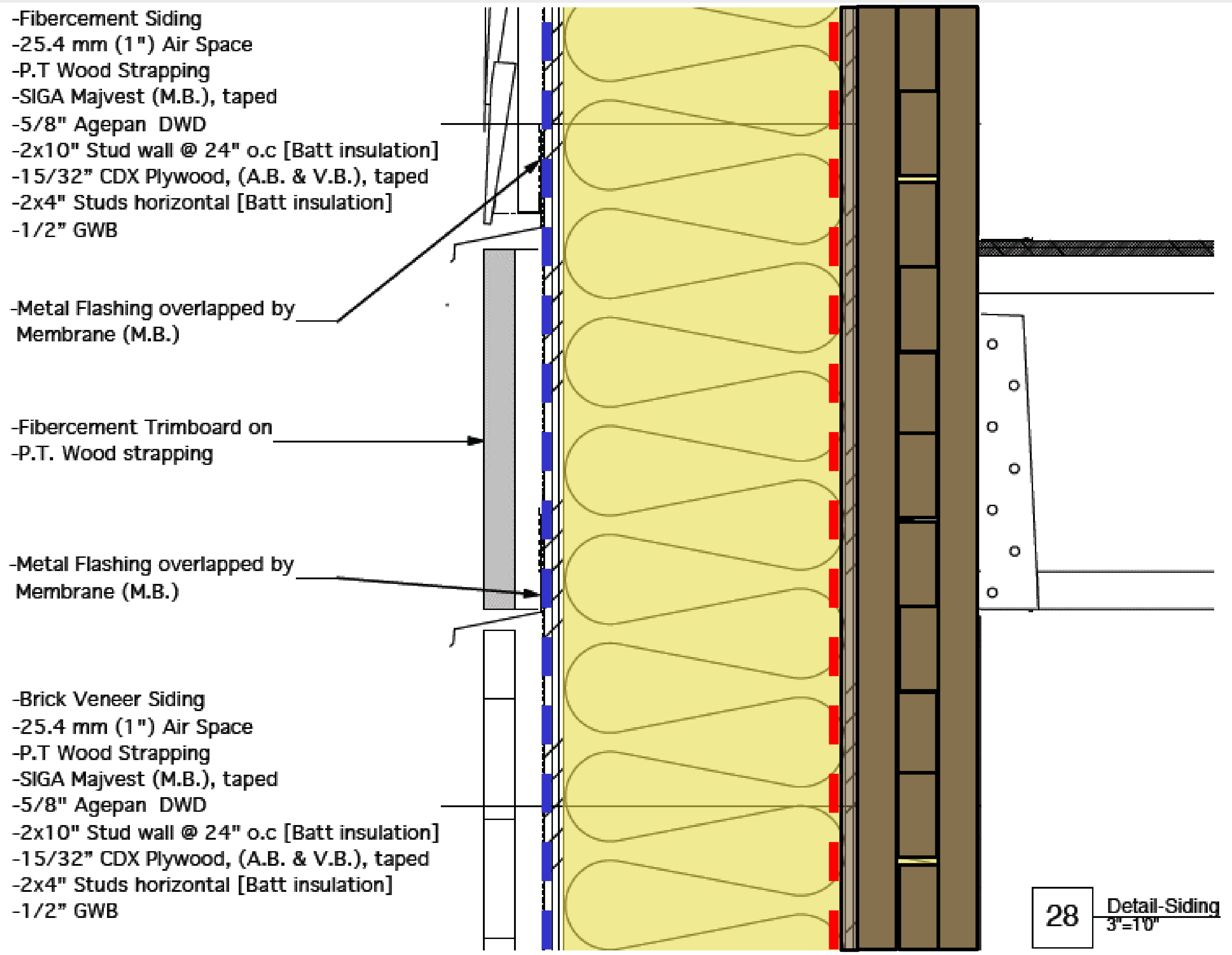
Author & Graphic: Wimmers

Airtight Floor Connection (Prefab)



Graphic: Wimmers

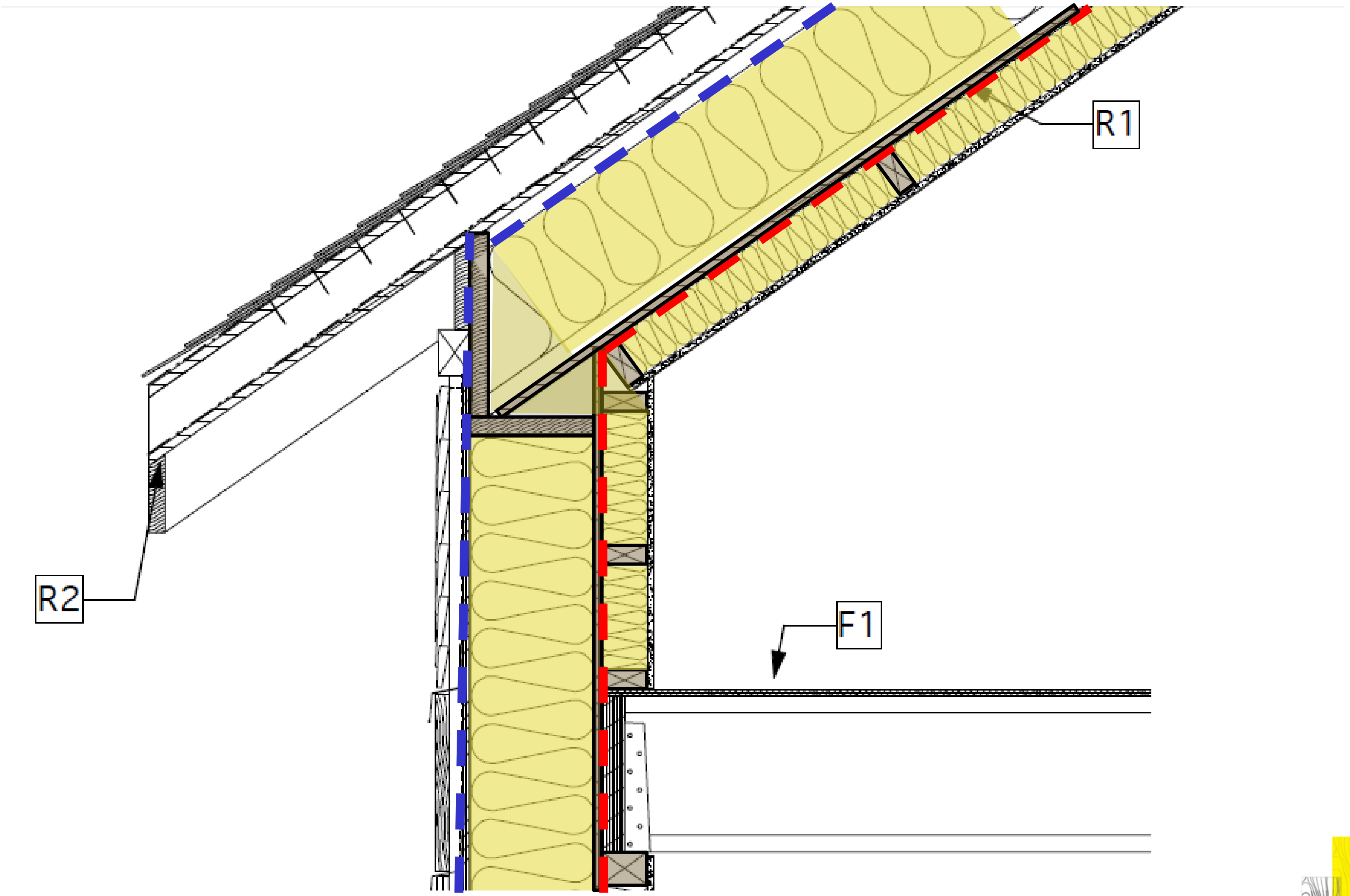
Airtight Floor Connection to CLT



CLT is not Airtight!
Additional Membrane or Plywood necessary.
Careful with Penetrations for Electrical.
Ideally use CLT only for Interior Walls as airtightness is challenging.

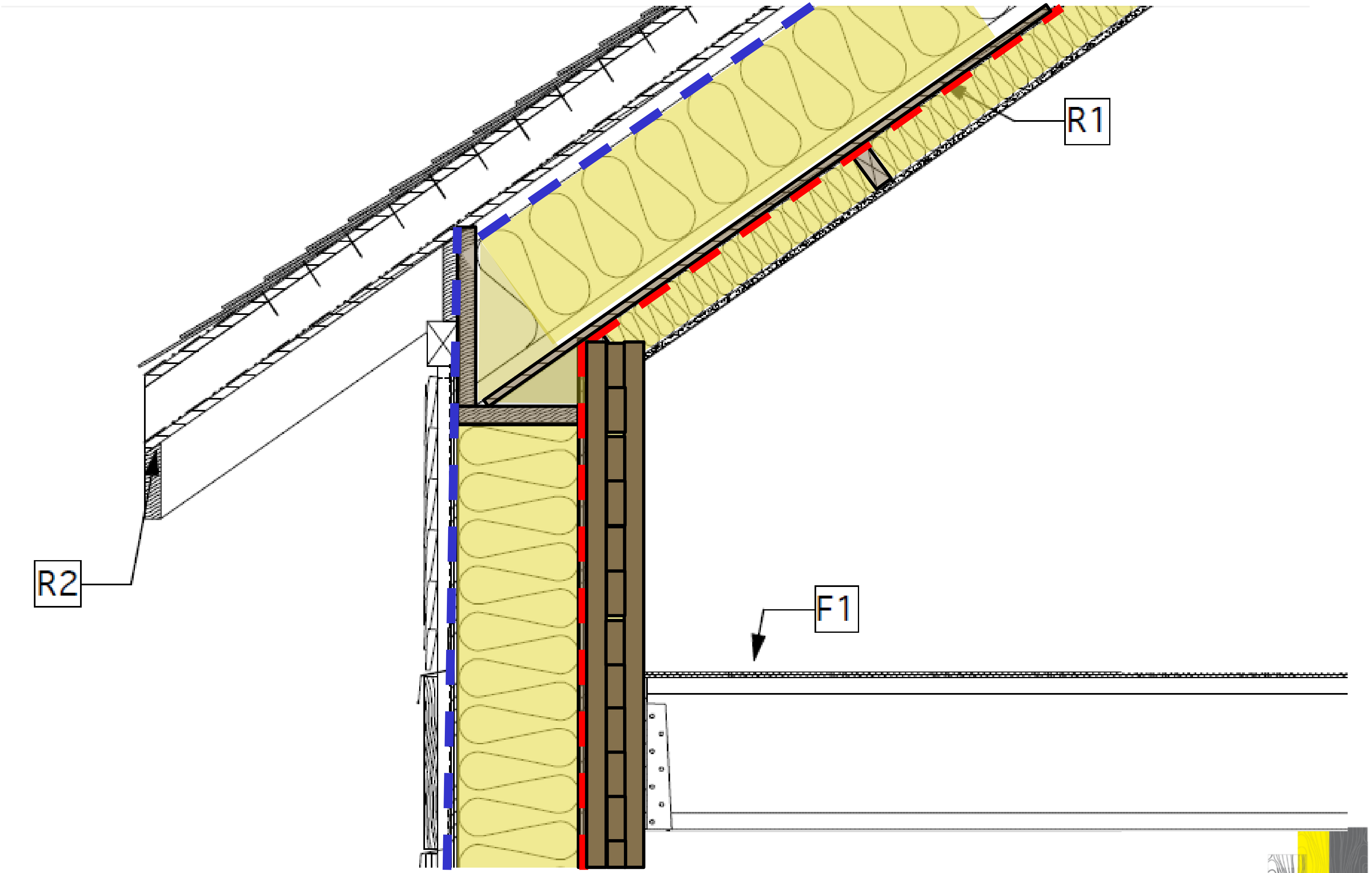
Graphic: Wimmers

Airtight Eaves, Wall to Roof (Prefab)



Graphic: Wimmers

Airtight Eaves, Wall to Roof (CLT)



Graphic: Wimmers

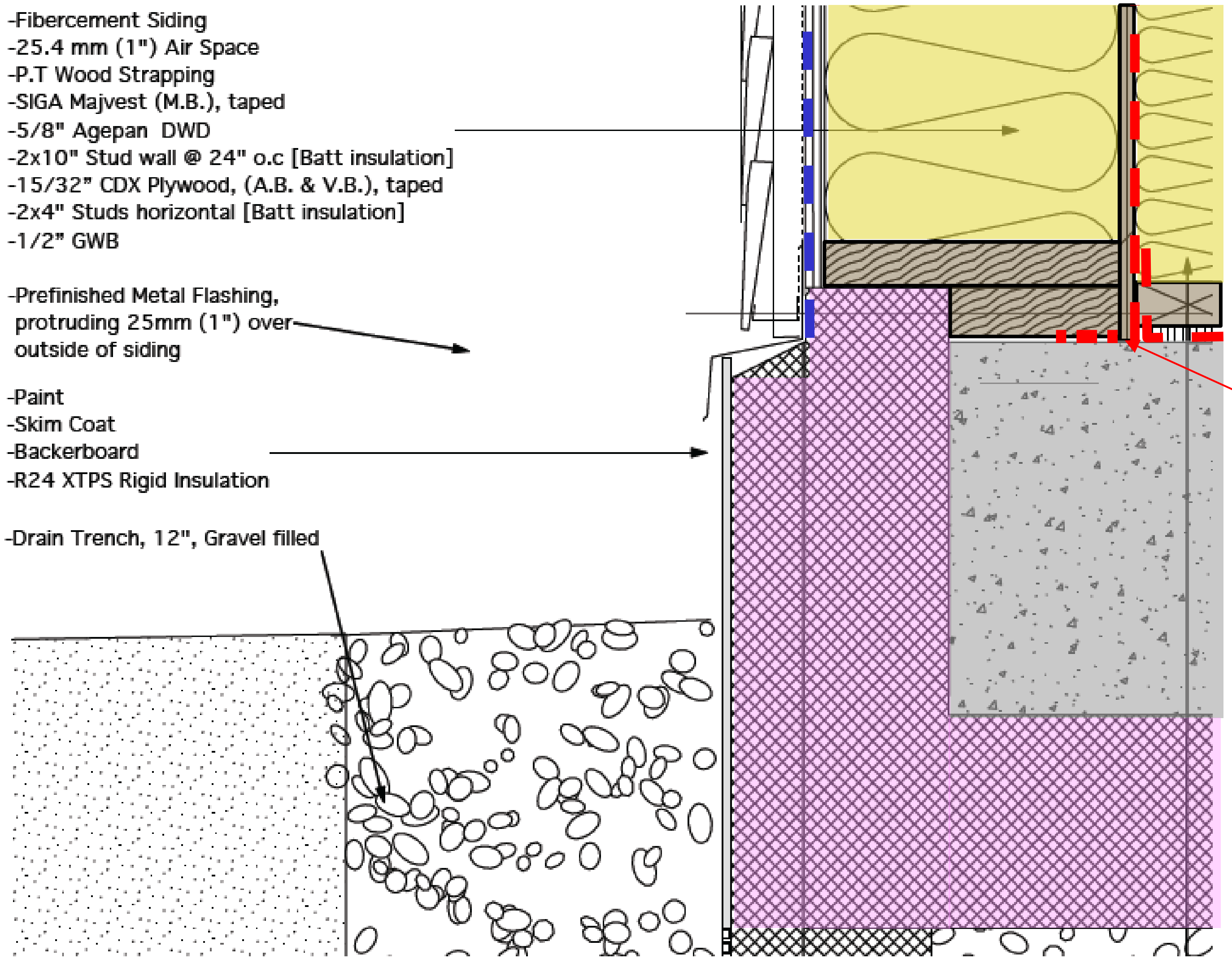
Airtight Footing Detail, no Basement

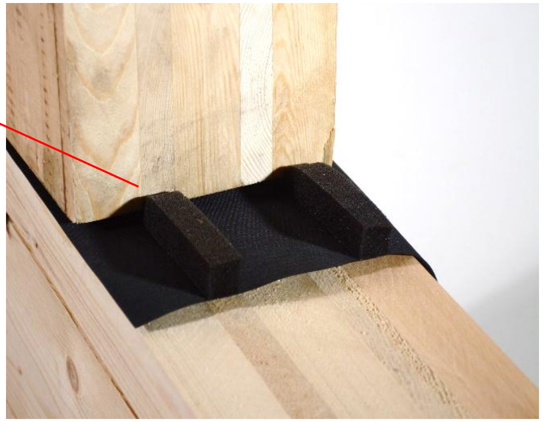
-Fibercement Siding
-25.4 mm (1") Air Space
-P.T Wood Strapping
-SIGA Majvest (M.B.), taped
-5/8" Agepan DWD
-2x10" Stud wall @ 24" o.c [Batt insulation]
-15/32" CDX Plywood, (A.B. & V.B.), taped
-2x4" Studs horizontal [Batt insulation]
-1/2" GWB

-Prefinished Metal Flashing,
protruding 25mm (1") over
outside of siding

-Paint
-Skim Coat
-Backerboard
-R24 XTPS Rigid Insulation

-Drain Trench, 12", Gravel filled





Graphic & Photo: Wimmers

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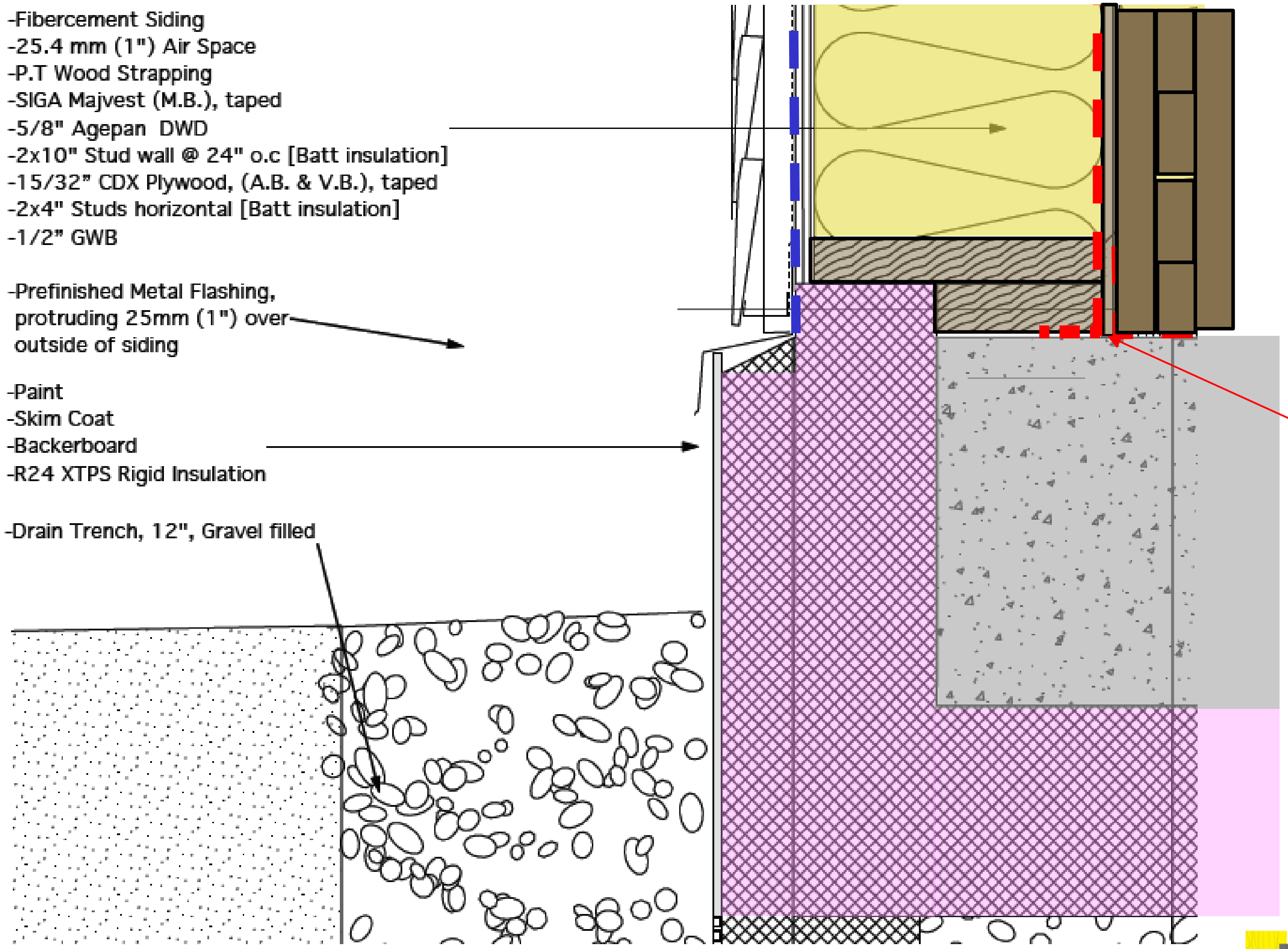
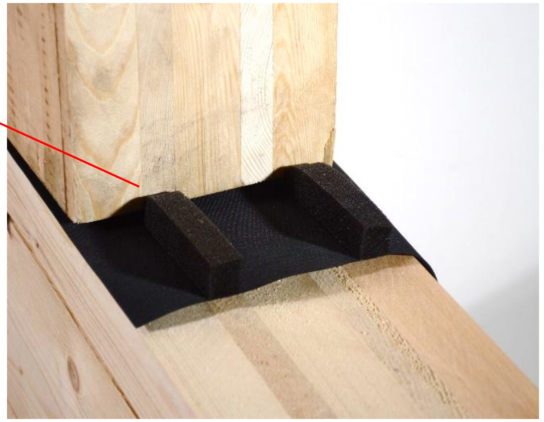
Thermally Optimized CLT Detail, no Basement

