University of Waterloo

High Performance Buildings meet PassivHaus

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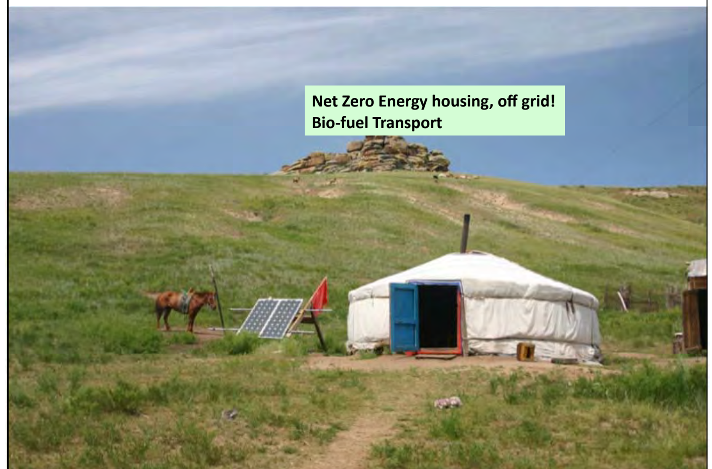


Outline

- Low-energy homes / small buildings
  - Cold to Mixed-Cold Climates
- PassivHaus as one approach
- Passive House US
  - How is it the same/ different than PH?
- Other approaches and metrics
  - Effinergie, Minenergie
- Then … Building, Enclosure, Mechanicals.

Major Energy Use Categories

kWh/yr for a typical US 2200 sf 3 BDR home

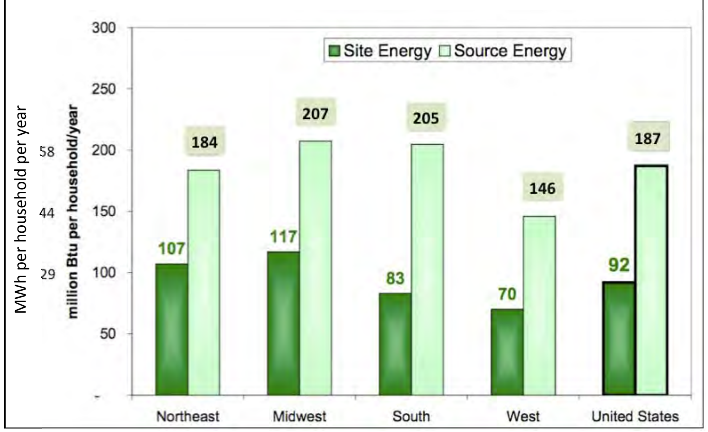
- Space Heating (cold climate
  - 10000 – 30 000 very climate dependent 35 to 100 MMBTU
- Space Cooling
  - 0 – 10 000 very climate dependent
- Domestic Hot Water
  - 4000-6000 small climate dependency
- Appliances
  - 1000 – 3000 (dryer, 900, fridge 500)
- Misc Electrical Loads + plug
  - 1000-3000
- Lighting
  - 750- 2000
- Total: **Typical Household: 15 000 to 35 000 kWh**
  50 MMBTU to 120 MMBTU

How much do US houses use?

- RECS2005 is great data. RECS2009 soon.
- Avg *new* US home uses 50 kWh/yr/m² gas
  - Gas usually means heat + DHW
- North-east homes use avg $808 of gas/yr!
- North-east home use avg 72 kWh/yr/m² gas

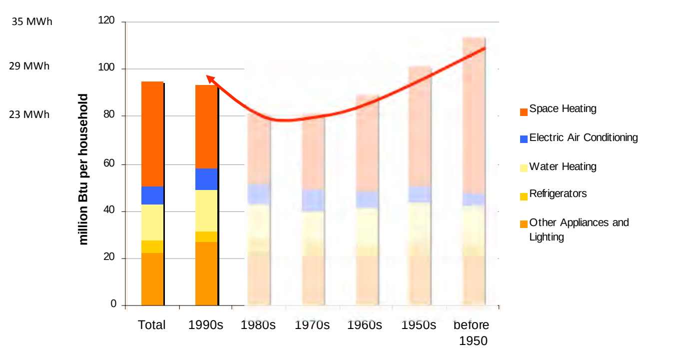
Range is 45 to 60 MWh/yr source
20 to 35 MWh/yr site

Energy Use per Household



US Overall Old & New Houses Energy Use

Total Btu Consumption per Household, 2001

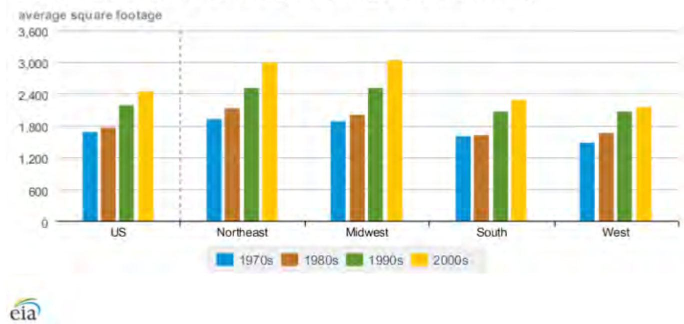


Source: US Census Bureau, Annual Housing Survey: http://www.census.gov/hhes/www/housing/ahs/ahs.html

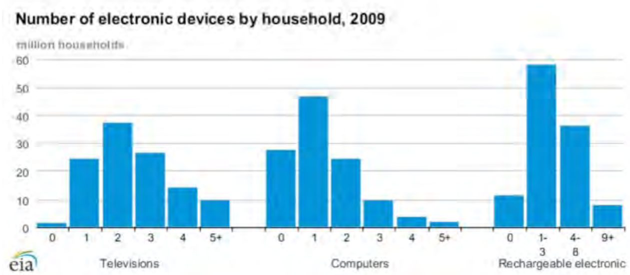
www.BuildingScience.com

US Homes. Bigger

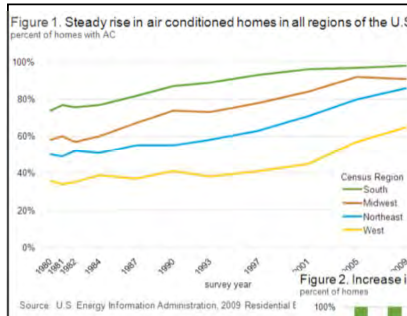
Figure 1. Newer homes trend larger in all regions of the country

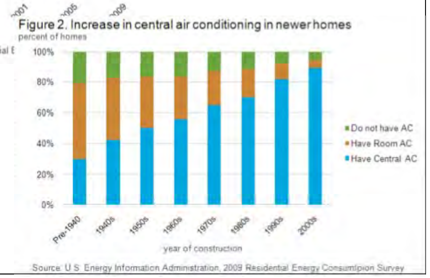


Misc Elec Loads



People use AC





Site Source Aside

Source-to-Site Conversion

- January 2009, NREL figures for Building America
- Of course, varies with source of electricity supply
  - Most coal plants are 35% efficient, new NG plants 60%+
  - 5% transmission loss

Energy Source	Source Energy Factor
Electricity	3.365
Natural Gas	1.092
Anthracite Coal	1.029
Bituminous Coal	1.048
Subbitumious Coal	1.066
Lignite Coal	1.102
Residual Fuel Oil	1.191
Distillate Fuel Oil	1.158
Gasoline	1.187
LPG	1.151
Kerosene	1.205

eGRID 2006 NERC Regional Interconnects

Electrical GHG Emissions

- April 2007, EPA eGRID files

NERC region acronym	NERC region name	Output emission rate				
		CO_2 (lb/MWh)	SO_2 (lb/MWh)	NO_x (lb/MWh)	Ozone season NO_x (lb/MWh)	Hg (lb/GWh)
ASCC	Alaska Systems Coordinating Council	1,106	1.203	3.679	3.980	0.0014
ERCOT	Electric Reliability Council of Texas	1,421	3.174	0.981	0.950	0.0291
FRCC	Florida Reliability Coordinating Council	1,328	3.620	2.269	2.240	0.0091
HICC	Hawaiian Islands Coordinating Council	1,655	4.190	3.757	3.829	0.0117
MRO	Midwest Reliability Organization	1,820	6.107	3.734	3.578	0.0415
NPCC	Northeast Power Coordinating Council	908	2.924	1.019	0.915	0.0099
RFC	Reliability First Corporation	1,434	9.252	2.481	1.667	0.0419
SERC	SERC Reliability Corporation	1,387	6.369	2.114	1.537	0.0264
SPP	Southwest Power Pool	1,830	4.636	3.017	2.850	0.0350
WECC	Western Electricity Coordinating Council	1,107	1.170	1.622	1.560	0.0112
U.S.		**1,363**	**5.436**	**2.103**	**1.704**	**0.0269**

National **1.36 lb CO_2/kWh (0.91 to 1.83)**
RFC **1.43 lb CO_2 / kWh**

Fossil Fuel GHG Emissions

- Assuming combustion @ 100% efficiency
- Nat gas
  - 117 pds CO_2 / MMBtu = 0.40 /kWh
  - 92% eff. = 0.435 lb/kWh
  - Around 3 times less GHG emission vs electric
- Propane
  - 139 pds CO_2/MMBtu = 0.475 /kWh
- Heating oil No. 2
  - 161 pds CO_2/MMBtu = 0.54 /kWh

Source: DOE EIA Emissions Coefficients

Energy Performance Labels

- Plus Energy- Carbon neutral
- Off-grid
- Net Zero-energy
- "80% reduction"
- PassivHaus
- Architecture2030.org
- "50% reduction"
- Energy Star V3 (20%?) or LEED Platinum

EnergyStar v3 is too meek

The EPA's own analysis shows it wastes consumers money in most places. Assumes no increase in energy costs over time.

Exhibit 1: ENERGY STAR Qualified Homes, Version 3 Illustrative Cost & Savings Summary

							Annual Utility Bills: Costs		Annual Utility Bills: Savings	ENERGY STAR Version 3 Upgrade Cost		ENERGY STAR Version 3 Cash Flow Impact		
Home	CZ	Location	Stories	Foundation	HVAC Equipment Type	Heating Fuel	2009 IECC	ENERGY STAR Version 3	ENERGY STAR Version 3	Total Cost	Monthly Mortgage Cost	Monthly Utility Savings	Monthly Mortgage Cost	Net Cash Flow
1	1	Miami, FL	One-story	Slab	Air-Source Heatpump	Electricity	$1,706	$1,402	$304	$4,243	$23	$25	$23	$3
2	1	Miami, FL	One-story	Slab	Gas Furance / AC	Gas	$1,603	$1,303	$299	$3,952	$21	$25	$21	$4
3	2	Daytona Beach, FL	One-story	Slab	Air-Source Heatpump	Electricity	$1,674	$1,404	$271	$4,011	$22	$23	$22	$1
4	2	Daytona Beach, FL	One-story	Slab	Gas Furance / AC	Gas	$1,589	$1,317	$273	$3,720	$20	$23	$20	$3
5	3	Fort Worth, TX	One-story	Slab	Air-Source Heatpump	Electricity	$1,950	$1,580	$370	$4,451	$24	$31	$24	$7
6	3	Fort Worth, TX	One-story	Slab	Gas Furance / AC	Gas	$1,858	$1,499	$360	$4,159	$22	$30	$22	$8
7	4	St. Louis, MO	One-story	Basement	Air-Source Heatpump	Electricity	$2,228	$1,812	$416	$4,074	$22	$35	$22	$13
8	4	St. Louis, MO	One-story	Basement	Gas Furance / AC	Gas	$1,977	$1,608	$368	$3,555	$19	$31	$19	$12
9	5	Indianapolis , IN	One-story	Basement	Air-Source Heatpump	Electricity	$2,276	$1,783	$493	$4,893	$26	$41	$26	$15
10	5	Indianapolis , IN	One-story	Basement	Gas Furance / AC	Gas	$1,972	$1,571	$401	$3,488	$19	$33	$19	$15
11	6	Burlington, VT	One-story	Basement	Air-Source Heatpump	Electricity	$2,763	$2,058	$705	$5,190	$28	$59	$28	$31
12	6	Burlington, VT	One-story	Basement	Gas Furance / AC	Gas	$2,261	$1,727	$534	$3,627	$19	$44	$19	$25
13	7	Duluth, MN	One-story	Basement	Gnd-Source Heatpump	Electricity	$3,365	$1,749	$1,616	$9,154	$49	$135	$49	$86
14	7	Duluth, MN	One-story	Basement	Gas Furance / AC	Gas	$2,547	$1,881	$666	$3,627	$19	$56	$19	$36

Notes:

- Purchased energy costs were calculated assuming a national average cost of $0.11 / kWh and $1.33 / therm. The electricity rate was determined by averaging the data for 2008 from the Energy Information Administration's Average Retail Price of Electricity to Ultimate Customers, Residential Sector. The natural gas rate was determined by averaging the data for 2008 from the Energy Information Administration's U.S. Price of Natural Gas Delivered to Residential Consumers.
- Monthly mortgage cost was calculated assuming a 30-year fixed mortgage with a 5.0% interest rate.

