Advanced Building Science for Mainstream Construction

Building Envelope Science | Passive House Design | Air & Moisture Flow Management

The Healthy Side of Zero-Energy: Passive House Buildings

Building Envelope Science | Passive House Design | Air & Moisture Flow Management

Healthy Side of Zero-Energy

- Energy Conservation, Compensation, and Lock-In Risk
- Climate, Assembly Design and Heat Losses
- Thermal Bridges, Mold, Condensation
- Windows/Doors, Thermal Comfort
- Indoor Air Quality
- Durability and Resilience

Conservation vs Compensation

Passive Solar

+

= ?

Net Zero

+

≥ 0

Passive House

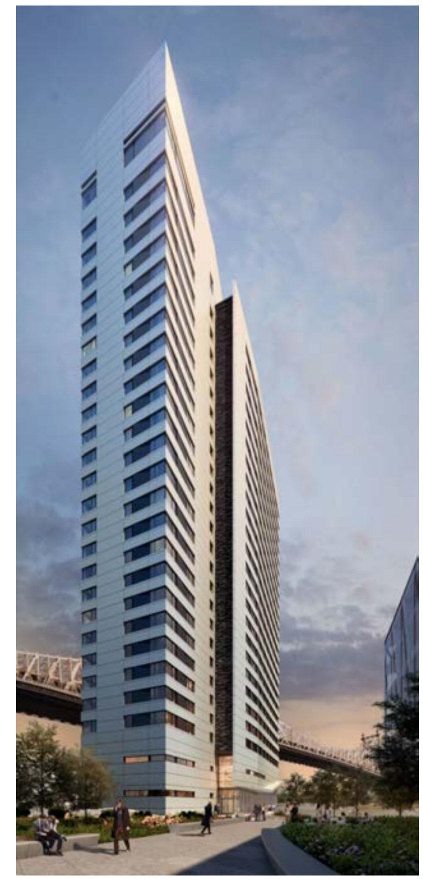
-90%

-75%

+

+

(≥ 0)

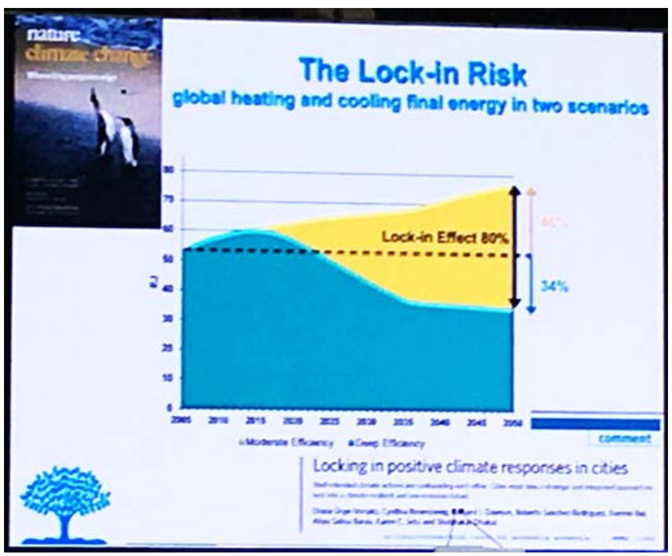


Lock-In Effect vs Dramatic Impact

Leave the use of '**green electricity**' to **other sectors**, because it is more difficult for them to implement it (e.g. **transportation**).

Buildings can reduce energy demand by **90%**

'**Net Zero**' is a **fashionable** term, but ***demand reduction is the most important part*** of the picture for buildings

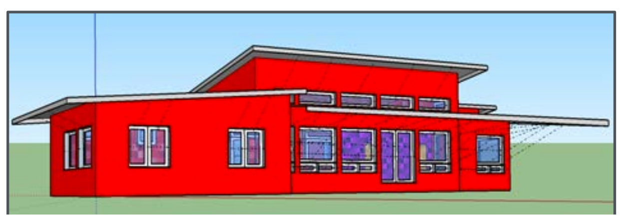


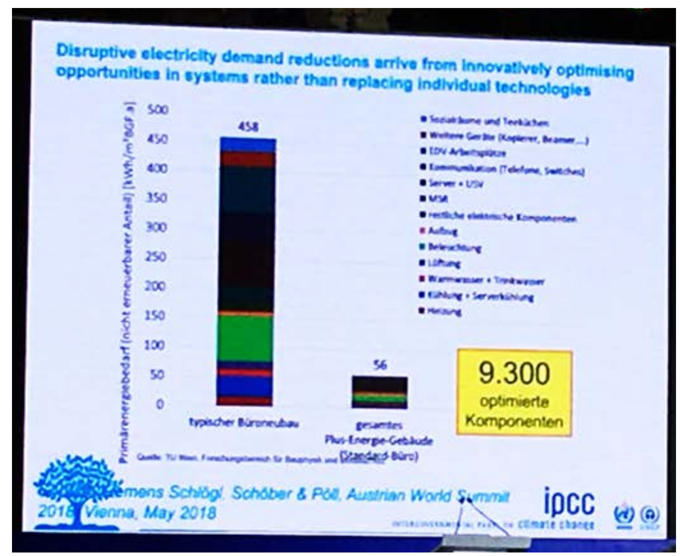
Example:

Building near Fraser, CO

Climate Zone 7

Heating Demand **-85%** compared to **2018 IECC**, thanks to **PH Envelope**

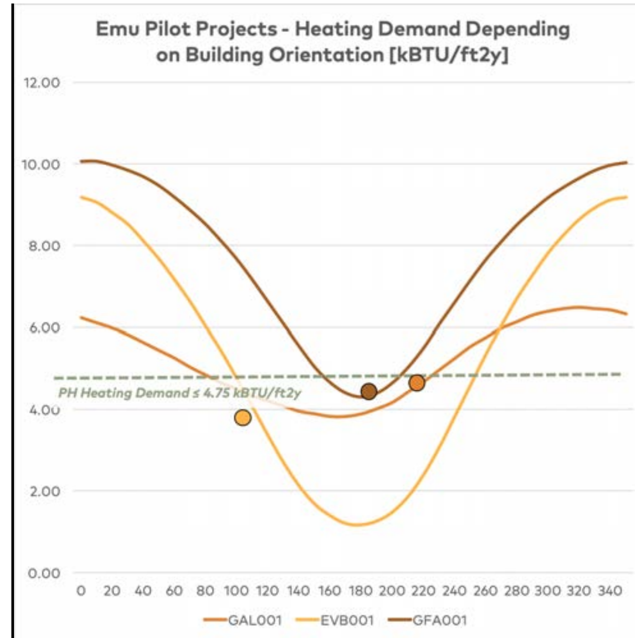


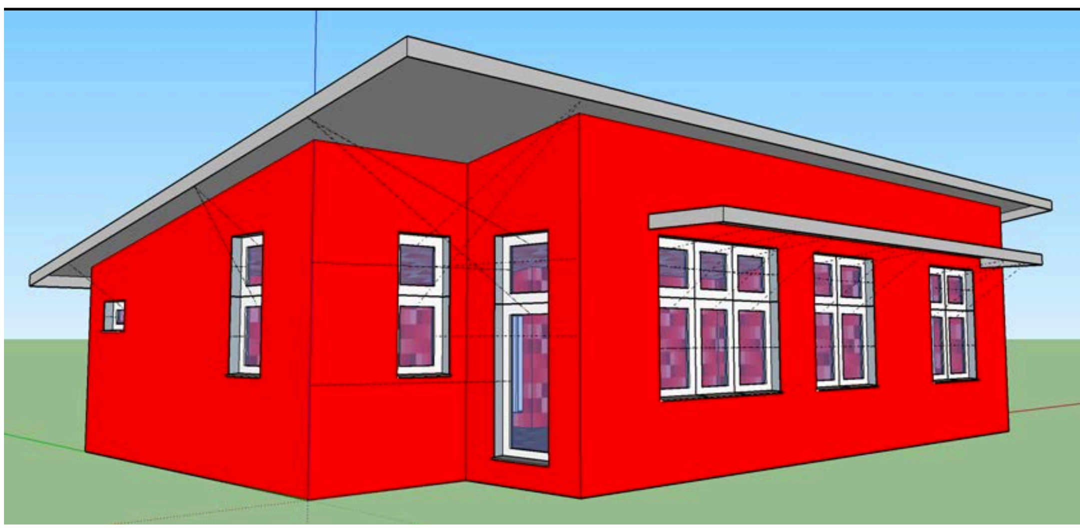


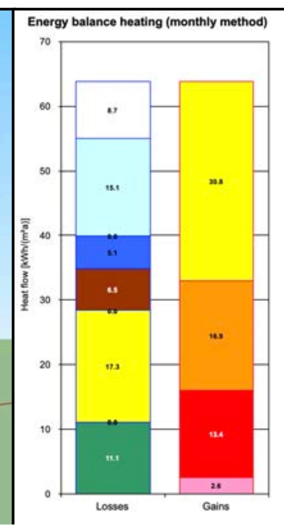
Size, Form, Orientation, Shading

Architectural design has a **huge impact** on **performance** of a building

Besides orientation, **size**, **form factor**, and shading are **architects' tools** for **energy efficiency**







