Building an Energy Efficient House

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Updates since 2011

- Added slide 51 the temperature measurements on the floor and wall

Experience

- Only passive solar heat since the last snowfall 5 days ago
  - Daytime highs of about zero and nighttime lows of about -12C since then
- Only passive solar heat for about a week before it clouded over for the last snowfall

Contents

My Background

- Mech Eng Graduate at UW
- Energy Transfer in Buildings Course
- Solar Engineering Course KGT Hollands
- 1970's interest in Solar Energy
- home and barn renovations growing up

Current Work

- Consulting in the vibration and pressure pulsation test field
- Industries
  - pulp & paper
  - automotive
  - process industries
  - UV disinfection systems
- Minor amount of consulting in heat transfer, thermally induced distortion, etc

Impetus

- Previous house was a 1000□’ bungalow
- Any other house we looked at did not meet our criteria
- Our solution was to buy vacant land and make our own mistakes

Why a Green House?

- Stewardship of Natural Resources
- Healthy to live in – especially if allergies present
- Robust – continues working even if utilities fail
- Local – not dependant upon distant places

Requirements to Build a House

- Common sense
- Engineering principles
- Building experience helps
- A wife open to adventure

Design Requirements

- Energy efficient
- Healthy
- Robust – failure of hydro or utilities accommodated
  - Local fuel supply
  - No sump pump required
- Future expandability
  - Home office
  - Granny flat

Energy Efficiency Requirements
robust & local

- Minimize energy loss through efficient envelope
- Maximize passive solar energy gain
- Wood heating
- Active solar DHW heating
- No air conditioning
- Integrate systems into overall design

- Considered off-grid
  - PV
  - Wind
  - Battery storage
- Considered hydrogen based house

Healthy Home Requirements

- Allergen free
  - No carpets
  - Sniff test on construction materials
  - Not susceptible to mould growth
- Relative humidity between 30% - 80 %
  - Breathable walls instead of vapour barrier
  - Well insulated to prevent cold spots
  - Efficient windows to prevent condensate
  - Minimize infiltration but use HRV for fresh air
- Eliminate furnace fan to avoid blowing dust

Research Sources

- Web research–NRCan, CMH
  - Tap the Sun
  - Habitable Attics
  - Advanced House Program
- Windows Research
- Advanced Houses Project
- Telephone contacts in various fields
- Supplier information

Outside Expertise Suggestions (Paid)

- Durisol foundation
- SIP roof and walls
- fiberglass windows
- window overhang on south side to prevent summer overheating
- skylight with interior solar fins and thermo-syphon for DHW preheating
- roof @45˚ slope (12-12)
- ground tube for air pre-heating
- cupola for natural ventilation (no air conditioning)
- Clivus Muldrum composting toilets
- bio-gutters

Outside Expertise (Other)

- Durisol ICF walls throughout
- Length to width ratio depending upon climate
  - I think it was 1.6:1 for our latitude
- Insulate basements on outside – Durisol does this

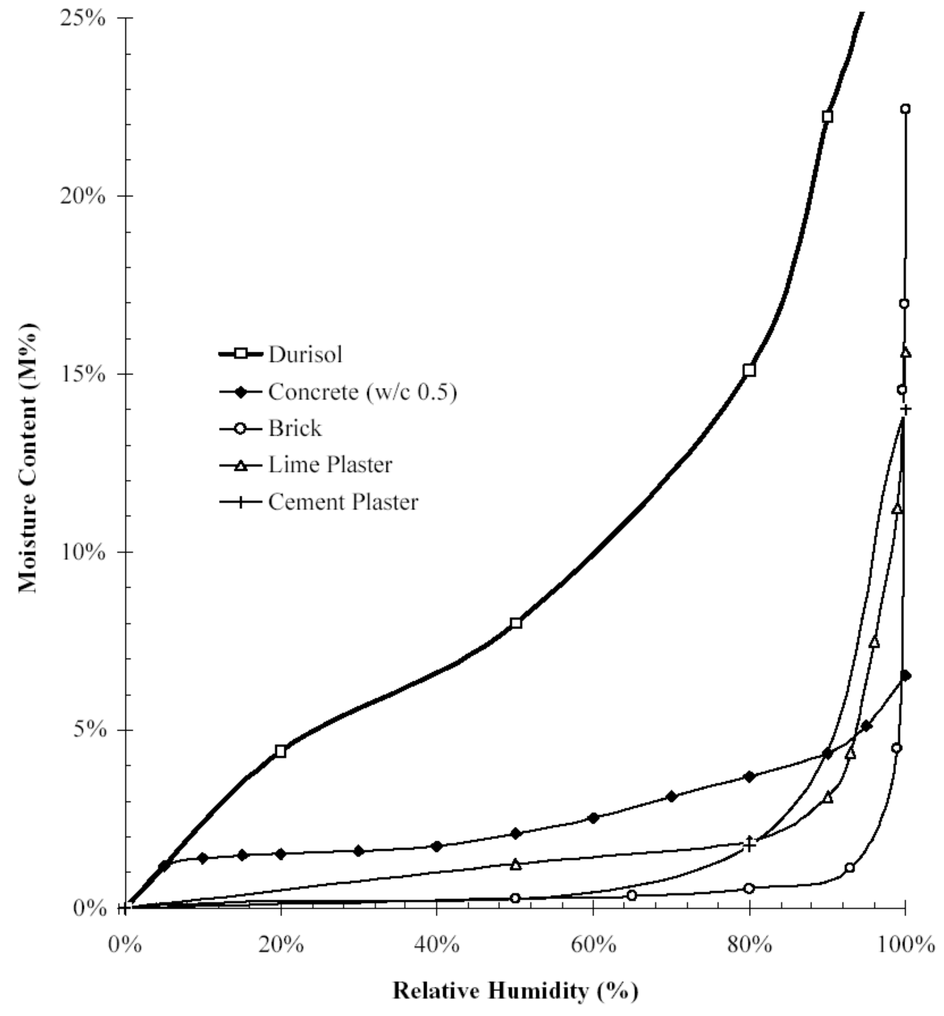
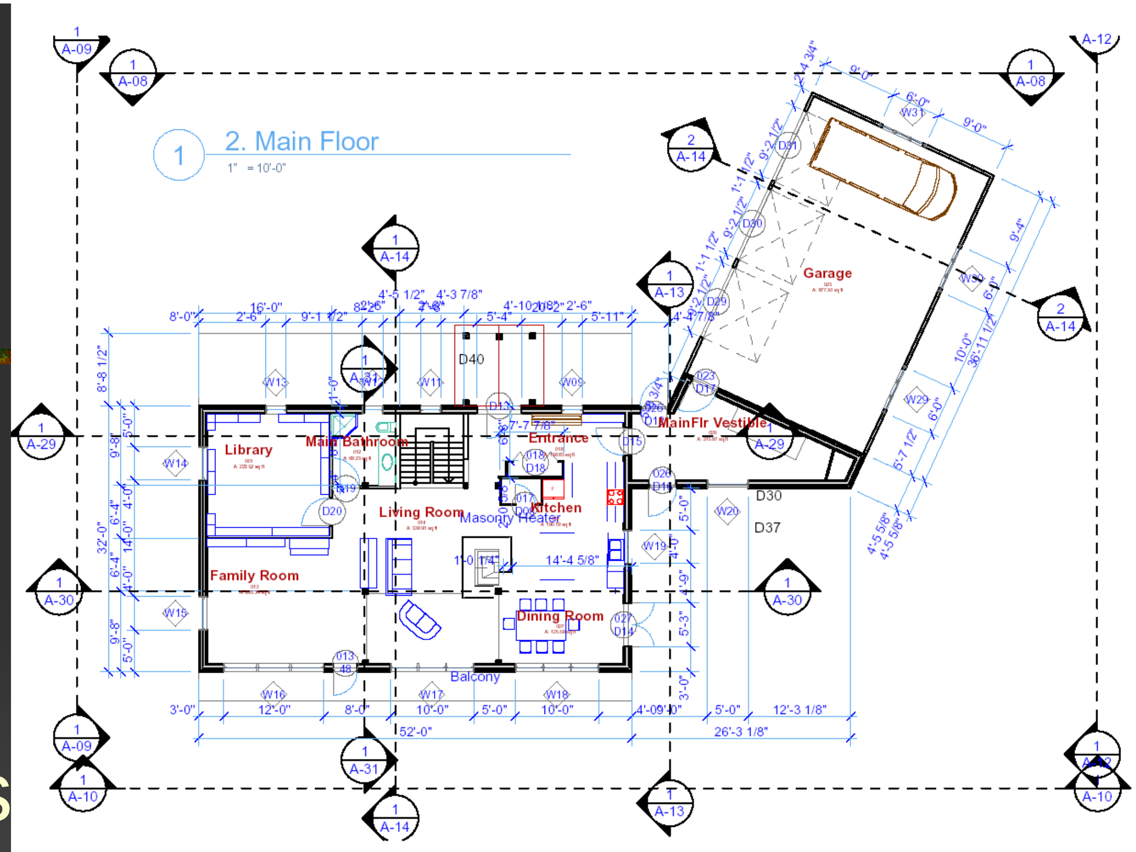


Figure 2: Sorption Isotherm for Various Building Materials

Design Tools

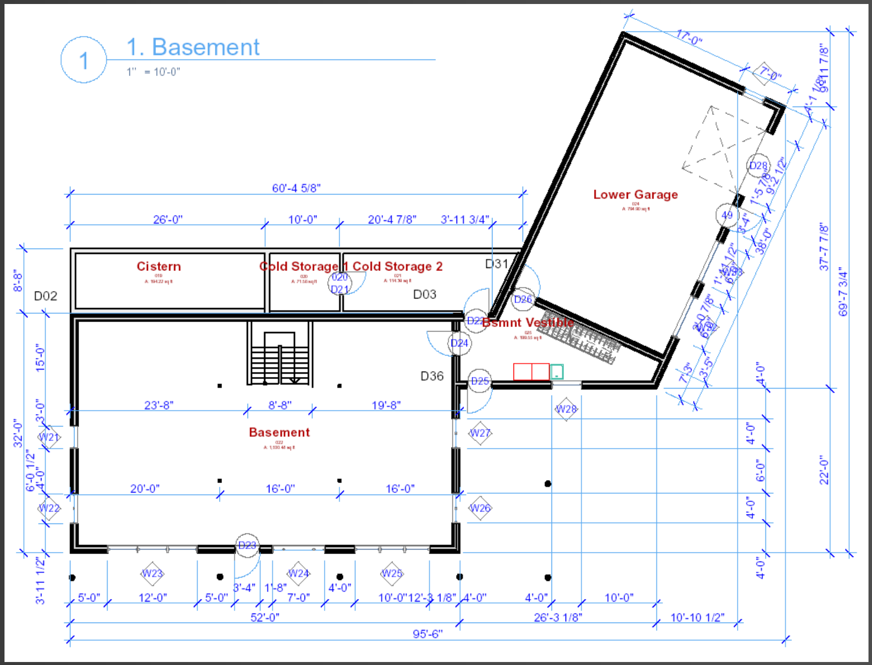
- ArchiCad used for design
- MathCad used to calculate loadings and footing design
- StruCalc for simple structural elements
- RISI Calc for garage truss design
- Some design using first principles from design textbook
- Excel for costing and material requirements