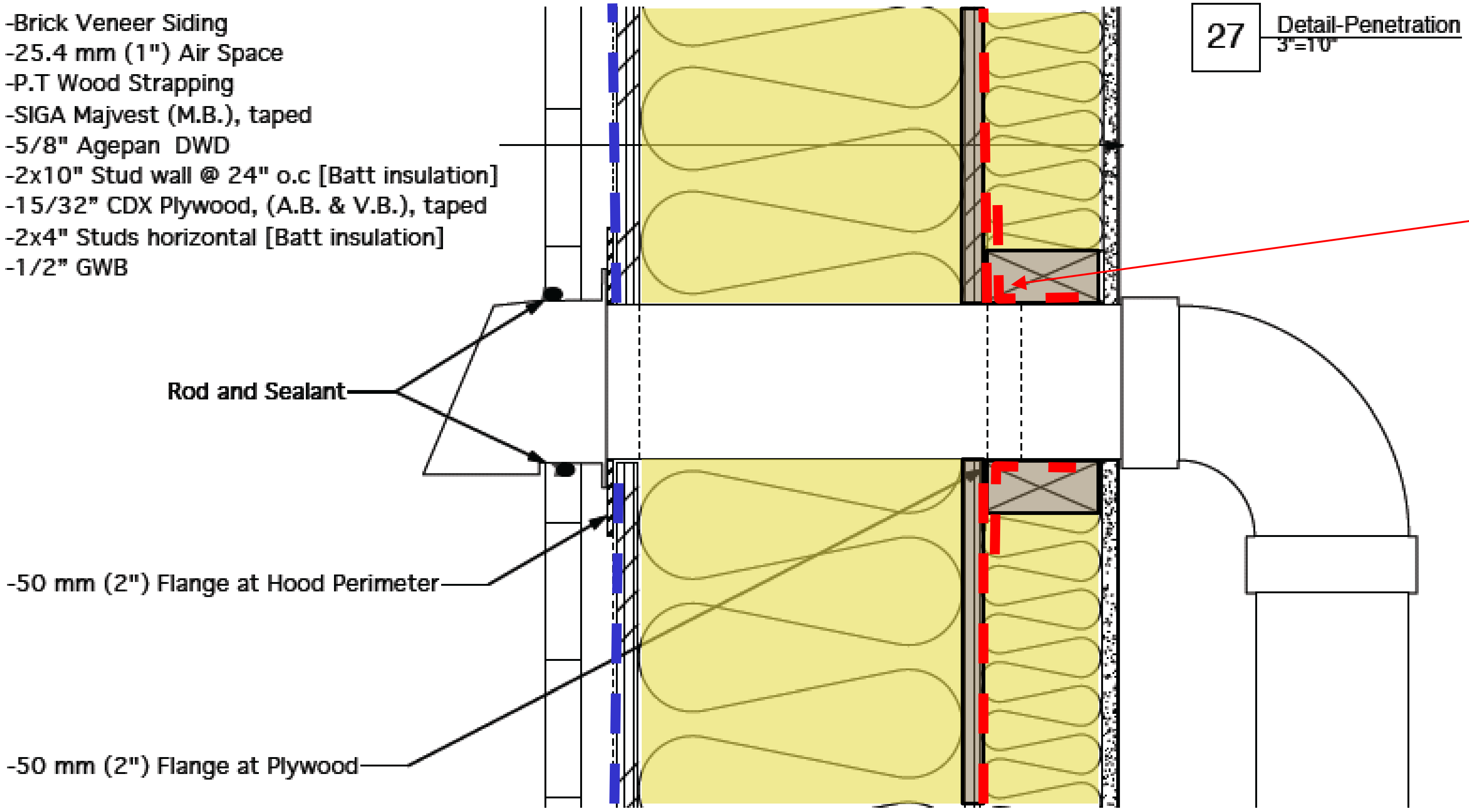


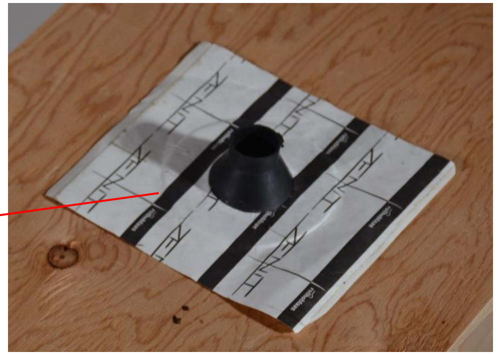
CLT is not Airtight!
Additional Membrane or Plywood necessary.
Careful with Penetrations for Electrical.
Ideally use Mass Timber only in the Interior as Thermal Bridges and Problems with Airtightness more likely if Exterior use.



Graphic & Photo: Wimmers

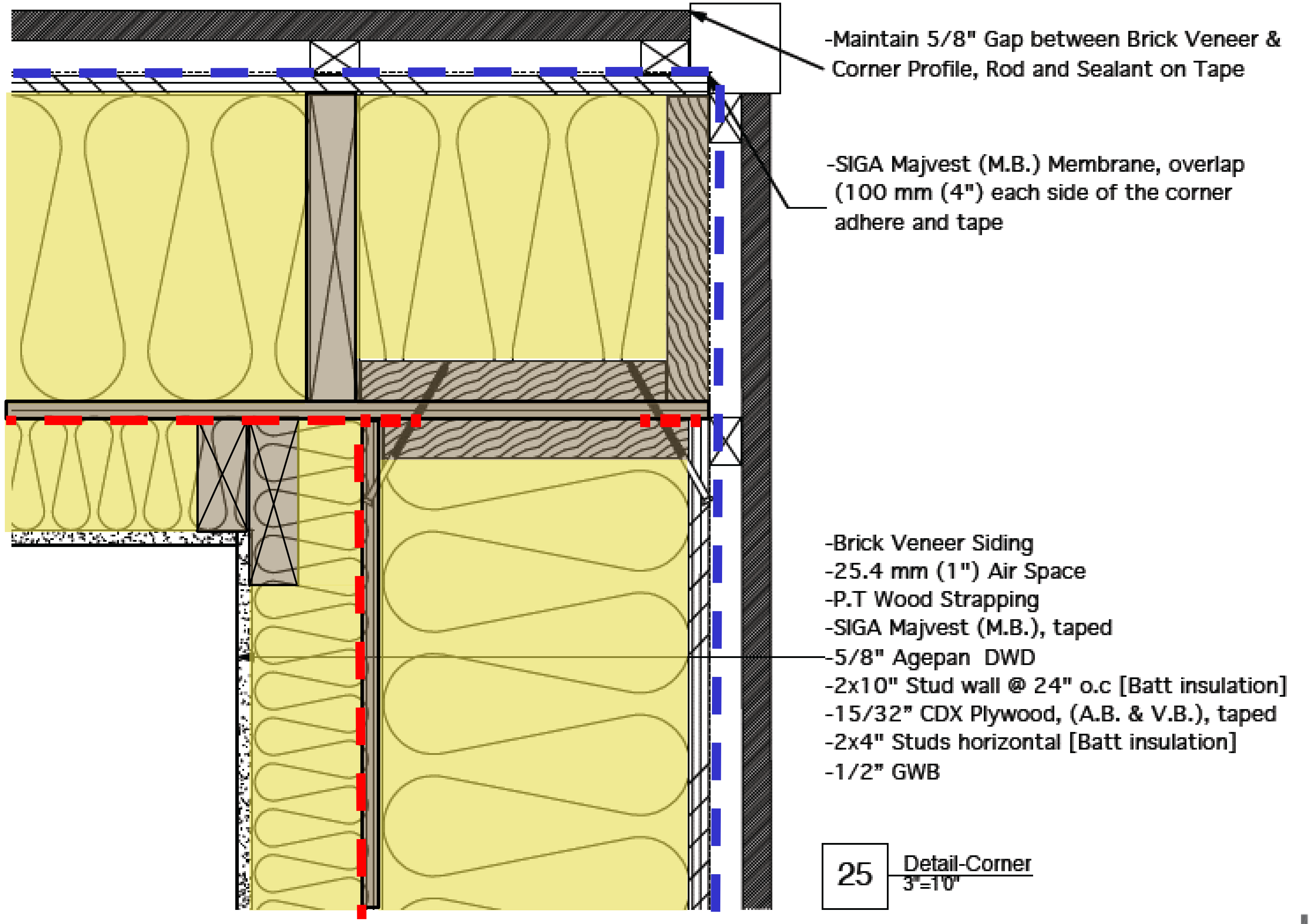
Airtight Penetration





Graphic & Photo: Wimmers

Airtight Corner (Prefab)



Graphic: Wimmers

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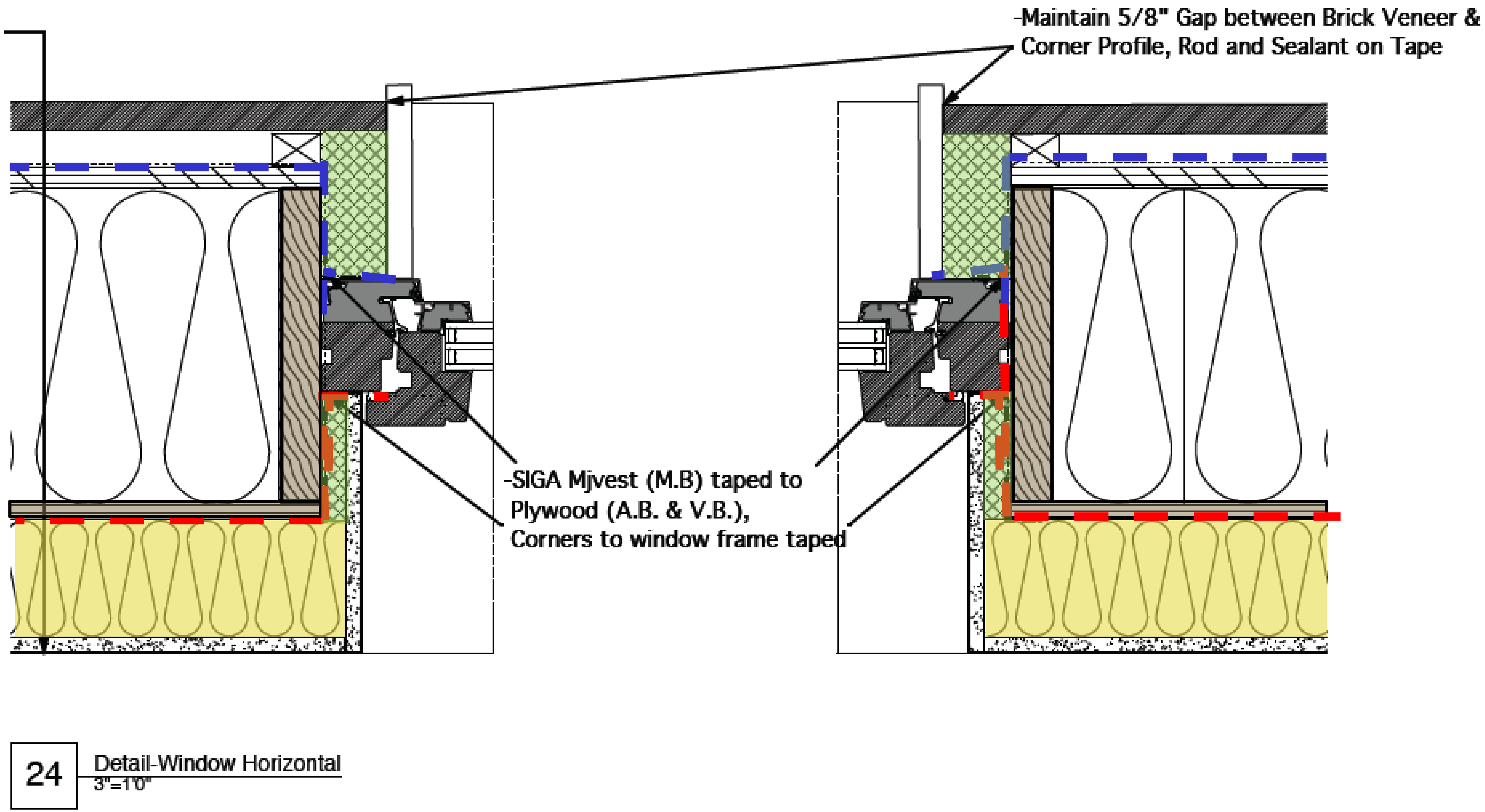
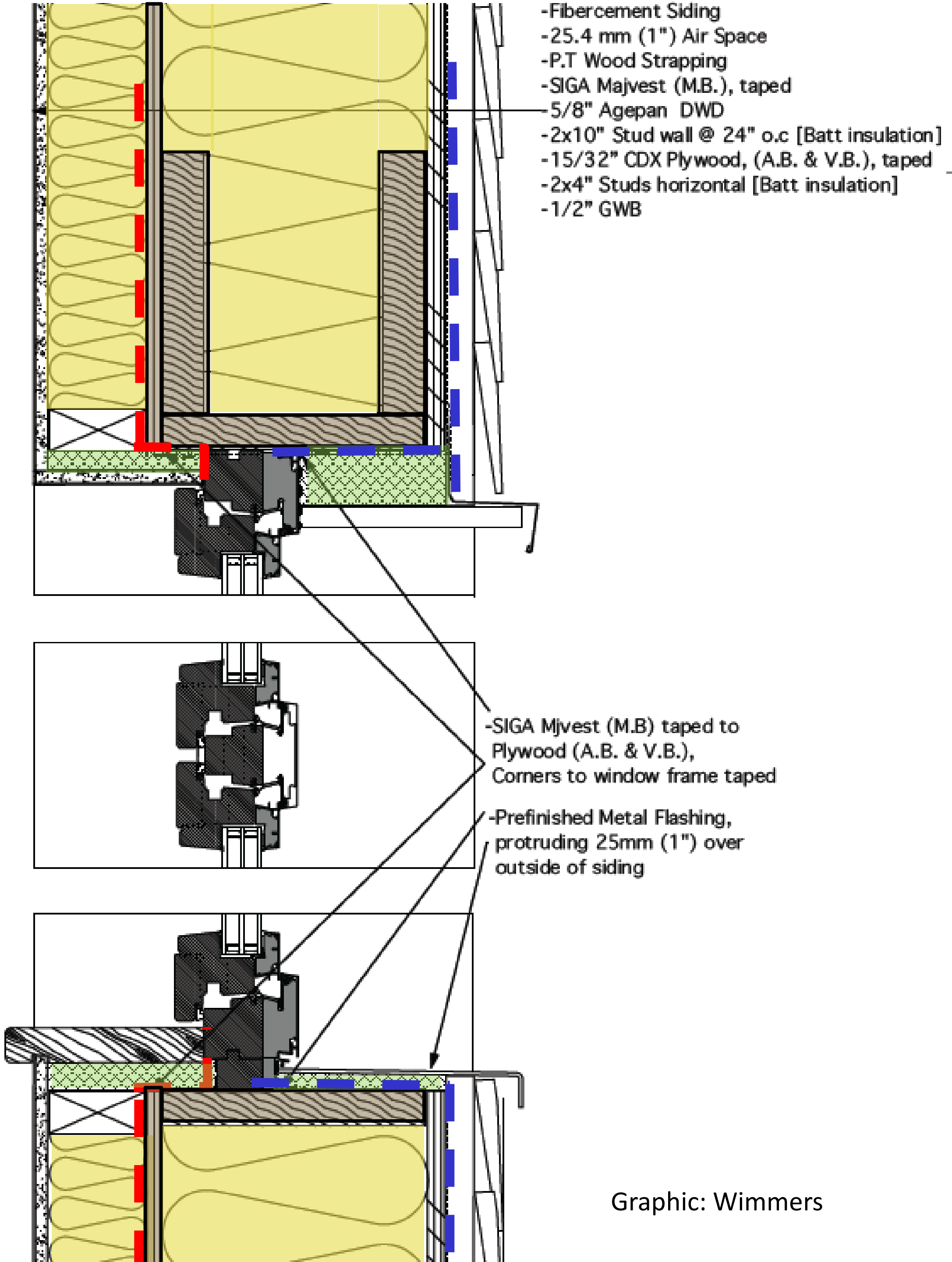
Airtight Window Installation, sides



Graphic: Wimmers

Airtight Window Installation



Graphic: Wimmers

Airtightness Test

- Blower Door Test Standards
- Airtightness Milestones
- Volume calculation

Blower Door Test (BDT)

- Blower Door Test Fan installed in opening
- Pressurization and depressurization in 10 Pa increments
- 50 Pa is the important value in several codes
- Hot 2000 (mid 80’s) ≤1.5 ach@50Pa
- Passive House (beginning 90’s) ≤0.6 ach@50Pa

Photo: Retrotec.com Author: Wimmers

BDT Standards

- CAN / CGSB 149.10 - M86
- ISO 9972
- EN 13829 - 2001 [Method A & B]
- Passive House Standard, Guidelines and Best Practices

Important:
Regardless the Standard used, BDT has to be tested in both direction, pressurization and depressurization to be conclusive! Just testing one direction can conceal significant leakage through valve effect.

