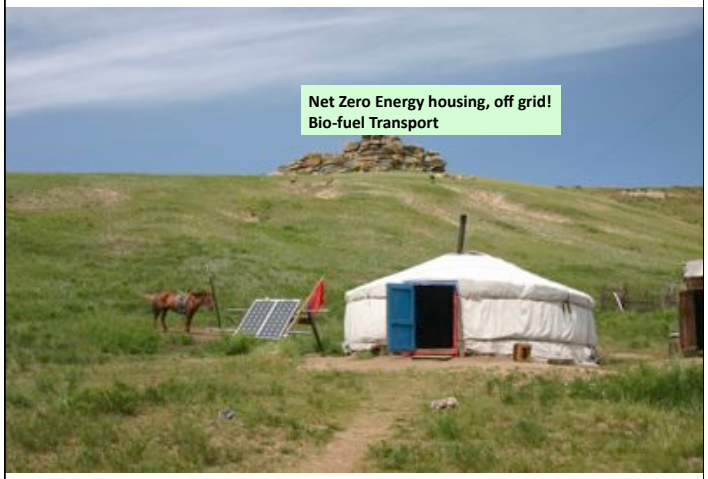


Towards Net Zero Housing

www.BuildingScience.com

Dr John Straube P.Eng
University of Waterloo
Building Science Corporation

Presentation Outline

- What is Net Zero Energy
- Why build NZE
- General

Net Zero Energy

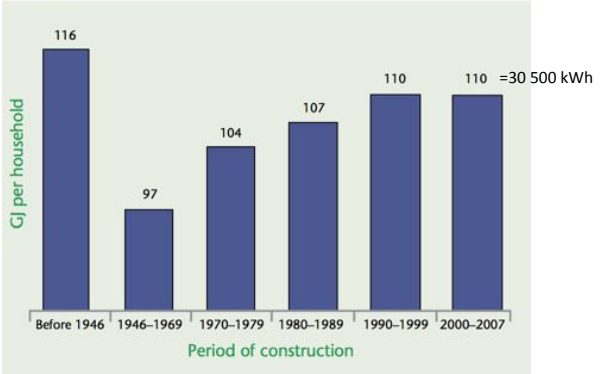
- **Generate** as much **energy** in a **year** as you consume
  - Generation: on site, usually solar, sometime wind
    - 1.0 kWh = 3.6 MegaJoule = 3412 BTU =0.12 m^3 NG
  - Energy can be electricity, natural gas, oil, LPG
  - Annual: Make up for low winter solar gain
    - Wind can be more in winter than summer
    - Uses the grid as a big 100% efficient battery
- PlusHouses *produce* more than they consume

What uses energy in a house?

- Space heating: Big deal in Canada! (50-65%)
  - 10 000 to 30 000 kWh and up for newish house
- Other
  - Domestic hotwater (≈4000+ kWh)
  - Refrigeration (500 kWh)+ Range (500 kWh) = 1000
  - Washer (250 kWh), Dryer (900 kWh) = 1150
  - Lighting (750-2000 kWh) 750
  - Plug and misc (1000-3000 kWh) 2000

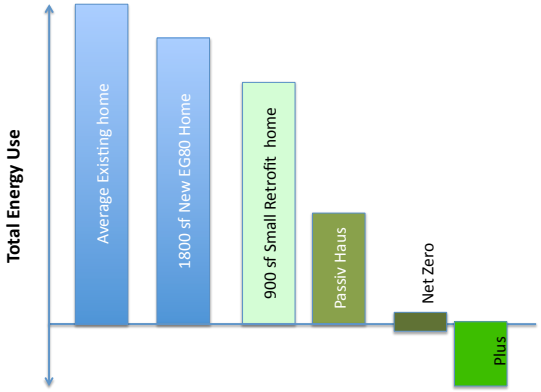
Typical Household: 15 000 to 35 000 kWh

Chart 9. Energy consumption by year of construction, 2007 (GJ per household)



Natural Resources Canada, OEE, 2007 Survey

Energy Use Comparison



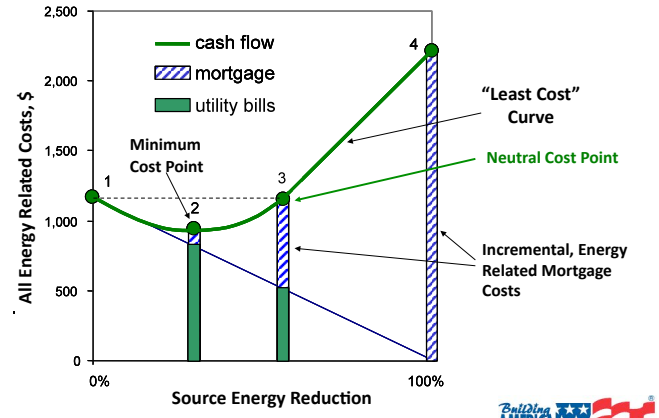
Generation or Conservation?