House Layout



- Open concept
- walkout basement
- 2nd floor bedrooms
- west windows for sunset
- masonry heater for main heat supply
- kitchen in the east for the early morning sun

Layout Continued

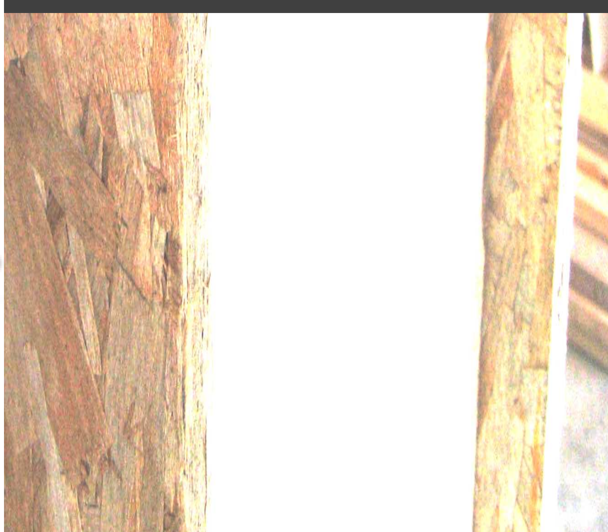


- workshop under garage
- 3 car garage to keep some vehicles in garage
- garage and workshop connected to house via vestibule
- laid out to follow contour of land and maximize view from house

Structural and Energy Integration

Main Construction Materials

- Hybrid Construction
  - Durisol ICF envelope
  - timberframe interior
  - SIP cathedral ceiling



Air Conditioning

- No air conditioning as design goal
- Cupola was suggested to help achieve this
- Simulation was used to determine effect of cupola and to determine if air conditioning was required
- Result was that cupola had very little effect with upper windows installed
- Careful design allows use with no air conditioning

House Heating

- Minimize energy loss through an efficient envelope
- Large south facing windows
- Thermal mass
- Masonry heater
- Radiant floor heating

Minimize Heat Loss

- Well insulated
- Good windows
- Minimal infiltration
- Maximum space utilization in the envelope

Healthy Home

- Moisture control – ideal RH is 30% - 80%
- Breathable walls gets away from potential condensation problems inherent with vapour barriers
- If you or someone in your family has allergies, take them along to give the building material under consideration the sniff test, to see how they respond

Insulation Types

Properties to Consider

- Air infiltration resistance
- Natural convection possibility
- Moisture effect

Types

- Polyurethane
- Polystyrene
  - Extruded
  - Expanded
- Rock Wool
- Fiberglass
- Cellulose fiber

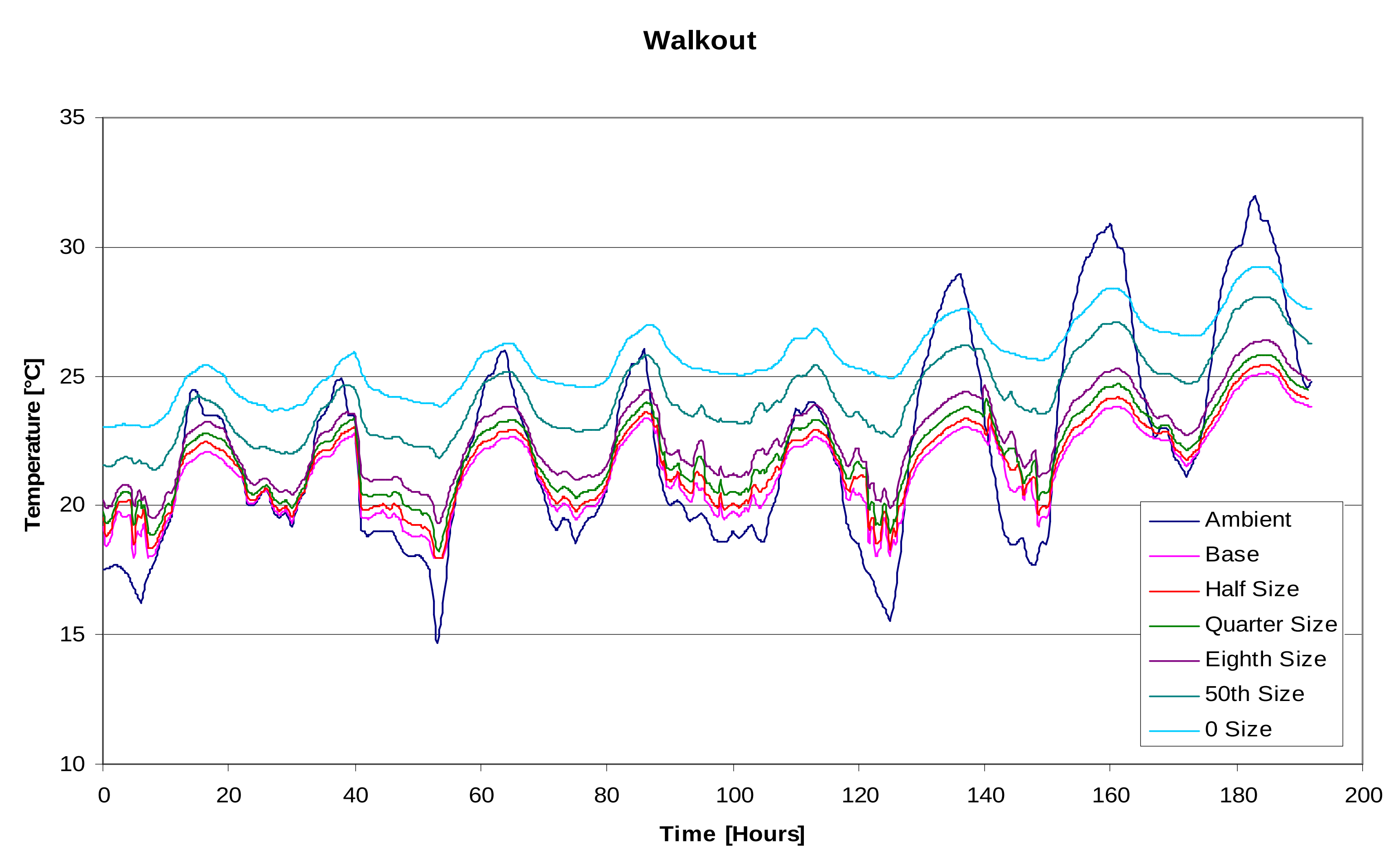
Basement insulation

- I used the principle of having the heat loss downward be of about the same value as through the walls or ceiling
- Used cutouts from exterior doors as the insulation
- Found a door manufacturer that allowed us to pick up so just pickup cost

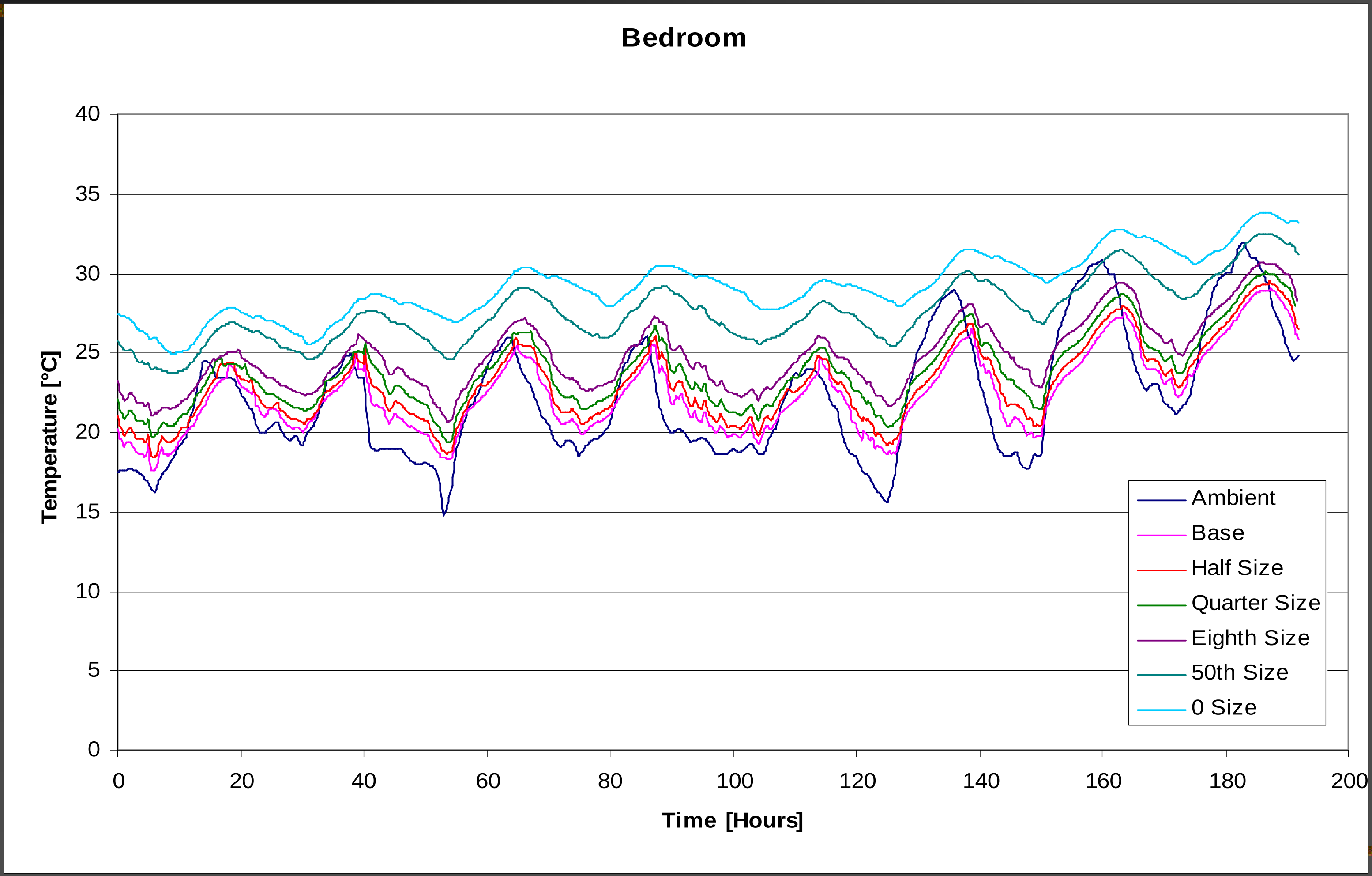
Energy Simulators

- User Friendly
  - HOT2000
    - Canadian government supported
    - Bin based
    - Easy to use interface
    - Many variables defaulted – good for typical house
  - HOT3000
    - ESP-R simulation engine
    - Time based simulation
    - Easy to use interface
  - EnergyPlus
    - US program
  - Others
- Advanced Simulators
  - ESP-r
    - Best for envelop analysis
    - Open Source
    - NRCan supported
    - High learning curve
  - Trynsis
    - Best for plant analysis
    - Expensive
    - High learning curve
  - Others

Energy Simulation



Energy Simulation



Windows

Windows

- Probably the most important element
- Rated in Canada with the ER (energy rating) number
  - Defined as the energy gain minus conductive energy loss minus convective energy loss [W/m^2] averaged for all Canadian locations and orientations
  - Our window Center of Glass (CoG) ER is ~21