BDT Volume in Passive House Standard

Calculation of the building volume [V_{n50}]

- Room by Room [width x length x height]
- Roof inclined, width x length x medium height
- Volumes excluded :
- Partition Walls, Floor Cavities, Bulkheads, Dropped Ceilings

Figure 1: House Section (image courtesy of Andrea Hobbs)

PH uses a standardized calculation method for the <u>internal air volume across all jurisdictions</u>. This makes the 0.6 ach@50Pa significantly more difficult to achieve, compared to CAN / CGSB 149.10 - M86

Author: H&H

Saskatchewan Conservation House 1978

- Harold Orr and a Team of Scientists from NRCAN **invented the Blower Door Test** in 1977-79
- 0.8 ach@50Pa (pressurization)

Photo: H. Orr, Author: G. Wimmers

Austria House, Whistler 2009

- 0.28 ach@50Pa, First Certified Passive House in Canada




- pressurization @ 50 Pa = 0.26 air changes/hour
- depressurization @ 50 Pa = 0.30 air changes/hour

Author & Photos: Wimmers

Canadian Milestones in Airtightness 2010-2011

0.35
ACH@50
Montebello Passive House

0.43
ACH@50
Kenworthy Passive House

0.25
ACH@50
Rainbow Passive House

0.20
ACH@50
Naugler House

0.5
ACH@50
Bedford Road House

Source: passivehousecanada.com, Author: G. Wimmers

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Wood Innovation Research Laboratory, Prince George 2018

- 0.07 ach@50Pa, North America’s most Airtight Building (as of Dec 2020)

Author & Photos: Wimmers

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Exercise

In a Passive House with a net air volume of 500 m³, an air flow rate of 420 m³/ h was determined with a differential pressure measurement at 50 Pa. Was the requirement for Passive Houses of $n_{50} < 0.6$ 1/h met in this measurement?

$$n_{50} = \frac{V_{50}}{V_{Air}}$$

Calculation: $\frac{\text{measured air flow rate}}{\text{net interior air volume}}$

$\frac{420\ m^3/h}{500\ m^3}$ = **0,84** $^1/_h$ (n_{50}) (> 0,6 $^1/_h$ requirement not met)

Author: Wimmers

Exercise

For a Passive House with a net air volume of 500 m³: How big is the maximum permissible air flow rate at 50 Pa pressure difference, so that the limit of <0.6 1/h is not exceeded?

$$V_{50} = V_{Air} \times n_{50}$$

Calculation: $500\ m^3 \times 0.6\ {}^{1}/_{h} = \mathbf{300 m^3/h}$

Author: Wimmers

Exercise

How big is the rough equivalent leakage area of a Passive House with a measured n_{50} value of 0.35 1/h and a resulting volumetric air flow V_{50} of 300 m³/h?

$$LeakageArea = \frac{V_{50}}{2m^3/(h * cm^2)}$$

Calculation: $\frac{300m^3/h}{2\ m^3/(h*cm^2)}$ = **150cm²**

150 cm² = 15cm x 10 cm

The result for the equivalent leakage area (A_{50}) is expressed in cm² and represents an approximate value for illustrative purposes!

Author: Wimmers

Lesson 6: Vapour Diffusion and Moisture Management

(5min summary + 40min + 5min Q&A)

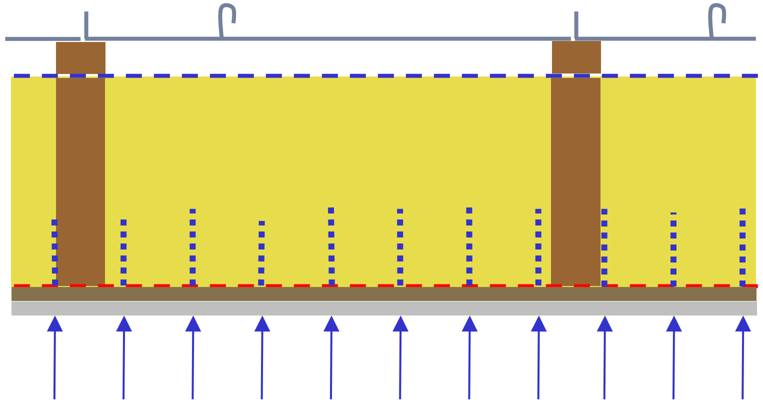
- ***Objectives:***
  - Analyze the principles of vapor diffusion
  - Investigating the potential for associated problems within super-insulated building components (e.g. WUFI)
  - Evaluate available materials
  - Generate strategies for addressing vapor management in buildings with high thermal insulation performance

Moisture Sources

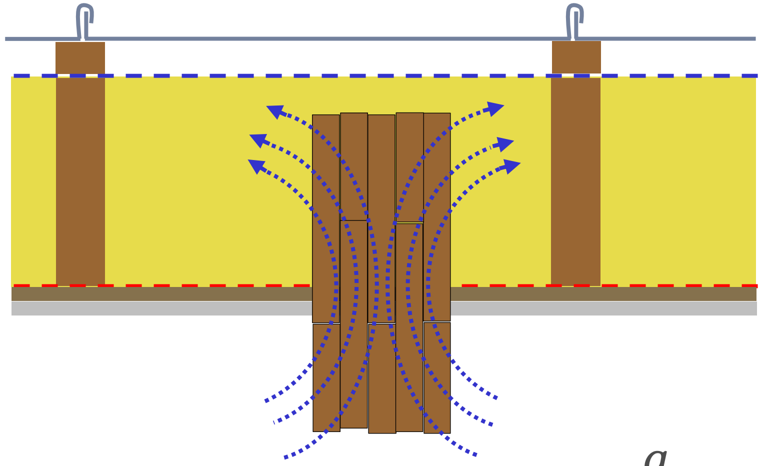
- Rain
- Diffusion
- Flank Diffusion
- Drying of Materials
- Convection

Author: Wimmers

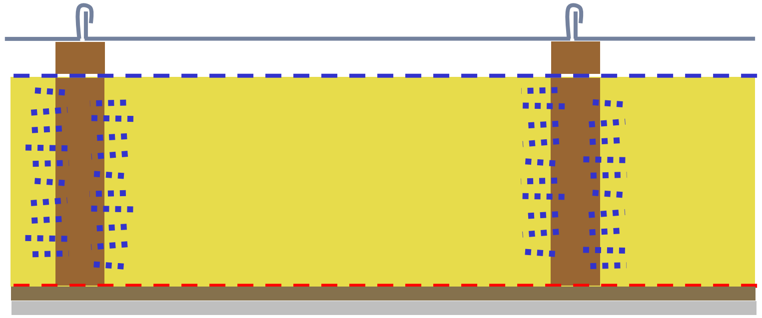
Possible Moisture Loads in Construction Assemblies



Diffusion $\approx 3 \frac{g}{m^2 day}$



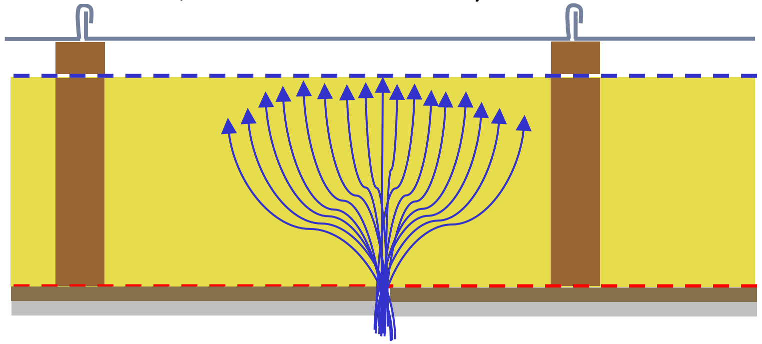
Flank Diffusion $\approx 30 \frac{g}{m^2 day}$



Drying of Wood $\approx 50 \frac{g}{m^2 day}$

(only short term)

Outside 0° C; 80% relative humidity



Convection 1mm gap $> 300 \frac{g}{m^2 day}$

Inside 20° C; 50% relative humidity

Source: S. Peper, W. Feist, V. Sariri: Luftdichte Projektierung von Passivhäusern – eine Planungshilfe. Fachinformation PHI 1999/6, Passivhaus Institut, Darmstadt 1999/ 9. Auflage 2008, Graphic: G. Wimmers

Vapour Diffusion

- Permeability
- Resistance
- Sd Value
- Rules of Thumb
- Glaser Diagram
- Drying Out Potential

Author: Wimmers

Vapour Diffusion Resistance factors: perms and Sd

- Metric perm (used in Canada, SI unit kg/(s·m^2·Pa))
  - Unit [ng/(s·m^2·Pa)] (ASTM E96)
  - Metric perm = 60ng/(s·m^2·Pa) defined as vapour barrier (by NBC)
- Water Vapor Diffusion Thickness (used in Europe)
  - Sd = µ x d
  - µ = specific Vapour Diffusion Resistance of any given Material
  - d = Thickness of Material
  - Sd = 1 is the equivalent of the vapor diffusion resistance of 1m of air (EN 1931)
- US perm (used in U.S.)
  - 1.0 US perm = gr/(h·ft^2·in. Hg) defined as vapour retarder
  - The units grain of water (64.8mg) and inch of mercury seemed to come from a different time

Author: Wimmers

U.S. Perm

- Vapor impermeable: <0.1 perms or less
  - Example: 6-mil polypropylene
- Vapor semi-impermeable: 0.1 - 1.0 perms
  - Example: Bitumen-coated Paper, ½”Plywood (dry) = 0.5-1.0 U.S. perms
- Vapor semi-permeable: 1.0 - 10 perms
  - Example: ½”Plywood (wet) = 9-10 U.S. perms
- Vapor permeable: greater than 10 perms
  - Example: Most common house wraps e.g. Tyvek = 58 U.S. perms

Author: Wimmers

Vapour Diffusion Resistance μ - Value

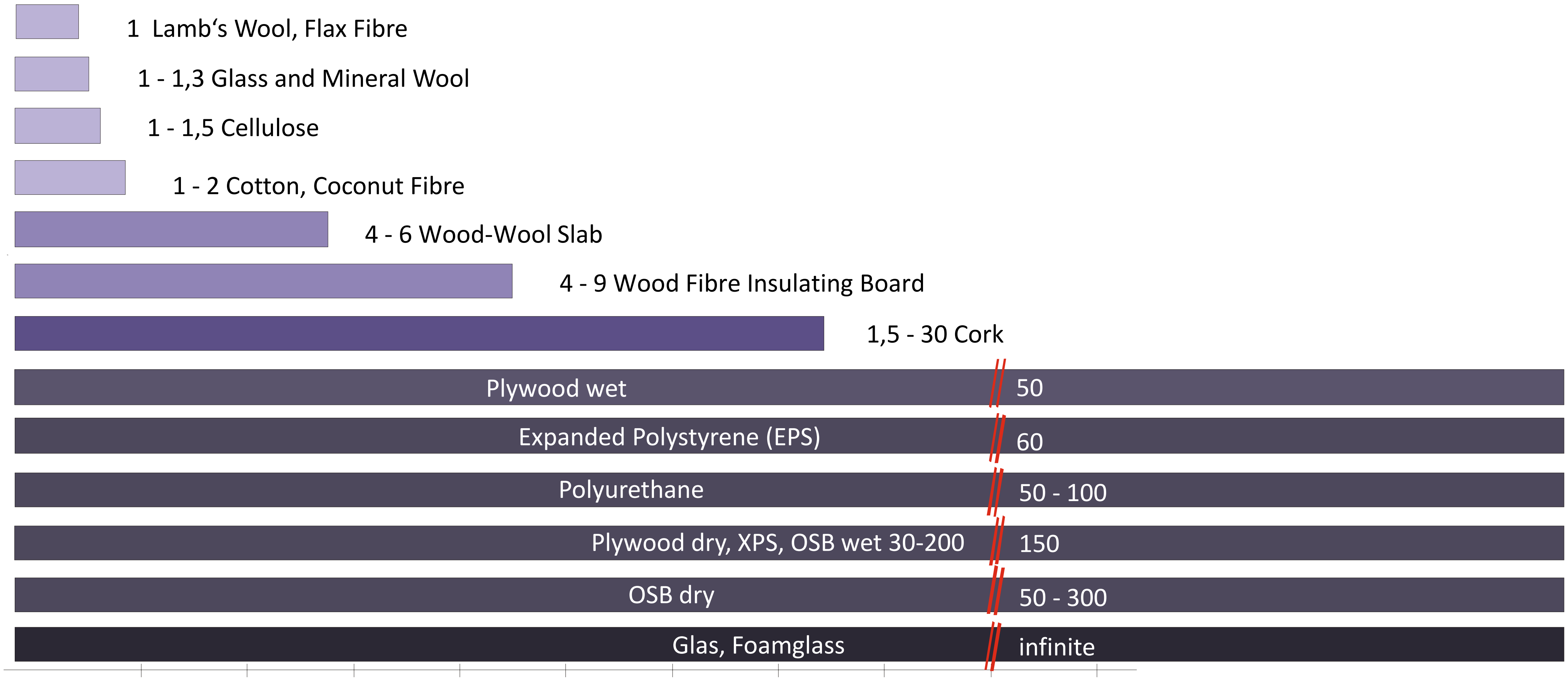
Air	$\mu = 1$	
Insulation	$\mu = 1\text{-}10$	
e.G Mineral/Glass Wool, Cellulose Fiber, ...		
Vapour Retarder	$\mu > 10{,}000$	
Membranes		
Vapour Barrier	$\mu > 100{,}000$	
Bituminous Membranes, Foils		

μ is the specific Vapour Diffusion Resistance of a specific material

μ has to be set into ratio to the thickness of the material in question to get the Vapour Diffusion Thickness, expressed as Vapour Diffusion equivalent Air Layer s_d in m for the component in question

Author: Wimmers

Vapour Diffusion Resistance of various Insulating Materials = μ - Value



μ = The Diffusion Restistance Factor of materials is a unit-free factor
(the smaller the value, the lower the vapor diffusion resistance of the insulating material)

Source: ISO 10456 Graphic: G. Wimmers

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Water Vapour Diffusion Thickness s_d – Value Examples

$$\boxed{s_d = \mu * d}$$

$$s_d = \textit{Water Vapour Diffusion Thickness as equivalent Air Layer}\ [\mathrm{m}]$$

$$\mu = specific\ Vapour\ Resistance$$

$$d = thickness\ (dimension)\ in\ [m]$$

Example: vapour retarder/check

Resistance against vapour penetration: μ = 10,000

Thickness: d = 0.3 mm (0.0003 m)

Equivalent thickness of air layer s_d-value:

$s_d = \mu * s$ = 10,000 x 0.0003 m = 3.0 m

3.28/3.0 = 1.09 US perms

Example: s_d ½''plywood = 150*0.0127 = 1.9m

Author: Wimmers

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Author: Wim

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Water Vapour Diffusion Thickness s_d – Value (DIN 4108)

- Vapour Diffusion open: $s_d \leq 0.5$m
  - e.g. 0.3m Mineral Fiber Insulation s_d = 0.3-0.4m
- Vapour Diffusion Retarder: 0.5m < $s_d \leq$ 10m
  - e.g. 12.7mm Plywood s_d = 1.9m, SIGA Majvest 200 s_d = 0.5m
- Vapour Diffusion inhibiting: 10m < $s_d \leq$ 100m
  - e.g. common interior Membranes SIGA Majpell 25 s_d = 25m
- Vapour Diffusion Barrier: 100m < $s_d \leq$ 1000m
  - e.g. RothoBlaas Barrier 200 s_d = 200m
- Vapour Diffusion impermeable: >1500m (also ISO 12572)
  - e.g. Foam Glass Panels

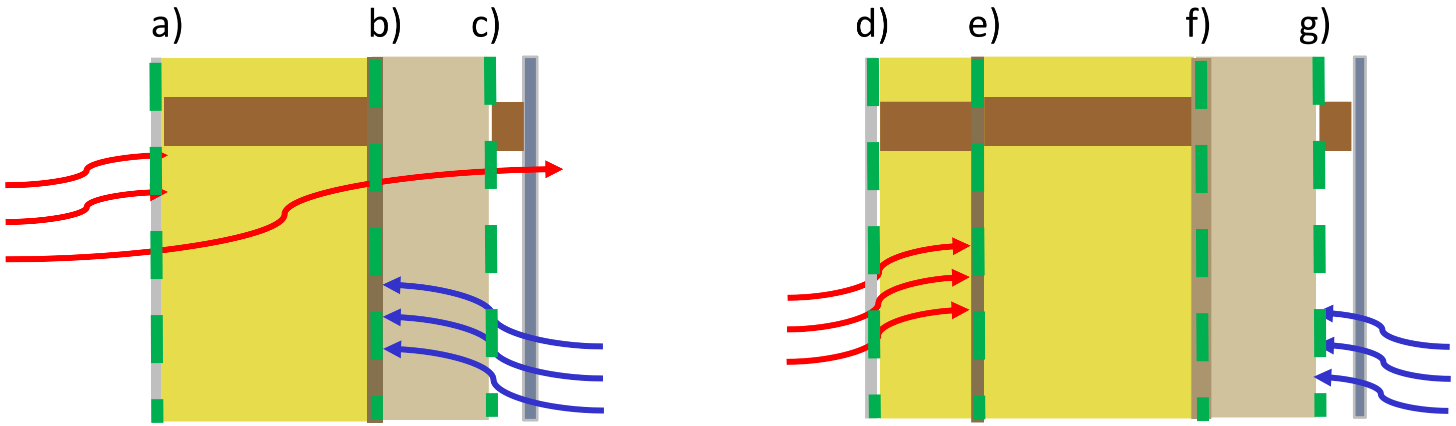
Author: Wimmers

Vapour Diffusion Rules

1. Vapour “barriers” are misleading if BDT is >0
2. Vapour diffusion “open” construction is safer
3. Vapour diffusion is important for drying out
4. Code is only asking for vapour retarder (such as Plywood)
5. If the airtightness on the inside is compromised, the vapor retarder/check is compromised!

Positioning Rules of Thumb

- 1st RoT: Vapour Diffusion Resistance on inside (warm side) should be >3 (better 4) times higher than on outside
- 2nd RoT: Vapour retarder should be at the inner 1/3 (better ¼) of the wall
- Exercise: Where is the safest position for the Vapour Diffusion Retarder?



Author & Graphic: Wimmers

Discussion

- The most important Rule: Decrease the Vapour Diffusion Resistance towards the outside!
- This will allow any humidity, which found its way into the cavity, to dry out towards the outside, staying below the saturation pressure and not turning into liquid water.
- How does the use of Plywood or OSB on the outside (cold side) of the envelope fit into this rule?