Emu Pilot Program

Standardized construction methods that are 'good enough' to **achieve Passive House** and **Net Zero**

Goal: enabling the **'guy with a pickup truck and a nail gun'** to build Passive House

System #1 (2017 on): **new construction**

System #2 (2019 on): **retrofit**

System #3 (TBD): **mixed use**

Millhaus Project

Single Family, 2,840 ft2 TFA

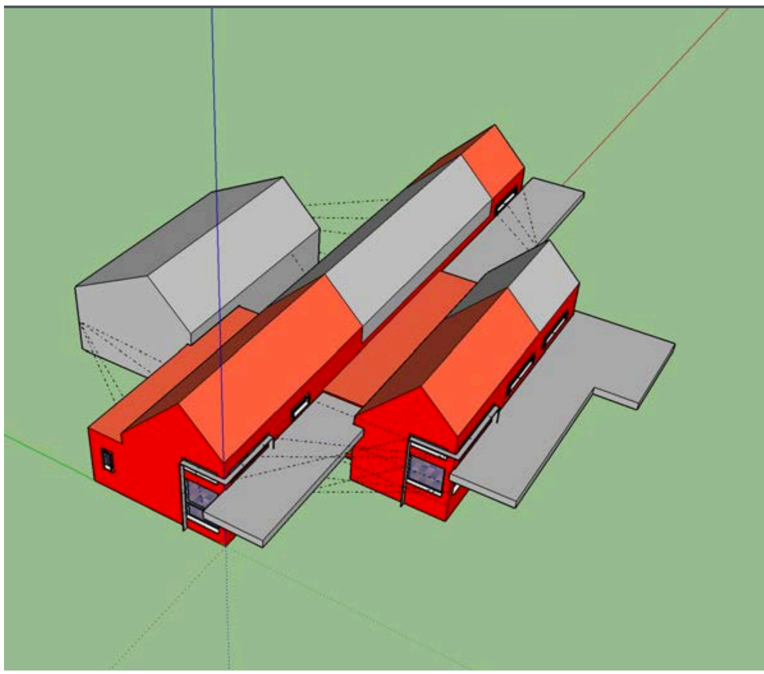
Climate 5

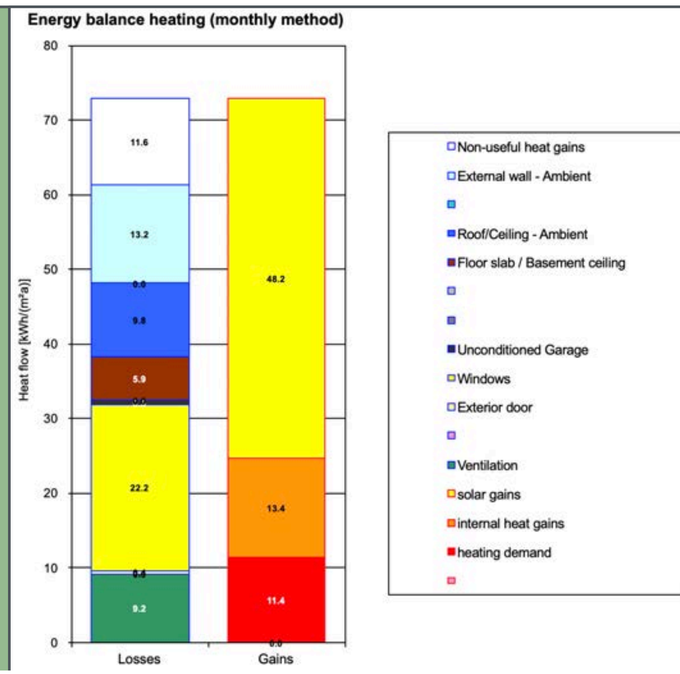
Stick frame, site built (self)

Form Factor: 4.23 ft2/ft2

Main Orientation: 190˚

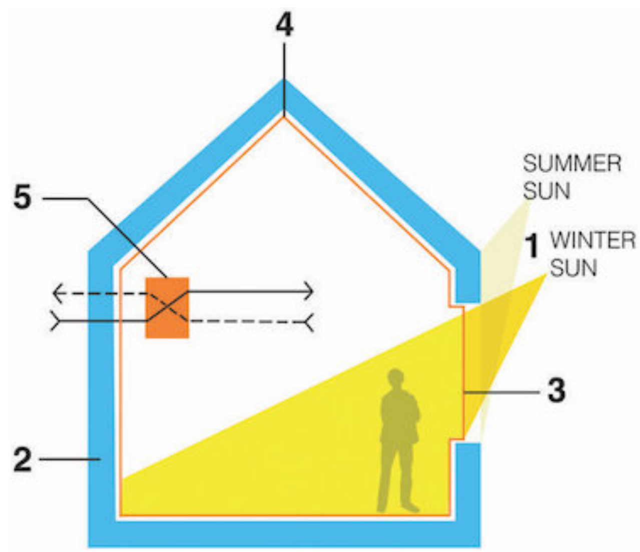
Ground Coupling: 0.52





Passive House Thermal Envelope

- Thermal Insulation/Mass
- Avoiding Thermal Bridges
- Quality Windows/Doors
- Indoor Air Quality
- Air Tightness



Thermal Insulation and Thermal Mass

Thermal Insulation

- keeps **heat** in or out
- keeps **sound** in or out
- allows easier **control** over internal environment
- **protects** from swings of external temperature
- **reduces need** for heating/cooling

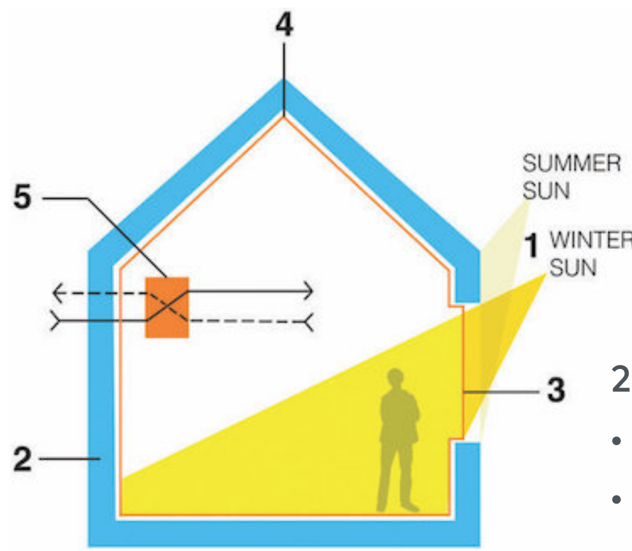
Thermal Mass

- improves uses of **solar gains**
- helps balancing **temperature** (and **moisture**)

Passive House Thermal Envelope

Thermal Insulation

- All envelope assemblies to be insulated
- Larger building require less insulation
- in Climate 5:
  - R40-50 for walls, incl. to unconditioned/ground
  - R25-30 for floors, incl. on grade
  - R40-60 for roof/ceiling