Window Calculations

- Three programs available
  - Windows 5.2 from the LBLN (US gov)
    - One I used and most often used in NA
  - WIS from TNO (NRC of the Netherlands)
    - I could not get it to work
    - seems to be the European standard
  - FramePlus by Enermodal
    - Previous Canadian standard

Energy Rating

Name	Rvalue	SHGC	ER CoG
Durisol Wall	25.00	0.00	-4.99
Cathedral Ceiling	43.00	0.00	-2.91
Single Clear	0.96	0.86	-67.48
Double Clear Air	2.10	0.70	-8.57
Double Clear with Argon	2.21	0.76	-1.40
Double Low-e Air	3.43	0.47	-2.45
Triple Clear	3.26	0.61	6.14
3mm Low-e air	3.18	0.50	-3.06
Sample GlzSys	2.94	0.68	7.05
322 Triple LOF Gen 9921 9801 9921	6.42	0.56	21.22
322 Triple AFG ins 928 9801 928	7.71	0.37	10.55

- ER=72.2*SHGC-21.9Uw – 0.54*(L75/Aw)
  - W/m^2 usable heat gains averaged over the heating season
  - SHGC solar heat gain coefficient
  - Uw is the overall window U-value
  - L75 is the window air leakage rate
  - Aw is the window area

ERS better for Passive Solar Design

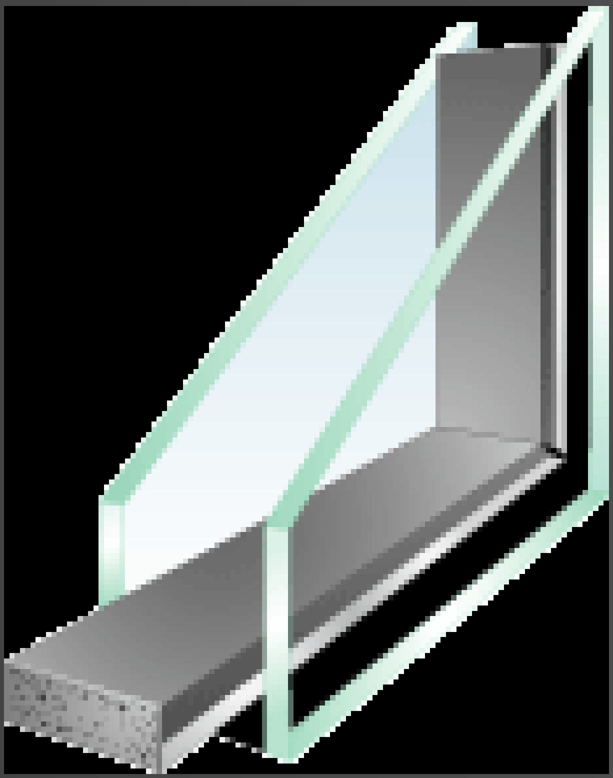
- Specific energy rating for center of glass for Toronto

- Outside atmosphere 1350 W/m^2
- 950 W/m^2 on sunny day
- 300 W/m^2 on a cloudy day

Name	322 Triple LOF Gen 9921 9801 9921
U-value	0.88
Rvalue	6.42
SHGC	0.56
ER Gain	40.60
ER Loss	19.37
ER Glass	21.22
ERS S	28.95
ERS SE/SW	20.84
ERS E/W	6.29
ERS NE/NW	-3.81
ERS N	-5.93

Glazing Spacers

- NRCan website has detailed documentation
- A Canadian invention, the Superspacer is the best
- A steel spacer Bayform Thermal Edge is the most commonly used
- Aluminum is the worst