Author: Wimmers

Wood Fiber Board as Exterior Sheeting

- Product manufactured in Europe for over 70 years
- Used as breathable, insulating, structural sheathing
- Very good for Soundproofing
- Environmentally benign - made from forestry waste
- One Canadian Manufacturer, **BP Smart Core,** but does not currently offer board for building insulation
- Various Euro Manufacturers (underlined currently available in Canada) e.g. **<u>Agepan</u>, <u>Gutex</u>, Homatherm, <u>Pavatex</u>, <u>Schneider</u>, Steico**
- Insulation performance $\lambda \approx 0.04$ W/mK (similar to EPS)
- Vapor diffusion resistance $\mu \approx 5$ (10x lower than EPS)
- Tensile strength $\geq$ 2.5kPa

Photo: Wimmers

Author: Wimmers

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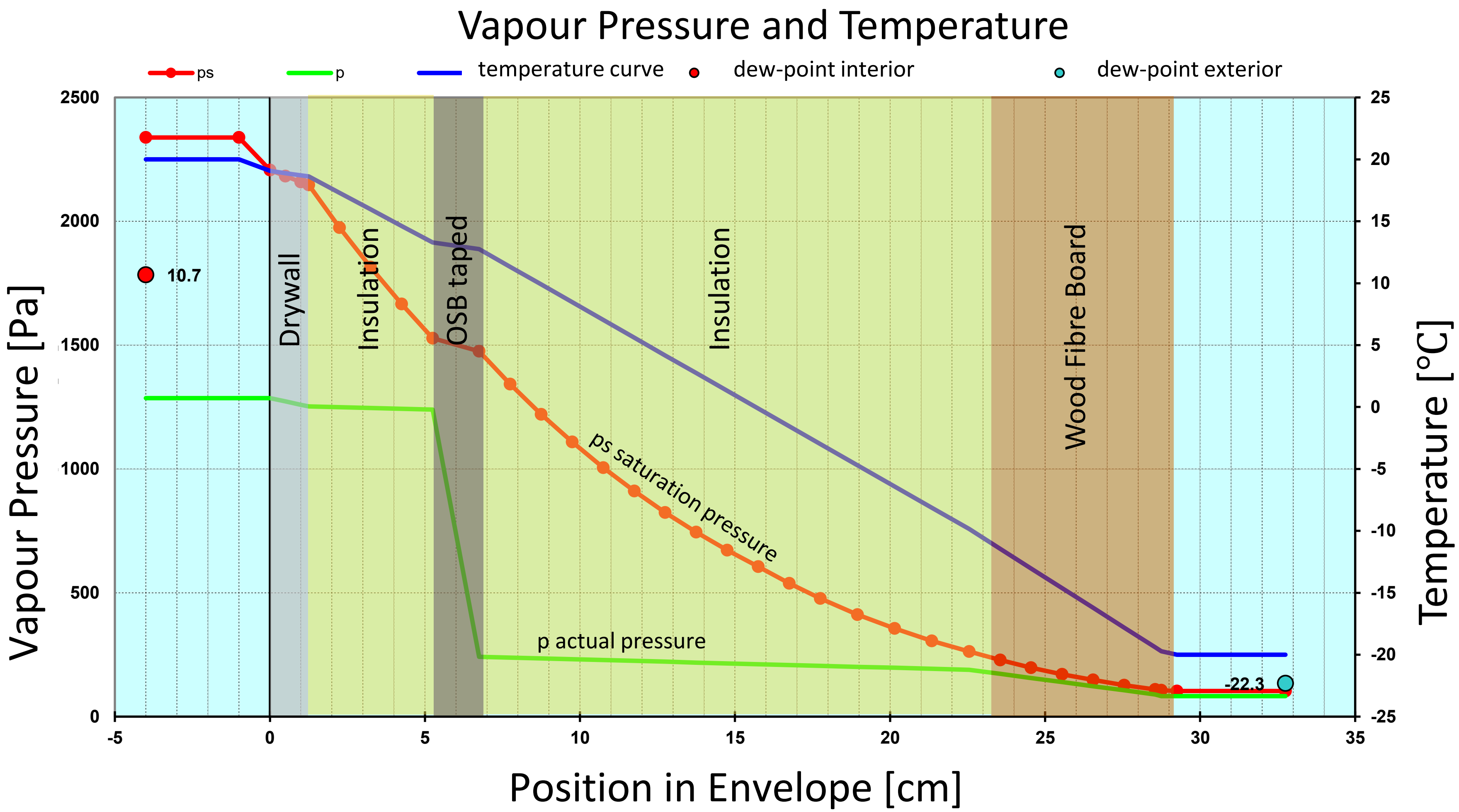
Glaser Diagram for Vapour Diffusion in Wall



At no point is the saturation pressure reached, no liquid water occurs

Author & Graphic: Wimmers

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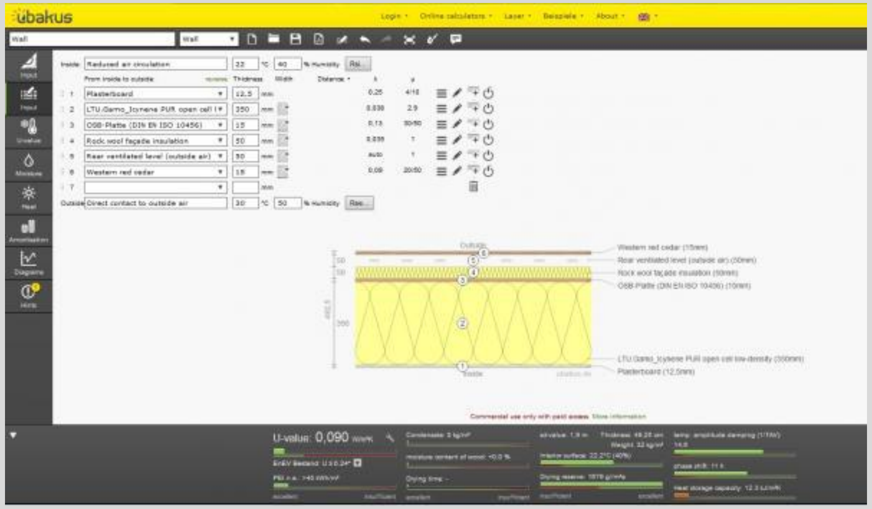
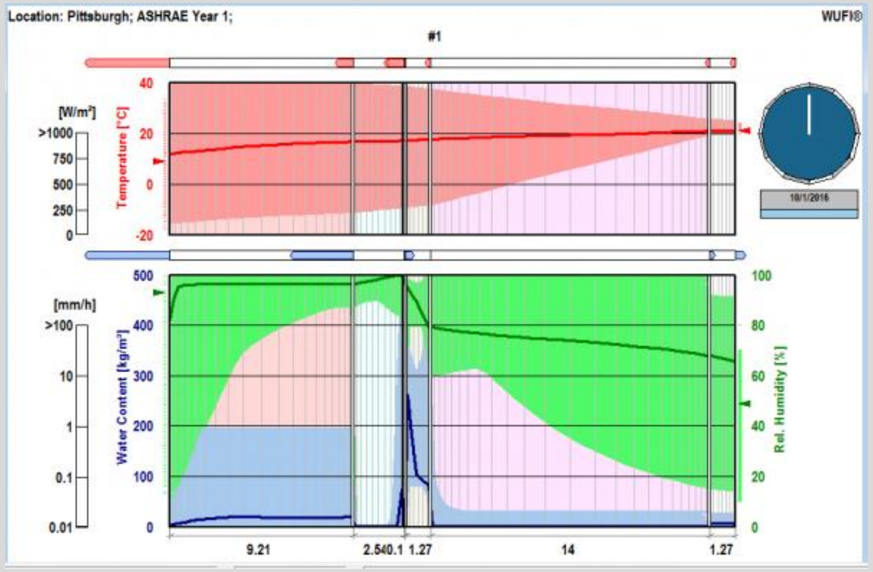
Exercise

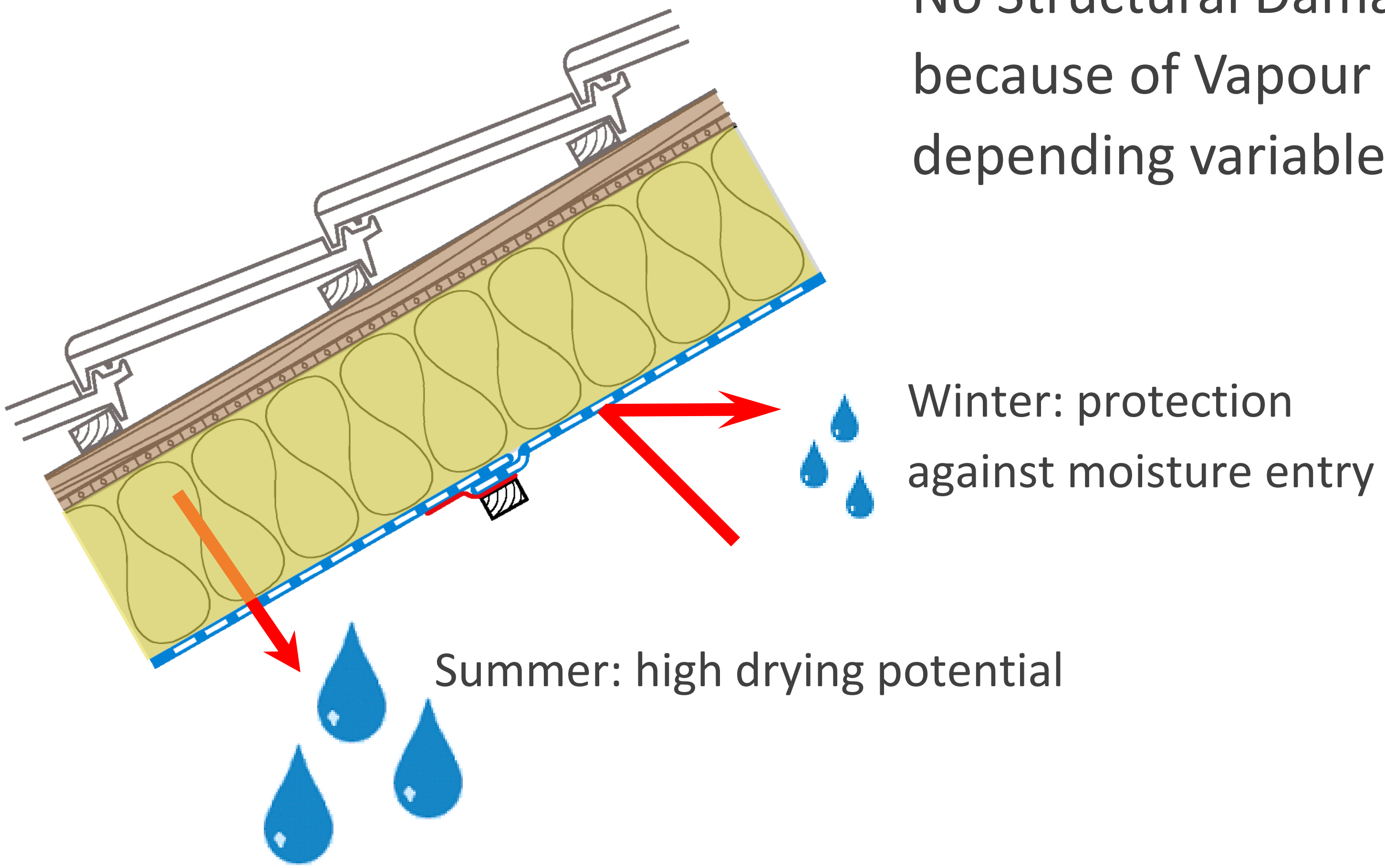


https://www.ubakus.com/en/r-value-calculator/



https://wufi.de/en/service/free-wufi-versions/

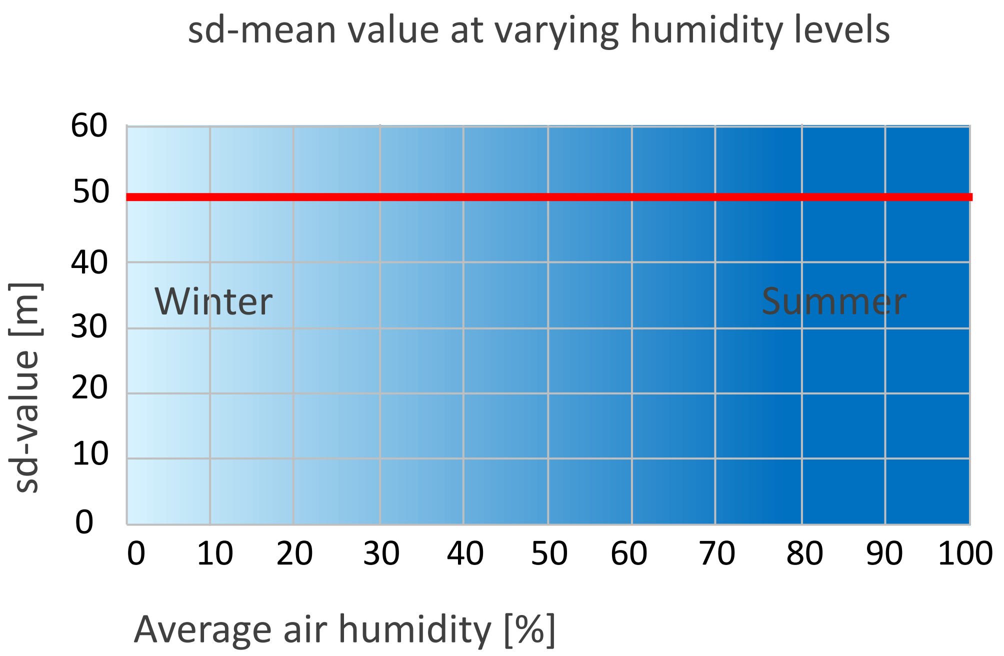
Vapour Membranes with Variable Diffusion Resistance



No Structural Damage due to Condensation because of Vapour Membranes with humidity depending variable diffusion resistance

Author & Graphic: Wimmers

Constant Diffusion Resistance



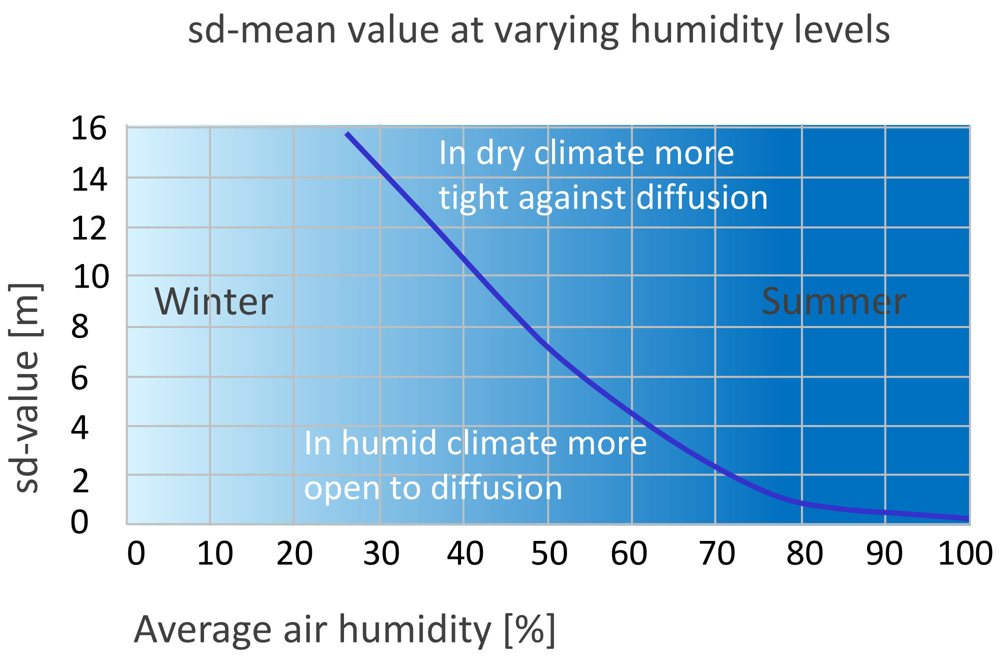
Vapour Barrier

e.g. Polyethylene sheet sd-Value = 50 m

<u>No possibility</u> for construction assemblies to dry out through poly when unexpected moisture occurs - a moisture trap is formed

Author & Graphic: Wimmers

Variable Diffusion Resistance



Vapour Membrane ‘Intello’

Variable sd-Value ≈0.2 – 16m

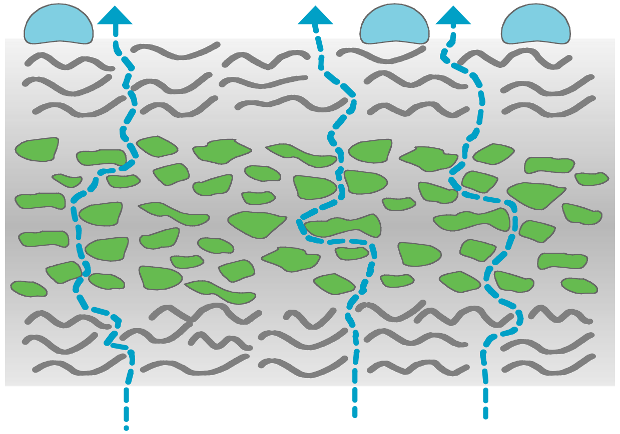
Construction Assemblies can dry out when unexpected moisture occurs – no moisture trap is formed

Author & Graphic: Wimmers

Methods of Moisture Transport

Microporous Membrane
(e.g. Typar, Tyvek)

Fleece



Fleece

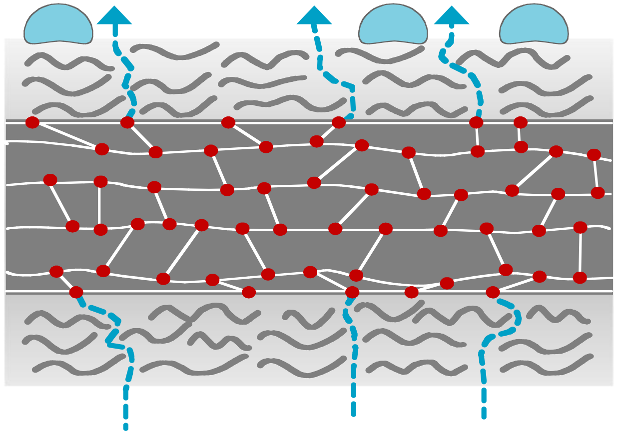
Convection

Moisture Transport
physically by air exchange
not by diffusion

Passive transportation

Monolithic Membrane
(e.g. pro clima)

Fleece



Fleece

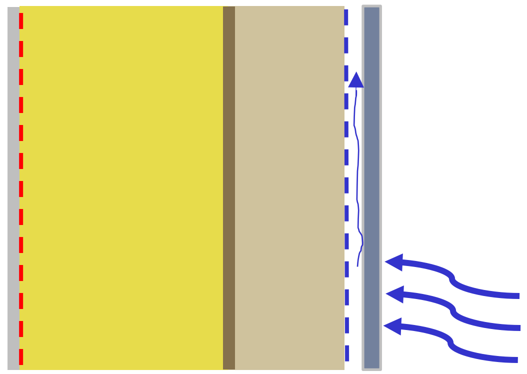
Diffusion

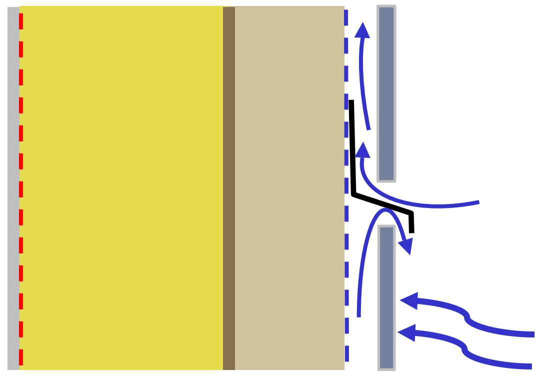
Moisture transport along
the molecular chains as
chemical reaction

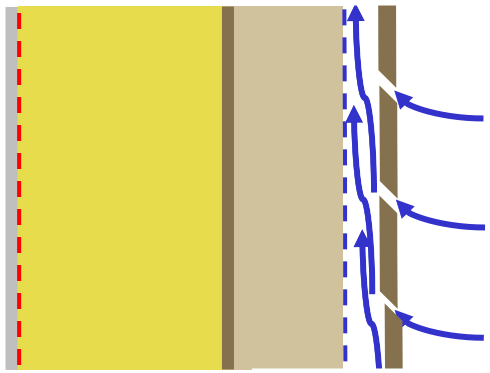
Active transportation

Author & Graphic: pro clima, Wimmers

Façade Design, Capillary Break vs Ventilated Facade







Capillary Break <19mm:

- Decent Protection against Rain
- Be careful with Caulking as it has to be maintained, better design maintenance free
- Very limited Moisture Transport from outside
- very limited Ventilation
- very limited Drying Potential

Ventilation Layer >19mm:

- Good Protection against Rain
- Very limited Moisture Transport from Outside
- Better Ventilation
- Better Drying Potential

Ventilated Facade:

- Depending on Climate and Overhang, sufficient Protection against Rain
- Occasionally Moisture Transport from Outside
- Best Ventilation
- Very fast Drying Out

When using Ventilation Cavities <19mm check with local Building Code and consider Fire Dynamics

Author & Graphic: Wimmers

Exercise

- Selection of materials (resistance)
- Defining position (sequence)
- Defining thickness (ratio)

- What is the NBC saying about “Vapour Barrier”?