- Big Question!
  - Easy Economics when Net-Zero Energy
  - Compare $/kWh/yr for each choice
- PV costs $7500/kWp installed
  - Produces 1100-1250 kWh/yr
  - About >$5/kWh/yr (so $150 000 for typical home)
- Wind costs vary a lot. Large are cheapest.
  - Small wind (<50 kW) is expensive because it does not produce as much as they say

Strategy

- Should we build NetZero Houses?
  - On site renewables are not very cost or resource effective
  - Who will pay for the grid when we get a lot of NZE?
- But, Fun to try!
- Reduce heating loads ***first and foremost***
- Reduce DHW, appliance, lighting loads

Capital Investment vs Operating Cost



Underlying Source: Dr Ren Anderson, NREL

Heating Load Reduction

- Cut heating load by around half
  - Insulation levels should be roughly doubled
  - Airtightness should be cut as much as practical
- Precise values will depend on relative costs
- Attics are cheaper to insulate with loose fill
- Smaller and simpler houses are easier

Heating Equipment

- High efficiency heating
  - Condensing furnace if you have gas
  - Combo instantaneous boilers w/microstorage
  - Air-source heatpumps with no or little backup
  - Ground-source heatpumps (esp for large houses)
- High efficiency, low wattage HRVs
  - Ventilation rates are often too high
  - Distribution is important for IAQ
- Active solar should be investigated

DHW

- Solar assisted hotwater usually justified
  - Cheaper than PV
- Low hotwater draw appliances are important

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

CMHC Riverdale House:

- NetZero in Edmonton! Duplex
- 5.6 kW PV, 6-30 tube solar hotwater
- 17 000 liter storage tank

5700 HDD C / 10 200 F

Riverdale Performance Data

- Duplex: key!
- R100 roof
- R55 wall
- Triple windows
- R50 basement
- R24 slab
- 0.5 ACH@50 Pa

Predicted Annual Energy Consumption (by heated floor area)	
Total annual energy use:	61.51 kWh/m²
Space heating:	33.65 kWh/m²
Domestic water heating:	9.44 kWh/m²
Appliances/lighting:	16.39 kWh/m²
Mechanical ventilation:	2.02 kWh/m²
Predicted Annual Energy Production (by heated floor area)	
Total annual energy production:	63.01 kWh/m²
Passive solar space heating:	18.68 kWh/m²
Active solar space heating:	9.57 kWh/m²
Active solar domestic water heating:	8.15 kWh/m²
Solar electricity:	26.60 kWh/m²
Predicted Annual Energy Balance:	**+1.5 kWh/m²**

CMHC Avalon House Red Deer, AB

- Single Family, wow
- R87 roof
- R70 wall
- R60 slab, No basement
- Triple windows, R5
- 0.5 ACH@50 Pa
- 8.6 kW PV
- SHW

5500 HDD C / 10 000 F

CMHC Minto House Ottawa

- Larger 310 m^2 floor area
- R60 roof, R44 Wall R5.7 Triple windows
- R40 basements R15 slab
- 0.65 ACH50
- 6.2 kWp PV
- Large SHW
- Market ready design

CMHC Toronto Now House

- Retrofit of a 1500 sf (incl basement) 1950 house
- R36 roof, R40 wall, R25 basement, R25 slab, R6 triple glazing, 2.6 ACH50
  - Somewhat under-insulated for NZE, even in Toronto
- 2.7 kW PV, 52 sf evacuated tube solar collector
- **Not** Net Zero Energy
  - Needs 8000 kWh of natural gas/yr

4000 HDD C / 7200 F

Now House

- Excellent low-energy retrofit
- Could be NZE with another 6+ kWp of PV
- Better roof insulation would likely have made sense
- Better airtightness important
- Too much thermal bridging

Figure 2. Dimension lumber and plywood trusses screwed to the sheating on sixteen-inch centers provide adeqate insulation space and a nailing base for finish siding.