Spacer Types

- IG7 – aluminum
- IG6 – Bayform
- IG8 - SuperSpacer

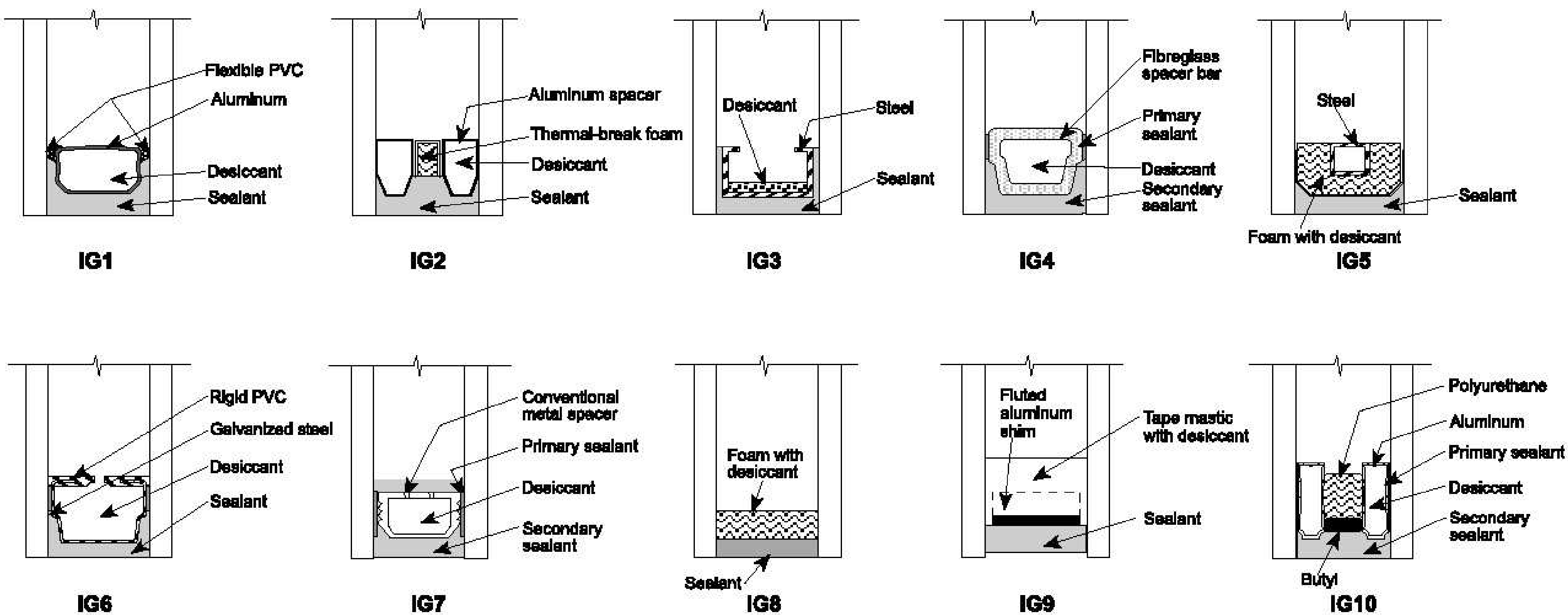


Figure 2. *Spacer bar assemblies IG1 to IG10*

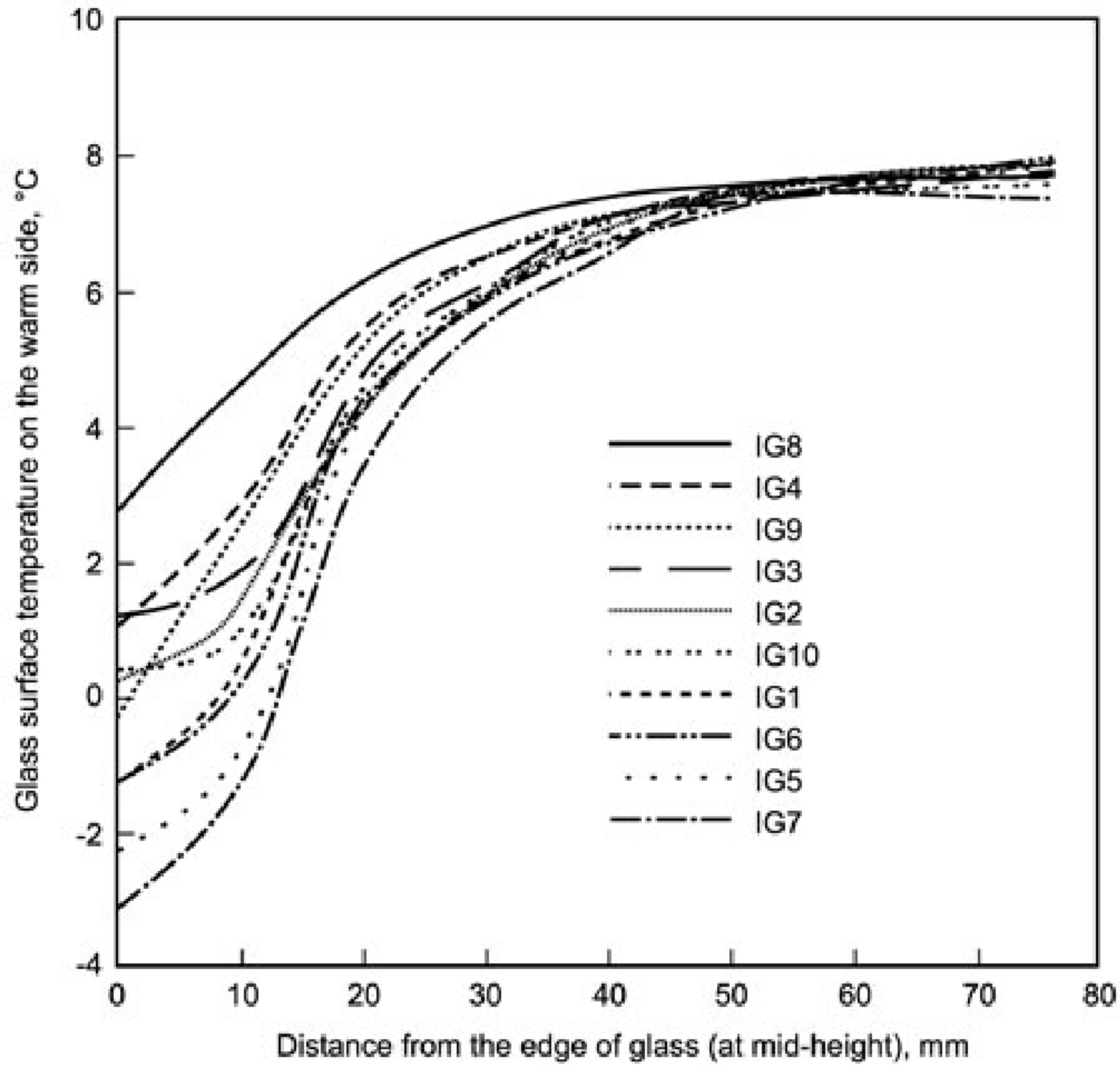


Figure 3. Warm-side glass surface temperatures for IG units

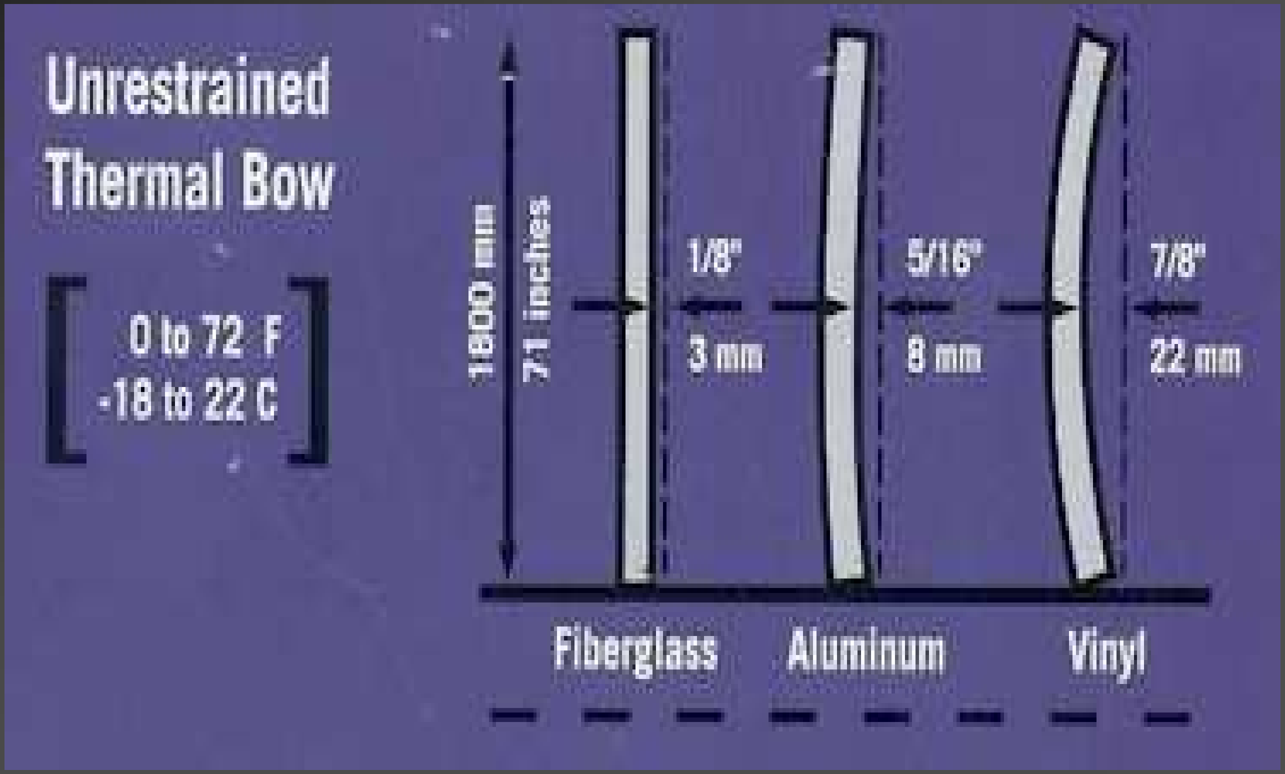
Window Frames

- Glass (CoTE 8.7 μm/m)
  - reference to compare with frame material
- Fiberglass (CoTE 7.4 μm/m)
  - Best insulating value
  - Smallest profile
  - Coefficient of thermal expansion same as glass
- Wood (CoTE 0 μm/m but dimensional changes with humidity)
  - Good looking
- Vinyl (CoTE 62 μm/m)
  - Most common
- Aluminum (CoTE 23 μm/m)
  - Often used commercially

Temperature Effects

Coefficient of Thermal Expansion

- Infiltration
- Stress on Locking Mechanisms



Thermotech.com

Window Frame Performance

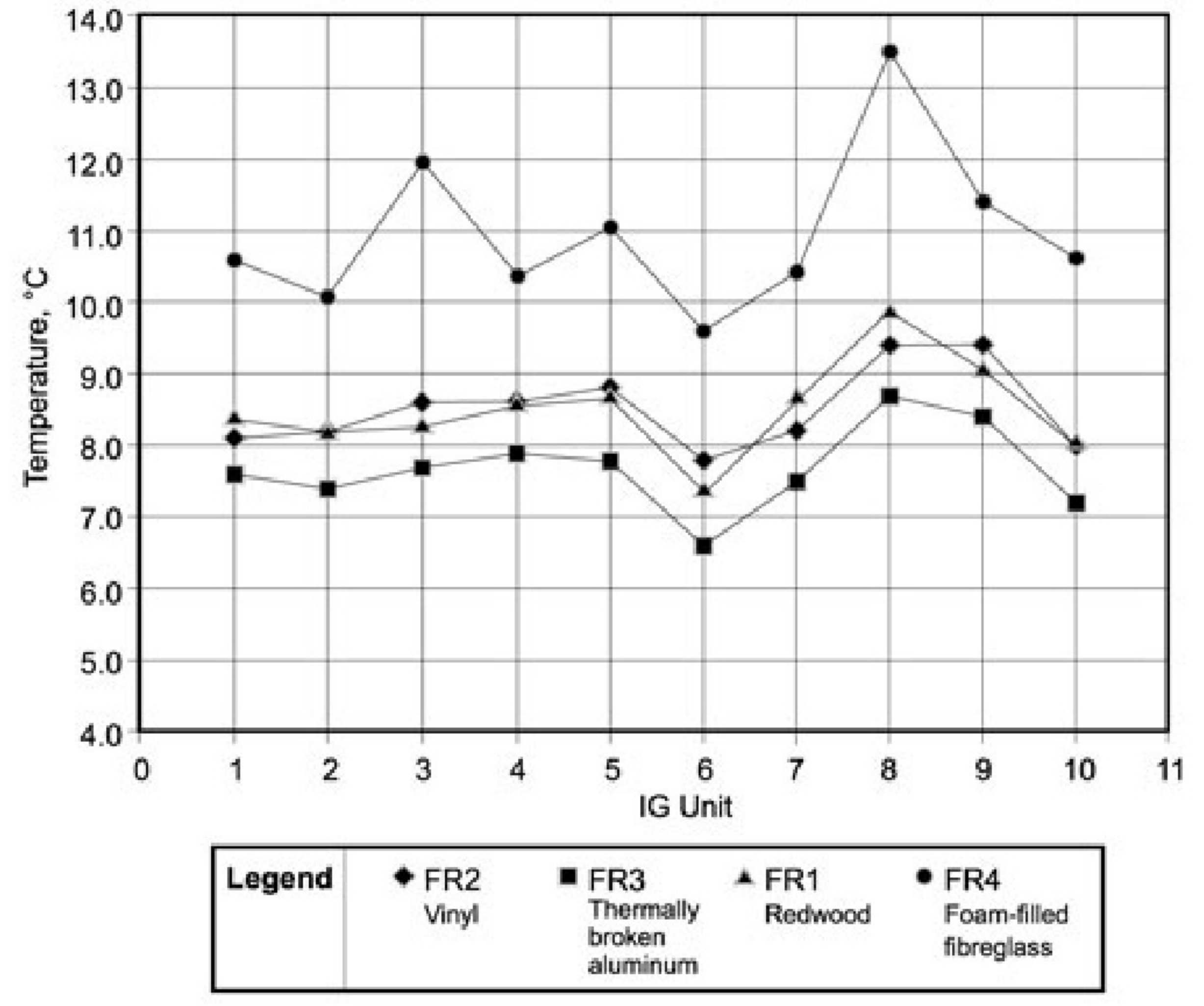


Figure 4. Effect of frame material on glass surface temperature 10 mm from sight line

Overhang Calculations

- Window is fully shaded in the summer
- Window is unshaded in winter
- Window is unshaded or partially shaded on March 21 and Sept 21
- Tap the Sun and a solar engineering text for equations

Passive Solar Window Design

Properly Calculated Overhang

Fiberglass Window Frames

Efficient Triple Pane Glazings

Large South Facing Windows

Shading

Overhang Prevents Summer Sun from Overheating House and Allows full Winter Exposure

Reflective West Windows

Afternoon Sun is at Low Angles in West (Summer and Winter)

Overhangs will not Work

I selected windows with lower SHGC (more reflective)

Afternoon Sun

View from West

View from North

Thermal Mass

- Need sufficient thermal mass in the house to prevent day time overheating and store the solar heat for the night
- Concrete floor and ICF walls help in this regard
- Use rules of thumb from a book such as “Tap the Sun” or simulation
- Simulator needs to be hourly
- 4” thick is about the limit for a reasonable time constant of one day

160 Design

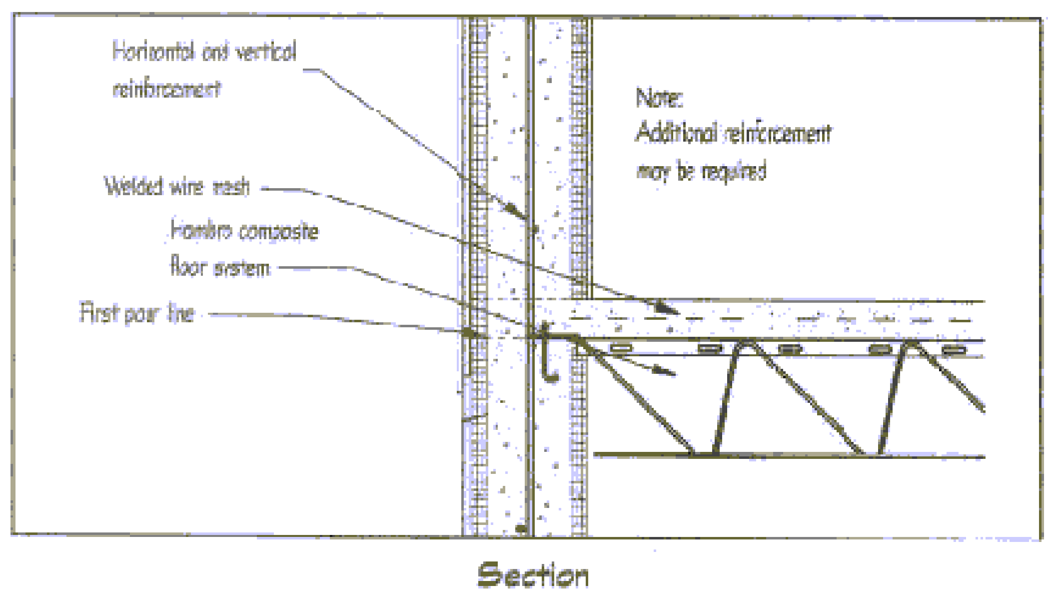


Figure 7-4 Hambro steel joist floor deck.