- What happens if a “Vapour Retarder” of 1 perm is used on the outside of a façade?

Author: Wimmers

Lesson 7: Developing Durable and High Performing Envelope Assemblies and Details

(45min + 5min Q&A)

- ***Objectives:***
  - Apply basics of thermodynamics, hydrodynamics and air tightness by designing building envelope assemblies
  - Rank suitability of specific materials for different tasks
  - Evaluate or compare or rank their strengths and potential weaknesses

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Envelope Assemblies

- Discussion of Examples
- Databases
- Design Exercise

Basics of Durable Design for Wood Buildings

- Protect façade from getting in touch with rain
- Protect the base of the wall against humidity
- Protect wall from water traveling further into the envelope.
- Drying out potential usually more important than blocking moisture.
- Avoid design which mandates maintenance (caulking)
- Insure drainage around windows towards the outside

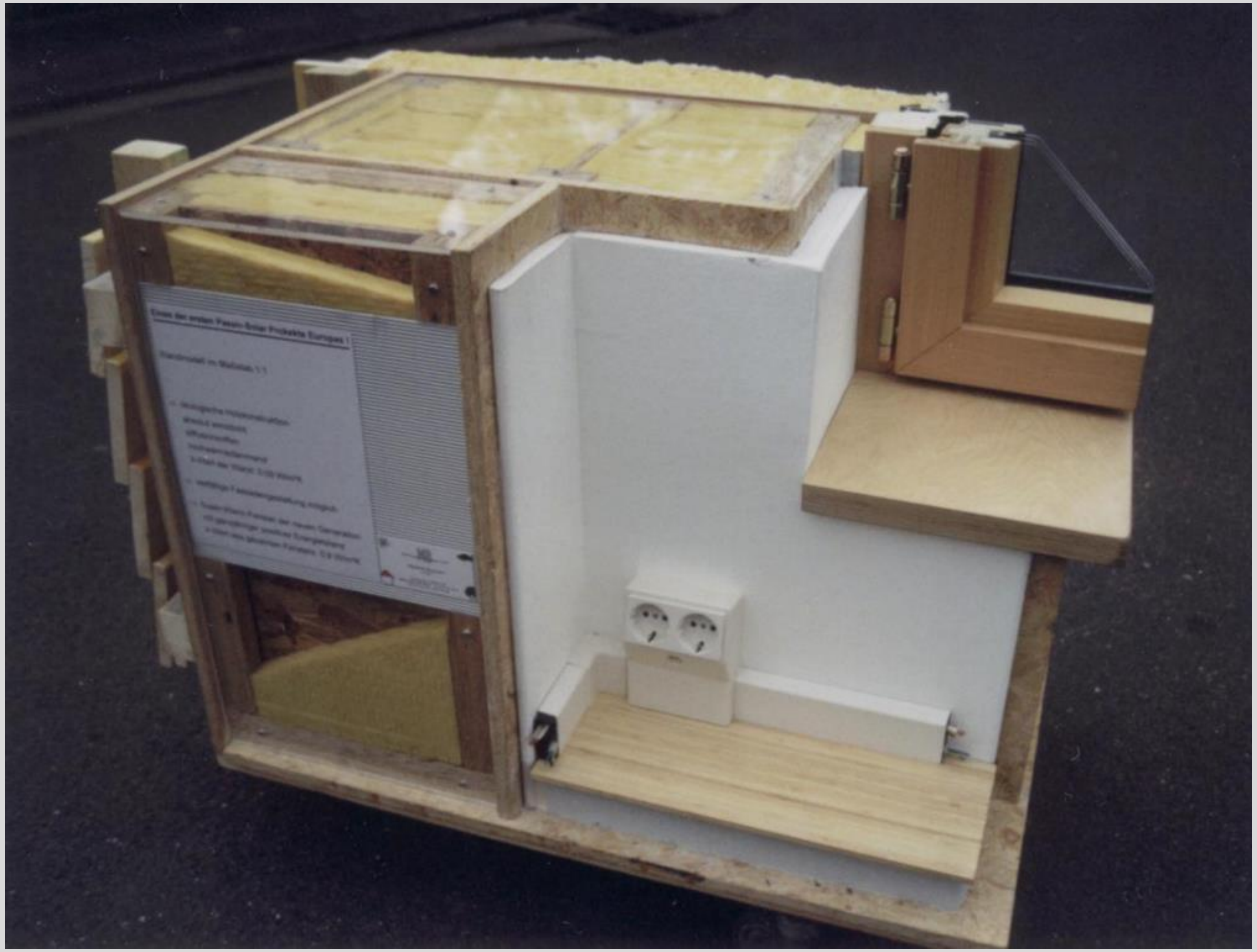
Author: Wimmers

Vapour Diffusion from Outside

Vapour Diffusion from outside towards the inside is in Canada a rare phenomenon but can happen in two different scenarios

- If exterior air is significantly warmer and more humid compared to the interior air of a buildings.
- If the Cladding Material is very wet (through rain) and intense Solar Radiation (low altitude of sun) causing façade temperatures to reach 40 °C or higher.

Analyze Assembly a)



- What are the pros and cons?

Author & Photo: Wimmers

Analyze Assembly b)

- What are the pros and cons?

Author & Photo: Wimmers

Analyze Assembly c)

- What are the pros and cons?

Author & Photo: Wimmers

Analyze Assembly d)

- What are the pros and cons?

Author & Photo: Wimmers

Analyze Assembly e)

- What are the pros and cons?

Author & Photo: Wimmers

Online Guides

CWC Wood Design Tools

dataholz.eu

baubook

www.cwc.ca

Design Tools are several online Calculators including: Effective R Calculator and Carbon Calculator

www.dataholz.eu

dataholz is an online Database of sample envelope assemblies including: Fire Performance, U values, Acoustic Performance and Eco Sustainability

www.baubook.info

Baubook Construction Calculator is an online Database of sample envelope assemblies including: U values, Total of Non-Renewable Energy Embodied Consumption, Global Warming Potential and Acidification Potential

Design Exercise (10-15min)

- Wall should be:
  - well insulated with $U < 0.15$ W/mK, $R_{si} > 6.67$ m^2K/W
  - Reliable Airtightness
  - Safe Humidity Management
- Consider Durability
- Consider Prefabrication as a Method
- Present and Explain your Design

Author: Wimmers

Design Exercise

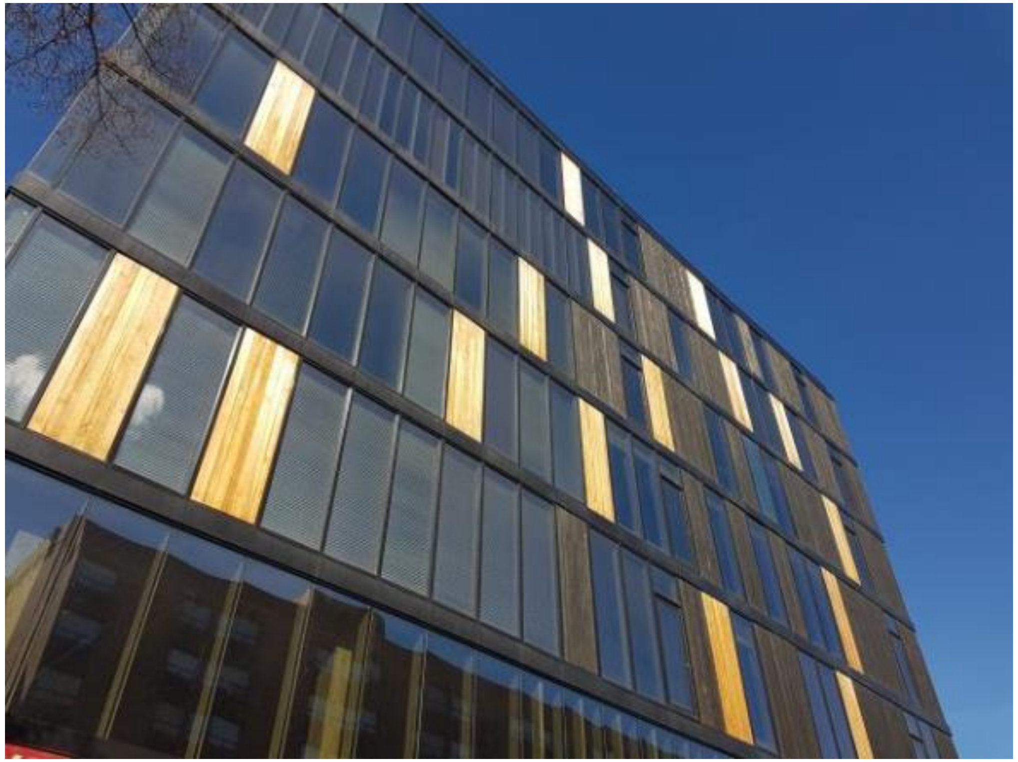
- Roof should be:
  - well insulated with $U < 0.15$ W/mK, $R_{si} > 6.67$ m^2K/W
  - Reliable Airtightness
  - Safe Humidity Management
  - Consider Durability
  - Consider Prefabrication as a Method
- Present and Explain your Design
- Is there any significant difference to the Wall Design?

Author: Wimmers

Envelope Details

- Discussion of Examples

Rain Water Protection



Author & Photo: Wimmers

- Protect the building façade against water from above
  - Awning
  - Overhang per Floor
  - Rain Screen
  - Ventilation Layer
  - Base Detail
  - Drainage around window openings

Pedestal Details a)

Wooden Glulam Post on elevated foundation

Potential week spots?

Author & Photo: Wimmers

Pedestal Details b)

Base Details exposed to Weather. What is well designed, what could be improved?

Author & Photo: Wimmers

Pedestal Details c)

Base Details exposed to Weather. What is well designed, what could be improved?

Author & Photo: Wimmers

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Exercise: Spot the Difference

The first building is featuring a compact thermal envelope. The building has four corners, one roof, and eyebrows or overhang and balcony to protect against overheating.

The second building is featuring, as far as shown on the photo, at least 16 corners and 7 roof areas, assuming that the two other facades have no further features.

The first building has 320mm thick walls, the second 6”.

Discuss construction costs and monthly costs of ownership.

Author & Photo: Wimmers

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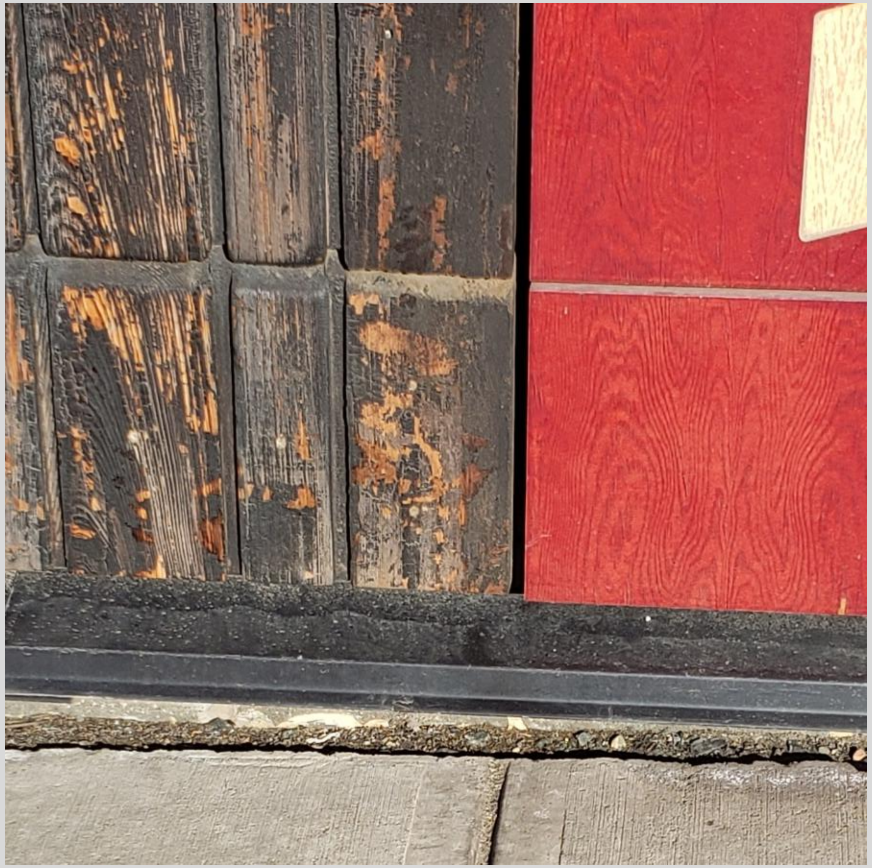
Base Details a)

Base of the Wood Innovation Research Laboratory (WIRL) in Prince George. Mineral Boards cover the first 300 mm to protect the insulation behind and keep the wood façade out of the “splash zone”.

Base of the Wood Innovation Design Center (WIDC) in Prince George. Similar to former detail but one additional thought.

Author & Photo: Wimmers

Base Details b)



Base of the Wood Innovation Design Center (WIDC) in Prince George. The bottom 300 mm are sacrificial and could be replaced. The close-up also shows the shortcoming of the charring technique used in this particular case.

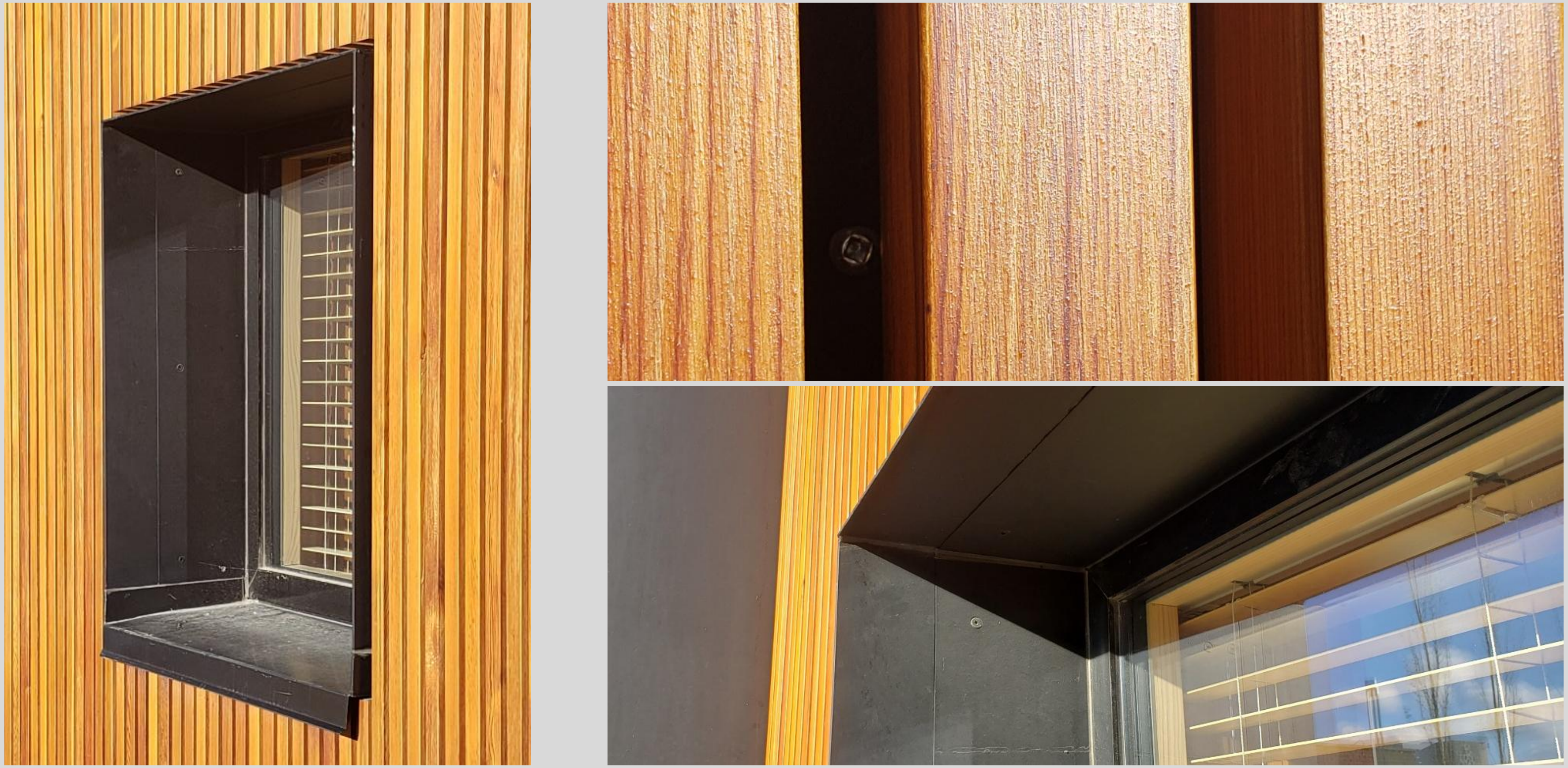
Author & Photo: Wimmers

Charred Facade

Facades exposed to rain (here the WIDC) can be protected from moisture by various coating, such as paint, oil finish or Nano coatings. A historical method experiencing a renaissance over the last 20 years in Europe and North America is charring.

Author & Photo: Wimmers

Cedar Façade



Façade of the Wood Innovation Research Laboratory (WIRL) in Prince George. The open Red Cedar Façade allows for very high drying potential. The façade depths of about 80 mm reduces the amount of water reaching the membrane. Windows have a large reveal of about 200mm (500mm wall depth) with frame for water drainage.

Author & Photo: Wimmers

Cement Fiber Board Façade

Cement Fiber Board Façade of the Wood Innovation Research Laboratory (WIRL) in Prince George. The open cladding allows for high drying potential. Perforated metal sheeting keeps insects and rodents out.

Author & Photo: Wimmers

Metal Façade

Metal Façade of the Wood Innovation Research Laboratory (WIRL) in Prince George. The very limited ventilation layer of only 19mm and extremely small openings does not allow for much ventilation. Not advisable in more humid climate zones and/or buildings with higher internal moisture loads.