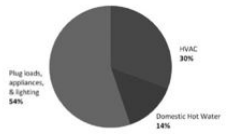
Comparison of CMHC Equilibrium

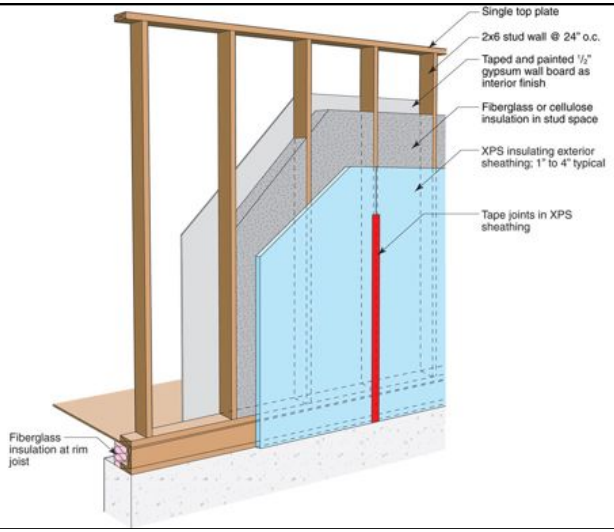
- NZE Possible: Super-insulated, Super-tight, large PV arrays, large SHW systems

Location	Now Toronto	Avalon Red Deer AB	Riverdale Edmonton	ecohome Ottawa
HDD (18C)	4000	5500	5600	4600
Floor Area (heated m2)	139	240	234	310
Total Site Energy (ekWh)	13475	13094	14391	20646
Heat Energy (kWh/m2)	23.1	23.9	33.7	40.2
Roof (R)	36	87	100	60
Wall	40	70	56	44
Window	5.7	5	7.3/10	5.7
Basement walls	25	none	54	40
Slab	25	60	24	15
ACH@50	2.6	0.5	0.5	0.65
PV Installed (kWp)	2.7	8.6	5.6	6.2
SHW produced (kWh)	1824	3886	1907	6665
PV produced (kWh/yr)	2800	9569	6224	8184
Notes	Not NZE		Duplex	

Pill House, Vermont, 2800 ft2

- 10 kW wind turbine on 120 ft tower=6500 kWh
- R56 ceiling, R40 walls, triple-glazed window
- R20 basement, 2 ACH50
- South-facing
- **GSHP**

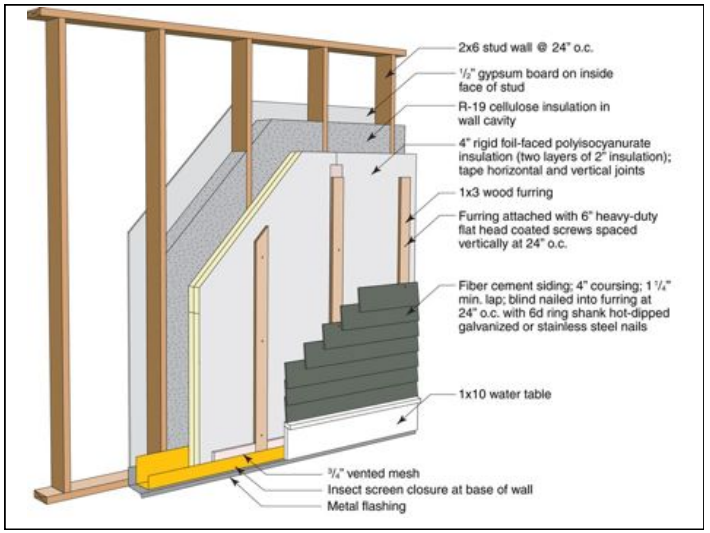




Thermal bridges

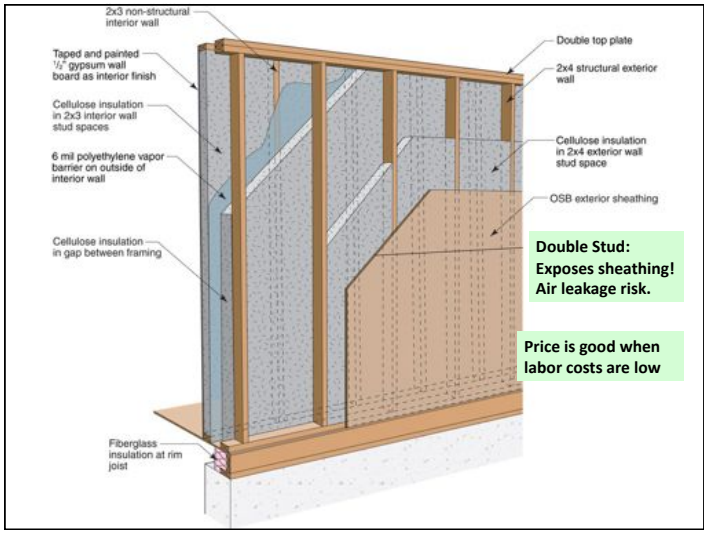
- Thermal bridges provide shortcut for heat through insulation
- Heat passes through the structural members
- Common offenders
  - Floor and balcony slabs
  - Shear walls
  - Window frames
  - Steel studs