Heating

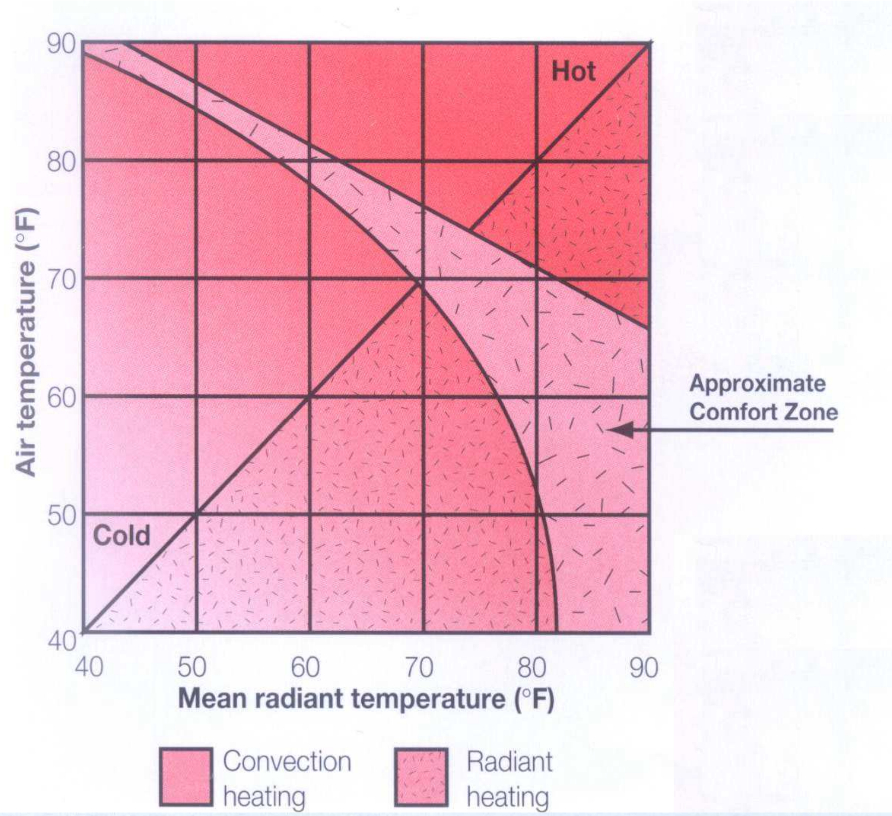
- Cost
- Distribution
- Boiler

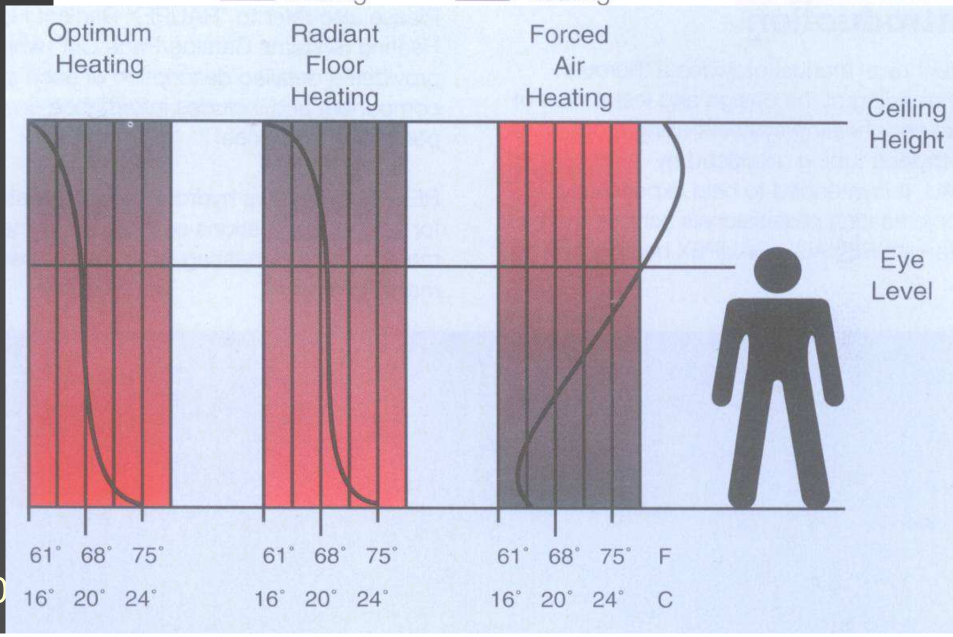
Energy Cost per GigaJoule (about 1996 prices)

Natural Gas	$10
Oil	$20
Propane	$30
Electricity	$35
Ground Loop Heat Pump (based on a CoP of 4)	$8

Heating Types

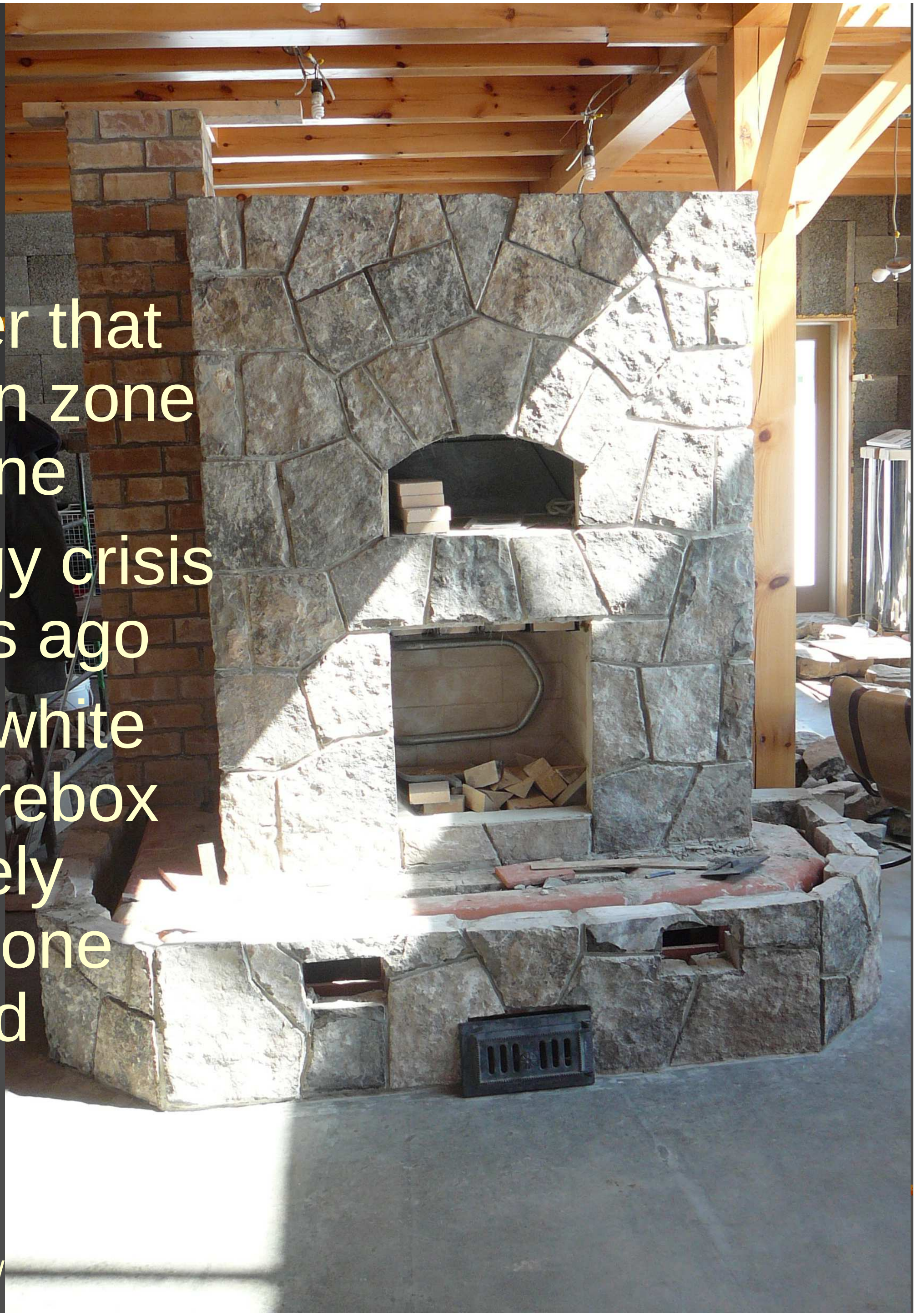
- Forced Air
  - Most common and thus lowest cost
  - Blows dusts around
- Radiant Heating
  - Comfort with cooler air temperature
  - Warm feet with in floor heating





Masonry Heater

- Only wood burning heater that separates the combustion zone from the heat transfer zone
- Invented during an energy crisis in Europe a few centuries ago
- Used Heatkit as it has a white bake oven, rebuildable firebox and the owner is extremely knowledgeable, having done much research in the field