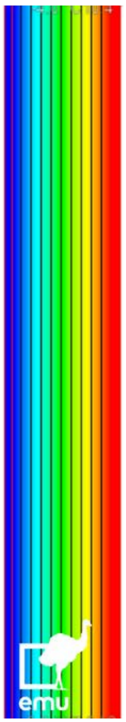
Millhaus Project

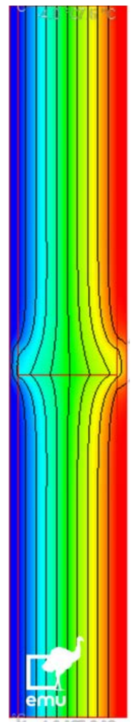
2018 IECC	Emu Pilot
Slab: R5 +p.	Slab: R50
Wall: R20	Wall: R54
Ceiling: 49	Ceiling: 60-80

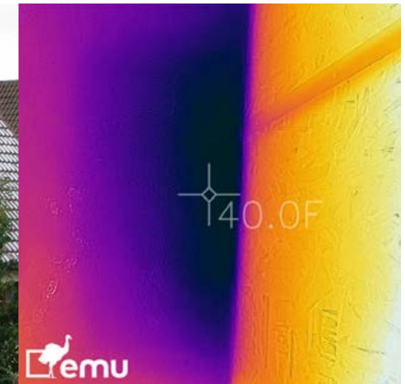
Thermal Mass

- exposed mass one counts most
- driven by climate and use

Thermal Bridges







Weak Spots in the Thermal Envelope

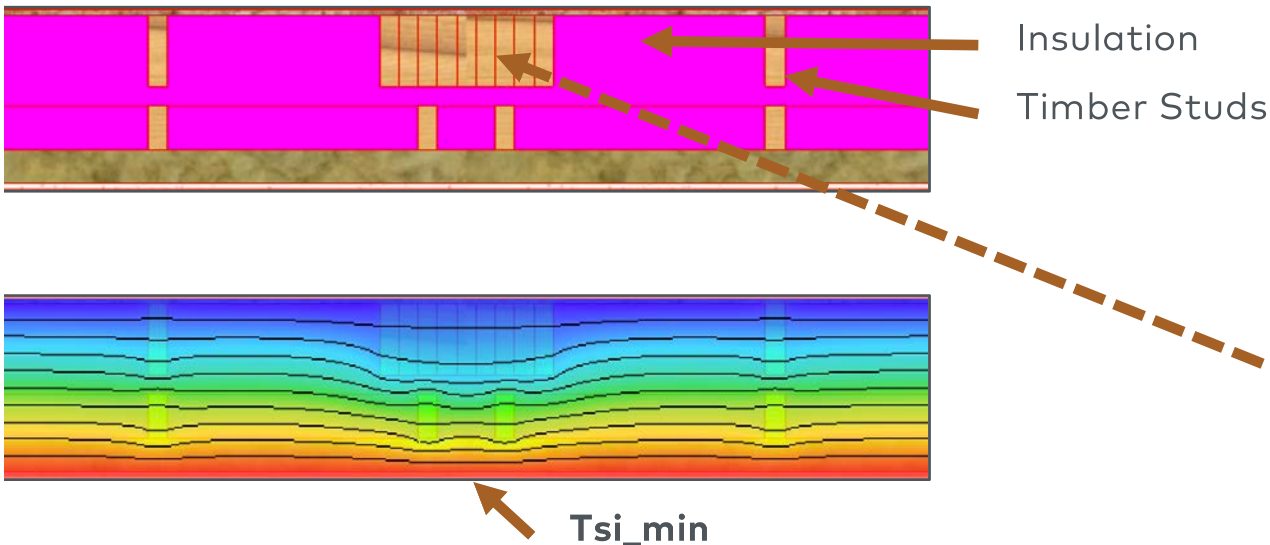
Worse Energy Performance

Risk of mold/condensation

fRsi value: minimum local temperature

PSI value: heat flow (compared to U-value calculation)

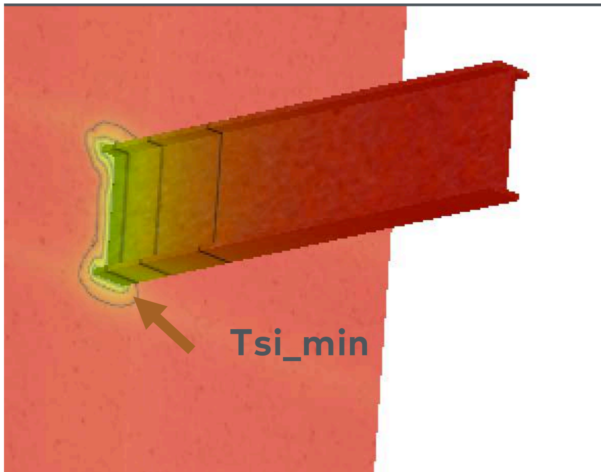
Thermal Bridges - Timber

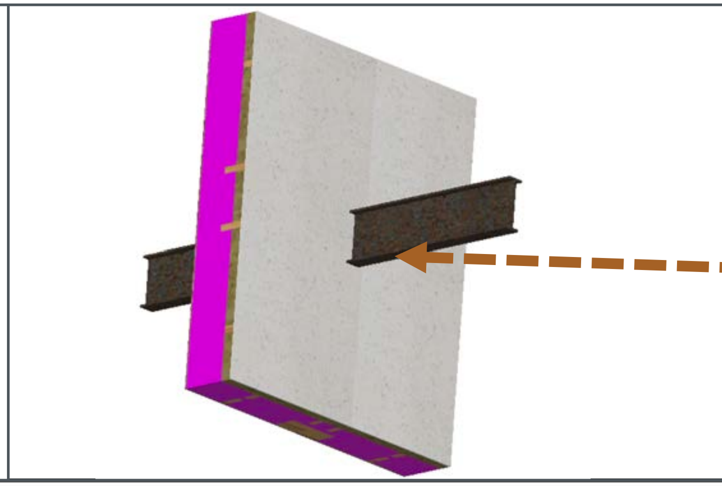


Timber Studs Thermal Bridge

Average Room Temperature, Ti [°F]	Temperature Factor - fRsi Value [-]	External Temperature, Te [°F]					
		50.0	40.0	30.0	20.0	10.0	0.0
70		Local Minimum Temperature, Tsi_min [°F]					
Unmitigated	0.962	69.2	68.9	68.5	68.1	67.7	67.3

Thermal Bridges - Steel



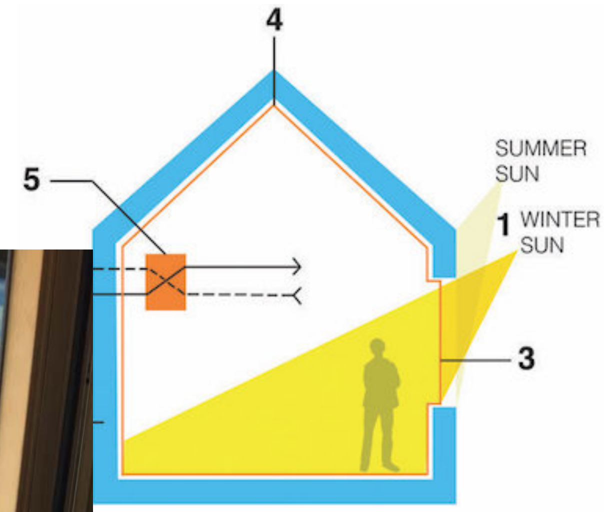


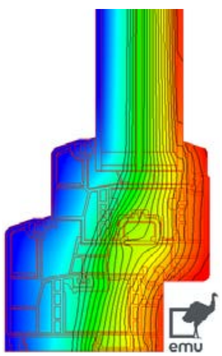
Metal Beam Thermal Bridge

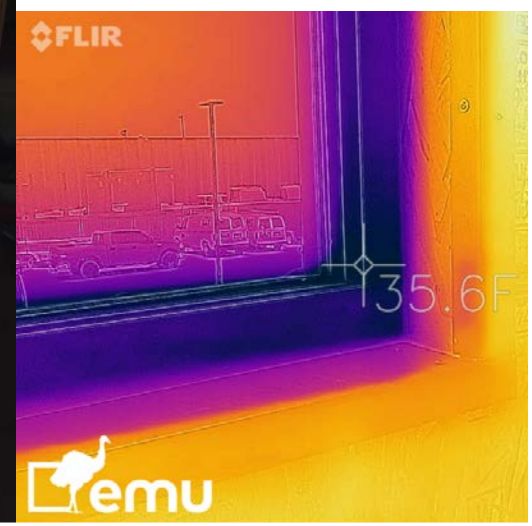
Average Room Temperature, Ti [°F]	Temperature Factor - fRsi Value [-]	External Temperature, Te [°F]					
		50.0	40.0	30.0	20.0	10.0	0.0
70.0		Local Minimum Temperature, Tsi_min [°F]					
Unmitigated	0.648	63.0	59.4	55.9	52.4	48.9	45.4
Mitigated	0.902	68.0	67.1	66.1	65.1	64.1	63.1