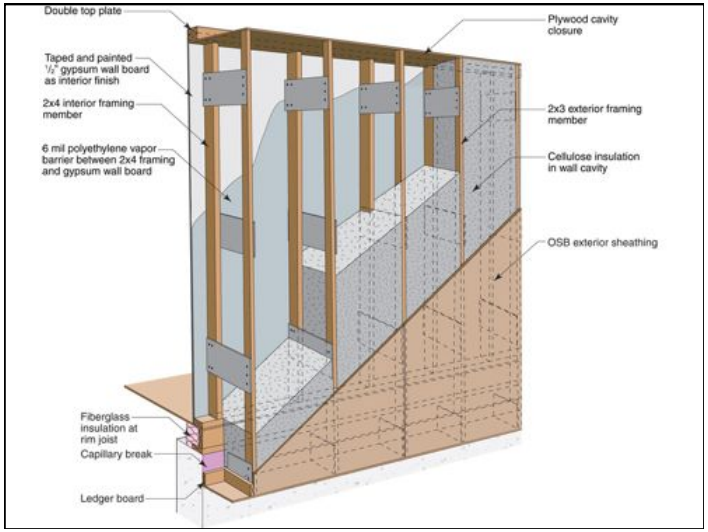

Find the thermal bridge


2x6 stud wall @ 24" o.c.
½" gypsum board on inside face of stud
R-19 cellulose insulation in wall cavity
4" rigid foil-faced polyisocyanurate insulation (two layers of 2" insulation); tape horizontal and vertical joints
1x3 wood furring
Furring attached with 6" heavy-duty flat head coated screws spaced vertically at 24" o.c.
Fiber cement siding; 4" coursing; 1 ¼" min. lap; blind nailed into furring at 24" o.c. with 6d ring shank hot-dipped galvanized or stainless steel nails
1x10 water table
¾" vented mesh
Insect screen closure at base of wall
Metal flashing


Brick veneer/stone veneer
Drained cavity
Exterior rigid insulation — extruded polystyrene, expanded polystyrene, isocyanurate, rock wool, fiberglass
Membrane or trowel-on or spray applied drainage plane, air barrier and vapor retarder
Non paper-faced exterior gypsum sheathing, plywood or oriented strand board (OSB)
Insulated wood stud cavity


• 4" of Taped Foam over 2x6
• About R40 incl. thermal bridges
Building Science
Rain Control 29


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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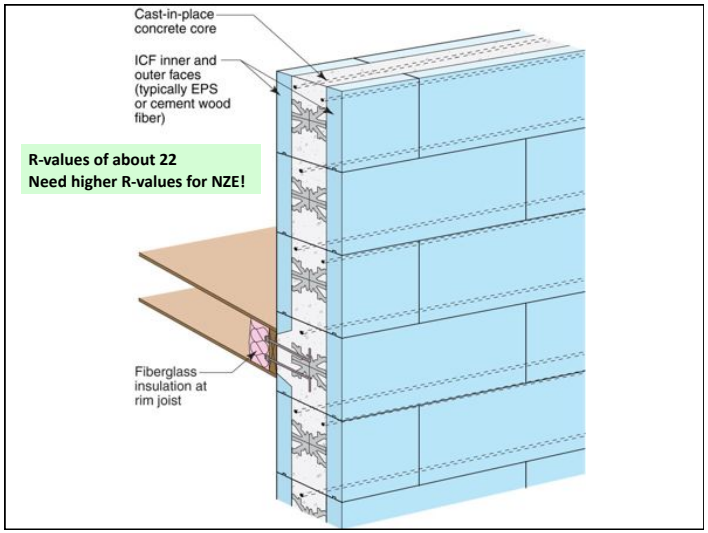
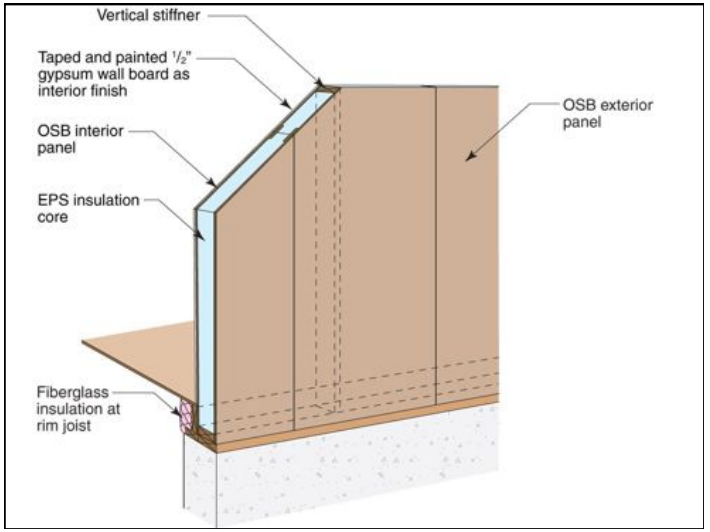