Comparison different performance standards

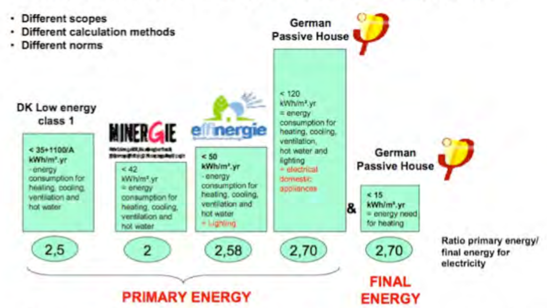


Figure 3. Comparison of the Danish low energy class 1, the Swiss energy calculation method (Minergie), French energy calculation methods (Effiinergie), with the two energy frames as defined in the Passive House standard (total energy consumption and heating consumption per year). Source: Pascal Eveillard, Effinergie presentation « Enjeux et référentiel », March 2007.

[1] Energy used for lightning in a 150 m² house with traditional technology is approx. 1000 kWh/y (approx. 6 kWh/m²) while the energy used for appliances is approx. 3000 kWh/y, (approx. 20 kWh/m²).The Danish Electricity Saving Trust has estimated that with energy efficient equipment and optimized conditions lightning can be reduced to 500 kWh/y (3 kWh/m²) and to 1500 kWh/y (10 kWh/m²) for appliances.

What is a Passive House?

Contact Us

Smith House residence built to Passive House standard in Urbana Illinois

Residence built to Passive House standards in Vorarlberg, Austria.

The Passive House concept represents today's highest energy standard with the promise of slashing the heating energy consumption of buildings by an amazing 90%. Widespread application of the Passive House design would have a dramatic impact on energy conservation. Data from the U.S. Energy Information Administration shows that buildings are responsible for 48% of greenhouse gas emissions annually and 76% of all electricity generated by U.S. power plants goes to supply the Building Sector [**Architecture2030**]. It has been abundantly clear for some time that the Building Sector is a primary contributor of climate-changing pollutants, and the question is asked: How do we best square our building energy needs with those of our environment and of our

Performance Characteristics

- Airtight building shell **≤ 0.6 ACH @ 50 pascal pressure,** measured by blower-door test.
- Annual heat requirement **≤ 15 kWh/m2/year (4.75 kBtu/sf/yr)**
- Primary Energy **≤ 120 kWh/m2/year (38.1 kBtu/sf/yr)**

In addition, the following are recommendations, varying with climate:

- Window u-value **≤ 0.8 W/m2/K**
- Ventilation system with heat recovery with **≥ 75%** efficiency with low electric consumption @ **0.45 Wh/m3**
- Thermal Bridge Free Construction **≤ 0.01 W/mK**

The Passive House - definition

From www.passipedia.org

The Passive House is not an energy standard but an integrated concept assuring the highest level of comfort. The exact definition is as follows:

> ***"A Passive House is a building, for which thermal comfort (ISO 7730) can be achieved solely by post-heating or post-cooling of the fresh air mass, which is required to achieve sufficient indoor air quality conditions – without the need for additional recirculation of air."***

This is a purely functional definition which doesn't contain any numerical values and is valid for all climates. This definition shows that the Passive House is a fundamental concept and not a random standard. Passive Houses have not been "invented" by anyone – in fact, the Passive House principle was discovered. It may be debatable whether the term "Passive House" accurately describes this concept – well, there is no other term better suited for it. Thermal comfort is achieved to a maximum extent through passive measures (insulation, heat recovery, passive use of solar energy and internal heat sources).

PassivHaus

- Total heating & cooling demand
  - <15 kWh/m^2/yr (4.75 kBtu/sf/yr)
  - 3000 kWh/yr (10 MMBtu) for 2200 sf house
- Total primary (i.e., source) energy
  - <120 kWh/m^2/yr (38 kBtu/sf/yr) (1/5 US avg)
  - 24 500 kWh/yr (84 MMBtu) for 2200 sf house
- Airtightness
  - <0.6 ACH@50 Pa

NZE Definitions

- NZE: A building that produces as much energy in a typical year as it consumes.
  - Consumes grid power when it needs it
  - Feed power to grid when it has extra
- ALL energy considered
  - Electric is not special.
- NOT Zero Carbon, or Zero GHG
- NOT off-grid
  - Much more difficult

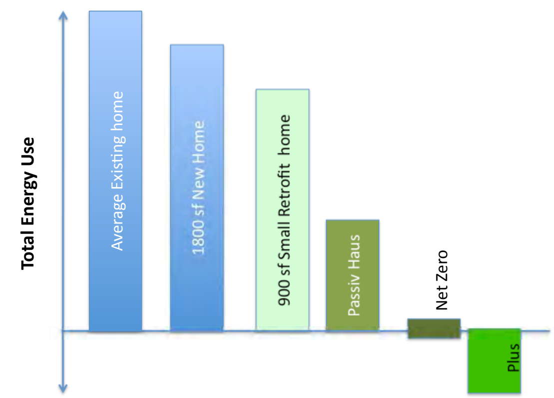
Comparison

Passiv Haus	**"Low-Energy"**
• High-levels of insulation	• Same
• Limit thermal bridging	• Some do, some don't
• Airtight & tested	• Mostly
• Target energy use	• Net-zero does, not other
• Target space heating use	• R2000 does, but not usually
• High-performance windows	• Same
• Heat recovery ventilation	• Usually, depends on need
• Solar DHW sometimes	• Sometimes
• Rarely photovoltaic	• Sometimes, usually NZE

Summary

- Passiv Haus is very similar to many low-energy programs for housing
- Differs in *specific limits, analysis methods, and limits means of achieving* more than level of performance or aspirations

Energy Use Comparison



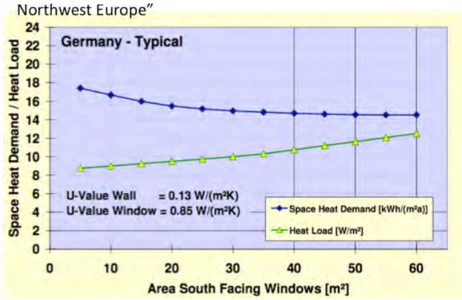
PH Challenges

- 15 regardless of climate, size or occupancy
- area calculation methodology different than US (Canada, UK, France, etc)
- Recommendations can seem like requirements
- Different measurement techniques influence rating for HRV, insulation, Windows, etc

Space Heating vs Priorities

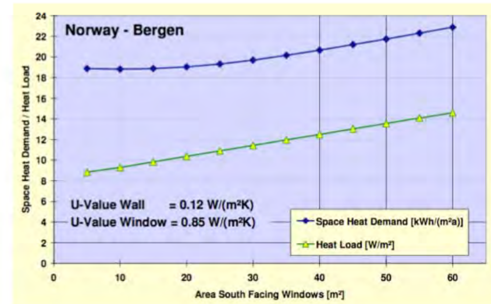
- PH: 15 $kWh/m^2/yr$ = 4.75 $kBTU/ft^2/yr$
- Consider a 460 kWh/yr fridge
  - With primary energy=3.3, this is 1518 kWh/yr
  - For a house with Floor Area=100 m^2
  - 15.2 $kWh/m^2/yr$
- Is it more important to hit a heating target than any other form of energy use?

From PHI Report: "Data for the Determination of Passive House Heat Loads in Northwest Europe"



The climate data for Germany are based on an example climate data set from the PHPP. U-values for the walls have to be about 0.13 W/(m²K) in order to reach the 10 W/m² limit. Typical Passive House windows with an overall U-value of 0.85 W/(m²K) must be used.

With increasing window area, the heat load is also increasing, whereas the annual space heat demand is decreasing. In this example, a heat load of 10 W/m² corresponds nearly exactly to a space heat demand of 15 kWh/(m²a).



For Norway, two "Representative Design Years for Solar Energy Applications" from IEA-SHCP, Task 9, were available. The first location, Bergen, is renowned for its high amounts of annual precipitation. Being situated at the North Sea, the climate is a lot milder than at other locations at the same latitude. Insulation levels may therefore be chosen similar to Germany. Due to the low solar radiation, though, small windows are advantageous for minimizing the space heat demand.

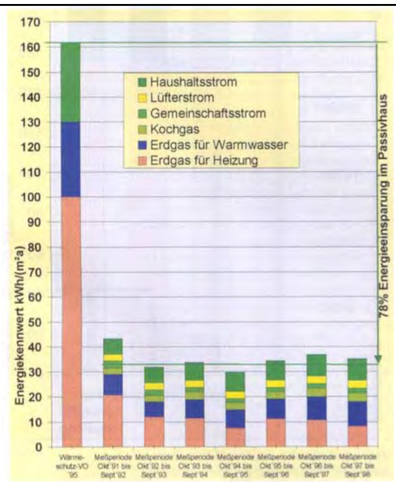


Abb. 11: Gemessener Energieverbrauch im

Generation or Conservation?

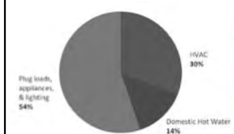
- Big Question!
  - Easy Economics when Net-Zero Energy
  - Compare $/kWh/yr for each choice
- PV costs $5000+/kWp installed
  - Produces 1100-1250 kWh/yr
  - About >$4/kWh/yr
- Wind costs vary a lot. Large are cheapest.
  - Small wind (<50 kW) is expensive because it does not produce as much as they say

PV versus demand reduction

- Recall total site energy for normal 3 BDR 2200 sf house
  – 15-35 000 kWh/yr
- Requires 15-35 kWp of PV
  - $75,000 to 140,000 +/- capital cost
  - Sloped south area of 1600 to 3500 sq ft
- Reducing energy is usually much cheaper!
  – At least to start….

Pill House, Vermont, 2800 ft^2

- 10 kW wind turbine-120 ft tower=6500 kWh
- R56 ceiling, R40 walls, triple-glazed window
- R20 basement, 2.0 ACH50
- South-facing
- **GSHP,SHW**
- **NetZero**



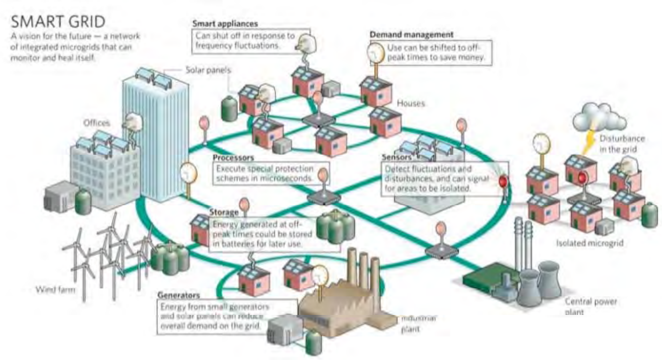
Net Zero

- Should we build NetZero Buildings?
  – Small-scale on-site renewables are not currently very cost effective
  – Who will pay for the grid when we get a lot of NZE buildings ?
- But, Fun to try!
  – Reduce heating loads ***first and foremost***
  – Reduce DHW, appliance, lighting loads

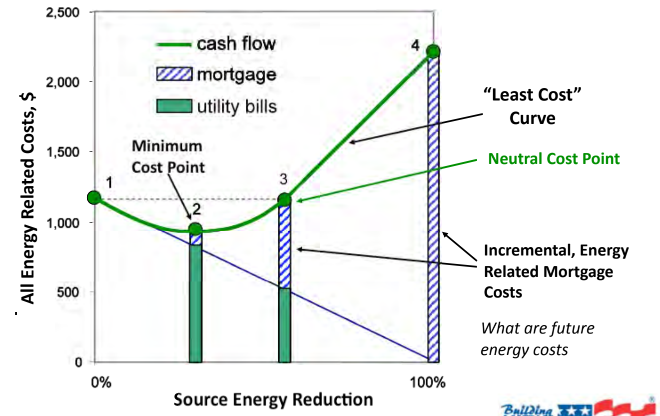
Long term Grid

- Currently transmission and distribution is about 10% of cost
- If many homes use less and produce more, still need a grid and hence T&D costs rise
- Generator still needs to provide peaking power plants (eg expensive)
- Hence simple reverse metering cant go on for long, or purchased kWh needs to be very expensive

Smart Grid



Capital Investment vs Operating Cost



Underlying Source: Dr Ren Anderson, NREL

Decisions and Durability

- Mechanical equipment
  - 15 to 25 yrs for furnace, heat pump etc
- Photovoltaic
  - 25 – 35 yrs
- Wind turbines
  - 15-30 yrs
- Insulation
  - 50 to 100 yrs
- Appliances
  - 13-20 years

Excess Precision

- fkldjgkl

Alan Abrams
[Greenbuilding] heretical observation

working on a project that is pretty damn close to hitting the passive house specs, and just for a hoot, I reduced insulation values by about 15% for the floor, walls, and roof. Bam! Specific heat demand went from 4.69 KBtu/sf/an up to 5.76.

the Passive House spec, tattoed on my right arm (over the one that reads "MOTHER"), is 4.75.

but then I put on a sweater and reset the interior temperature, from 68d Fh down two measly degrees to 66d. Pow! Specific heat fell to 4.52.

I know it is heretical to say so, but our expectations have something to do with sustainability.