Quality Windows/Doors

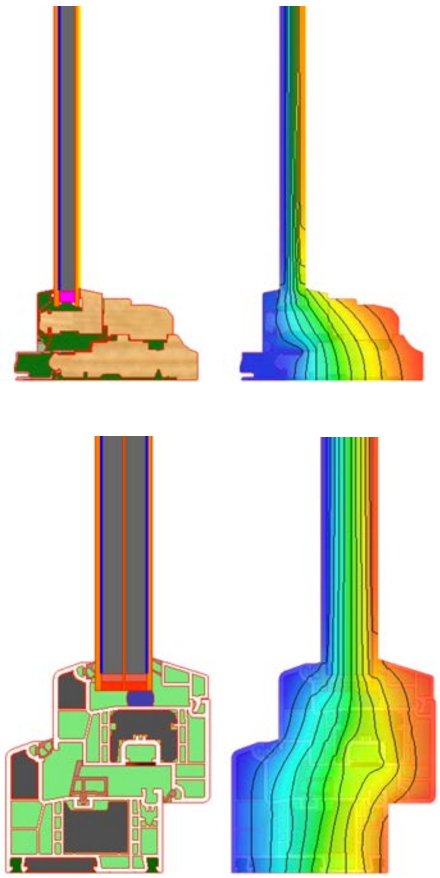
- **Holes** in the thermal envelope
- Provide **passive solar gains** (free heating)
- Critical for **mold/condensation**

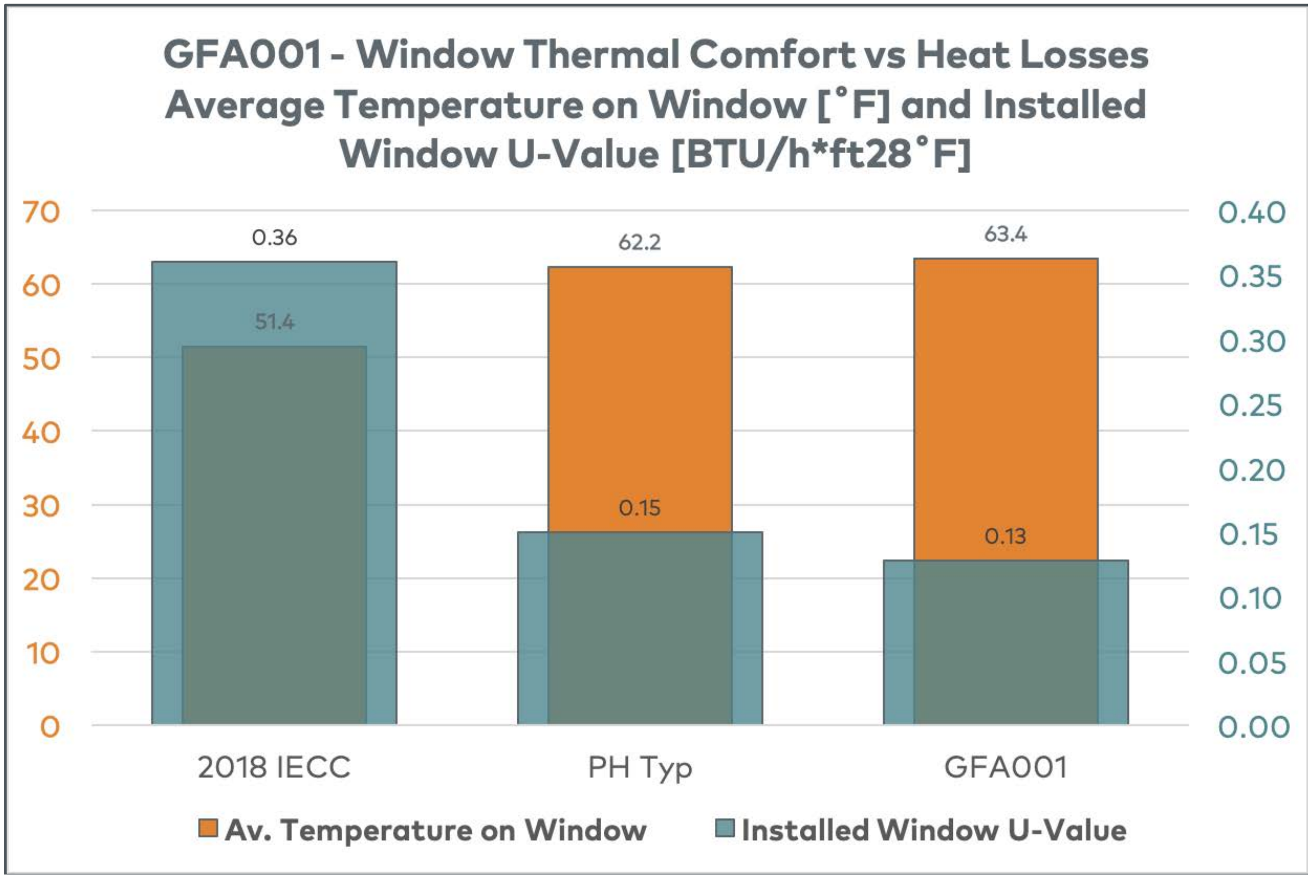




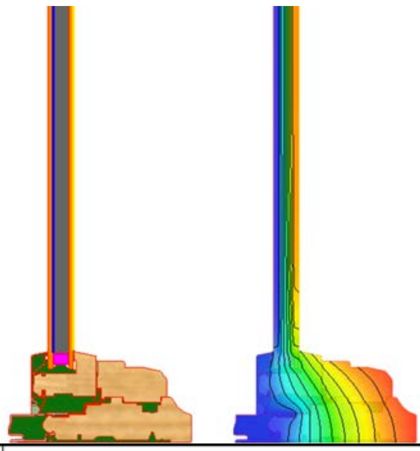


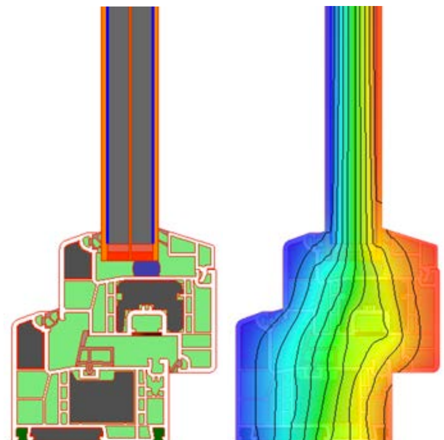
Windows: What About Comfort?





Windows: What About Condensation?