Insulated Concrete Fo

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



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

Solar Decathalon

- Design 800 sf all-solar powered house
- Be comfortable, healthy safe
- Ship to Washington DC and build on site in under 3 days
- Do all of above using University students in Architecture and Engineering

University of Waterloo

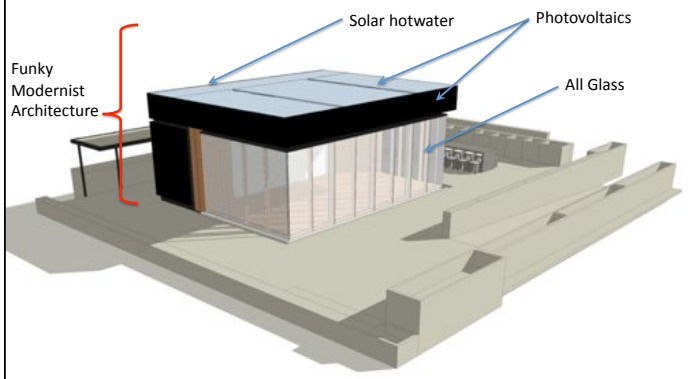
Decathalon- North House

University of Waterloo, Ryerson University, Simon Fraser University

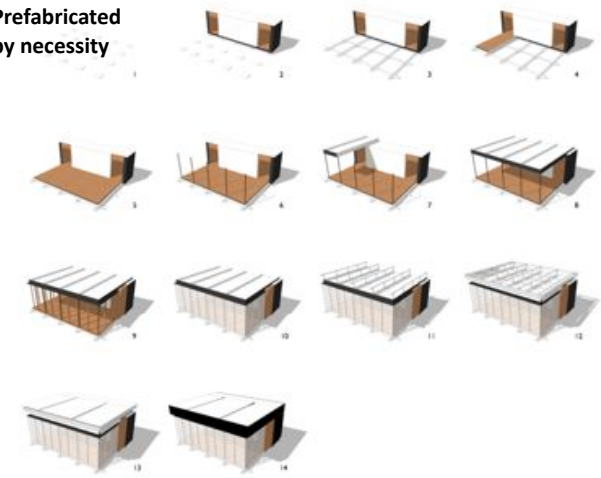
Solar Decathalon

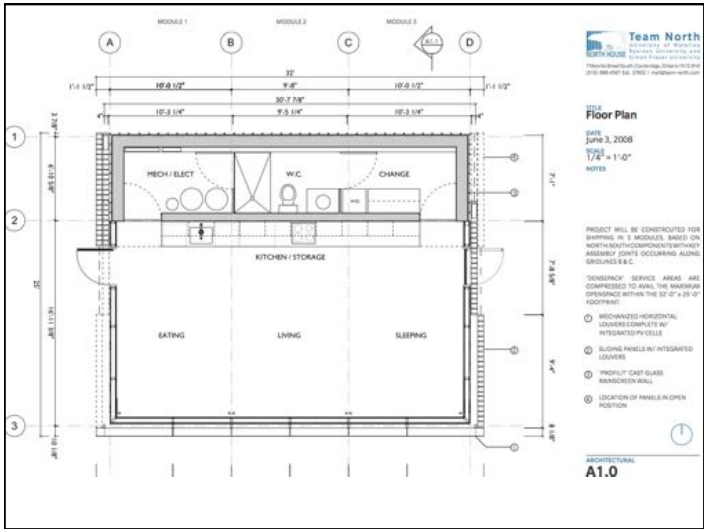
- Design 800 sf all-solar powered house
- Be comfortable, healthy safe
- Ship to Washington DC and build on site in under 3 days
- Do all of above using University students in Architecture and Engineering