AA

Alan Abrams

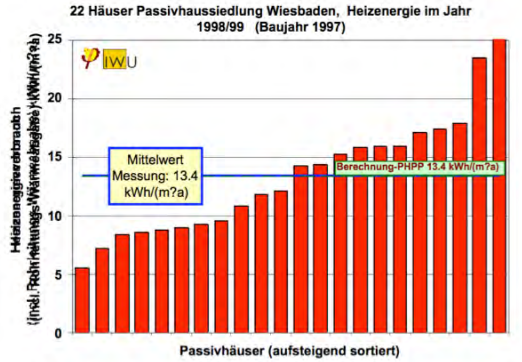


Abb. 2: Messungen zum Heizenergieverbrauch der Passivhaus-Siedlung mit 22 Häusern in Wiesbaden (Bauträger: Rasch&Partner): *Der Mittelwert des gemessenen Heizenergieverbrauchs im Meßzyklus 1998/99 lag bei 13,4 kWh/(m_a). Dieser Wert ist sogar etwas geringer als der rechnerische Heizwärmebedarf von 13,5 kWh/(m_a) nach dem Passivhaus-Projektierungs-Paket. Die Häuser verbrauchen somit um einen Faktor 10 weniger Heizenergie als herkömmliche Gebäuden.*

Getting high performance

How to get HP

- Durability
  - Rain control
  - airtight,
  - vapor control
- Comfortable
  - Surface temperatures,
  - stable interior air temperature,
  - avoid overheating / glare
- Plus Low-energy

How to get Low Energy

- Same for PH, NZE, etc. different degrees and emphasis
  - Compact form, oriented to south
  - Super-insulated
  - Air tight
  - Good windows
    - Manage solar
  - Provide mechanical ventilation
  - Use efficient mechanicals / appliances
  - Use renewable energy when it makes sense

Strategies- Airtightness

- Airtightness critical for all climates
  - Humidity loads from air critical health comfort and durability issue in hot-humid
  - Control condensation and energy waste critical in cold climates
  - Natural ventilation useful in dry (night) and moderate climates (e.g., marine)

47/175 6/8/12

Rigid Exterior Air Barrier

Building Science.com 48

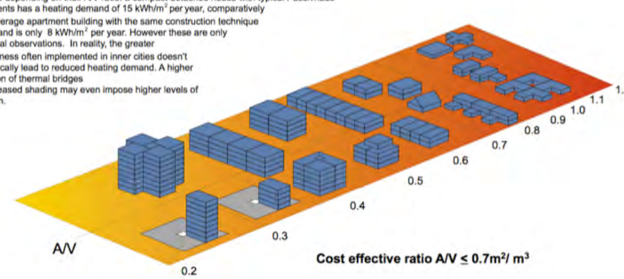
Strategies- Insulation

- Resists heat loss/gain = energy savings
  - Large temperature differences: cold and hot climates, roofs (hot)
  - Less important in warm-humid and mixed climates
- Warms surfaces = durability
  - Avoids condensation in hot and cold weather
  - = durability and health strategy
  - Keep structure warm and dry and stable

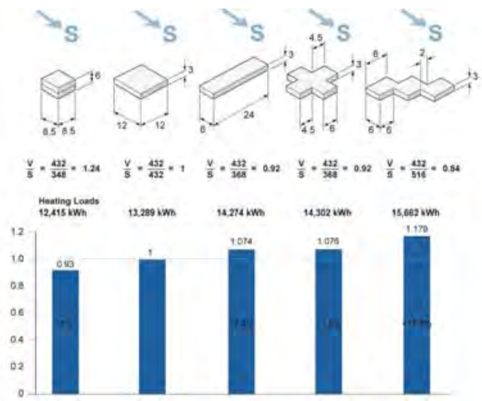
49/175 6/8/12

Compact Form A/V Ratio

The compactness of a building, indicated by the A/V ratio (A: area of building envelope surface, V: volume of the building) has a considerable influence on the heating energy demand of buildings, regardless of the level of fabric insulation. Buildings with identical U values and air change rates, with the same window area and the same orientation will feature different heating demands depending on their A/V ratio: a compact detached house with typical Passivhaus components has a heating demand of 15 kWh/m^2 per year, comparatively for an average apartment building with the same construction technique the demand is only 8 kWh/m^2 per year. However these are only theoretical observations. In reality, the greater compactness often implemented in inner cities doesn't automatically lead to reduced heating demand. A higher proportion of thermal bridges and increased shading may even impose higher levels of insulation.



For a typical house



Don't be boring

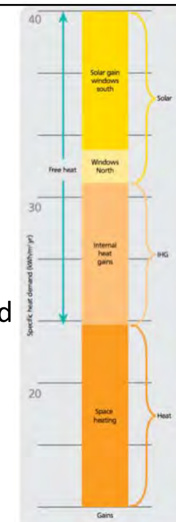
Simple compact is good and saves lots of money,

But..

Will this look for the masses?

Internal Gains

- Super-insulated means space heat is helped by interior gains
  - People/Pets, Appliances/lights
  - Solar Gains
- Former HDD Balance point assumed to be 65F
- Superinsulated?
  - 50F? Depends on gains, mass



Insulation

- What target should be used?
  - Roof and wall same? Or different… why?
- Below slab R-value
  - Why R40 or R60?
- Which R-value test should you use?
  - R-value as per USA? (mean 75 F)
  - R-value per Germany (mean 50 F)
  - R-value in service? (mean 30? 40?90?)

Environmental impact

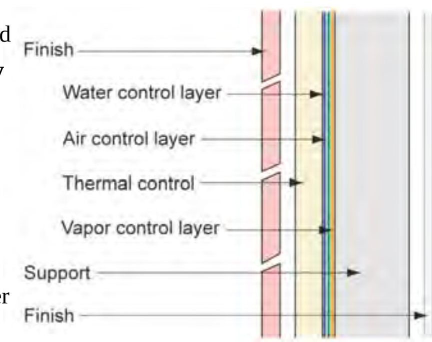
- Electric vs gas vs wood
- Materials
  - Spray foam EPS/XPS polyiso
  - Ashpalt shingles

Surface Temperatures

- Surface films
- R-values
- Calculate temperature drop

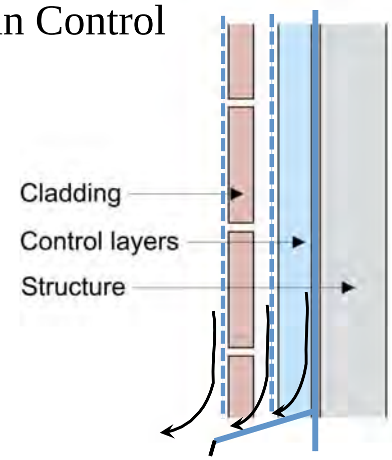
The "Perfect Wall"

- Finish of whatever
  - May need ventilated
- **Control continuity is the key**
  - Water: Drainage gap + drainage plane
  - Air: Air barrier
  - Heat: Insulation
  - Vapor: vapor barrier



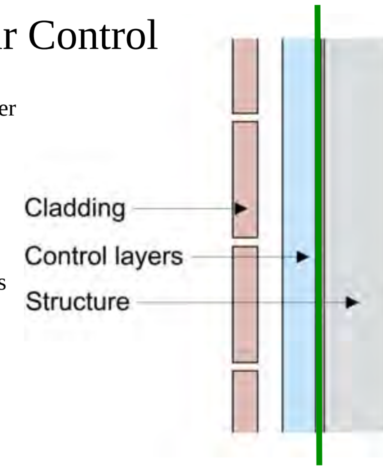
Rain Control

- Rain shedding
- Drainage preferred
- Must integrate with flashing, drain holes
- Overlap everything
- No holes



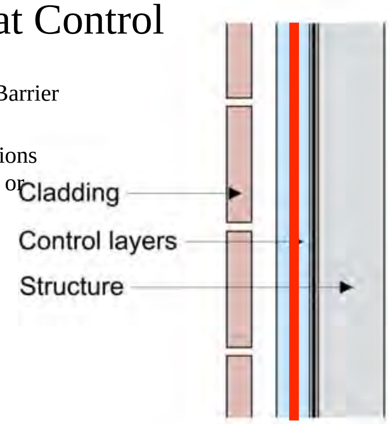
Air Control

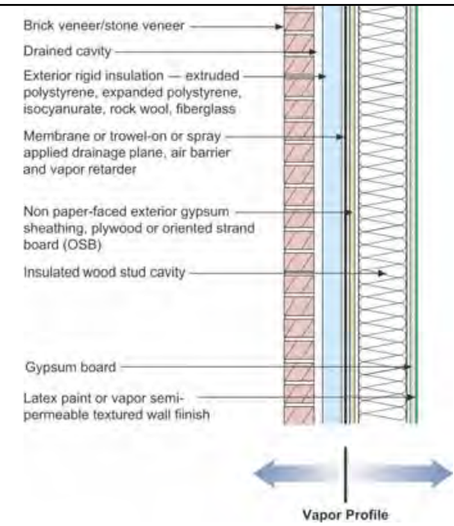
- Continuous Air Barrier
  - Continuous
  - Stiff
  - Strong
  - Durable
  - Air Impermeable
- Only very small holes tolerable



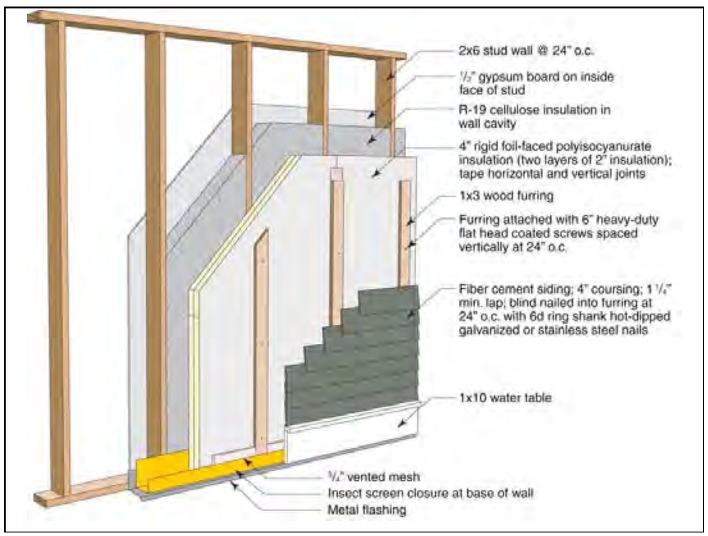
Heat Control

- Continuous Thermal Barrier
  - R10 to R40
- Accept small penetrations as long as no comfort or durability issues
- Windows are a major concern
  - Heat loss/gain
  - Solar gain

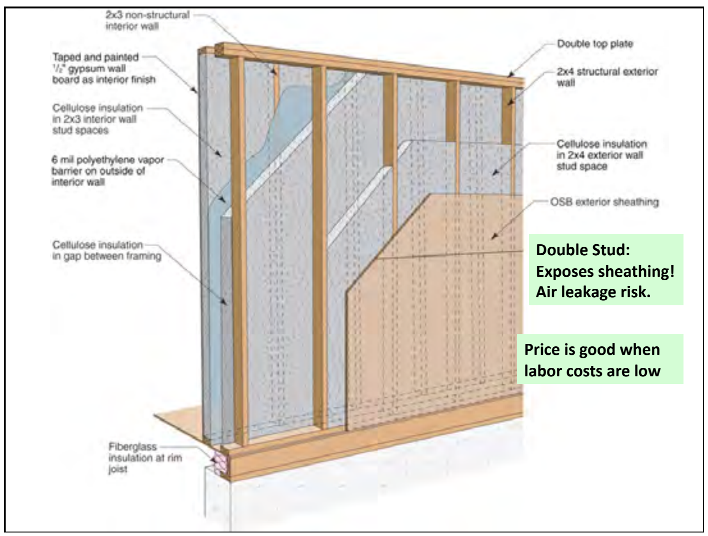


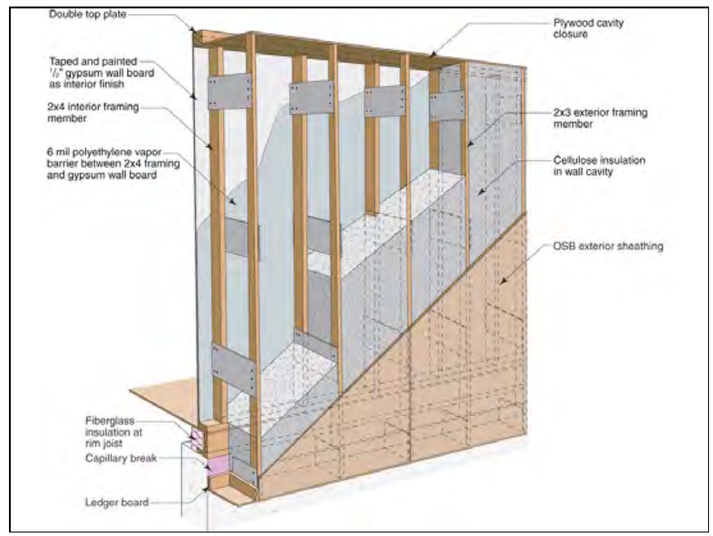


Thermal bridges




• 4" of Taped Foam over 2x6
• About R40 incl. thermal bridges


2x3 non-structural interior wall
Taped and painted ½" gypsum wall board as interior finish
Cellulose insulation in 2x3 interior wall stud spaces
6 mil polyethylene vapor barrier on outside of interior wall
Cellulose insulation in gap between framing
Fiberglass insulation at rim joist
Double top plate
2x4 structural exterior wall
Cellulose insulation in 2x4 exterior wall stud space
OSB exterior sheathing
Double Stud: Exposes sheathing! Air leakage risk.
Price is good when labor costs are low