Author & Photo: Wimmers

Discuss Façade

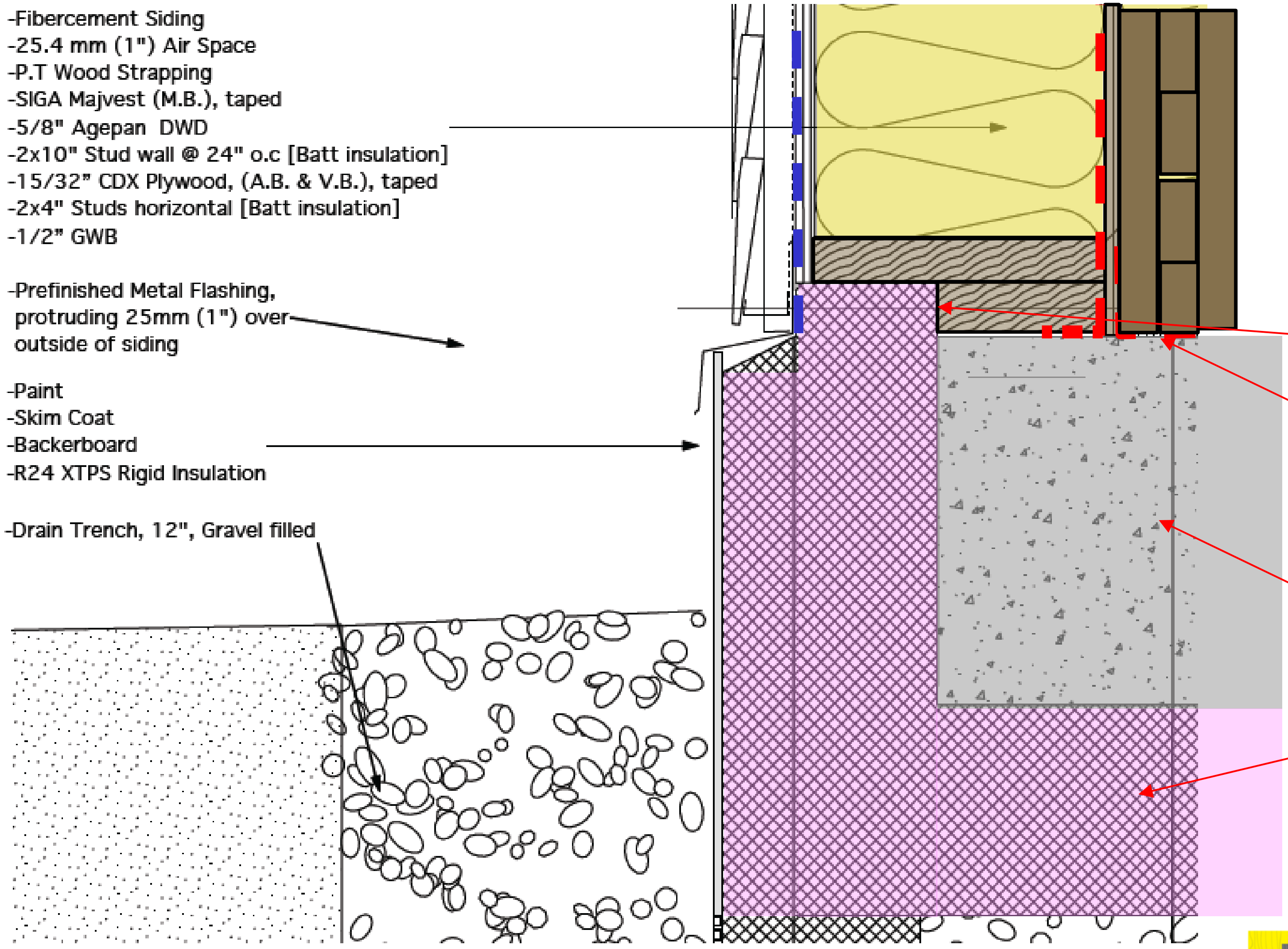
Wood Façade, WIDC, Prince George


RothoBlaas Headquarter, Kurtatsch, Italy

Two very different facades with weak spots because of very different reasons. Left façade is the charred wood at the WIDC, the right façade is made of coated ~40mm thick OSB lamella, between ~200 and ~500mm deep.

Author & Photo: Wimmers

Optimized CLT Detail, no Basement



CLT is not Airtight!
Additional Membrane or Plywood necessary.
Careful with Penetrations for Electrical.
Ideally use Mass Timber only in the Interior as Thermal Bridges and Problems with Airtightness more likely if Exterior use.

Reduced Thermal Bridge

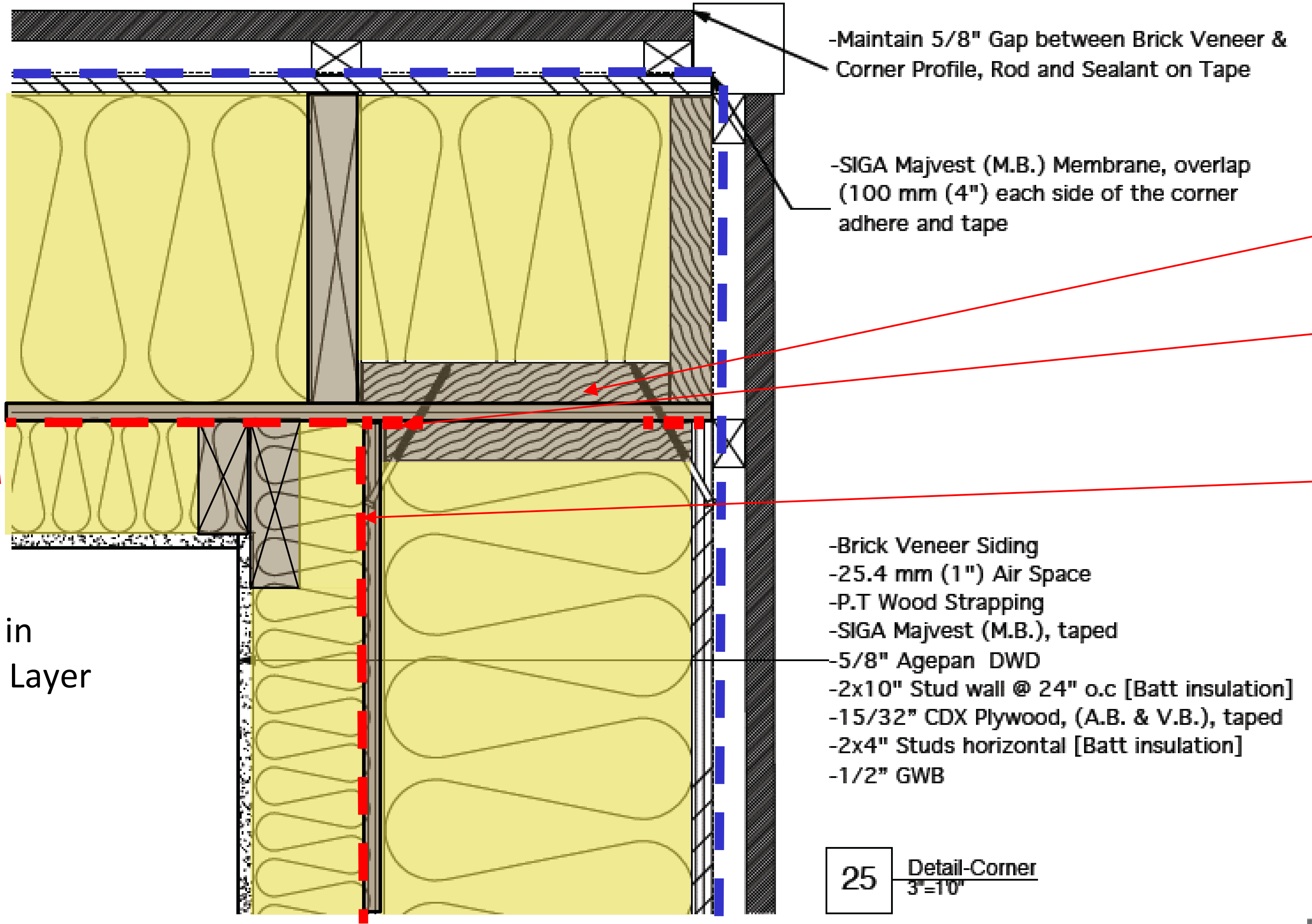
Self expanding sealing tape underneath to seal irregularities in concrete floor

Thickened Edge Slab to ensure structural integrity, airtightness and thermal bridge free foundation

Continuous Layer of Insulation to avoid thermal bridges

Author & Graphic: Wimmers

Optimized Corner (Prefab)



Corner Thermal Bridge optimized as far as possible

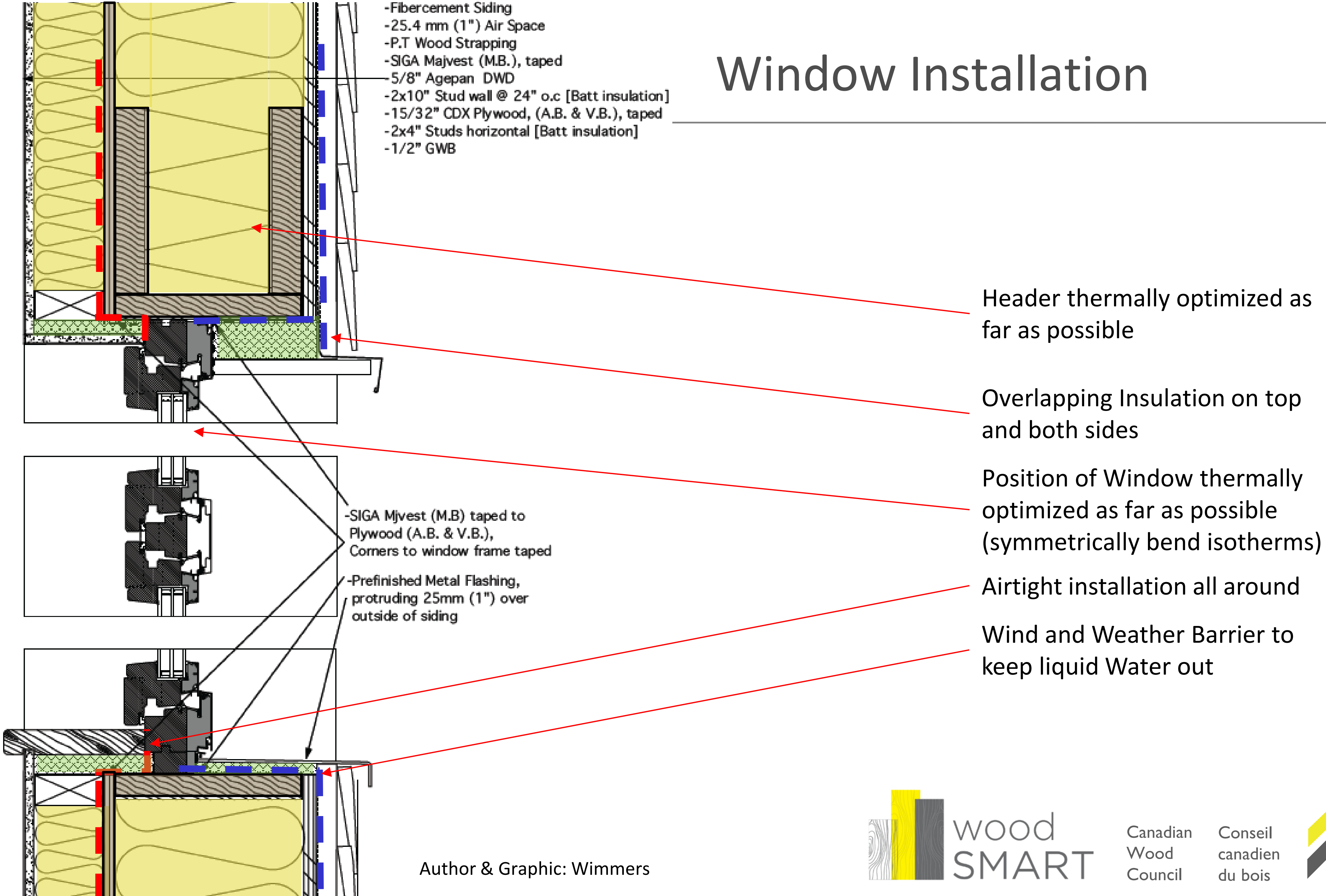
Taped and/or expanding foam tapes for Airtightness

Continuous OSB or Plywood taped, continuous Airtight Layer, no Penetrations for Interior Electrical and Plumbing

LVL Ledger in Installation Layer

Author & Graphic: Wimmers

Window Installation



Author & Graphic: Wimmers

Lesson 8: Case Study

(45min + 5min Q&A)

- ***Objectives:***
  - Final discussion and critical evaluation of envelope details and assembly of project
  - Compare and rank performance of components and different design solutions

Wood Innovation Research Laboratory (WIRL) for the University of Northern British Columbia (UNBC)

Constrains:

Wood Construction, Passive House Certified, State of the Art Research Facility, Budget, Time line

Graphic: STANTEC

Location and Climate

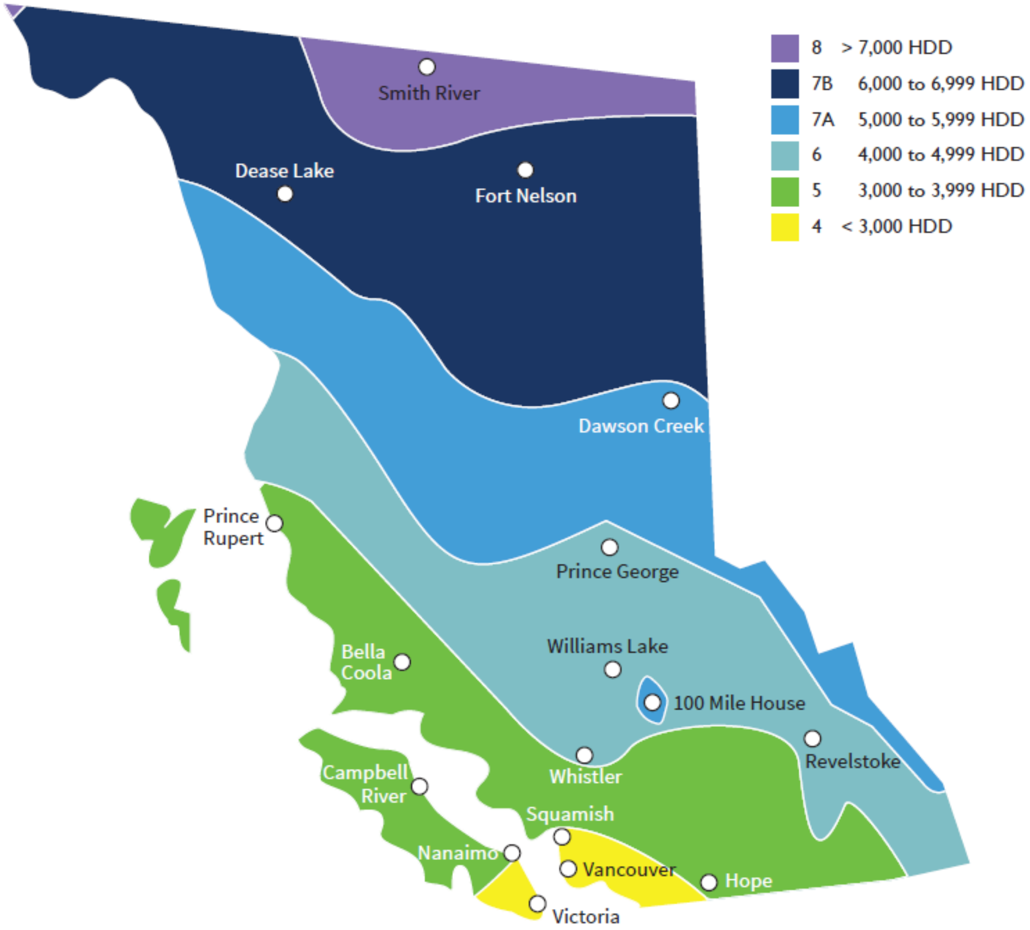


Photo: STANTEC, BC Gov

Requirements

- $1,042 \ m^2$
- Single story, with a mezzanine
- High head lab with overhead crane
- Three offices
- Seminar room for 30 people
- Wood conditioning room
- Dust extraction system
- Design-build procurement
- **Passive House**

Graphic: STANTEC

Passive House Key Requirements

Heating/Cooling energy demand	**15 kWh/(m²a)**
Heating/Cooling load	**10 W/m²**
Thermal performance of envelope	**U ≤ 0.15 W/(m²K)**
Thermal bridge free design	**Ψ (Psi) ≤ 0.01 W/(mK)**
Thermal performance of Windows	**U ≤ 0.8 W/(m²K)**
Themal Comfort in Winter and Summer	
Airtightness	**≤ 0.6 ach@50Pa**

10 W/m² = 3.171 BTU/hft²

ASHRAE 90.1 defines "semi heated space" as > 3.4 BTU/hft²

Author: PHI, Wimmers

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Challenge of Passive House

- Compact
- Super insulated
- Minimize thermal bridging
- No air leakage
- Proper glazing
- Efficient ventilation

Graphic: STANTEC, G. Wimmers

Calculated Performance

Parameter	Value	Units
Treated Floor area	1042	m^2
Volume of ventilated space	9686	m^3
Heating Demand	14	kWh/m^2a
Heating load	15	W/m^2
Primary Energy Demand	120	kWh/m^2a
Primary Energy Renewable Demand	65	kWh/m^2a
Airtightness (assumed value until blower door tests can be conducted)	0.6	ach @50 Pa

Component	U-Value (W/m^2K)
Walls	0.079
Roof	0.056
Floor	0.166
Windows (38.6 m^2)	0.67
Doors (11 m^2)	0.91-0.97

Graphic: STANTEC

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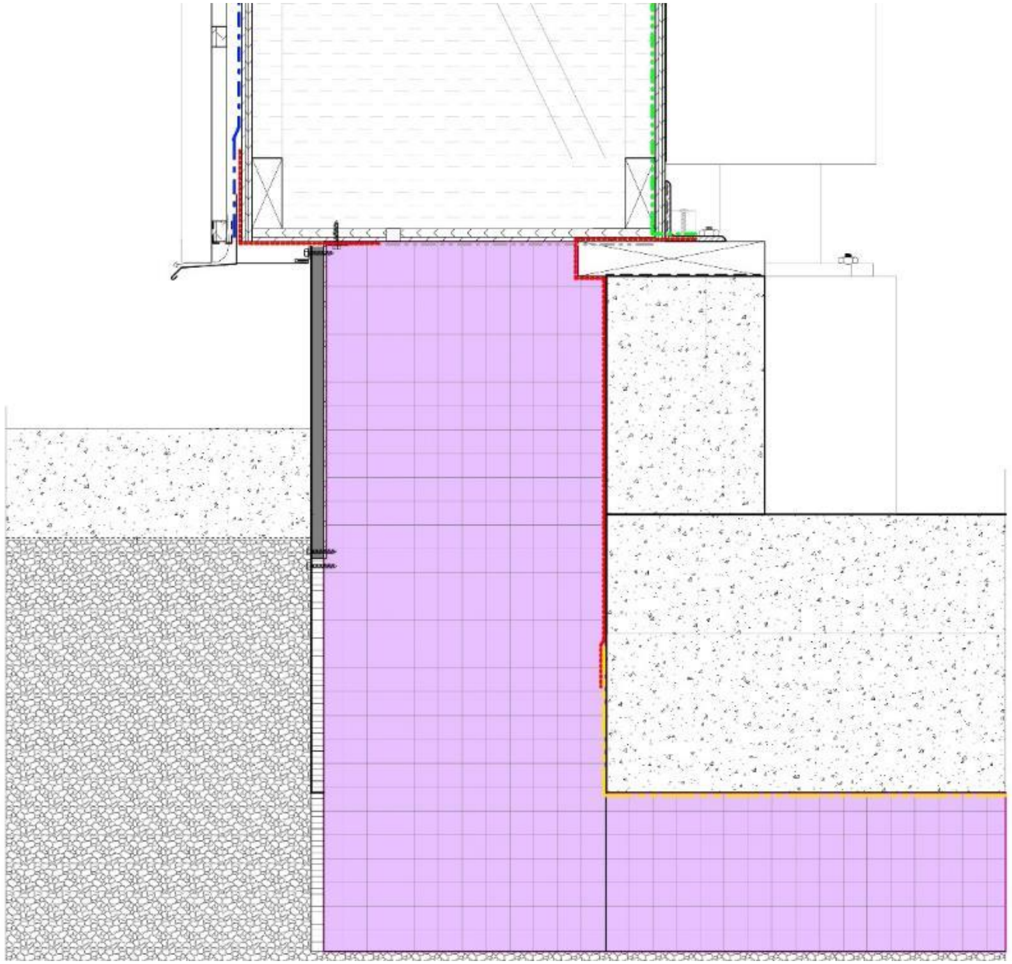
Start of Construction