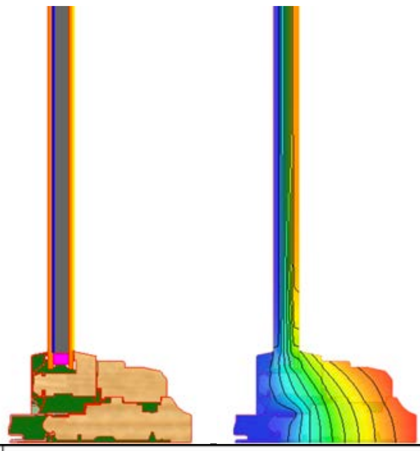




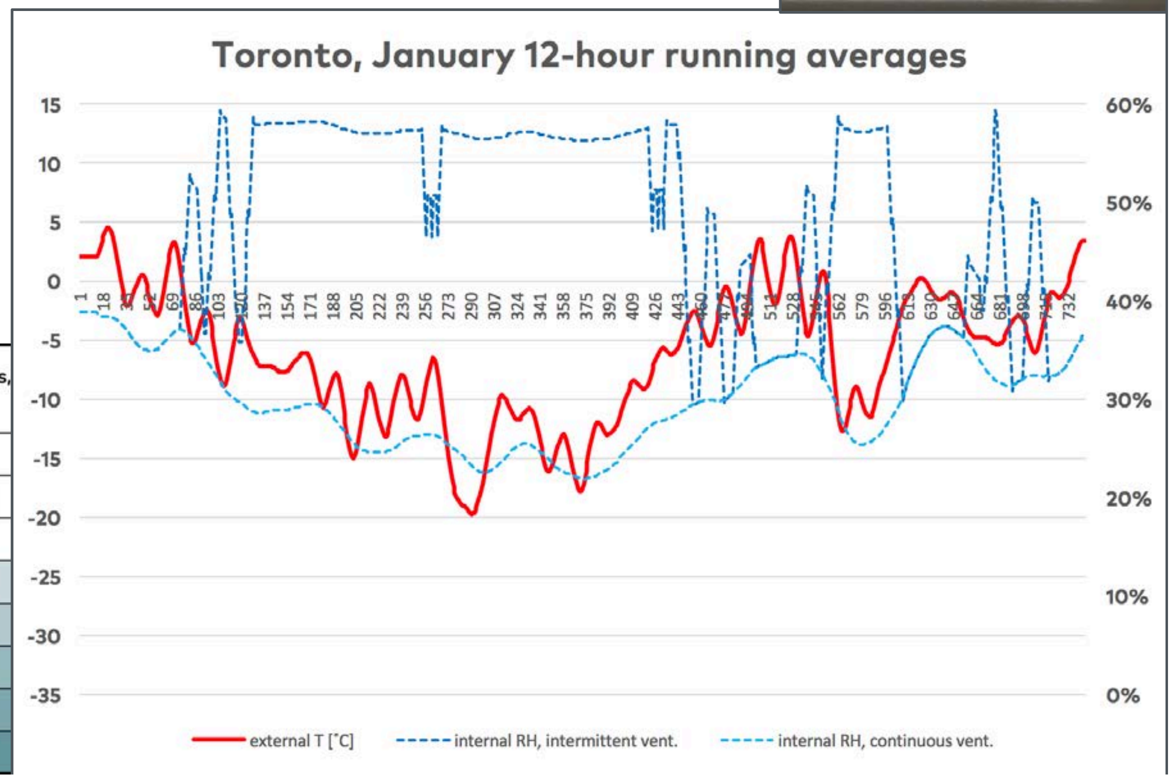
CONDENSATION RISK	Traditional Timber Frame Series, Casement Profile, Douple Pane Glass, low-e on #2 and #4, Stainless Steel Spacer				
	External Temperature [°F]				
Room Average Relative Humidity	10.0	20.0	30.0	40.0	50.0
	Local Relative Humidity at Glass Edge				
20%	64.5%	52.1%	42.6%	35.1%	29.0%
30%	95.9%	77.5%	64.4%	52.1%	43.0%
40%	100.0%	100.0%	85.3%	70.1%	57.9%
50%	100.0%	100.0%	100.0%	87.2%	72.0%
60%	100.0%	100.0%	100.0%	100.0%	86.9%

CONDENSATION RISK	Alpen Tyrol PH+ Series, Tilt/Turn Profile, Thin Triple Glass + Warm Edge Spacer				
	External Temperature [°F]				
Room Average Relative Humidity	10.0	20.0	30.0	40.0	50.0
	Local Relative Humidity at Glass Edge				
20%	28.4%	26.9%	25.4%	24.0%	22.6%
30%	42.3%	39.9%	37.6%	35.7%	33.7%
40%	56.8%	53.8%	50.6%	48.0%	45.3%
50%	70.6%	66.8%	63.0%	59.6%	56.3%
60%	85.2%	80.7%	76.0%	72.0%	67.9%

Who's in Charge?



CONDENSATION RISK	Traditional Timber Frame Series, Casement Profile, Douple Pane Glass, and #4, Stainless Steel Spacer			
	External Temperature [°F]			
Room Average Relative Humidity	10.0	20.0	30.0	40.0
	Local Relative Humidity at Glass Edge			
20%	64.5%	52.1%	42.6%	35.1%
30%	95.9%	77.5%	64.4%	52.1%
40%	100.0%	100.0%	85.3%	70.1%
50%	100.0%	100.0%	100.0%	87.2%
60%	100.0%	100.0%	100.0%	100.0%

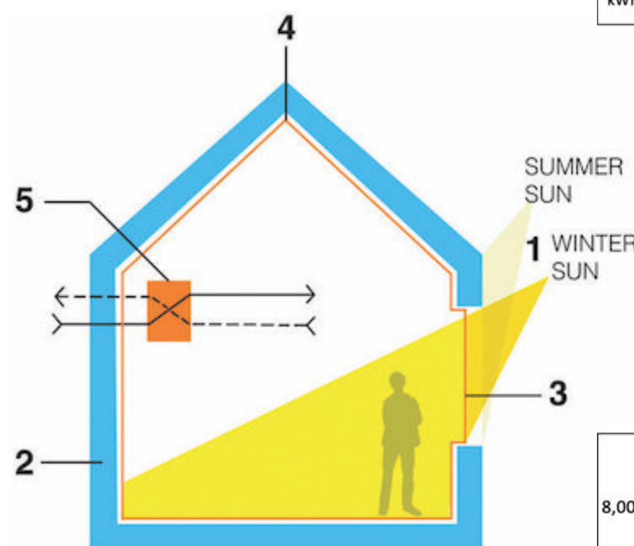


Passive House Thermal Envelope

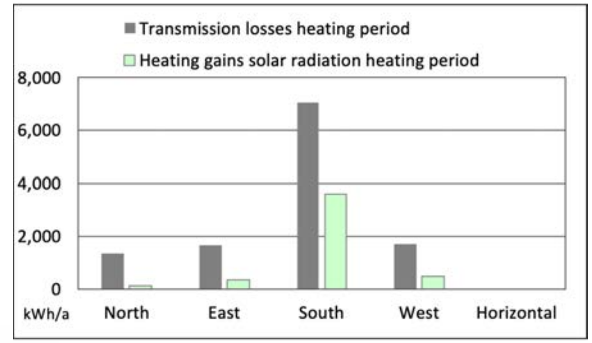
Passive House Windows

- Windows = Solar Collectors
- At least one operable window per main occupancy room
- In Climate 5:
  - Uw_inst ≤ 0.15
  - Uw ≤ 0.14
  - insulated wood or PVC frame, thermally broken aluminum or steel
  - triple pane glass w/ low-e coating
  - warm edge spacer (plastic)
  - Argon or Krypton gas fill
  - SHGC by project/climate

(same applies to doors, curtain walls, skylights, sun tubes etc.)