Double top plate
Taped and painted ½" gypsum wall board as interior finish
2x4 interior framing member
6 mil polyethylene vapor barrier between 2x4 framing and gypsum wall board
Fiberglass insulation at rim joist
Capillary break
Ledger board
Plywood cavity closure
2x3 exterior framing member
Cellulose insulation in wall cavity
OSB exterior sheathing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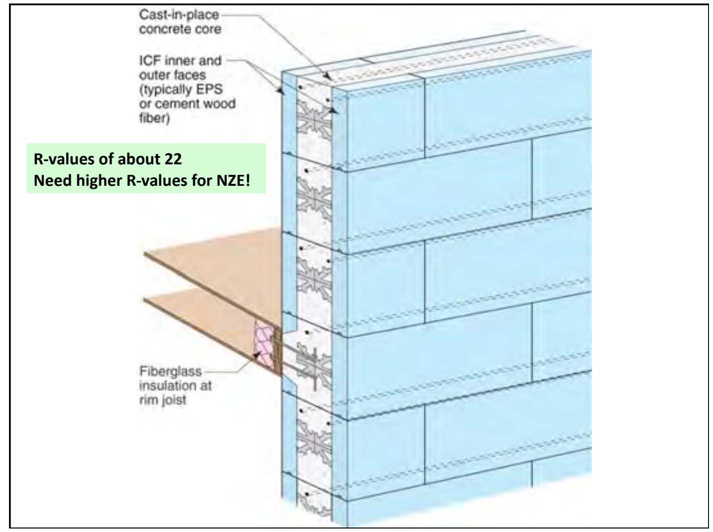
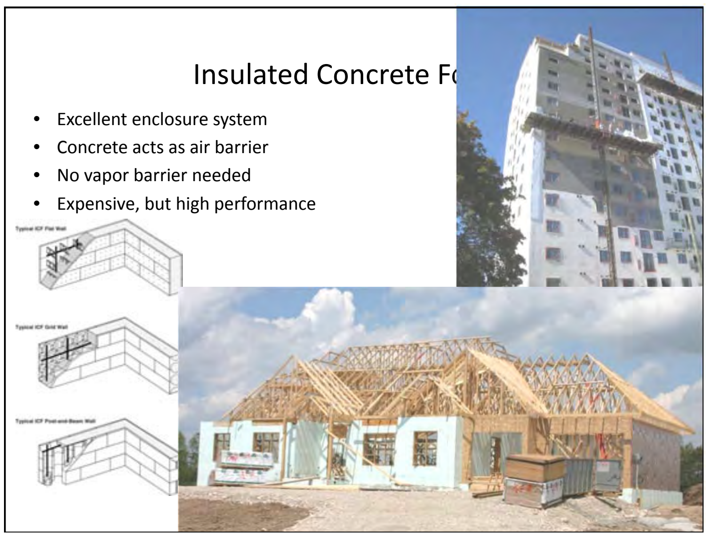
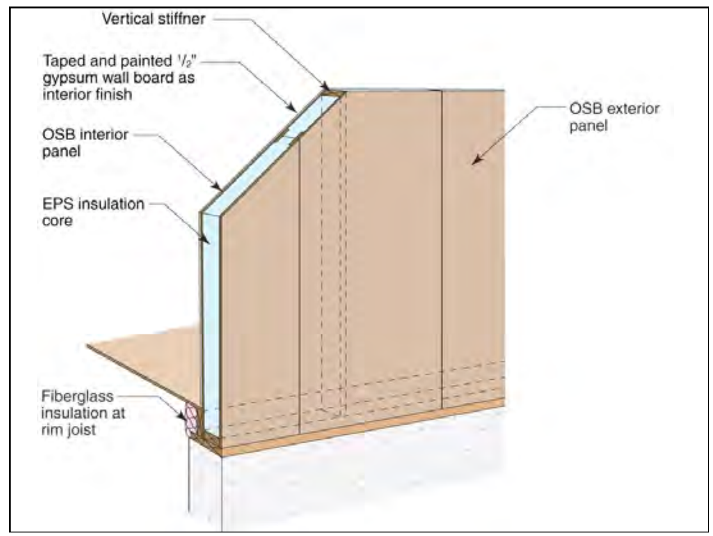
71


Cast-in-place concrete core
ICF inner and outer faces (typically EPS or cement wood fiber)
R-values of about 22
Need higher R-values for NZE!
Fiberglass insulation at rim joist


Insulated Concrete Fo
Excellent enclosure system
Concrete acts as air barrier
No vapor barrier needed
Expensive, but high performance


Vertical stiffner
Taped and painted ½" gypsum wall board as interior finish
OSB interior panel
EPS insulation core
Fiberglass insulation at rim joist
OSB exterior panel

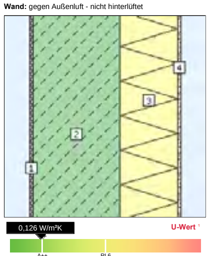
Structural Insulated Panels

- Advantages
  - Superior blanket of insulation
  - if no voids then no convection or windwashing
  - May seal OSB joints for excellent air barrier system
- Therefore, done right = excellent
- Small air leaks at joints in roofs can cause problems
- Don't get them too wet from rain
  - Low perm layers means limited drying

04. 05. 2012

re AWm 09 a Systemwandelement P2 / 0,4 - 30 cm + 20 cm EPS-FS+_varA

Wand: gegen Außenluft - nicht hinterlüftet



Nr.	Ty	Schicht (von innen nach aussen)	d cm	λ W/mK	R m²K/W	ΔOI3 Pkt/m²
1		Spachtel - Gipsspachtel	0,300	0,800	0,004	1
2		Porenbeton 400 kg	30,000	0,110	2,727	33
3		Polystyrol (EPS f. Wärmedämmverbundsysteme WDVS)	20,000	0,040	5,000	25
4		Silikatputz armiert	0,600	0,800	0,008	5
		si / se =			0,130 / 0,040	
		' / " (max. relativer Fehler: 0,0%) =			7,909 / 7,909	
		Bauteil	**50,900**		**7,909**	

Masse	**138,3 kg/m²**
$OI3_{KON}$	**28 Pkt/m²**
PEI n. e.	860,43 MJ/m²
GWP100	56,1764 kg CO_2/m²
AP	0,198517 kg SO_2/m²

re AWm 09 Systemwandelement P2 / 0,4 - 30 cm + 20 cm EPS-FS+_varP

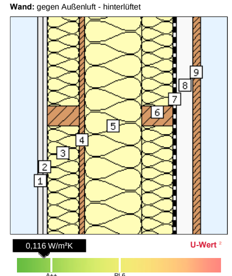
Wand: gegen Außenluft - nicht hinterlüftet

Nr.	Ty	Schicht (von innen nach aussen)	d cm	λ W/mK	R m²K/W	ΔOI3 Pkt/m²

04. 05. 2012

WI 01 a Holzständer- ußenwand, hinterlüftet

Wand: gegen Außenluft - hinterlüftet



Nr.	Typ	Schicht (von innen nach aussen)	d cm	λ W/mK	R m²K/W	ΔOI3 Pkt/m²
1		Gipskartonplatte	1,500	0,210	0,071	3
2		Gipskartonplatte	1,500	0,210	0,071	3
3		*nhomogen (Elemente vertikal)*	10,000			
		56,3 cm (90%) Glaswolle (15 < roh <= 25 kg/m³)	10,000	0,039	2,564	9
		6,3 cm (10%) Holz - Schnittholz Nadel rauh, lufttrocken	10,000	0,120	0,833	0
4		OSB-Platte	1,800	0,130	0,138	10
5		*nhomogen (Elemente horizontal)*	18,000			
		52,2 cm (83%) Glaswolle (15 < roh <= 25 kg/m³)	18,000	0,039	4,615	16
		10,3 cm (17%) Holz - Schnittholz Nadel, rauh, technisch	18,000	0,120	1,500	1
6		*nhomogen (Elemente vertikal)*	10,000			
		56,3 cm (90%) Glaswolle (15 < roh <= 25 kg/m³)	10,000	0,039	2,564	9
		6,3 cm (10%) Holz - Schnittholz Nadel, rauh, technisch	10,000	0,120	0,833	0
7		Windsperre PE, diffusionsoffen (Polyethylenbahn, -folie	0,008	0,500	0,000	1
8		*nhomogen (Elemente horizontal)*	5,000			
		53,1 cm (85%) Luftschicht stehend, Wärmefluss horizon	5,000	1	1	1
		9,4 cm (15%) Holz - Schnittholz Nadel rauh, lufttrocken	5,000	1	1	1
9		Holz - Schnittholz Nadel, gehobelt, technisch getrocknet	2,500	1	1	1
		R_{si} / R_{se} =			0,130 / 0,130	
		R' / R" (max. relativer Fehler: 4,8%) =			9,052 / 8,224	
		Bauteil	**50,308**		**8,638**	

Masse	**85,1 kg/m²**
$OI3_{KON}$	**17 Pkt/m²**
PEI n. e.	701,75 MJ/m²
GWP100	-29,2961 kg CO_2/m²
AP	0,259200 kg SO_2/m²

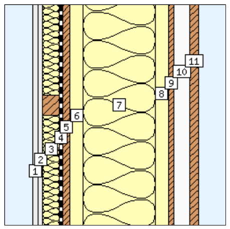
WI 01 b Holzständer- ußenwand, hinterlüftet

Wand: gegen Außenluft - hinterlüftet

04. 05. 2012

WI 06 a Doppel-T-träger- ußenwand, hinterlüftet

Wand: gegen Außenluft - hinterlüftet



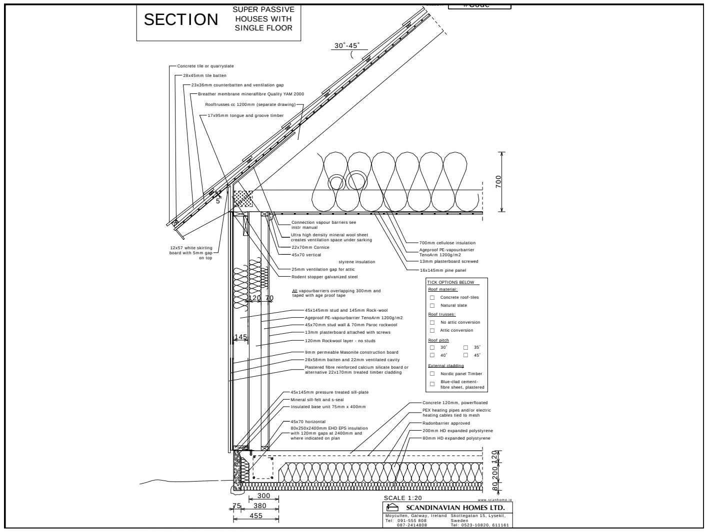
0,114 W/m²K — U-Wert [2]

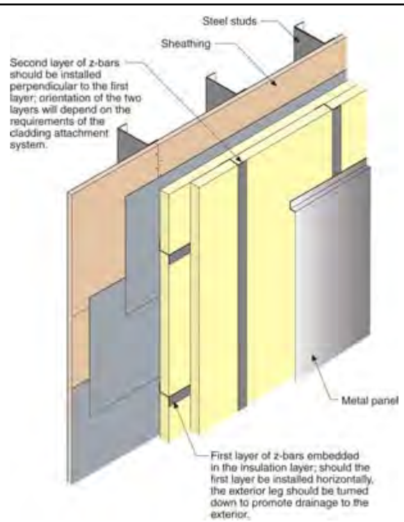
A++ | RL6

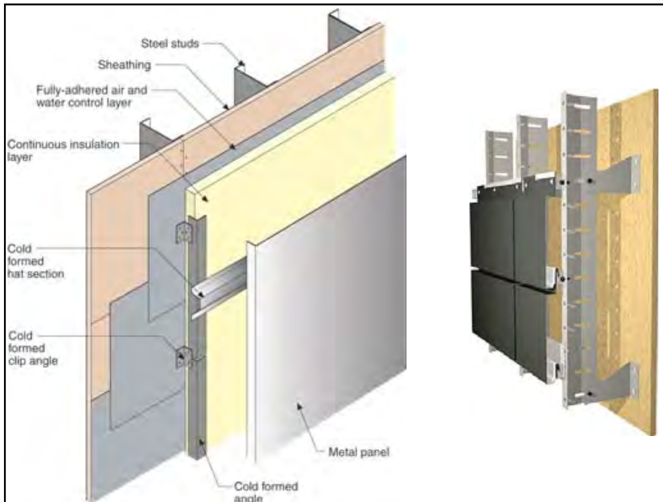
Masse	**80,9 kg/m²**
$OI3_{KON}$	**24 Pkt/m²**
PEI n. e.	920,09 MJ/m²
GWP100	-14,9684 kg CO_2/m²
AP	0,241936 kg SO_2/m²