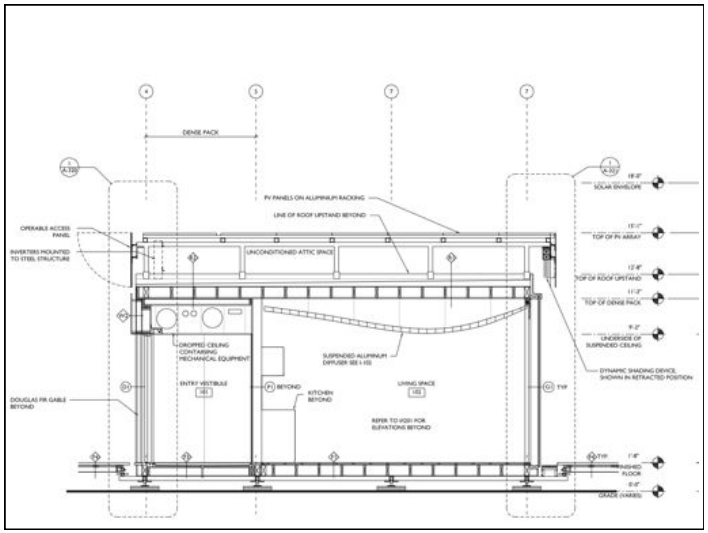
“Darth Vader helmet” design

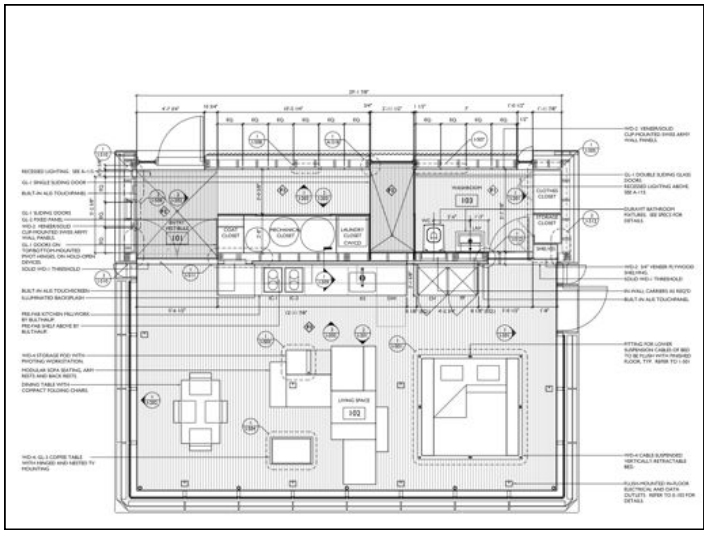


Prefabricated by necessity









Living Arrangements

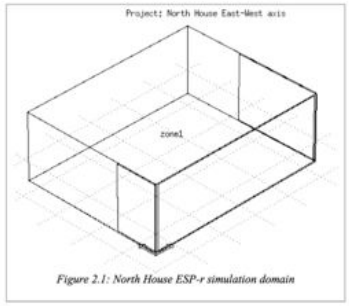


Figure 2.1: North House ESP-r simulation domain

Construction	R-value (imp.)	Composition
Walls	R56	per SK-2 W1 spec
Roof	R67	per SK-2 R1 spec
Floor	R56	per SK-2 F1 spec
Windows	R16	two insulated glazing units with evacuated cavities U-value=0.35, SHGC=0.42

	Heating Load (kWh/a)	Cooling Load (kWh/a)	Total (kWh/a)
Without shading	**834**	**8200**	**9034**
With Dynamic Shading	**2010**	**195**	**2205**

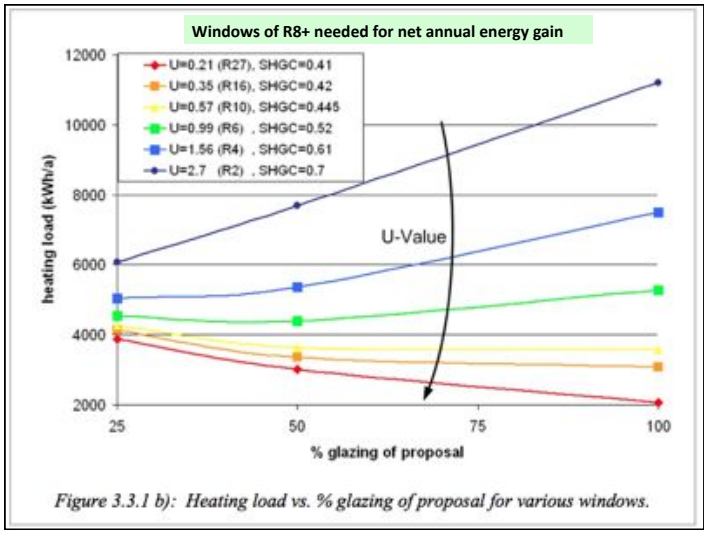
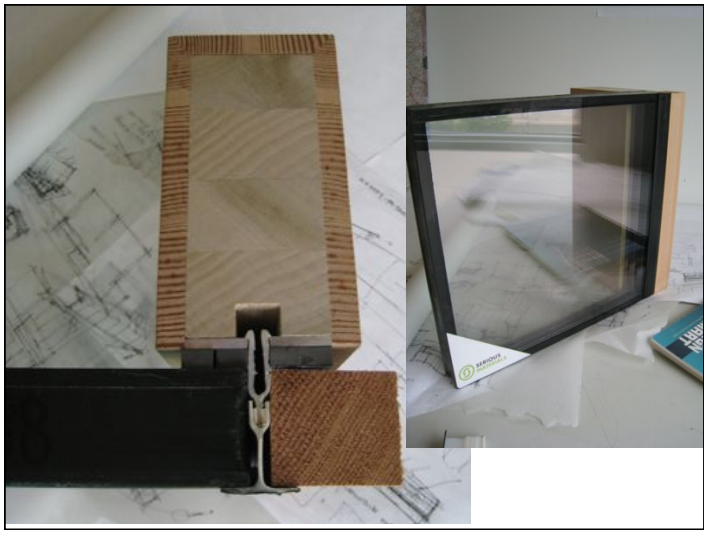