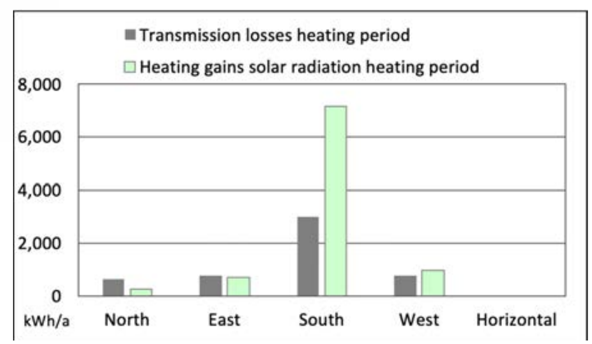


2018 IECC Windows



Millhaus Project

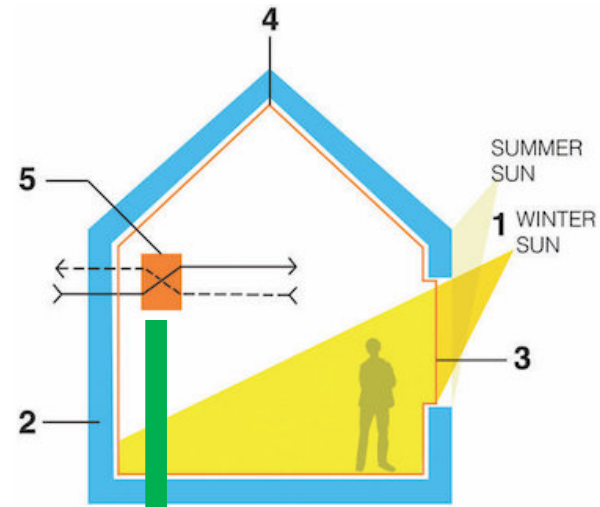
Passive House Windows

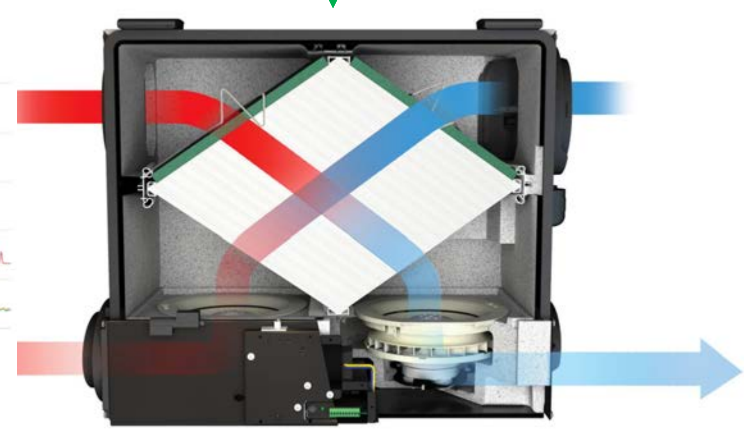


Indoor Air Quality

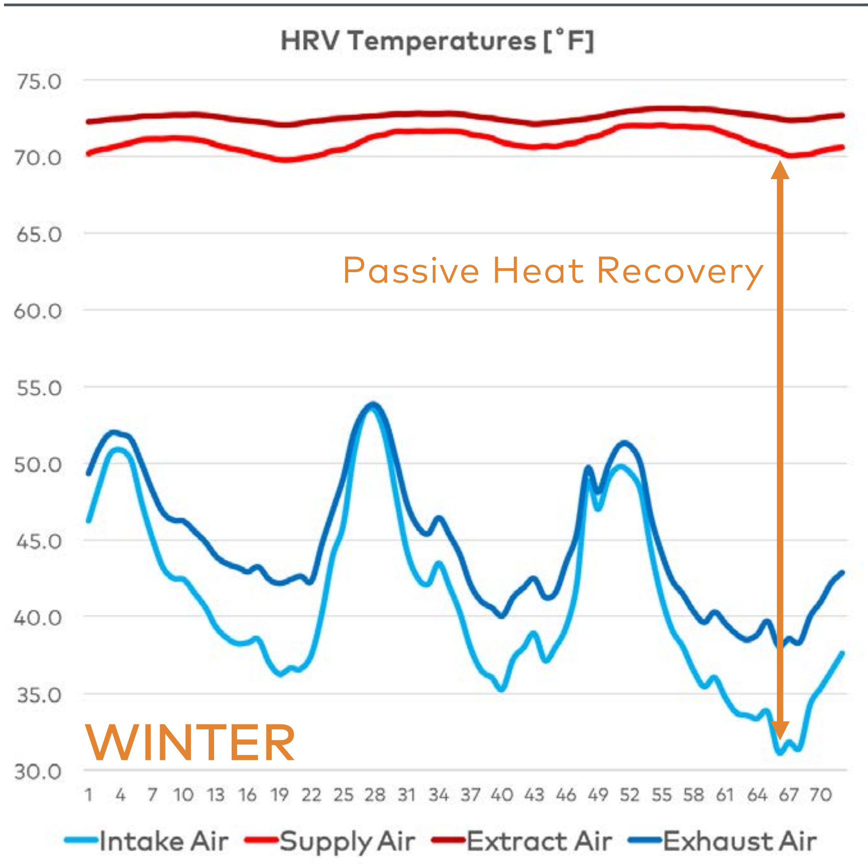
Breathing through the skin

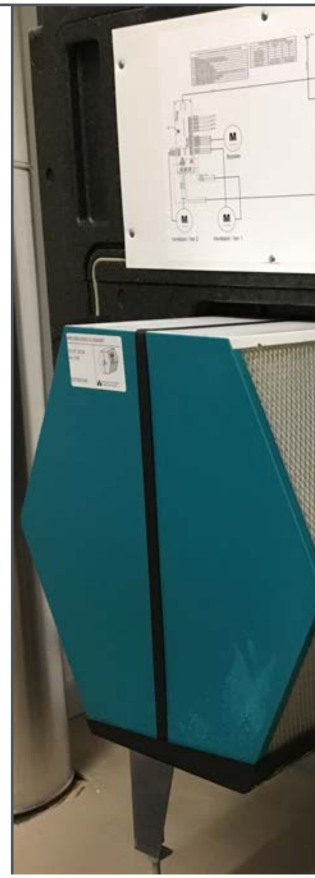
- inefficient exchange
- no heat/ moisture recovery
- no control over pollutants