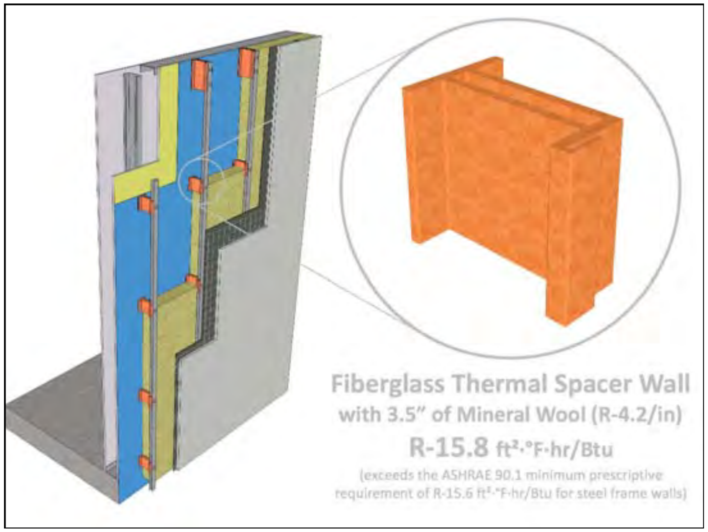
Nr.	Typ	Schicht (von innen nach aussen)	d cm	λ W/mK	R m²K/W	ΔOI3 Pkt/m²
1		Gipskartonplatte	1,500	0,210	0,071	3
2		Gipskartonplatte	1,500	0,210	0,071	3
3		*nhomogen (Elemente vertikal)*	5,000			
		56,3 cm (90%) Glaswolle (15 < roh <= 25 kg/m³)	5,000	0,039	1,282	5
		6,3 cm (10%) Holz - Schnittholz Nadel rauh, lufttrocken (	5,000	0,120	0,417	0
4		Dampfbremse PE (Polyethylenbahn, -folie (PE))	0,021	0,500	0,000	1
5		Spanplatte V100	2,200	0,135	0,163	7
6		*nhomogen (Elemente horizontal)*	4,000			
		57,5 cm (92%) Glaswolle (15 < roh <= 25 kg/m³)	4,000	0,039	1,026	4
		5 cm (8%) OSB-Platte	4,000	0,130	0,308	2
7		*nhomogen (Elemente horizontal)*	22,000			
		61,7 cm (99%) Glaswolle (15 < roh <= 25 kg/m³)	22,000	0,039	5,641	23
		0,9 cm (1%) Holz - Furnierperrholz	22,000	0,440	0,500	2
8		*nhomogen (Elemente horizontal)*	4,000			
		57,5 cm (92%) Glaswolle (15 < roh <= 25 kg/m³)	4,000	0,039	1,026	4
		5 cm (8%) OSB-Platte	4,000	0,130	0,308	2
9		Spanplatte V100	1,600	0,135	0,119	5
10		*nhomogen (Elemente horizontal)*	5,000			
		53,1 cm (85%) Luftschicht stehend, Wärmefluss horizon	5,000	[1]	[1]	[1]
		9,4 cm (15%) Holz - Schnittholz Nadel rauh, lufttrocken (	5,000	[1]	[1]	[1]
11		Holz - Schnittholz Nadel, gehobelt, technisch getrocknet	2,500	[1]	[1]	[1]
		R_{si} / R_{se} =		0,130 / 0,130		
		R' / R'' (max. relativer Fehler: 4,3%) =		9,179 / 8,424		
		Bauteil	**49,321**		**8,802**	

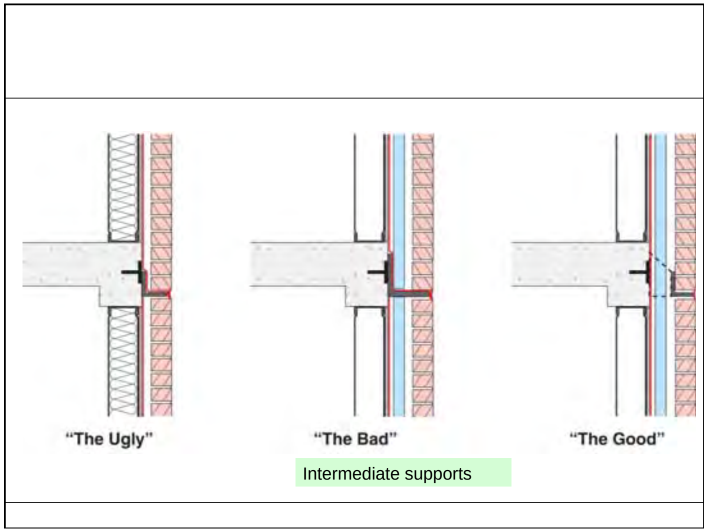
WI 06 b Doppel-T-träger- ußenwand, hinterlüftet

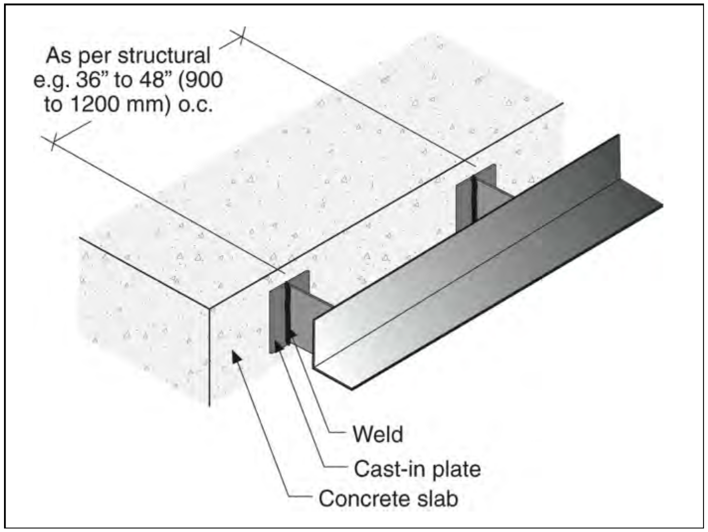


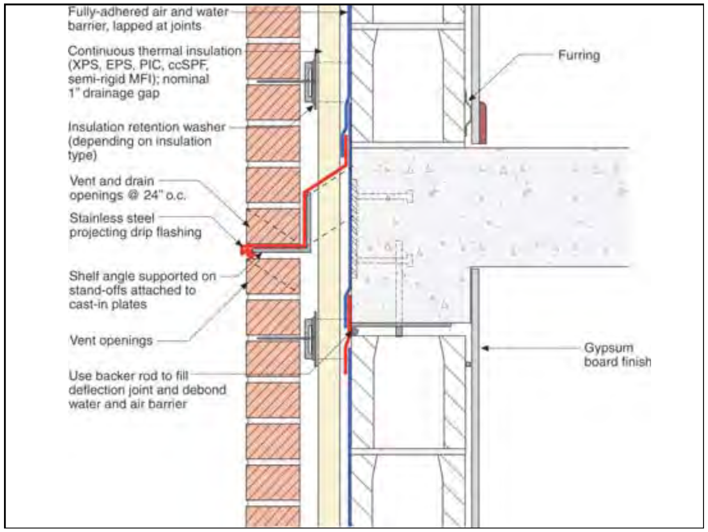




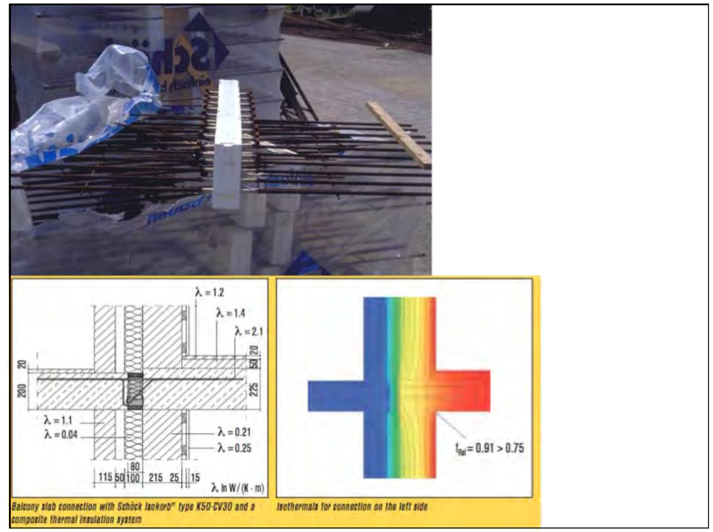

Fiberglass Thermal Spacer Wall
with 3.5" of Mineral Wool (R-4.2/in)
R-15.8 ft²·°F·hr/Btu
(exceeds the ASHRAE 90.1 minimum prescriptive requirement of R-15.6 ft²·°F·hr/Btu for steel frame walls)

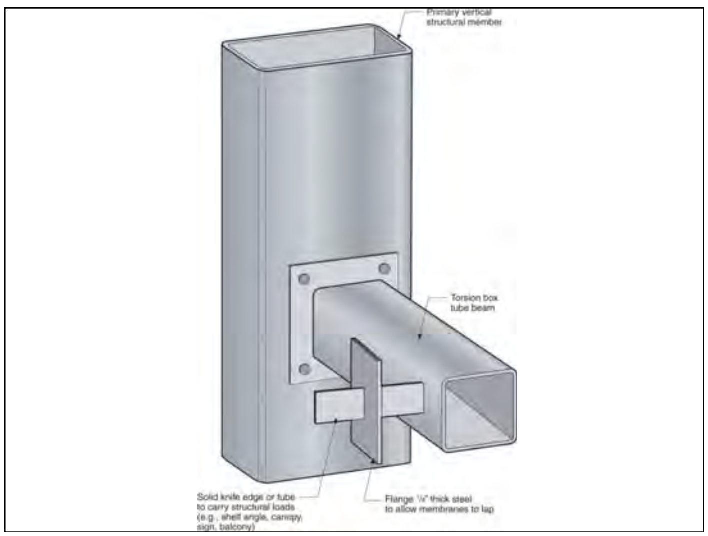

"The Ugly"
"The Bad"
"The Good"
Intermediate supports

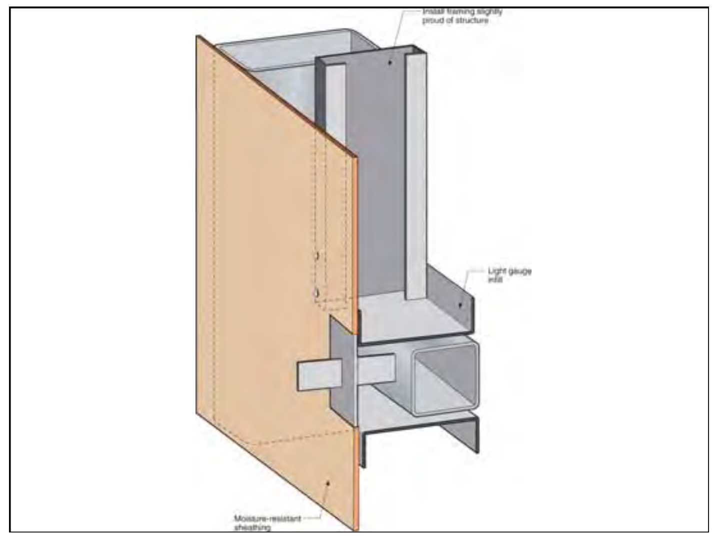

As per structural e.g. 36" to 48" (900 to 1200 mm) o.c.
Weld
Cast-in plate
Concrete slab

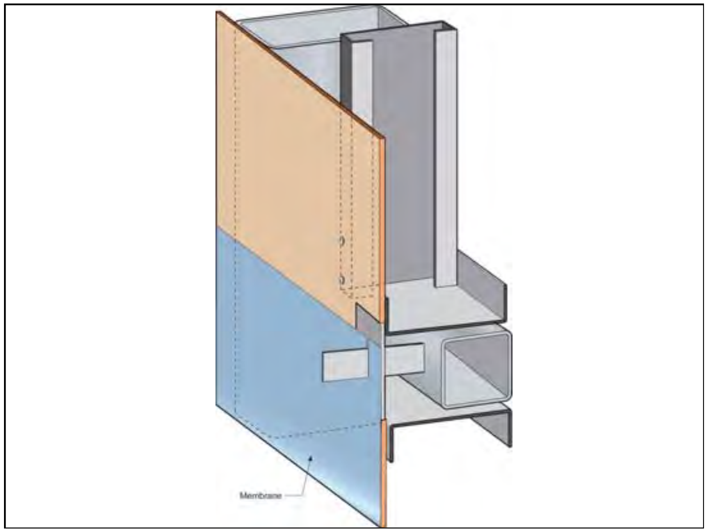

Fully-adhered air and water barrier, lapped at joints
Continuous thermal insulation (XPS, EPS, PIC, ccSPF, semi-rigid MFI); nominal 1" drainage gap
Insulation retention washer (depending on insulation type)
Vent and drain openings @ 24" o.c.
Stainless steel projecting drip flashing
Shelf angle supported on stand-offs attached to cast-in plates
Vent openings
Use backer rod to fill deflection joint and debond water and air barrier
Furring
Gypsum board finish