Figure 3.3.1 b): Heating load vs. % glazing of proposal for various windows.



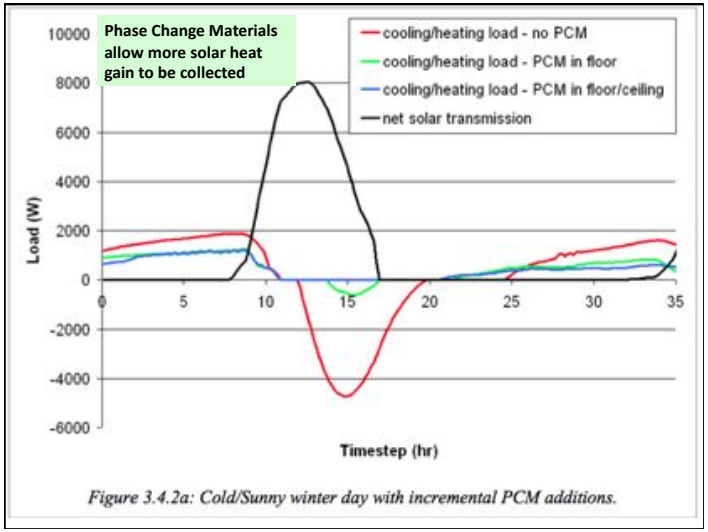


Figure 3.4.2a: Cold/Sunny winter day with incremental PCM additions.

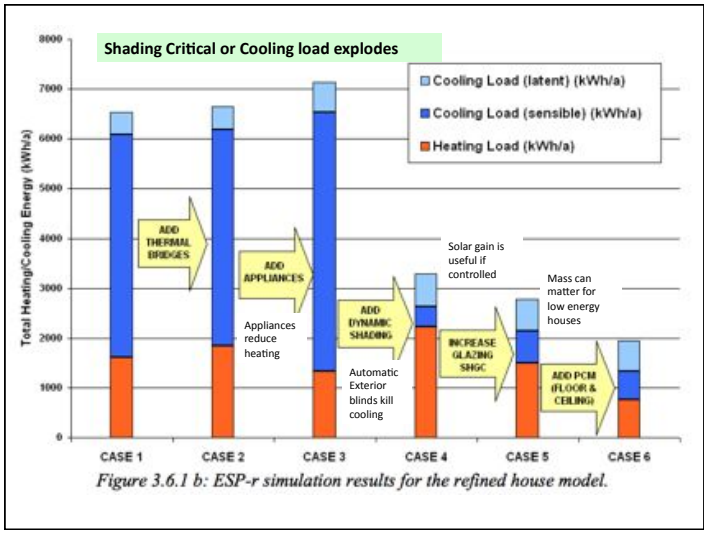
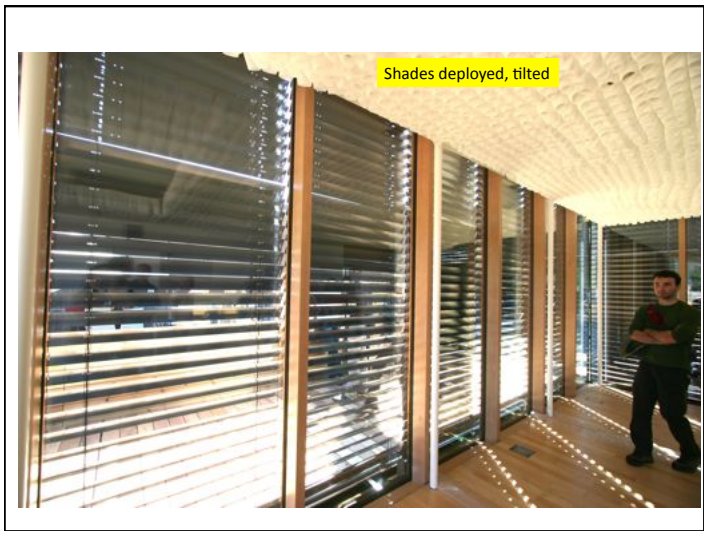


Figure 3.6.1 b: ESP-r simulation results for the refined house model.