Photo: Wimmers

Foundation Detail



Graphic: STANTEC

Insulation under thickened Edge Slab

Photo: Wimmers

Insulation forms thickened edge concrete slab

Photo: Wimmers

Concrete Pour Preparation

Photo: Wimmers

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Rebar and Floor Heating installed

Photo: Wimmers

Rebar for Strong Wall installed

Photo: Wimmers

Pouring concrete of Strong Wall

Photo: Wimmers

Gluing Insulation against sealed Concrete Foundation

Photo: Wimmers

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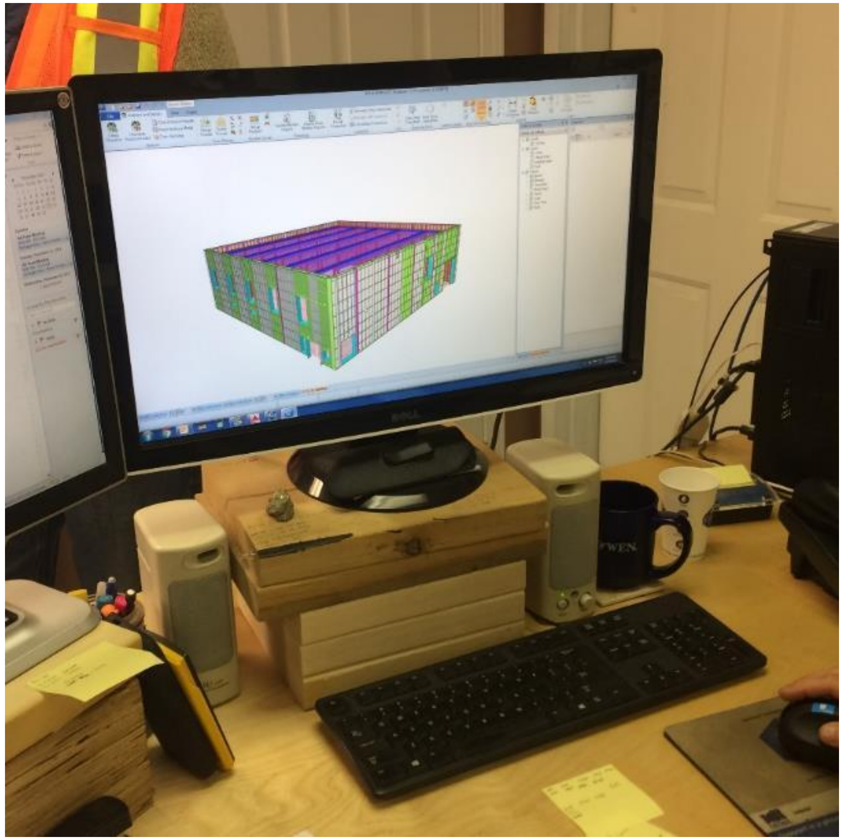
Glulam Connector

Photo: Wimmers

Prefabricated Post and Beam Glulam Structure

Photo: Wimmers

Prefabrication of Wall Panels



Photos: STANTEC

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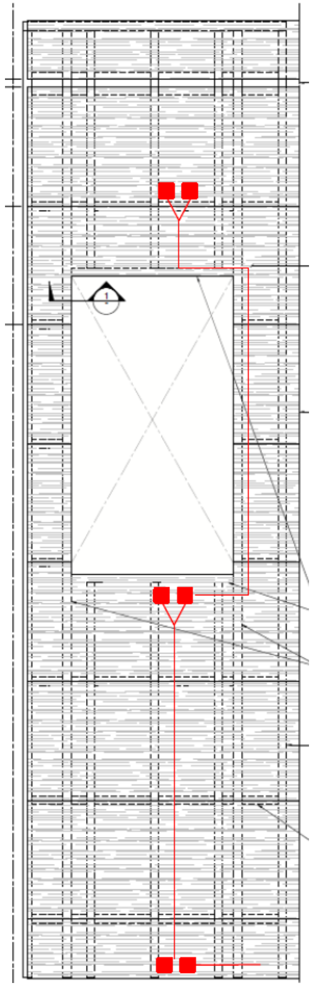
Upright Trusses as Wall Panels to fit 500mm Insulation

Photo: Wimmers

Sensors in Wall Panels



Graphic & Photo: Wimmers

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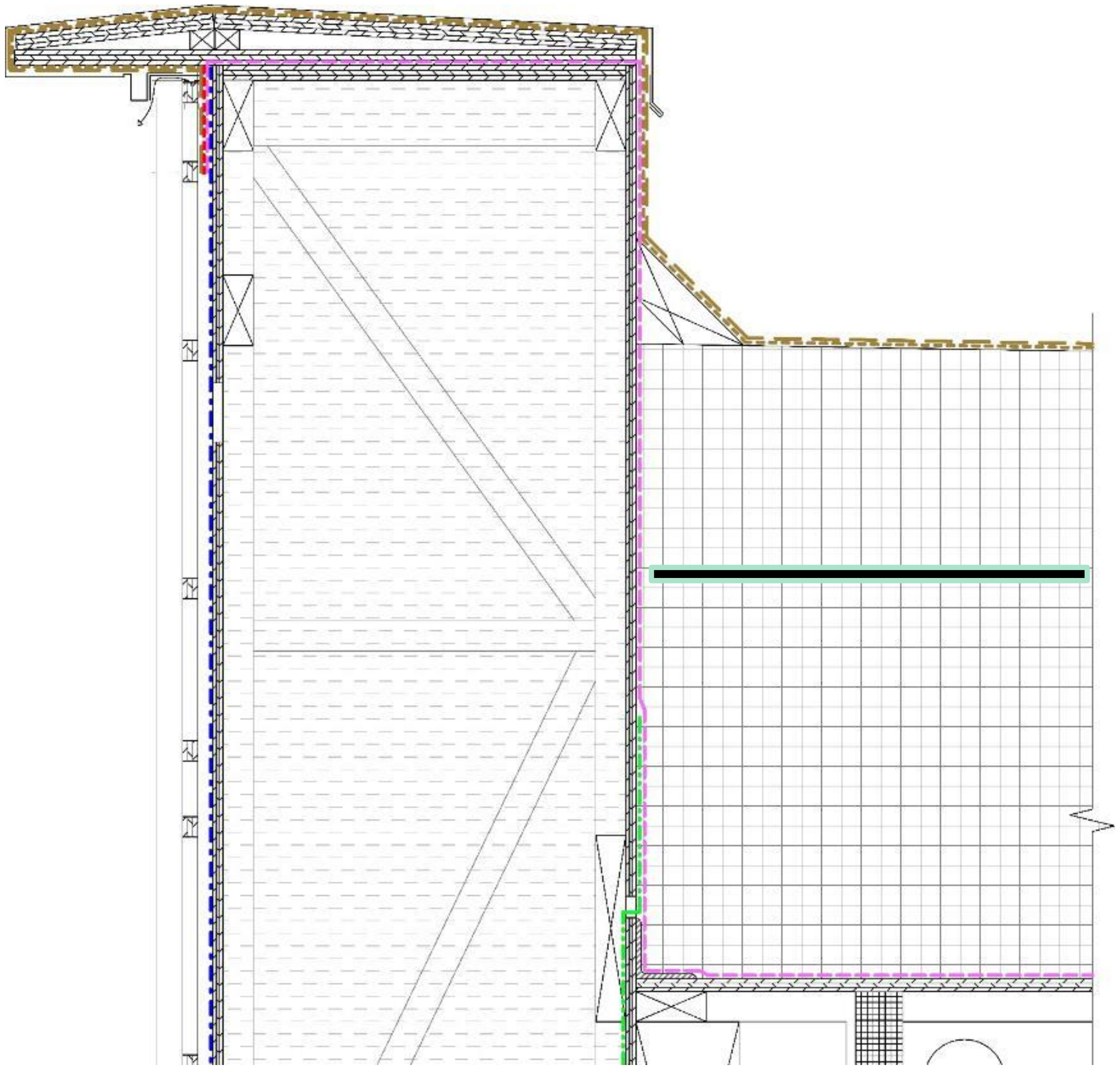
Parapet Detail



Sopravapr Roof Membrane

Intello Vapor Barrier

Tyvek Weather Barrier

Vapour Barrier (Sopra R VB)

Graphic: STANTEC

Partially prefabricated Wall Panels at installation

Photo: Wimmers

Filling of Cavity with Blown in Mineral Fiber

Photo: Wimmers

Sealing of Wall Panels

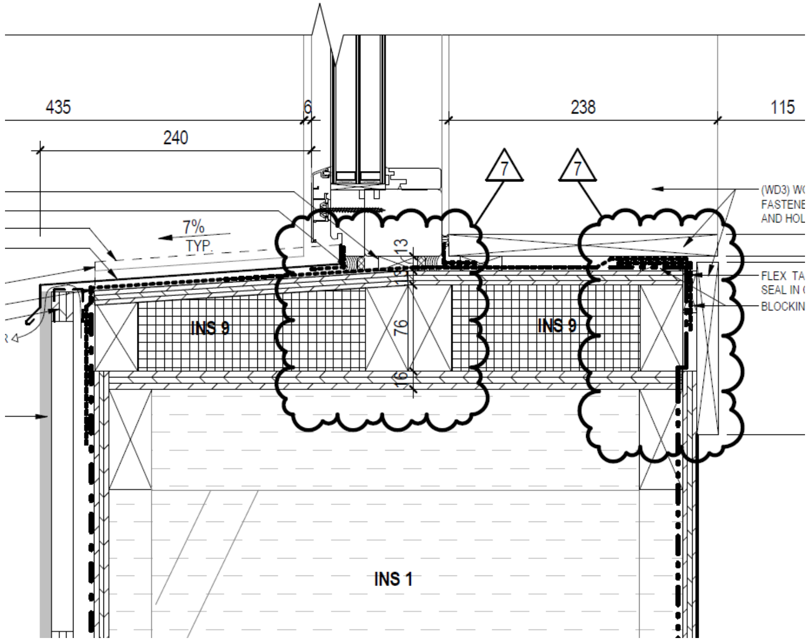
Photo: Wimmers

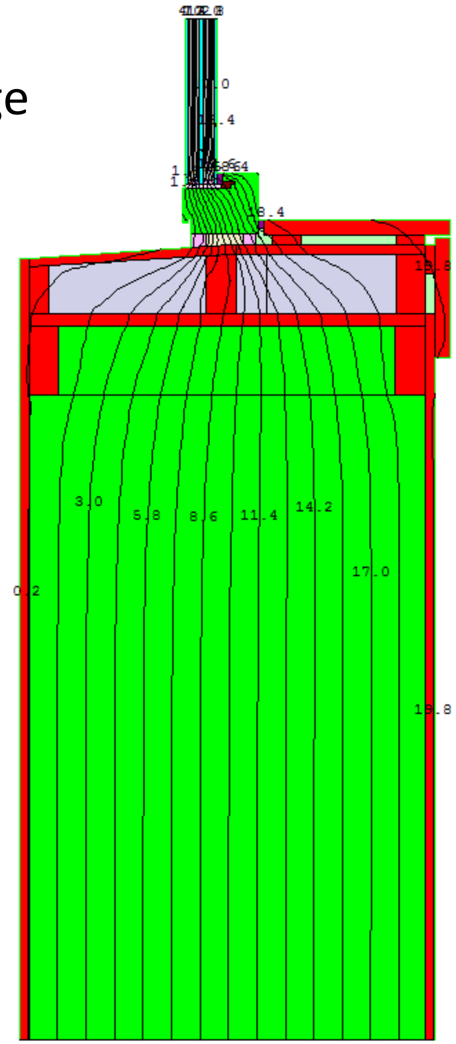
Closing of Envelope

Photos: STANTEC

Window Sill

Sill: 0.053 W/mK installation thermal bridge

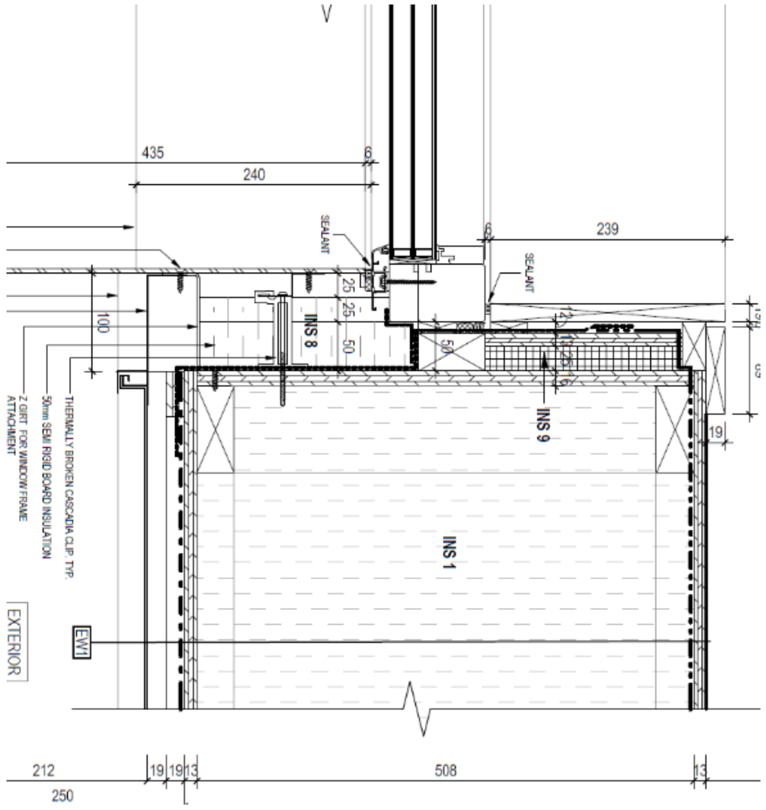


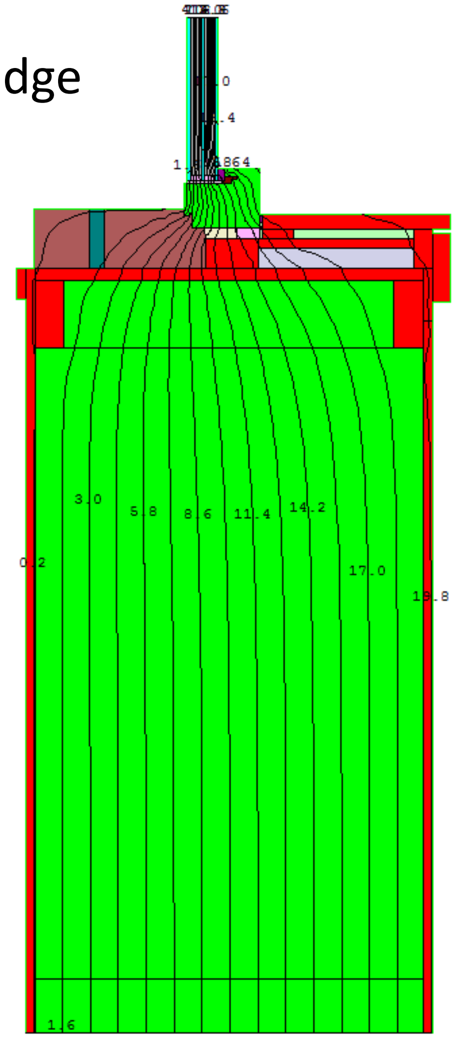


Graphic: STANTEC

Window Jamb

Jamb: 0.026 W/mK installation thermal bridge





Graphic: STANTEC

Insulation of Roof

Photo: Wimmers

Blower Door Test

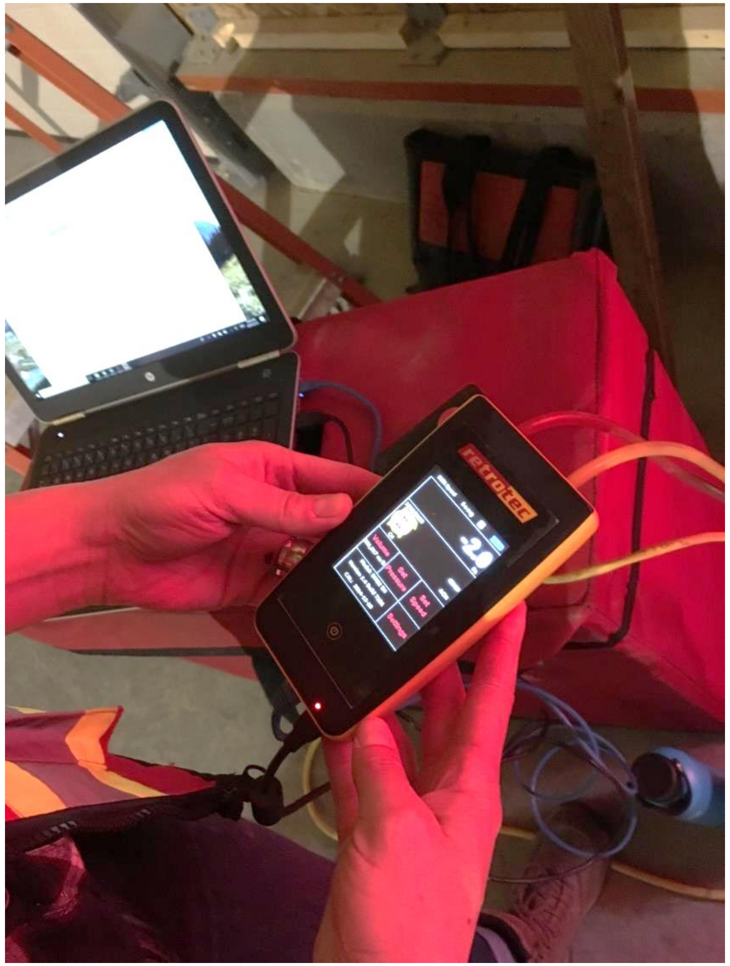


Photo: Wimmers

Most Airtight Building in North America

Photo taken during depressurization Test at 49.7 Pa (the goal was to take a picture at exactly 50Pa), showing an air change of 0.07195

Author & Photos: Wimmers

BDT Result

improvements resulted in approximately 22% improvement of overall building airtightness, as revealed by the official airtightness result.

The official airtightness test generated passing results for both the depressurization and pressurization tests. The tested combined (average) airtightness was much less than the Passive House maximum of 0.60 ACH50. Airtightness test data are included in Appendix A of this report.

Building Envelope Airtightness Results[3]

Test Phase	ACH50	Result
Pressurization	0.075	PASS
Depressurization	0.072	PASS
Combined, Average	0.07	PASS

Based upon the evidence acquired from airtightness testing, the airtightness rate of the constructed air barrier in the building was less than the maximum allowed by the Passive House standard while under depressurization or pressurization, and the building envelope airtightness test is considered a PASS.

Please contact our office with any questions.

Morrison Hershfield Ltd.