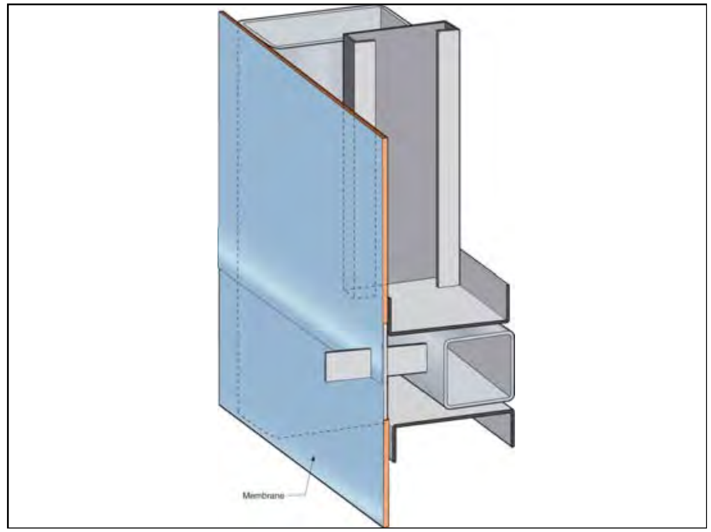

Small metal clips dramatically reduce thermal bridging


λ = 1.2
λ = 1.4
λ = 2.1
λ = 1.1
λ = 0.04
λ = 0.21
λ = 0.25
20
200
20
50
225
80
115 50 100 215 25 15
λ in W/(K · m)
Balcony slab connection with Schöck Isokorb® type K50-CV30 and a composite thermal insulation system
f_{Rsi} = 0.91 > 0.75
Isothermals for connection on the left side


Primary vertical structural member
Torsion box tube beam
Solid knife edge or tube to carry structural loads (e.g., shelf angle, canopy, sign, balcony)
Flange ¼" thick steel to allow membranes to lap


Install framing slightly proud of structure
Light gauge infill
Moisture-resistant sheathing





Windows

- Same functions as rest of enclosure
  - Support, control, finish
- Critical design element
  - Image, comfort, energy, durability, daylight
- New windows are often poorly insulated and air leaky
  - Must specify frames, spacers, fills, coatings

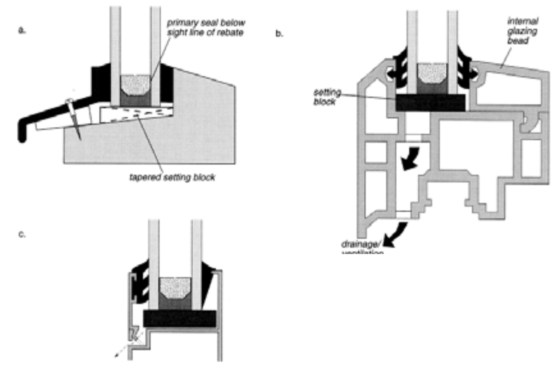
Building Science Windows and Curtainwalls No. 9480

Anatomy of IGU

- Hermetically sealed
- Gas leaks very slowly

Building Science 2008 Windows and Curtainwalls No. 9580

Interface: Glazing Rabbets



Drain these to control rain penetration and ensure IGU durability

Building Science Windows and Curtainwalls No. 9680

Performance Issues and Metrics

- Glazing alone or Complete Window Product
- Primary Metrics
  - Heat Loss / Gain (R,U)
  - Solar Heat Gain Coefficient (SHGC)
  - Visual Transmittance (VT)
- Other Important
  - Condensation resistance (CRI)
  - Air Leakage (AL)
  - Water penetration

Building Science Windows and Curtainwalls No. 9780

Controlling Heat (U/R)

- Windows usually have the lowest thermal performance of all parts of the enclosure
- Must control heat for
  - Comfort
  - Energy
  - Health
  - Durability

} ***Prevent Condensation*** (Health, Durability)

Building Science Windows and Curtainwalls No. 9880

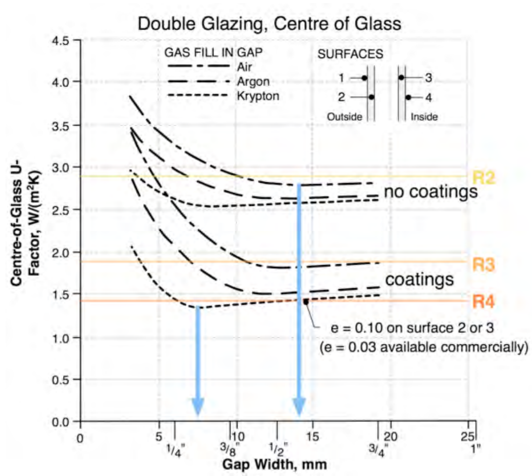
Window vs Wall Performance

	Window	Wall	Ratio
Conduction: **Q_c=U ΔT**	**U=0.33 / R3**	**U=0.05 / R20**	
T_{in}=70 F **T_{out}=10 F**	**Q_c= 20** Btu/sf/hr	**Q_c= 3** Btu/sf/hr	**6.6**
Solar: **Q_s = SHGC I**	**SHGC=0.60**	**SHGC=0.015**	
I_s= 250 Btu/sf/hr (bright sun)	**Q_s= 150** Btu/sf/hr	**Q_s=3.5** Btu/sf/hr	**42**
Alternate: solar control glazing	SHGC=0.3 Q_s= 75 Btu/sf/hr	U=0.125 / R8 Q_c= 7.5	10

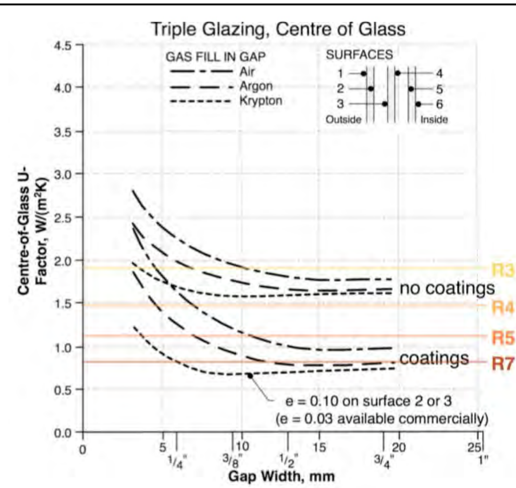
Building Science Windows and Curtainwalls No. 9980

Window Testing

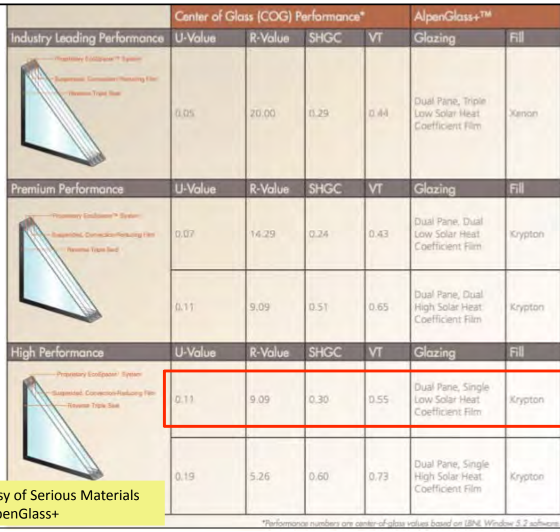
- How to measure?
- NRFC? DIN?
- Temperature of test matters
  - Colder temps results in narrower gaps to control convection looping



Building Science Windows and Curtainwalls No. 10180



Building Science Windows and Curtainwalls No. 10280



	Center of Glass (COG) Performance*				AlpenGlass+™	
Industry Leading Performance	U-Value	R-Value	SHGC	VT	Glazing	Fill
	0.05	20.00	0.29	0.44	Dual Pane, Triple Low Solar Heat Coefficient Film	Xenon
Premium Performance	U-Value	R-Value	SHGC	VT	Glazing	Fill
	0.07	14.29	0.24	0.43	Dual Pane, Dual Low Solar Heat Coefficient Film	Krypton
	0.11	9.09	0.51	0.65	Dual Pane, Dual High Solar Heat Coefficient Film	Krypton
High Performance	U-Value	R-Value	SHGC	VT	Glazing	Fill
	0.11	9.09	0.30	0.55	Dual Pane, Single Low Solar Heat Coefficient Film	Krypton
	0.19	5.26	0.60	0.73	Dual Pane, Single High Solar Heat Coefficient Film	Krypton

*Performance numbers are center-of-glass values based on LBNL Window 5.2 software.

Courtesy of Serious Materials and AlpenGlass+

Window Frames

- Influences thermal, structural performance
- Different modes of operation
  - fixed, awning, casement
  - Operable windows *leak more* rain, heat & air
- Different materials
  - Aluminum strong, durable
  - Wood insulating, attractive
  - Vinyl cheap
  - Fibreglass strong
  - wood-plastic composites

Building Science Windows and Curtainwalls No. 10480

Frames

- A large amount of heat can also be conducted through the frame
  - Conductivity of the material (lower = better)
  - Geometry of the frame

Frame Material	Conductivity W/mk	Conductivity R/inch
Wood	0.10 to 0.18	0.8 to 1.4
PVC	0.17	0.8
Fiberglass	0.30	0.5
Bronze	93	0.002
Aluminum	221	0.001

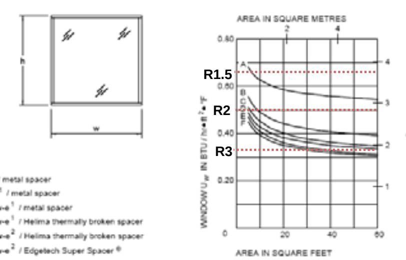
Building Science Windows and Curtainwalls No. 10580

More Frames = More Heat flow

OVERALL WINDOW U-VALUE (U_w)

For fixed window configurations as shown with height (h) equal to width (w).

Spec. one large window rather than many small ones



SEALED UNIT GLAZING TYPE

A = 6mm clear / ½" air / 6mm clear / metal spacer
B = 6mm clear / ½" air / 6mm low-e[1] / metal spacer
C = 6mm clear / ½" argon / 6mm low-e[1] / metal spacer
D = 6mm clear / ½" argon / 6mm low-e[1] / Helima thermally broken spacer
E = 6mm clear / ½" argon / 6mm low-e[2] / Helima thermally broken spacer
F = 6mm clear / ½" argon / 6mm low-e[2] / Edgetech Super Spacer ®

1 - low-e coating emittance = 0.10
2 - low-e coating emittance = 0.03

Kawneer Isoport 518

Building Science Windows and Curtainwalls No. 10680

Thermal

- Critical for alu windows

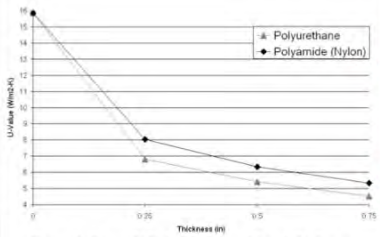
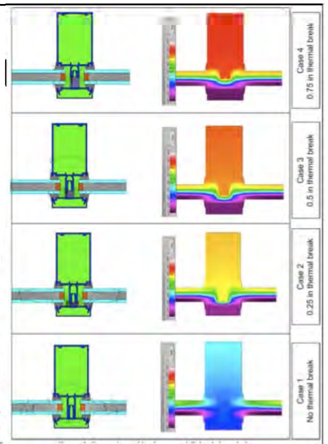


Figure 4: Frame U-Value vs. thermal break thickness.



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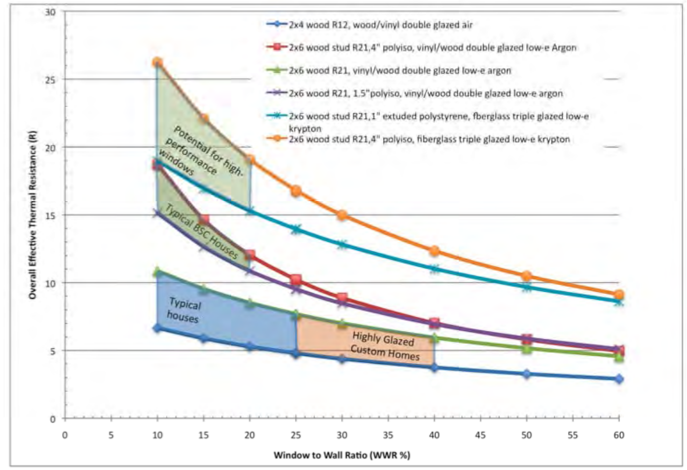

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Solar Heat Gain Coefficient

- SHGC = Solar Heat Gain Coefficient
  = % of solar heat that enters
- Typical clear, dbl-glazed window SHGC = 0.72
- Higher SHGC?
  – *Maybe* small residential buildings in *heating* climate
- Low SHGC? (<0.4)
  – Commercial buildings (less than 0.30 even better)
  – Houses with large glazing ratios (big window area)
  – Buildings in cooling or mixed climate

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Visible Transmittance

- VT = Visible Transmittance
  = Ratio of daylight that hits a window that enters the room
- Typical clear, dbl-glazed window VT = 0.70-0.75
- Windows with VT > 0.50 are perceived to be clear
- Tinting changes the color of light that passes
- Low-e coating does not change color
- *Spectrally selective*
  – Control solar heat gain (SHGC<<0.50)
  – Allow plenty of daylight (VT >0.50)

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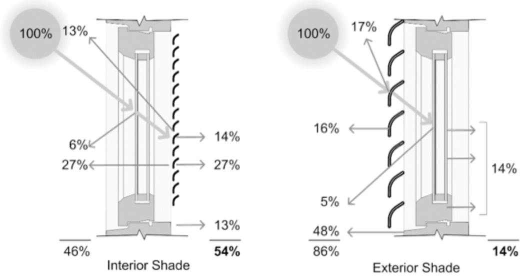
Interior or Exterior Shade

- Exterior Shades always beat low SHGC
  - But the cost capital and maintenance
- Interior shades don't work well with good windows