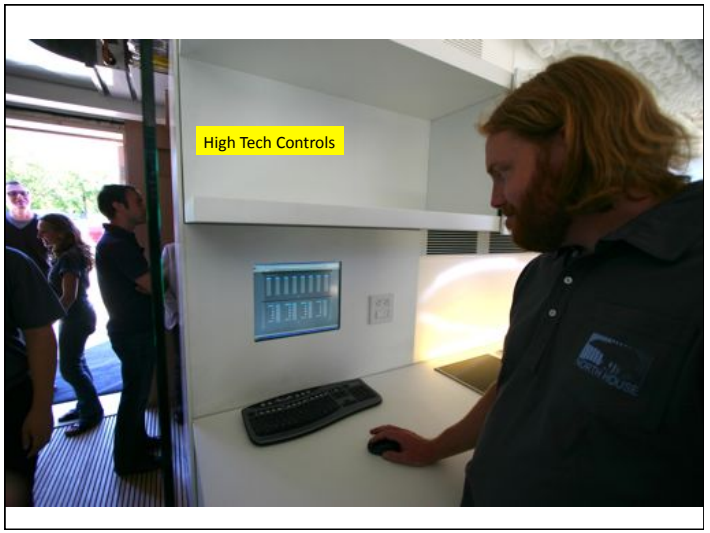


Important conclusions

- With exceptional windows (R10) and dynamically operated shades…
  - Increasing window area saves energy!
- For ultra low energy buildings
  - PCM can matter (small mass goes a long way)

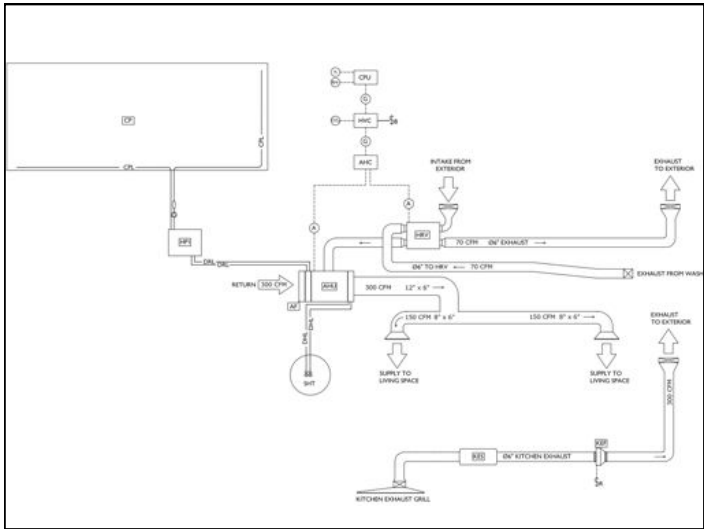
Blinds

- Interior
- Allow privacy & daylight

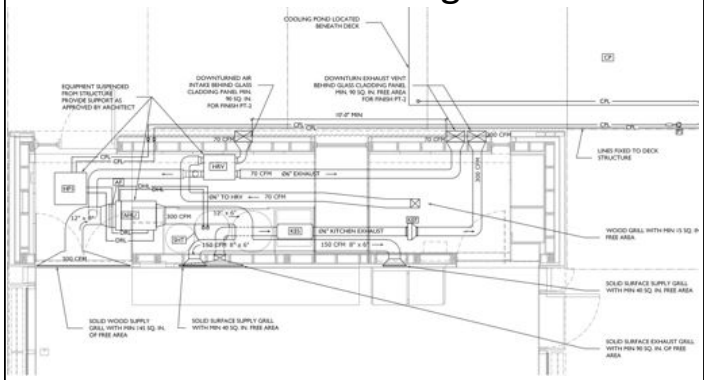


Mechanicals

- Two-stage water-water heat pump
- Supply of heat is vacuum tube solar
- 1st pump to 38 / 95F
- 2nd pump to 60 / 140 F
- Digital Scroll by Emerson, 10:1 turn down ratio
- Smallest unit now is 3.5 tons



Air Handling



Generates almost twice as much energy as it uses annually

Conclusions

- With enough money, we can build net positive houses that look “funky cool” or “normal”
- We have the technology
- Is the expense worth it?
  - Depends. Today it is expensive.
- Is net positive the best solution? What about off-site wind, hydro, biomass, natural gas, etc.