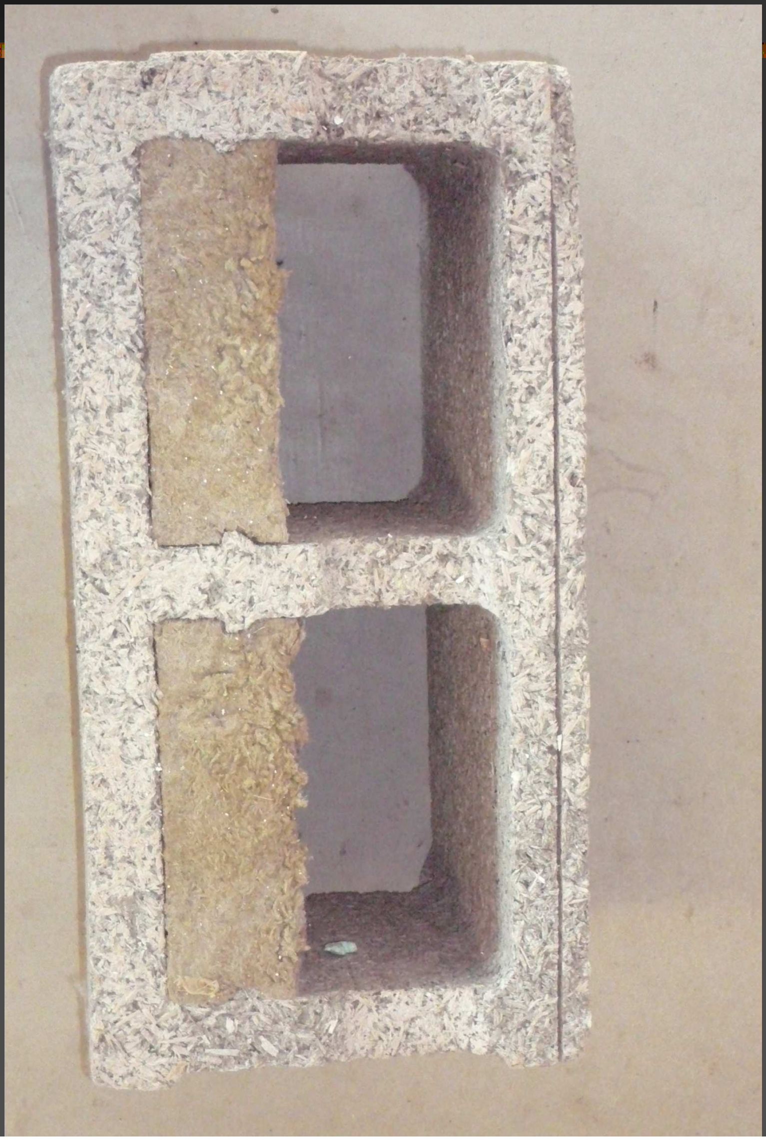


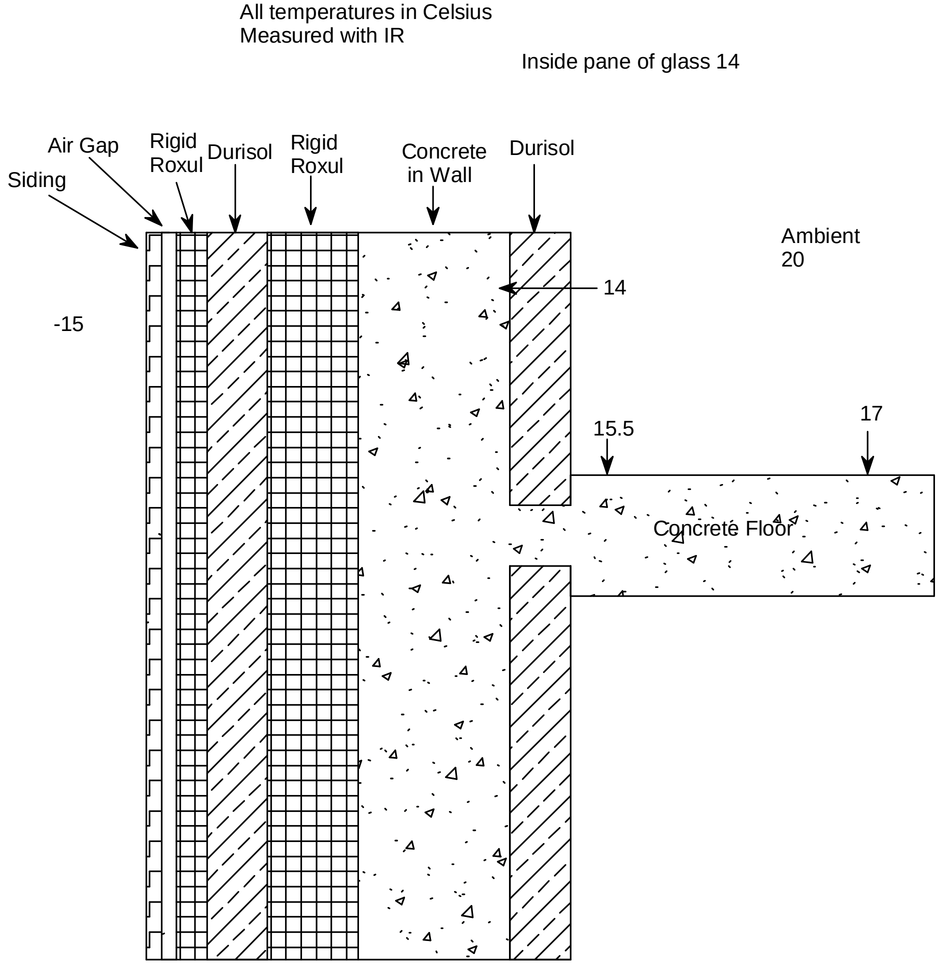
Radiant Infloor Heating

Radiant Infloor Heating

- You have the heat transfer background to figure this out now
- However, other people have put this information into software, and use previous experience and rules of thumb
- Used Rehau WarmSource software, available from their website to design
- Generally used a 1' tube spacing
- Did not particularly worry about adding extra heat to the periphery

Performance of Insulation



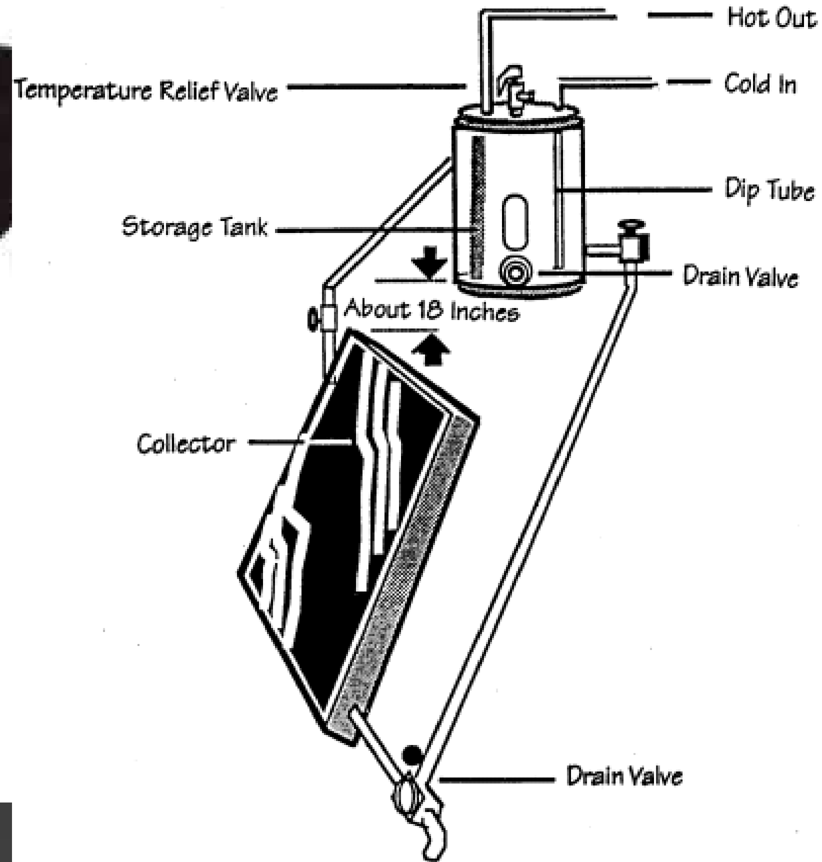


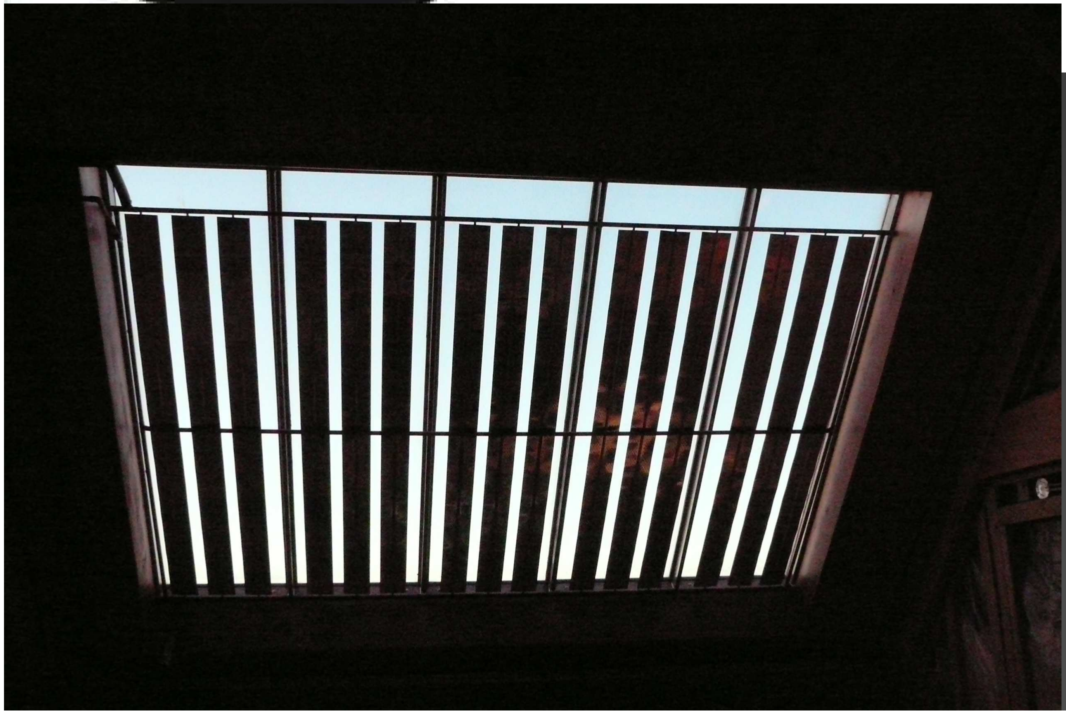
Boiler

- Since no natural gas available, propane would allow for a wall hung boiler
- Viessmann makes nice oil-fired boiler
- If no masonry heater I would use a ground source heat pump (Geothermal)
- Electrical resistance heating, for backup is least efficient, highest energy use, but may be the lowest capital cost

Domestic Hot Water

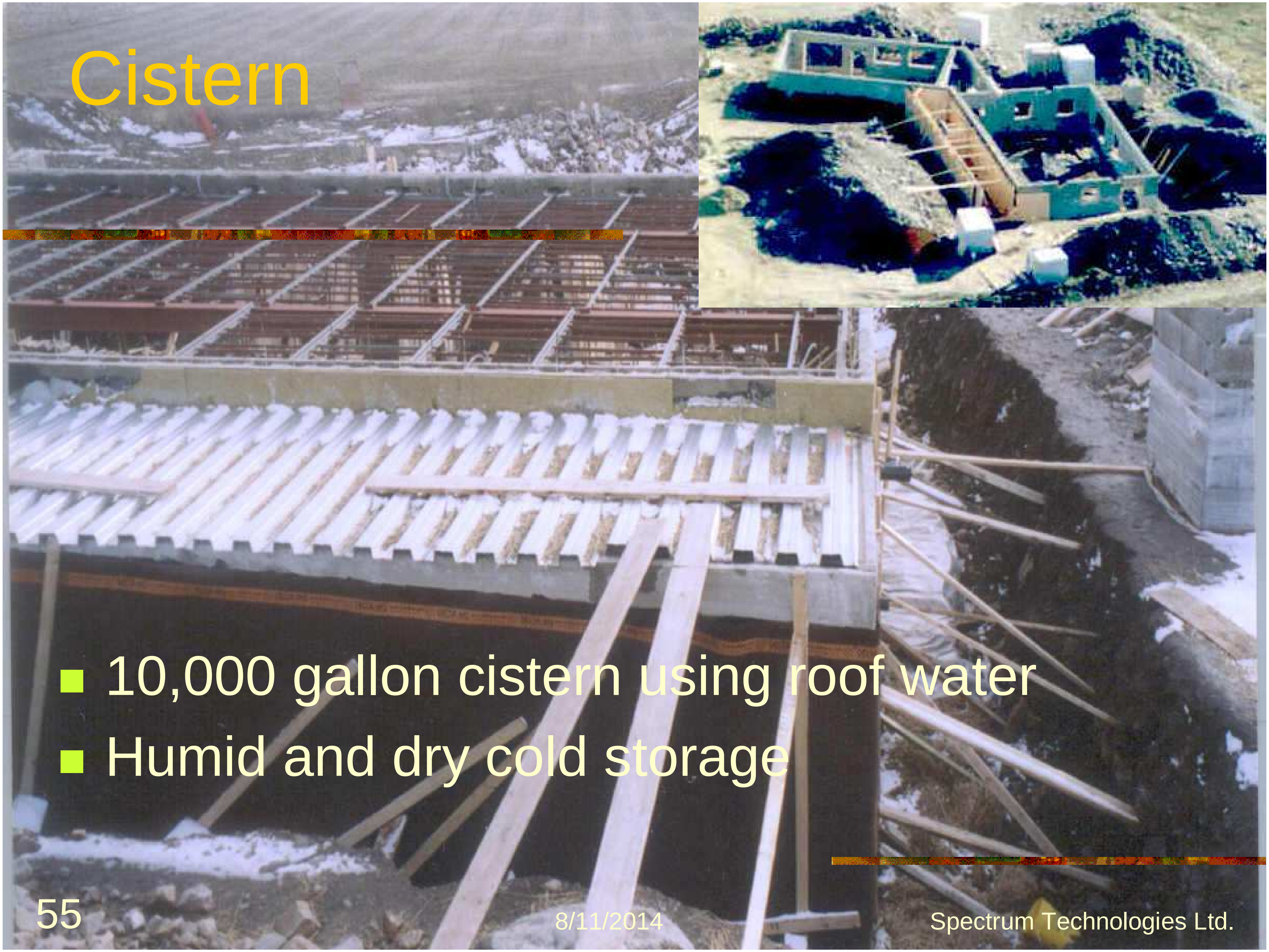
- Preheat
  - Solar thermosyphon (6 m^2)
  - Masonry heater thermosyphon
- Final
  - Electric hot water tank