Building S

Building Science Windows and Curtainwalls No. 11380

Spectrally Selective

- Allows low SHGC and high VT
- Coolness Factor (LSG)
  - VT / SHGC
  - Look of 1.7-2.0
  - E.g. VT=0.60, SHGC=0.30, LSG=2

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Windows: More than U-value

- Finding the air-water-thermal layer can be challenging
- Usually, best air and water seal is inner edge
  - –few chances for water leaks at corners
- Alu windows have thermal line at TB
  - –Line up with thermal control in wall

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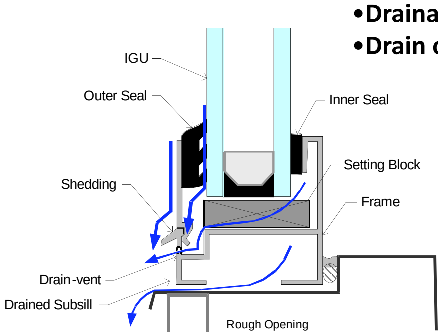
Leaky windows

- Windows and RO leak rain water

Window Joints

- **Control Surface Drainage**
- **Control Rain at Multiple (tightening) Levels**
- **Drainage at all Levels**
- **Drain opening**



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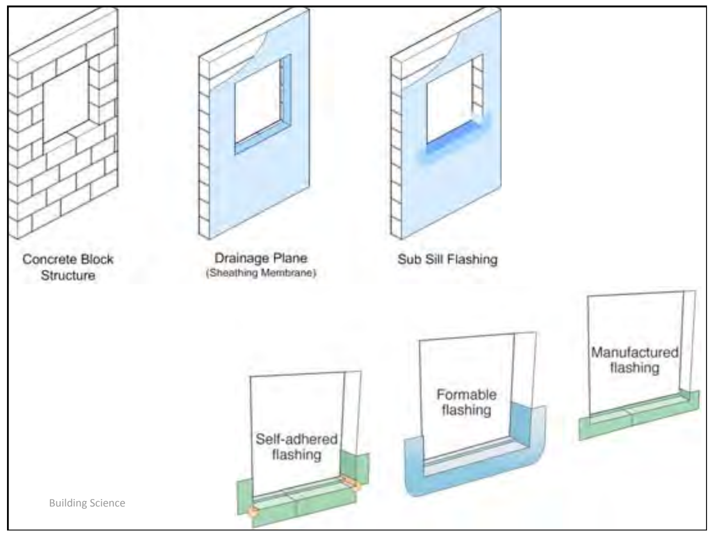

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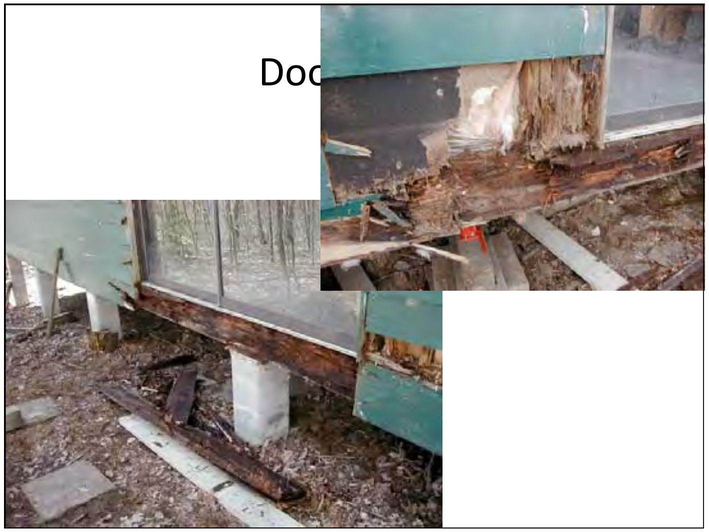
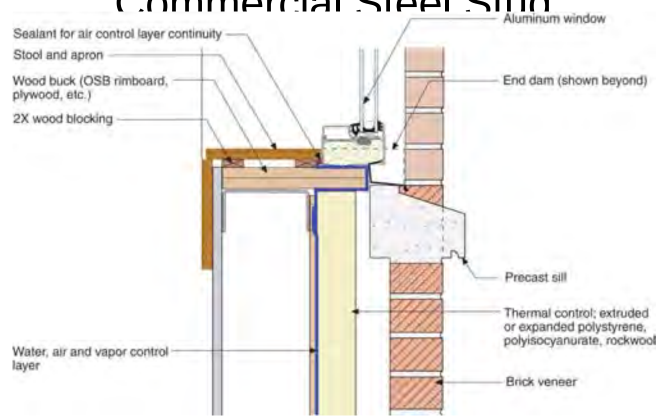


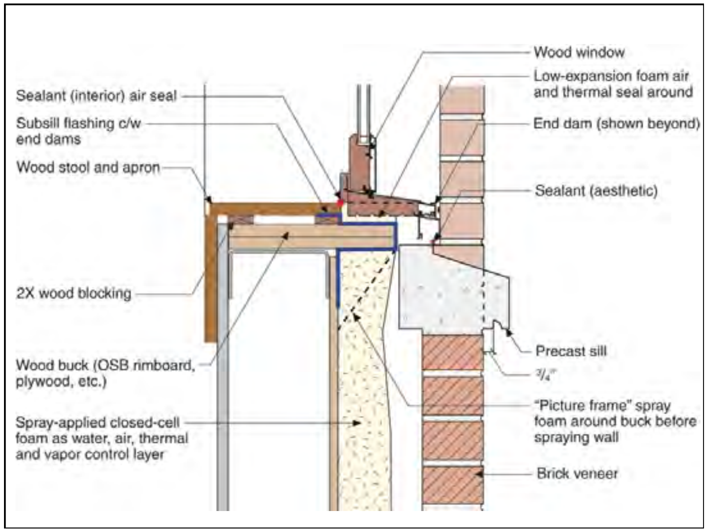
Mixed membrane + liquid

Often use membranes for transitions

Backdams / Slopes are Important

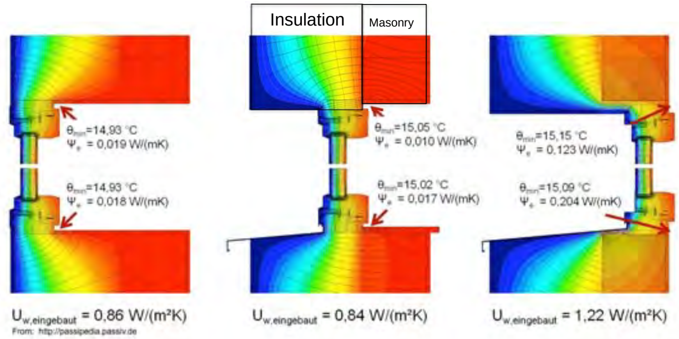
Commercial Steel Stud





Window Location

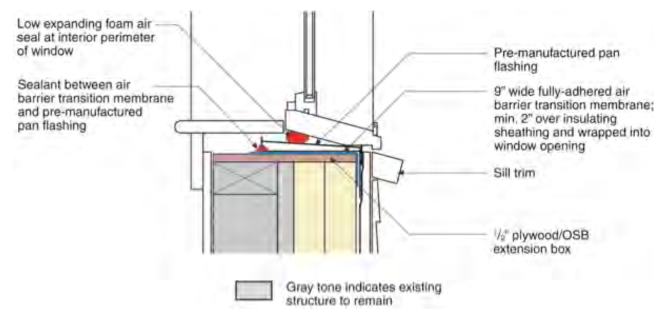
Align "within" thermal control line, not in middle of wall



Outie Window (but within thermal line) · Innie Window (but within thermal line) · Innie Window (inside of thermal line)

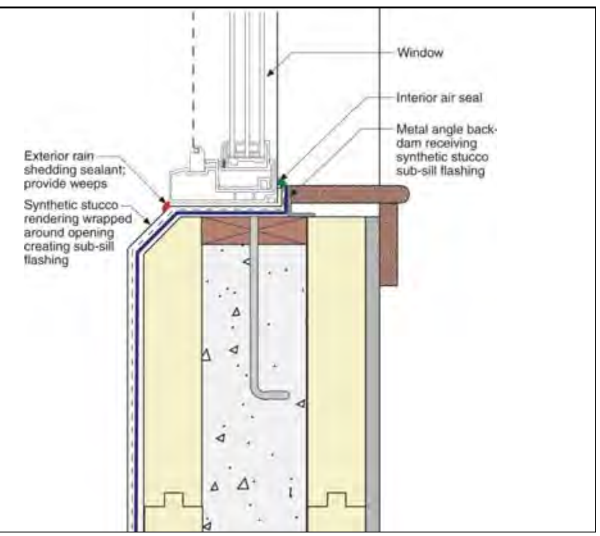
- Beware strap anchor air leakage

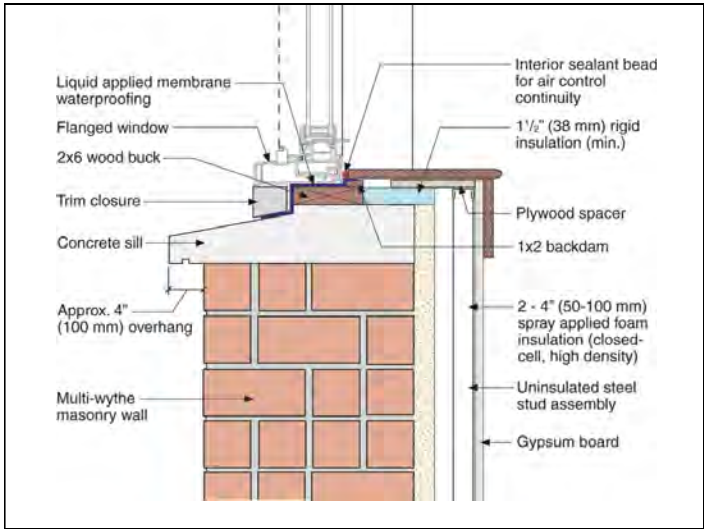
- Beware air leakage at premade sill flashing