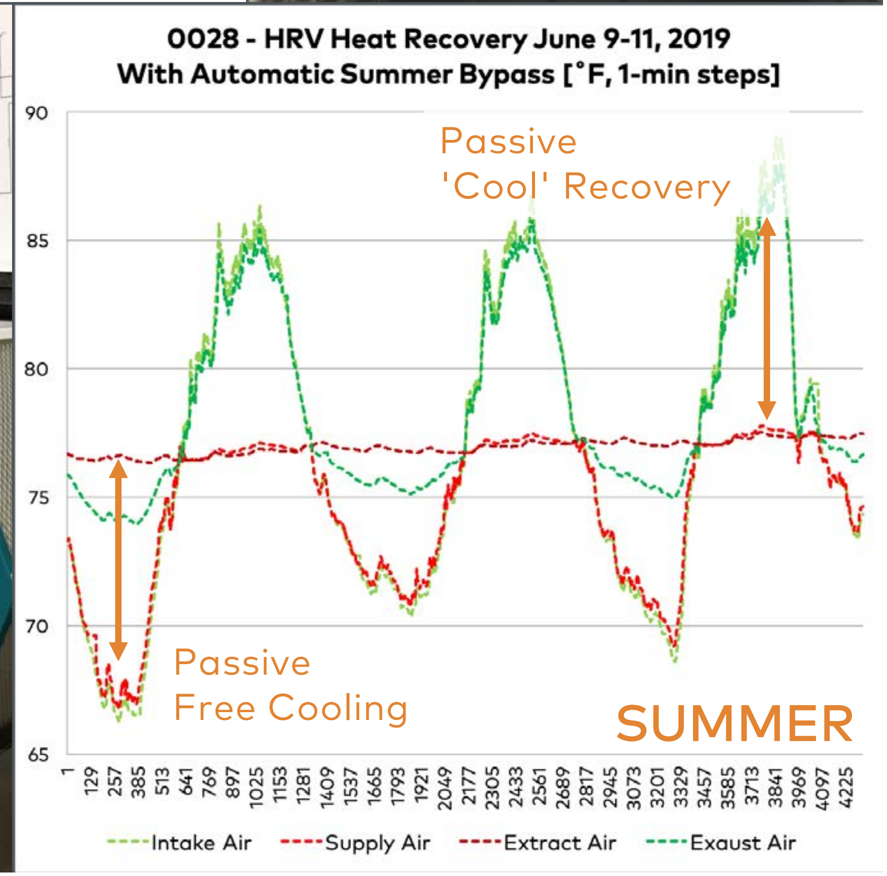




Ventilation, With Heat Recovery



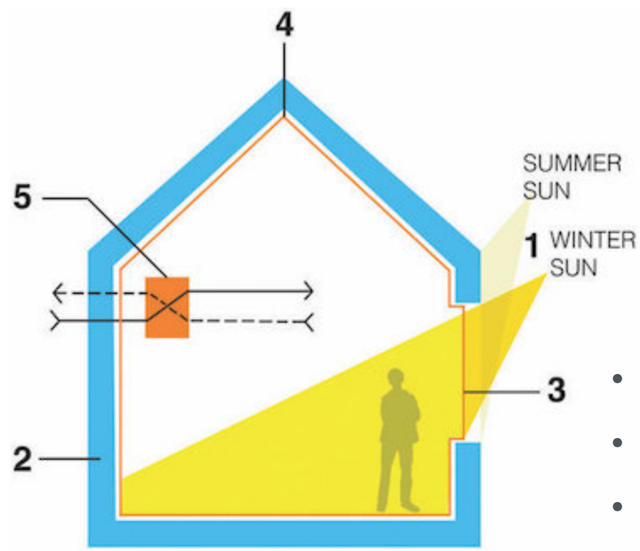




Passive House Thermal Envelope

Indoor Air Quality

- continuous filtered ventilation via mechanical system
- ERV or HRV, depending on climate/occupancy
- heat recovery > 75%
- integrated extract for e.g. bathrooms (no separate extract)
- separate exhaust for kitchen (for cleanliness



Millhaus Project

- ERV whole building sys.
- continuous ventilation
- average rate: 100 cfm
- dedicated kitchen extract

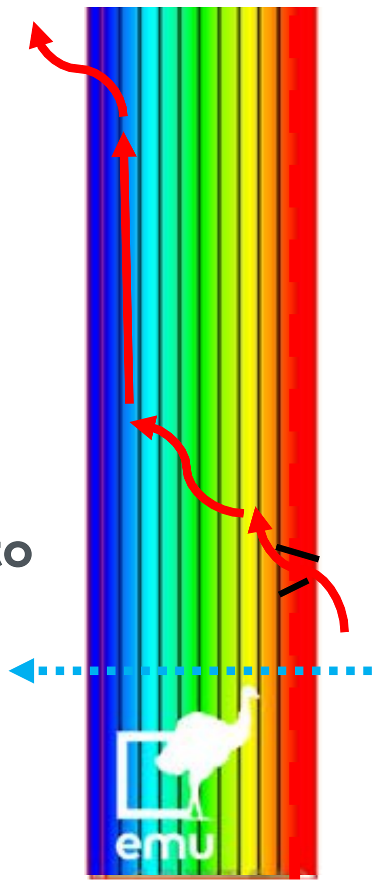
emu

Air Tightness and Building Durability

Moisture-driven Building Damages

- loss in performance
- biological decay (materials rot)
- corrosion

Air Convection: carries up to <u>30 times</u> more moisture than Vapor Diffusion

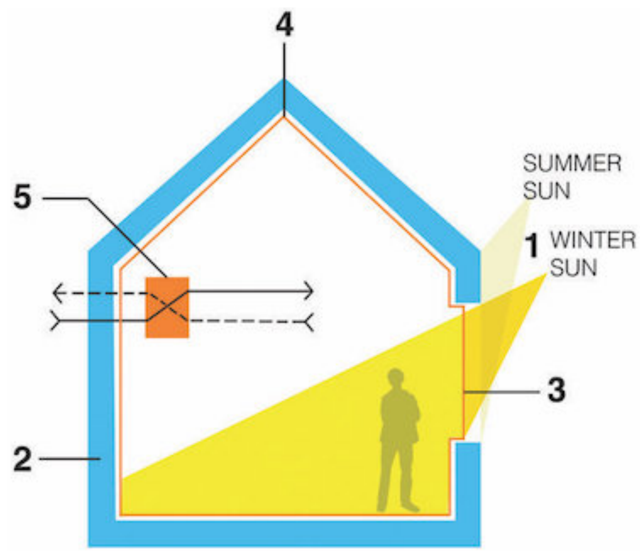


Withi buildings becoming more insulated and airtight, **thorough design** a **accurate installation** are critical

Passive House Thermal Envelope

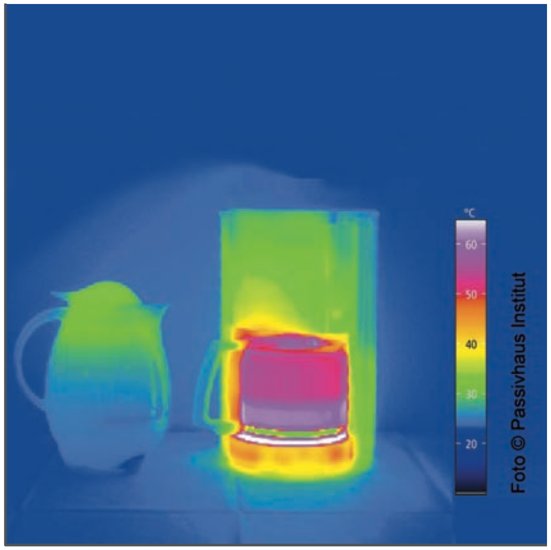
Air Tightness

- ≤ 0.6 ACH50
- preliminary test recommended before drywall
- larger buildings: easier to meet



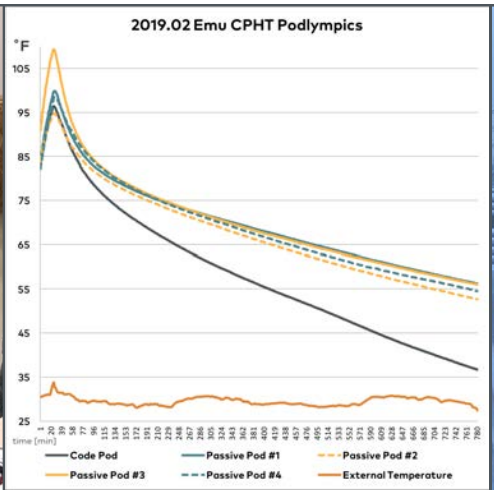
emu

Thermal Resiliency

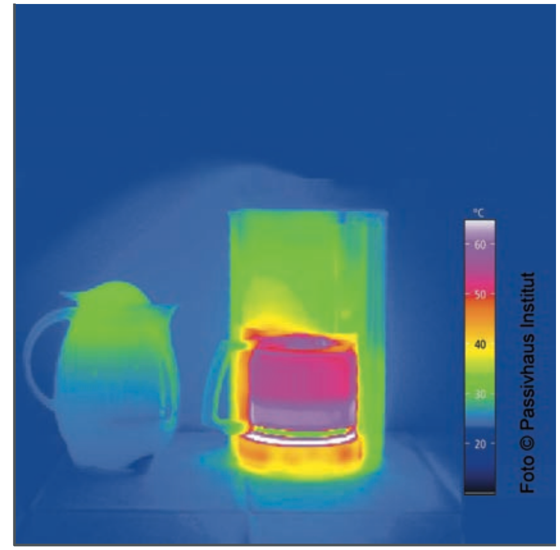


High Time Constant: combination of high thermal insulation, quality windows/doors, air tightness, and heat storage

Builder Training in Arvada, CO: proof of concept at the end of hands-on workshop

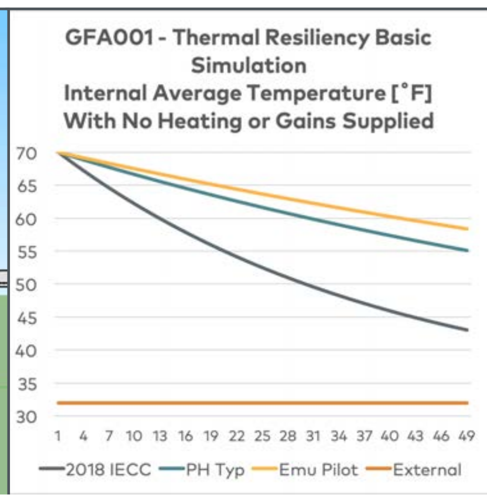


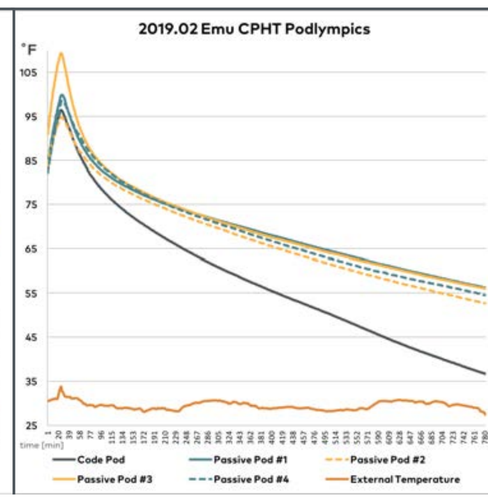
Thermal Resiliency



High Time Constant: combination of high thermal insulation, quality windows/doors, air tightness, and heat storage

Thermal resiliency basic simulation on Millhaus project shows same thermal behavior





It's Never Too Late!