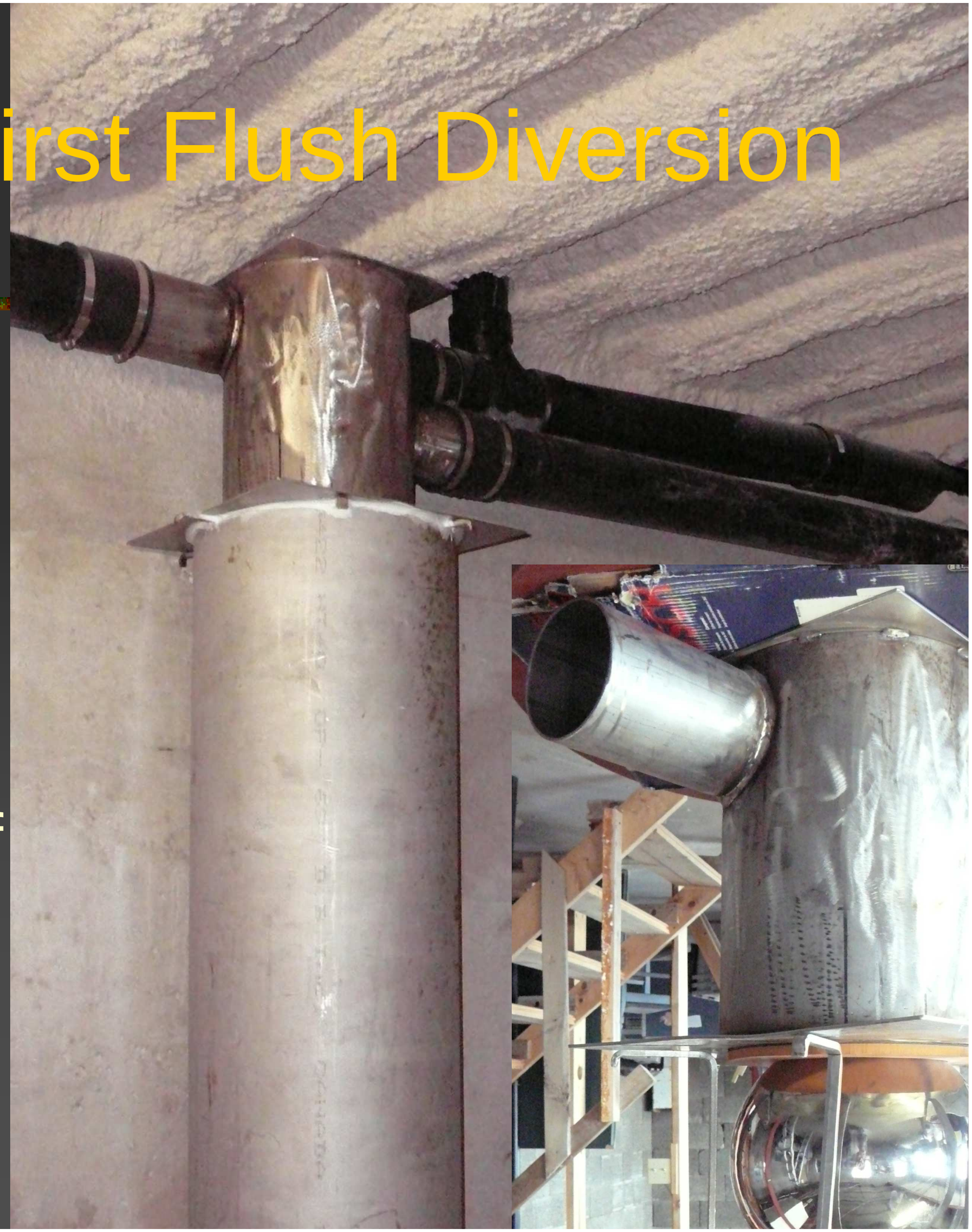
Spectrum Technologies Ltd.

Cistern



- 10,000 gallon cistern using roof water
- Humid and dry cold storage

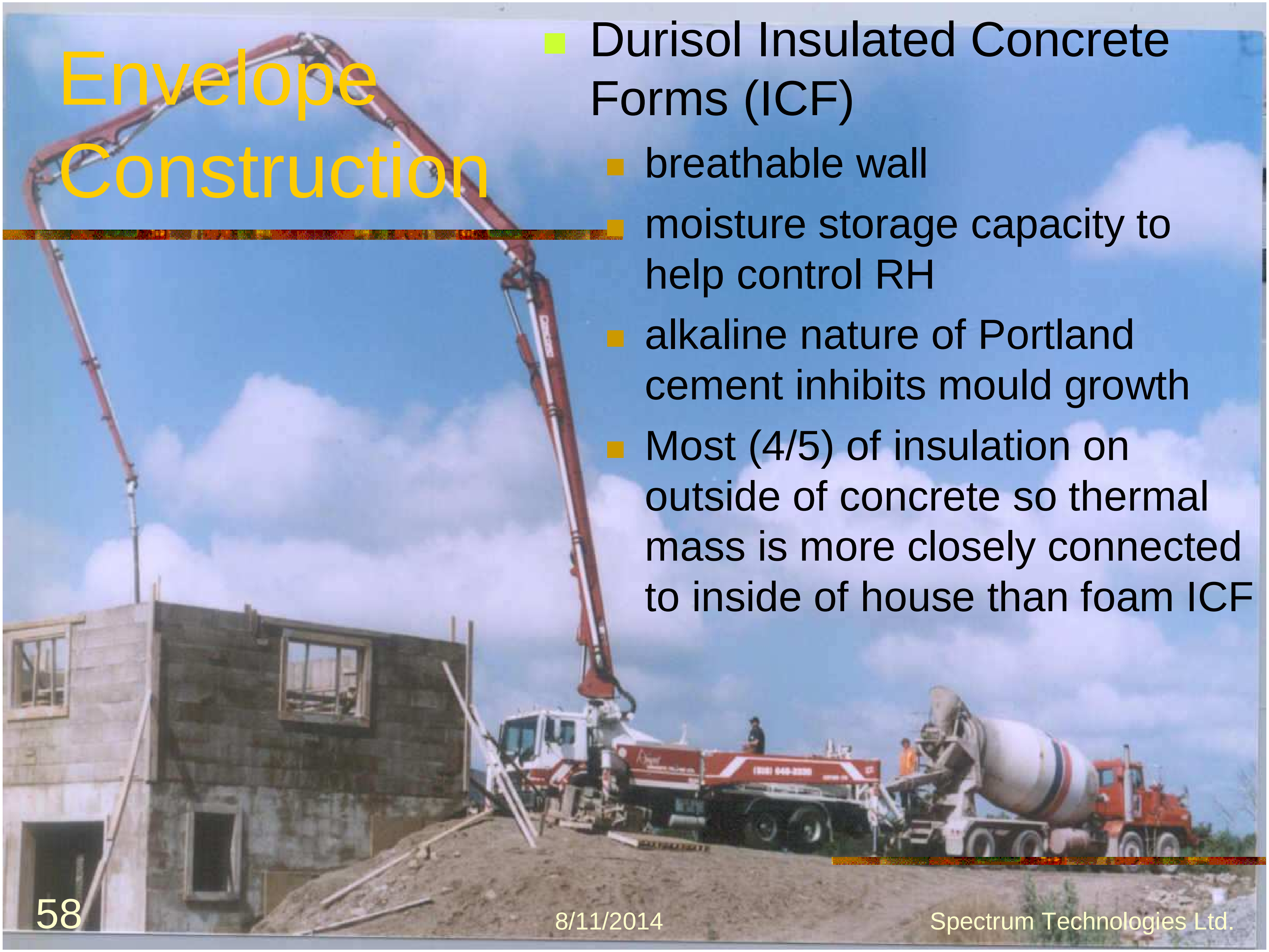
Rain Water First Flush Diversion



- Initial 1 mm rainwater is diverted from the roof to a tank to wash the dirt from the roof

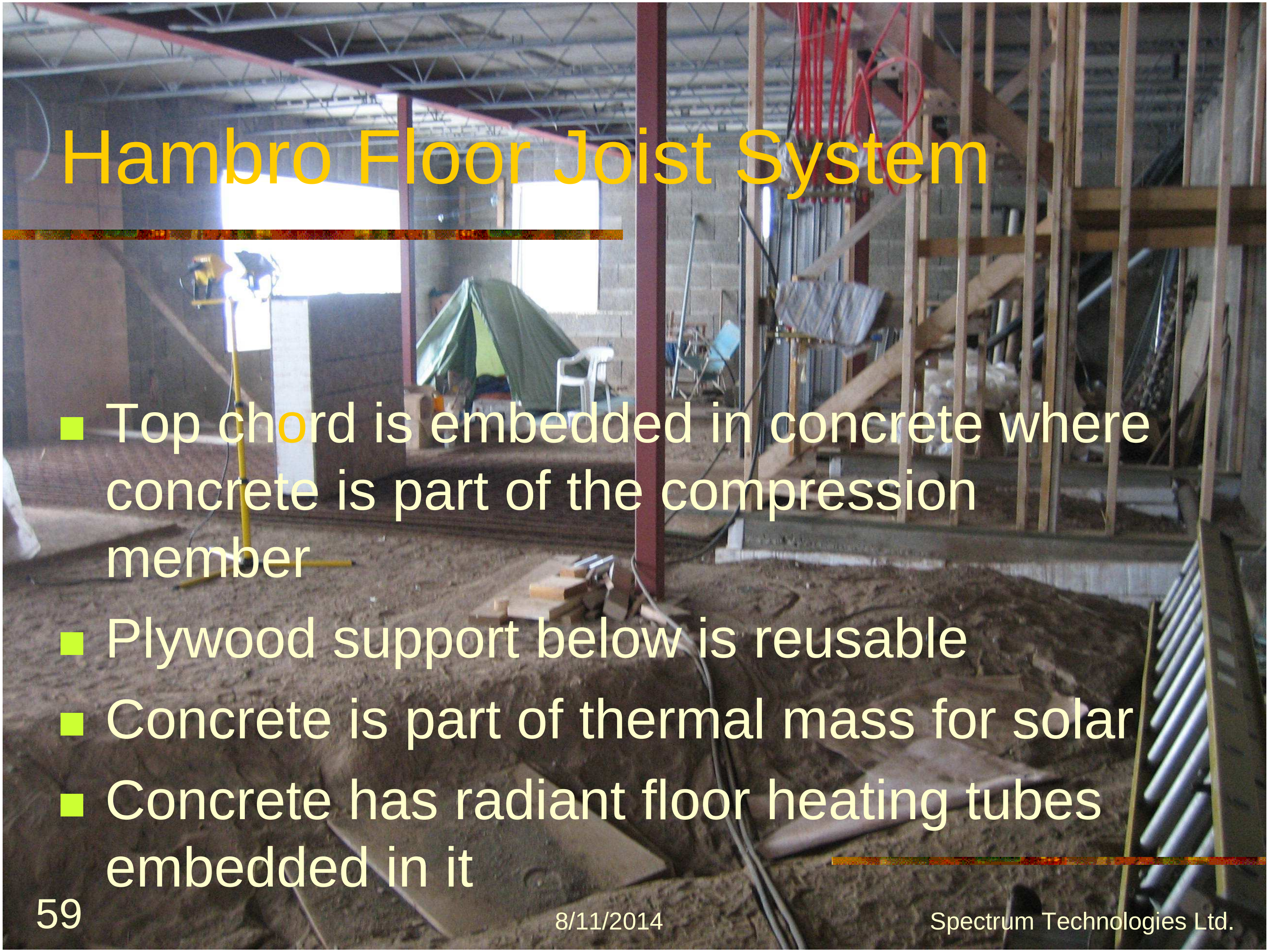
Slow Sand Filtration

- Water goes through sand very slowly
- Biological activity in the sand eats all organic matter in the water, including salmonella
- Used extensively in Europe, India and other parts of the world
- Considering this for the cistern