- Beware thermal bridge of metal sill pans

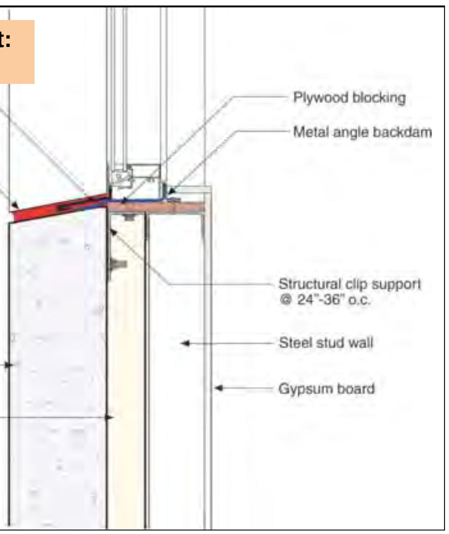
- Face of foam as air/water layer

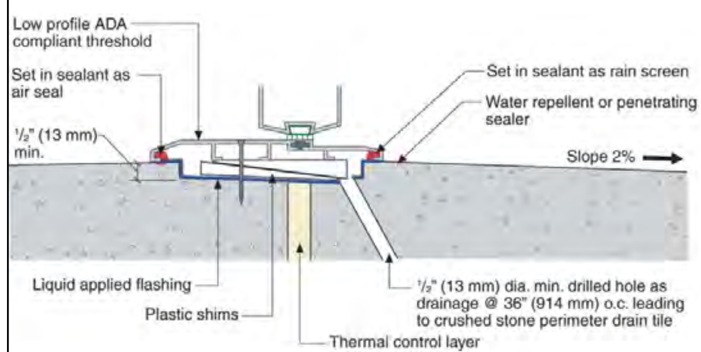




Continuous interior angle provides backdam and airseal continuity

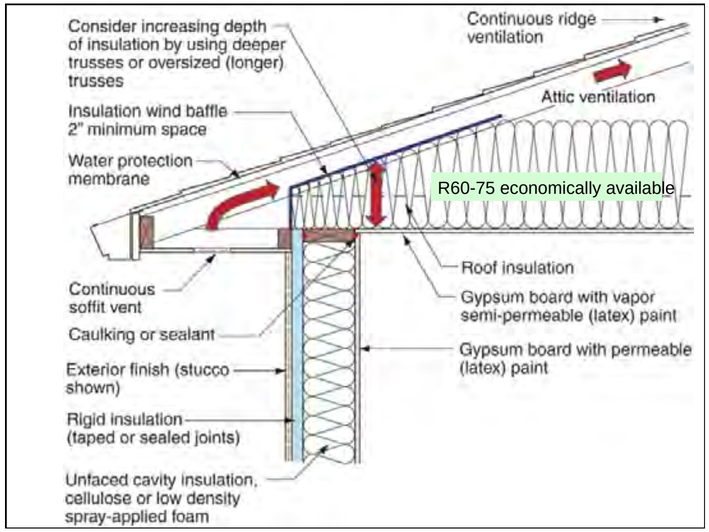
Architectural Precast: Punched Window

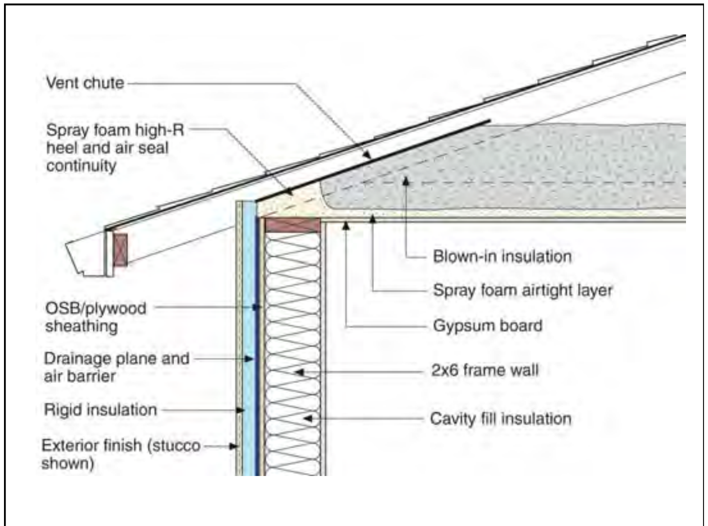


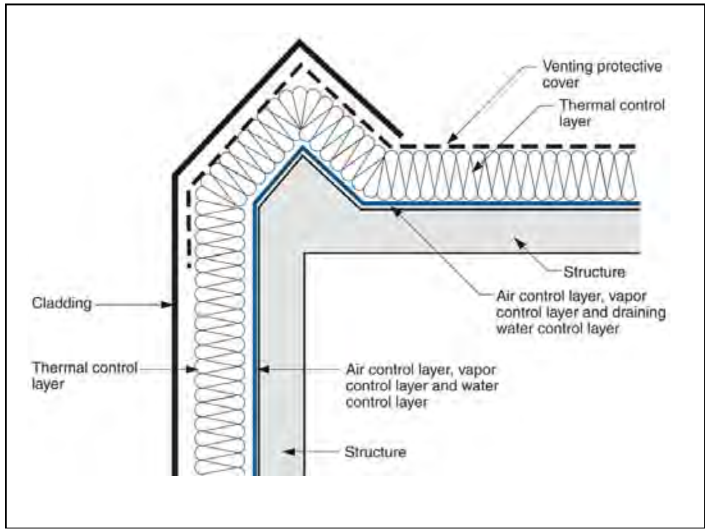


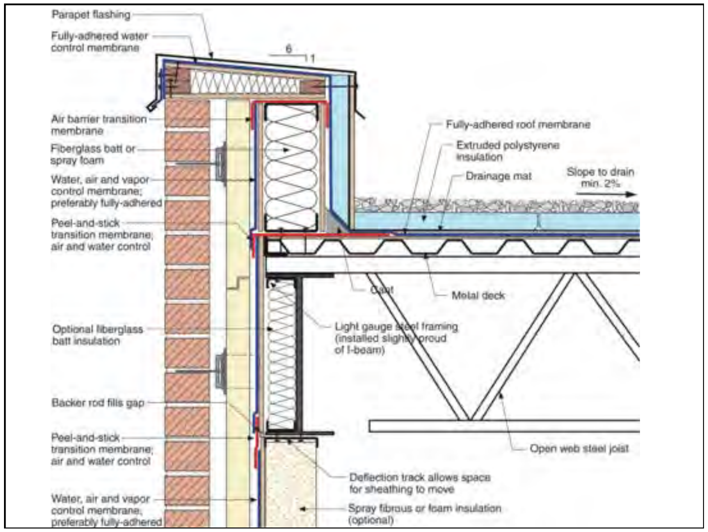
Roof-Wall

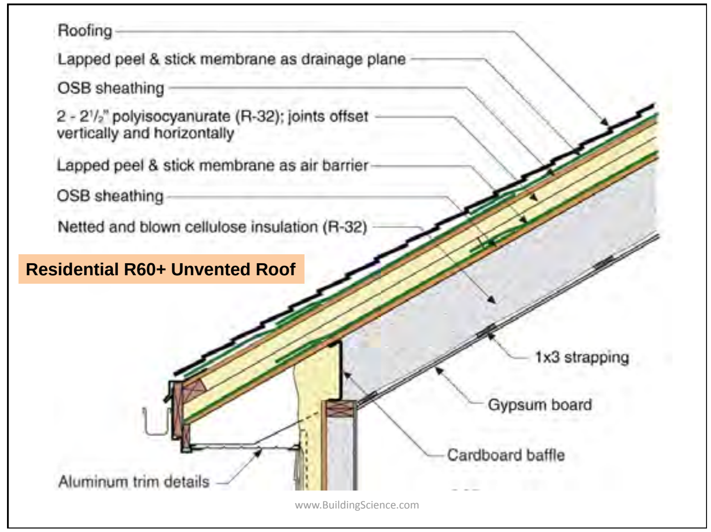
- Water control
  - sometimes overhangs, sometimes continuous
- Air control
  - Sometimes roof membrane, sometimes ceiling plane





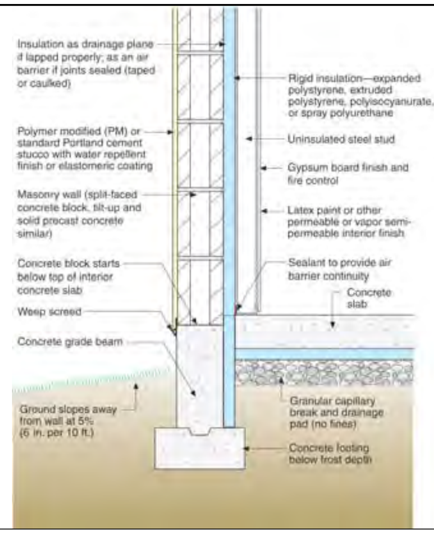


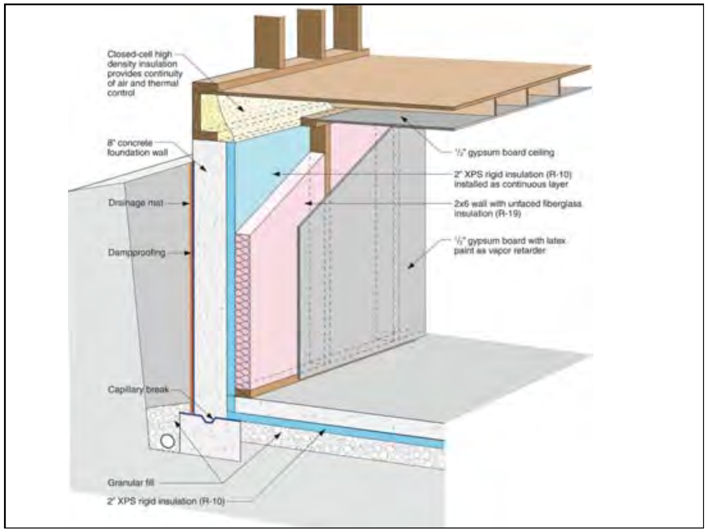


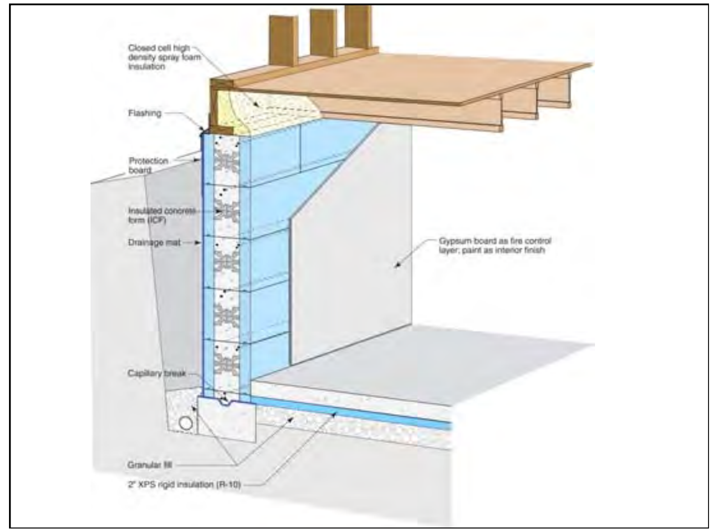


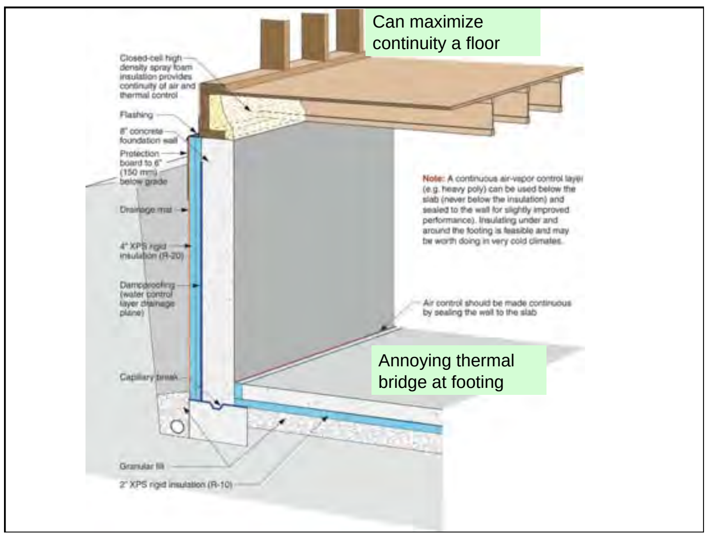
Basement Wall-Slab

- Continuity of air-thermal barrier a challenge at slab
- Continuity at floor slab also!




Closed-cell high density insulation provides continuity of air and thermal control
8" concrete foundation wall
Drainage mat
Dampproofing
Capillary break
Granular fill
2" XPS rigid insulation (R-10)
½" gypsum board ceiling
2" XPS rigid insulation (R-10) installed as continuous layer
2x6 wall with unfaced fiberglass insulation (R-19)
½" gypsum board with latex paint as vapor retarder


Closed cell high density spray foam insulation
Flashing
Protection board
Insulated concrete form (ICF)
Drainage mat
Capillary break
Granular fill
2" XPS rigid insulation (R-10)
Gypsum board as fire control layer; paint as interior finish


Can maximize continuity a floor
Closed-cell high density spray foam insulation provides continuity of air and thermal control
Flashing
8" concrete foundation wall
Protection board to 6" (150 mm) below grade
Drainage mat
4" XPS rigid insulation (R-20)
Dampproofing (water control layer drainage plane)
Capillary break
Granular fill
2" XPS rigid insulation (R-10)
Note: A continuous air-vapor control layer (e.g. heavy poly) can be used below the slab (never below the insulation) and sealed to the wall for slightly improved performance). Insulating under and around the footing is feasible and may be worth doing in very cold climates.
Air control should be made continuous by sealing the wall to the slab
Annoying thermal bridge at footing

walls

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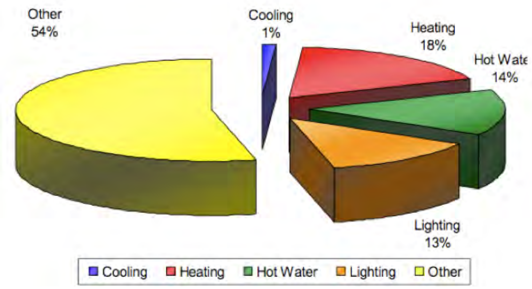
Lancaster V1

- Net Zero Energy Prototype
- Bay Area is very different climate: Goldilocks
  - Not too hot
  - Not too cold
- Solar is a good resource here
  - Subsidies are great

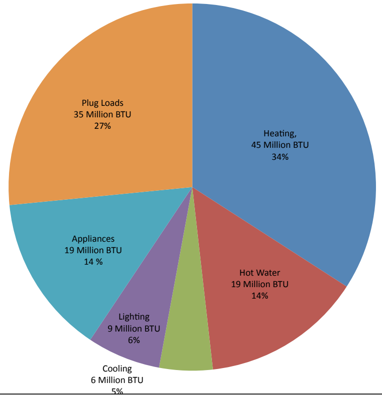
Lancaster

- Energy Use Distribution

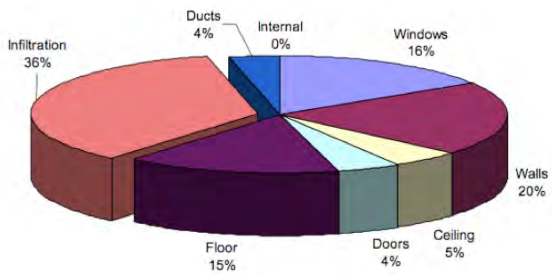


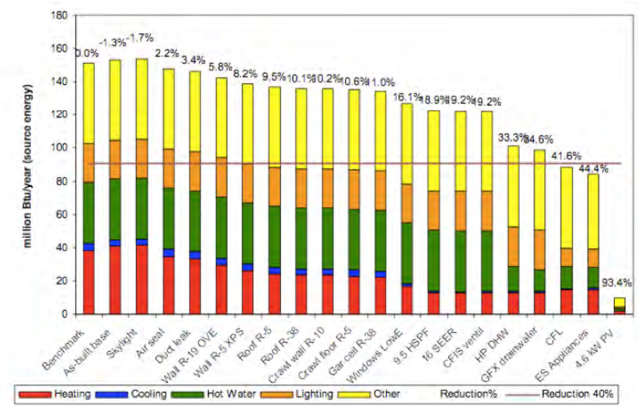
New England Example

5414 kWh and 19000 kWh heating DHW Predicted



Heating Load Breakdown





HVAC for Low-load houses

PH Economics of HVAC