Stephen Wong, EIT
Building Science Consultant

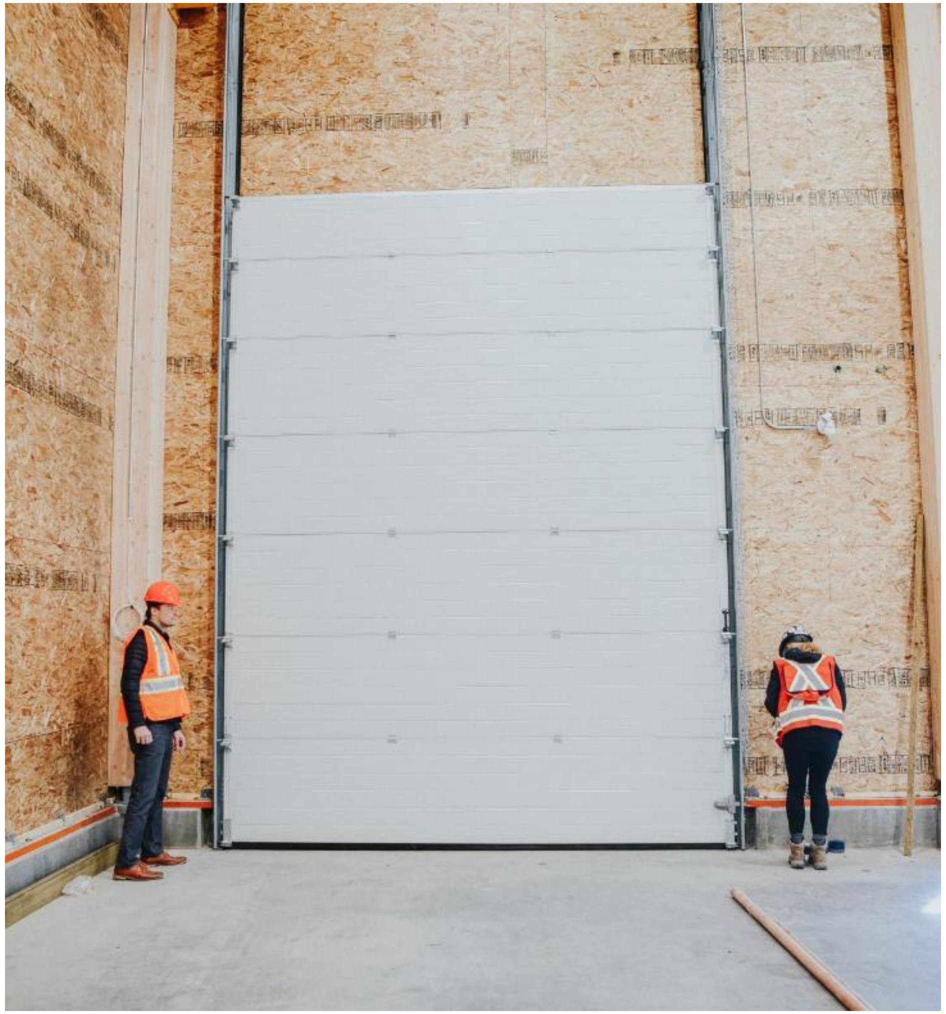
David Fookes, P.Eng.
Principal, Building Science Specialist

Test was performed according to:
ISO 9972, EN 13829 - 2001 and
Passive House Standard Guidelines

Combined Average rounded 0.07 ACH50
0.07 < 0.6 = pass

Source: Morrison Hershfield

Special Bay Door



Pressure in sealing gasket adjustable

EPDM layer reduces friction of seal against door

Author & Photos: Wimmers

wood SMART

Canadian Wood Council

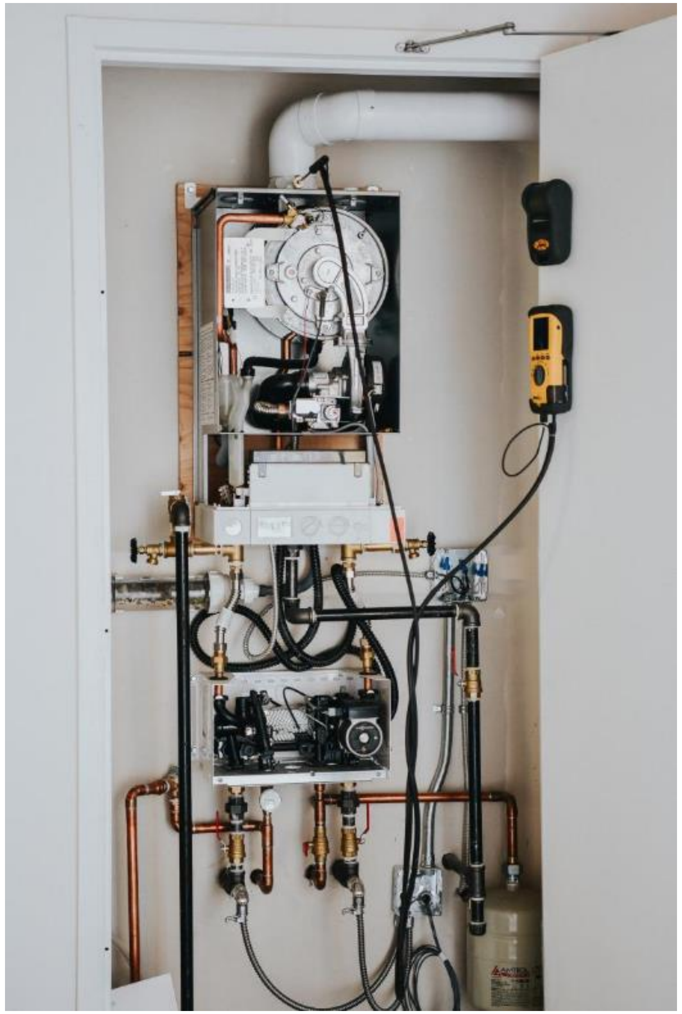
Conseil canadien du bois

Total Equivalent Leakage Area of Building

Half Letter Size sheet of paper is the equivalent of the entire air leakage area of the building

Author & Photos: Wimmers

Gas Heater



power installed: 35 kW

Only 15 kW (10W/m² * 1042m² plus warm water) was necessary but Contractor could not source a smaller unit.

Author & Photos: Wimmers

wood SMART

Canadian Wood Council

Conseil canadien du bois

Iterative Passive House Consultations

Date	Phase	Heat Demand kWh/m^{2}a	Infiltration n_{50}/h	Primary Energy kWh/m^{2}a	Comment
Passive House Requirement		15.0	0.60	120	
2017.03.14	Bid Submission	14.3	0.50	144	
2017.07.13	Precertification Submission	14.2	0.60	148	
2017.12.05	Certifier Review	14.9	0.60	115	Gas fired boiler instead of electric
2018.04.24	Certification Submission	11.1	0.07	113	Significant benefit from final air tightness test

Author: STANTEC

wood SMART

Canadian Wood Council

Conseil canadien du bois

PH Certification, final values

Certification Documentation

Passive House Verification

Building:	Wood Innovation Research Laboratory	
Street:	1153 4th Avenue	
Postcode/City:	V2L 3J2	Prince George
Province/Country:	BC	CA-Canada
Building type:	Research Laboratory	
Climate data set:	CA0018b-Prince George	
Climate zone:	2: Cold	Altitude of location: 576 m
Home owner / Client:	University of Northern British Columbia	
Street:	3333 University Way	
Postcode/City:	V2N 4Z9	Prince George
Province/Country:	BC	CA-Canada

Specific building characteristics with reference to the treated floor area

				Criteria	Alternative criteria	Fullfilled?[2]
	Treated floor area m²	1041.5				
Space heating	Heating demand kWh/(m²a)	12	≤	15	-	yes
	Heating load W/m²	10	≤	-	10	
Space cooling	Cooling & dehum. demand kWh/(m²a)	0	≤	15	15	yes
	Cooling load W/m²	1	≤	-	11	
	Frequency of overheating (> 25 °C) %	-	≤	-		-
	Frequency of excessively high humidity (> 12 g/kg) %	0	≤	10		yes
Airtightness	Pressurization test result n_{50} 1/h	0.1	≤	0.6		yes
Non-renewable Primary Energy (PE)	PE demand kWh/(m²a)	116	≤	120		yes
Primary Energy Renewable (PER)	PER demand kWh/(m²a)	61	≤	-	-	-
	Generation of renewable energy (in relation to projected building footprint area) kWh/(m²a)	0	≥	-	-	

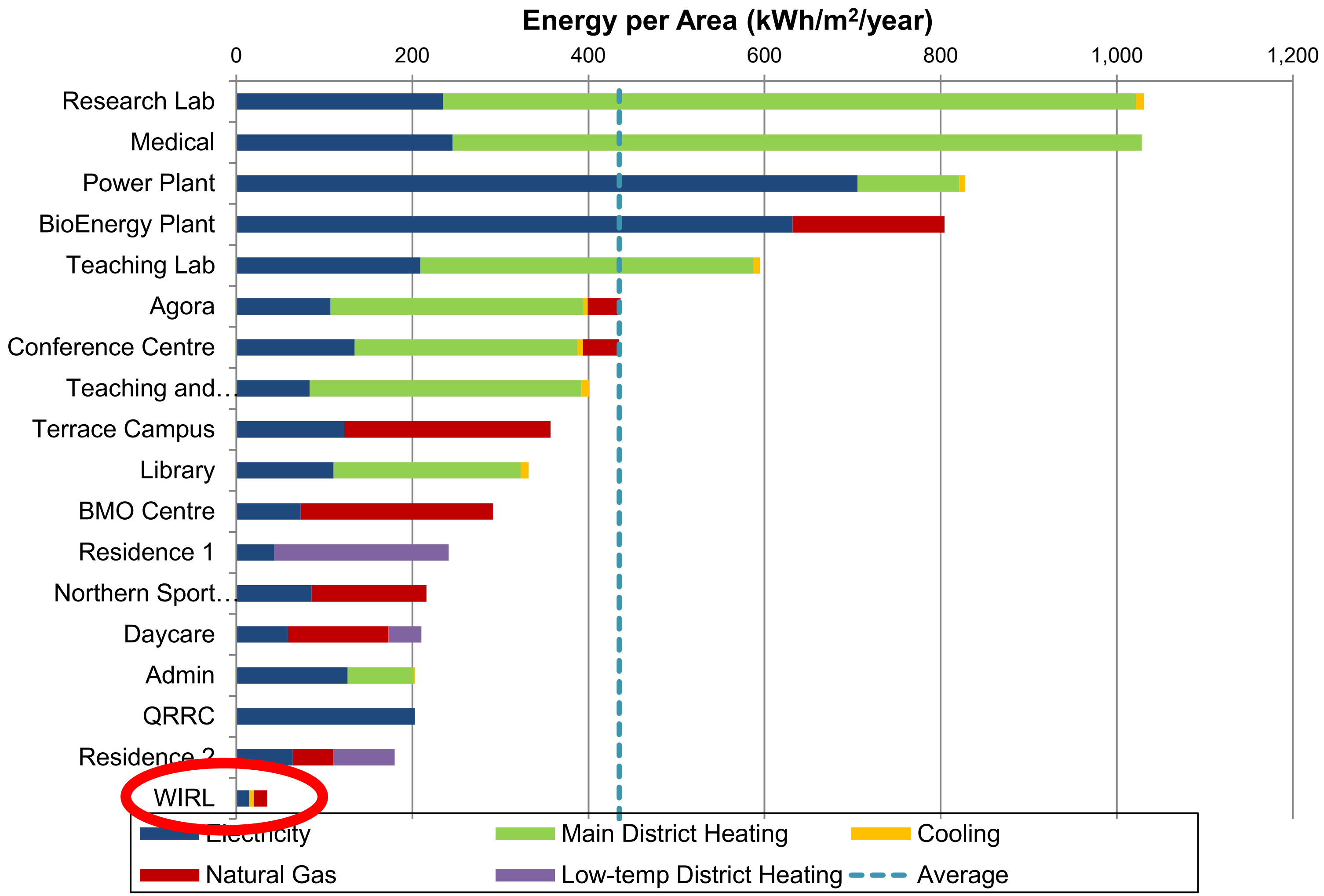
[2] Empty field: Data missing; '-': No requirement

This building has been awarded the Certified Passive House seal by the Herz & Lang GmbH.

Certified Passive House
Passive House Institute

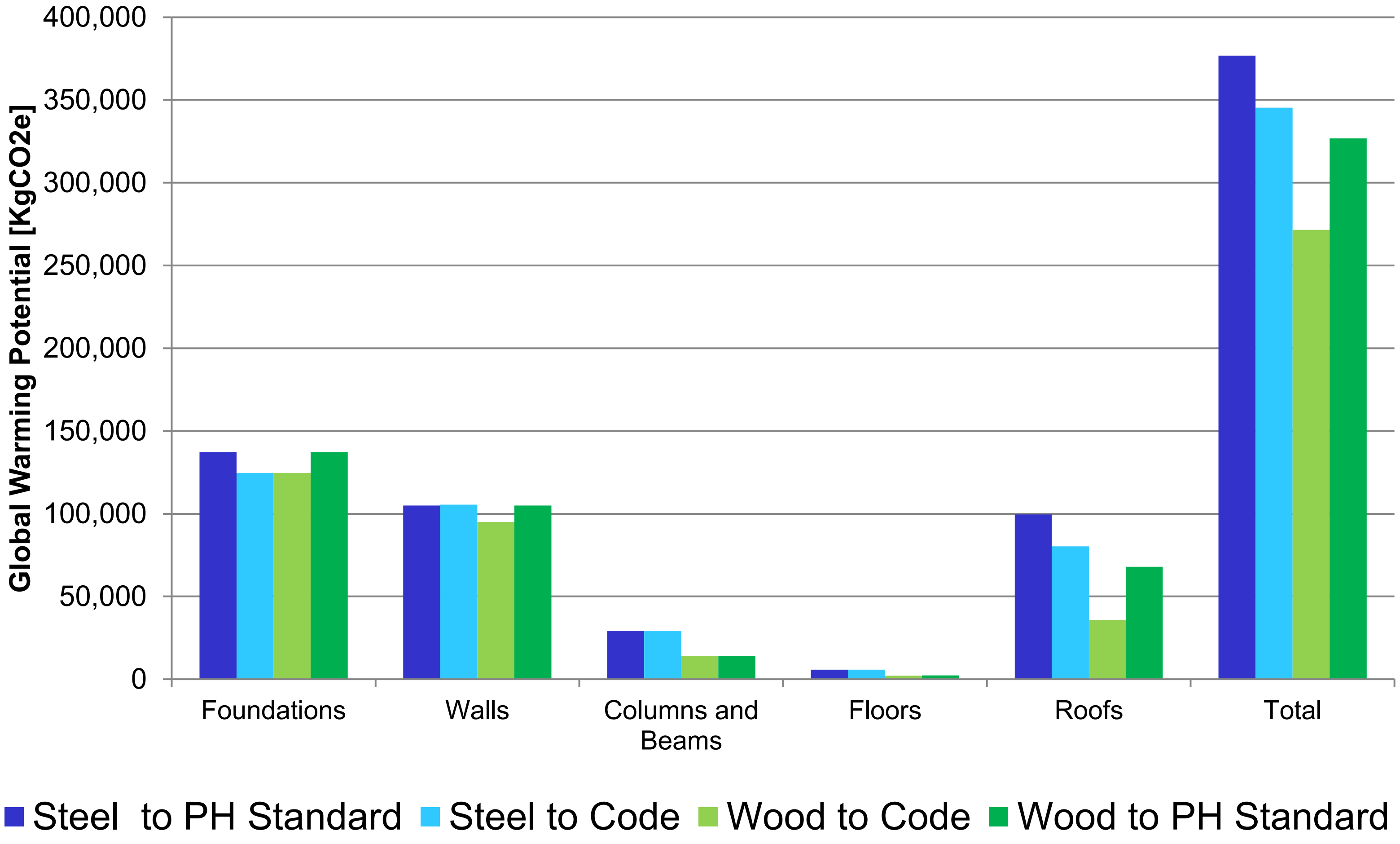
wood SMART
Canadian Wood Council
Conseil canadien du bois

WIRL in comparison to UNBC campus



Author: Wimmers, Graphic: UNBC

Comparative LCA for Materials, Construction and End of Life

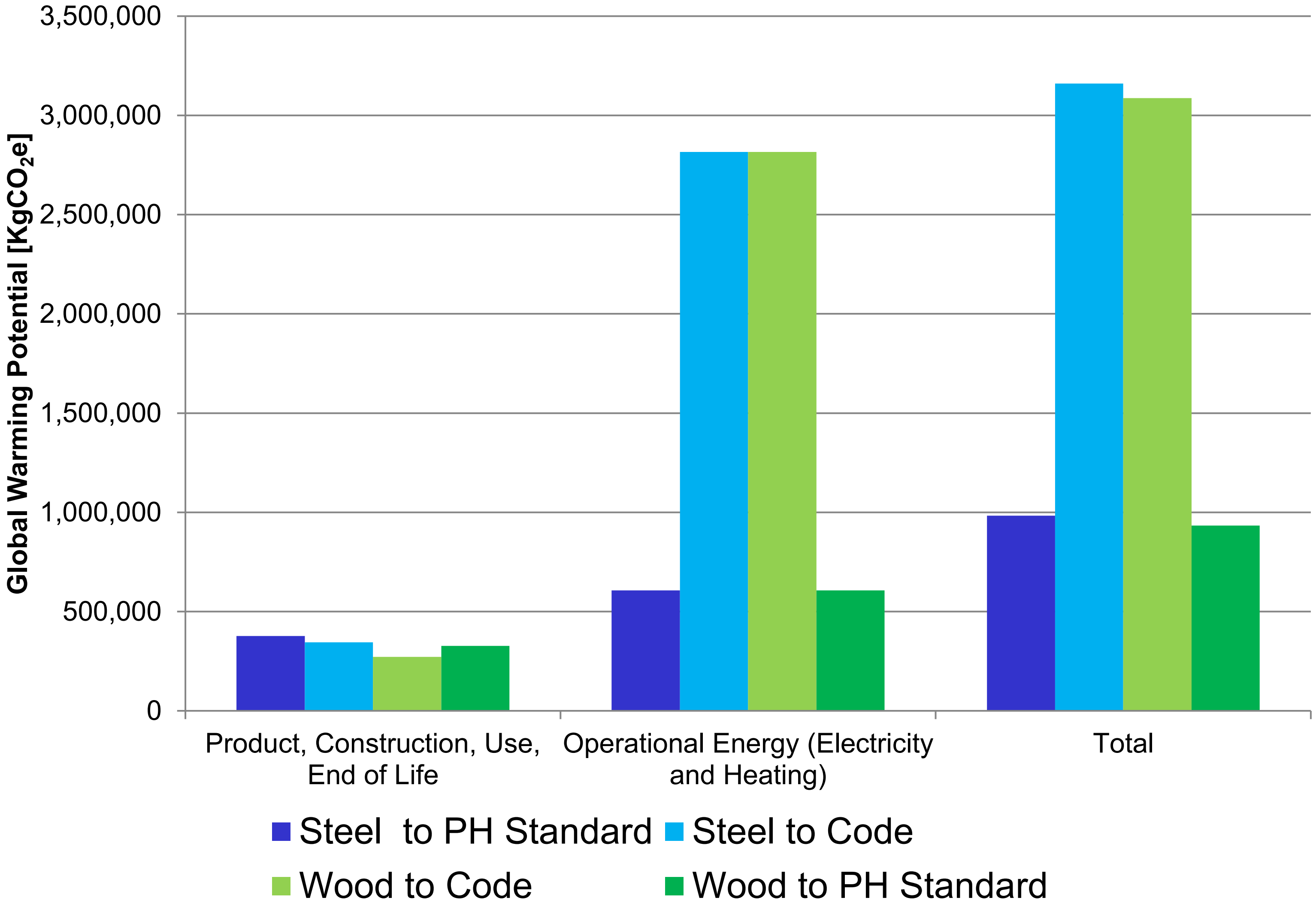


Passive House Version has a higher GWP than Code conforming Building.

Wood construction emits 50,000 kg of CO2 or 22% less GWP.

Authors: S. Wall, G. Wimmers

Materials, Construction and End of Life compared to Operational Energy



Operational energy, even in the most energy efficient building standard, is still by far the largest impact on the environment. A Passive House steel building would outperform an ordinary wood building by far over its lifetime.

Conclusion:

Embodied Energy matters, as the related GWP is emitted shortly before and during construction.

Operational Energy matters more, as the total impact over the next 80 years is far larger than the embodied energy

Authors: S. Wall, G. Wimmers

Building Innovation

Design by

Construction by

Research Funded by

Thank you to the Project Partners of this case study