Envelope Construction

- Durisol Insulated Concrete Forms (ICF)
  - breathable wall
  - moisture storage capacity to help control RH
  - alkaline nature of Portland cement inhibits mould growth
  - Most (4/5) of insulation on outside of concrete so thermal mass is more closely connected to inside of house than foam ICF



Hambro Floor Joist System

- Top chord is embedded in concrete where concrete is part of the compression member
- Plywood support below is reusable
- Concrete is part of thermal mass for solar
- Concrete has radiant floor heating tubes embedded in it

Acid Staining

- Decorative concrete finish
  - Each different acid reacts with alkaline concrete slightly differently yielding a different colour
- Finished with acrylic or polyurethane
- Cost effective

Timberframe

- Went to a timberframe supplier that uses numerically controlled machining tools
- Installed first floor with genie lift
- Installed second floor with crane

Structural Integration

- Durisol ICF and timberframe
- Timberframe and SIP

SIP Cathedral Ceiling

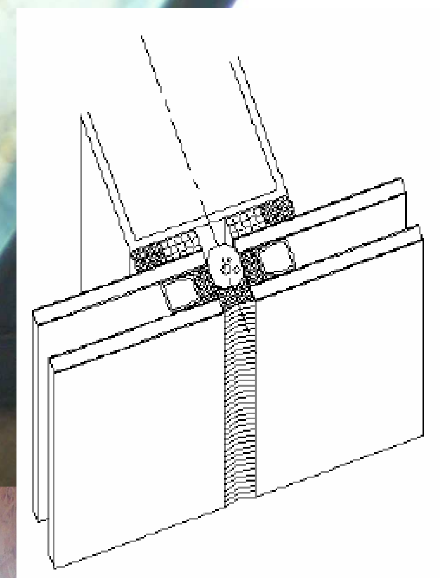
- Can span large distances and still support the roof load
- Used 10.25" panels for R-39 performance
- Used block and tackle, hand bombing and roofing ladder to install

Cold Roof Design

- Vent Cavity above SIP panels to ventilate between SIP and roofing material
  - Removes moisture
  - Keeps roofing material cooler
  - Added an extra R4 of insulation

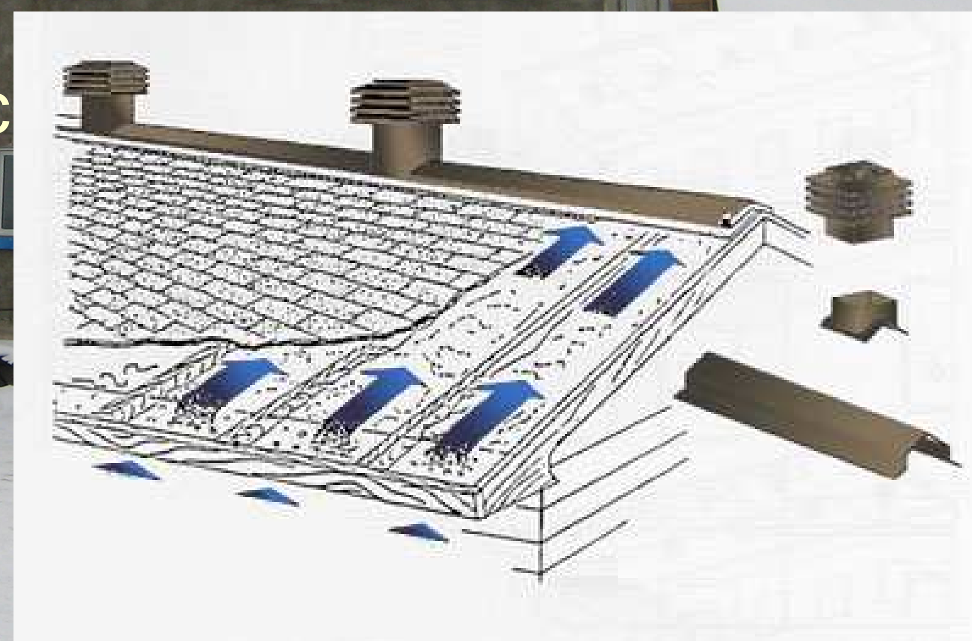
Skylight

- 8'-6" x 12'
- Skylights are normally double glazed
- Better glazing is only custom
- Structural Silicone Glazing used in office buildings
- Triple glazed units with SSG used for skylight
- Challenge to prevent overheating



Roof Vent

- Ventilation Maximum Roof Vents used
  - Provide suction with wind
  - No moving parts
  - Common in Quebec



Tyvek Attic Wrap

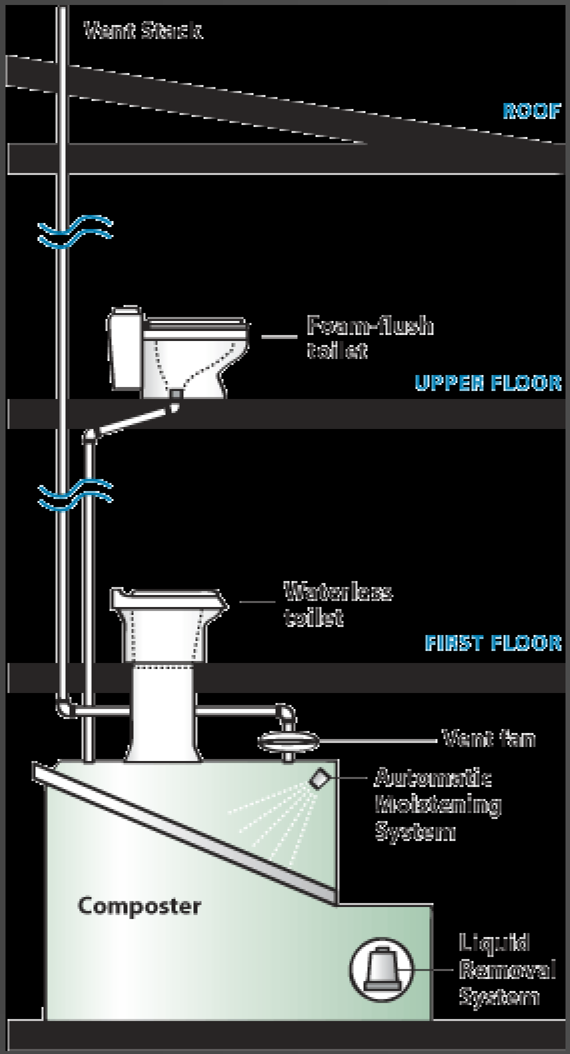
- Typical wall envelop has air barrier, but attic does not
- Gives an air tight attic and a fully vented roof; yet allows attic moisture to escape
- Attic is warmer in winter and cooler in summer reducing typical energy costs by 10 to 20% by reducing peak temperature difference between house and attic to about half

Ideas Evaluation and Implementation

Idea	Evaluation
Roof slope 12-12 (45^o)	Used
Skylight with interior solar fins	Used
Cupola for ventilation	No benefit – not used
Bio-gutters	Don’t work
ground tube	Source of mould
Durisol foundation	Used
SIP roof and walls	Used for roof
fiberglass windows	Used
window overhang on south	Implemented
Composting toilet	Not used

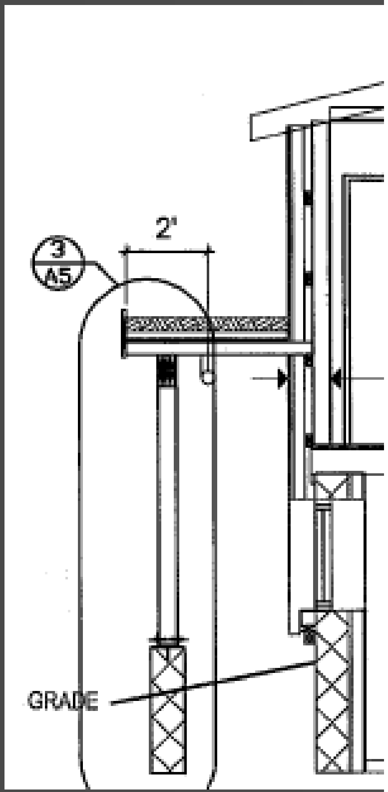
Composting Toilet

- Initially considered this
- On discovering we would still need a septic for gray water disposal we decided to go conventional
- Phoenix Composting Toilet System or Clivus Multrum are the only brands worth considering for anything but occasional use



Bio-Gutter

- Idea was to use the same biological activity that is in the ground to filter and purify roof water before entering a cistern
- Asked a few water experts about this and no real positive response
- Followed up with one reference – they removed the bio aspect and the gutters just became an expensive form of filtration
- Principle is that the slow diffuse movement of water through the soil will filter and clean water, cannot be scaled up to the huge volumes going down your roof



Ground Tube

- Recommended by a few people – 8” dia
- initial misgivings about condensate forming in summer and becoming mouldy
- Concrete resists mould so decided to try
- Turned up other research, unpublished that confirmed initial misgivings so quashed the ground tube idea

References

- Tap the Sun
- Solar Engineering Textbook
- Ashrae Handbook of Fundamentals
- NRCan website
- CMHC website
- John Straube’s website
- University of Strathclyde website ESP-r
- ICF, SIP and other building books
- Supplier information

Suppliers

- Durisol - ICF
- Thermotech - windows
- Discovery Dream Homes
- Thermapan – SIP roof panels
- GEM Euroslate - roofing
- Hambro - joists
- Rehau – infloor heating
- HeatKit Masonry Heater
- Turkstra Lumber
- Weeks Home Hardware
- Ventilation Maximum
- Dow Corning Silicone

Analysis Tools

ESP-r	thermal simulation
Windows 5.0	window simulation
MathCad	general analysis
StruCalc	structural analysis
RISI	truss design
Excel	general analysis and costing

Project or Thesis Opportunities

- Measure house thermal performance and compare with simulation
- Masonry heater performance
  - Measure performance especially the hot water coil
  - Numerically model masonry heater
- Water purification design
  - Design an on-demand UV lamp