The same principles apply to **new builds** as well as **energy retrofits**

Up to **95%** energy saving* potential compared to **existing buildings**

Up to **75%** energy savings* compared to **new buildings**

Net demand* for heating/cooling, ***before* renewables are factored in*

92
kBTU/ft²y

-94%

5.38
kBTU/ft²y

emu

Does Passive House Cost More?

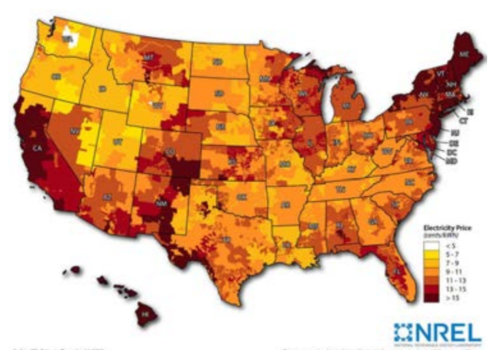
- single family
- multi family
- schools
- hotels
- hospitals
- offices
- factories
- supermarkets
- museums

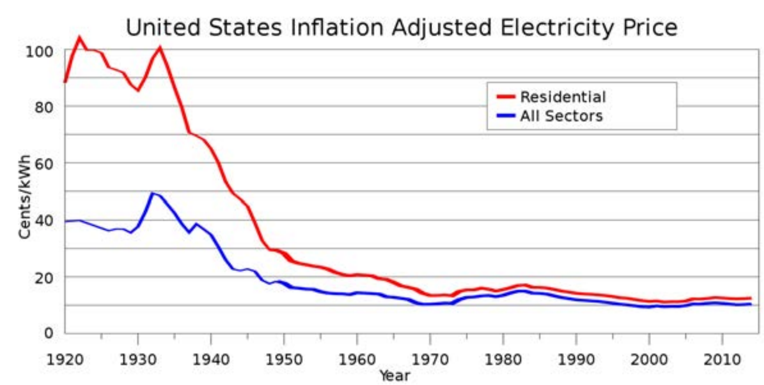
single family → probably yes

multi family, schools, hotels, hospitals, offices, factories, supermarkets, museums → probably no

cost-effectiveness requires:

- clear goals
- realistic expectations
- integrated design
- clear understanding of what PH is, and what it is not.





emu

What Will Cost More?

More Expensive

- Windows, Windows, Windows, Windows
  - In Climate 5: typical U-values of **0.14** (as opposed Code windows at **0.32**) – also applies to external doors, curtain walls etc.

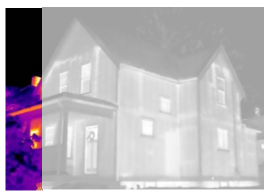
...

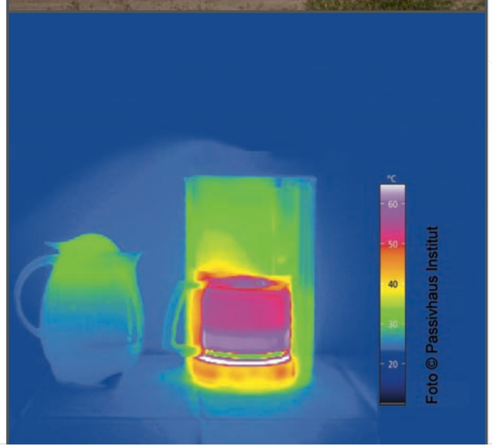
- Thermal Insulation
- Air Sealing

Cheaper

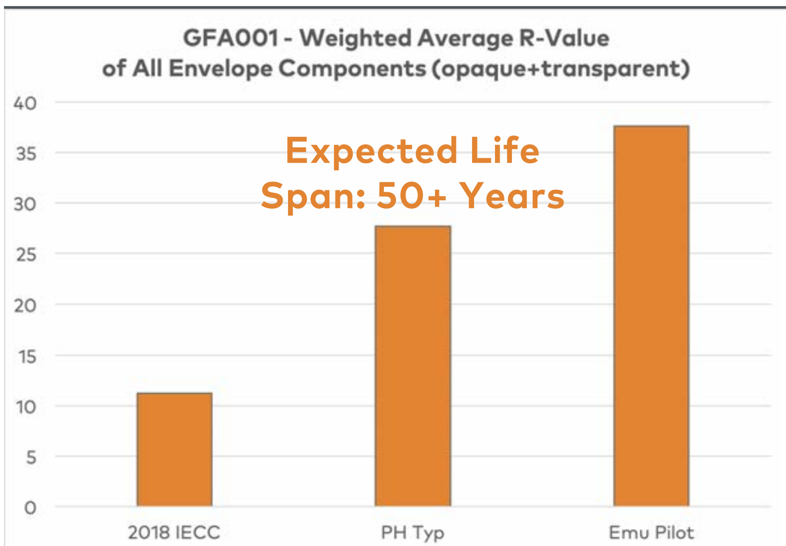
- Heating/Cooling Equipment
  - Typical heating/cooling loads reduced indicatively by **factor 5**
- PV System for Net Zero
  - Typical system size reduced by **factor 3**

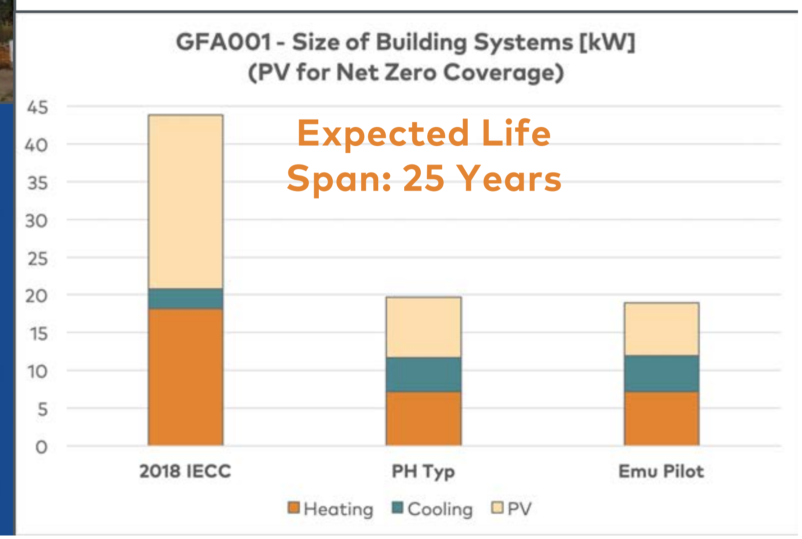
What Will Break Sooner?





Cheaper





Healthy Side of Zero-Energy

- Passive House building envelope is a **streamlined path** to Net Zero
- Compared to conventional buildings, **75-90% of heating/cooling demand** can be avoided by good envelope design
- Size of **heating/cooling equipment** can be reduced by **factor 5**, **renewables systems** (PVs) can be reduced by a **factor 3**
- Quality of building components incl. assemblies, windows/doors etc. influence **comfort** and **hygiene** (mold/condensation) besides energy efficiency
- Highly insulated, air tight building are more **durable** and **resilient** than conventional buildings

The Healthy Side of Zero Energy Passive House Buildings

Buildings are for People

emu