Why Control Heat flow?

1. Occupant Comfort
2. Control surface and interstitial condensation
3. Save energy, reduce operating cost & pollution
4. Save distribution & heating plant costs (capital)
5. Increase architectural options
6. Decrease load diversity
7. Meet codes and specs

How to Control Heat Flow?

Modes of heat transfer:
- Radiation
- Convection
- Conduction

Thermal Performance

- Thermal Conductivity
  - Symbol is “k” or “λ”
- Conductance
  - C = k / thickness
- Resistance “R-value”
  - R = thickness / conductivity
- Measures conduction only
- “effective” conductivity includes other modes
R Values

- An effective property including all heat flow modes

Trends in materials

- Low density materials insulate better!
- High density materials are structural
- Past – relied on high density (but thick) structural materials to control heat, air, and moisture flow
  - Wood R 1.000 /inch
  - Clay Straw R 0.700 /inch
  - Old brick R 0.180 / inch
  - Concrete R 0.070 /inch
  - Steel R 0.004 / inch
Changing Needs

- Now and tomorrow
  - Better heat flow control required
  - More environmental concerns re: energy
  - More demanding comfort standards
  - Building materials & finishes are less resistant to condensation (& mold)
Materials

- Thermal conductivity (& resistance) varies with
  - material type (conduction, radiation)
  - density and pore structure
  - moisture content
  - temperature difference
- Combination of insulation of air + material
- Still air is about R6/inch (k=0.024 W/mK)
- Only gas fills (e.g. HCFC) can improve this

Insulation

- A brief survey . . .

Fibers

- Mineral Fiber Insulation (vs organic fibers)
  - glass fiber
  - rock fiber
  - slag fiber
  - rockwool
- Glass vs rockwool
  - melts at a much lower temperature
  - has thinner fibers so can use lower density
  - Lower density means more air permeance, less strength, and low volume (less cost and energy) shipping
Blown/spray fibrous insulation

- Can use cellulose, glass, rockwool
- Net or adhesive holds sprayed fiber in cavity
- Fills space and around obstructions
- Avoids settling problems?
- May help control convection

- Are NOT vapour barriers

Cellulose Wall Spray Insulation

- Density 2.5 to 4+ pcf (> 3pcf is recommended)
- R value 3.5 +/- depending on density
- Helps controls convection (higher density=better)
- Can fill irregular cavity spaces
- Settling a concern with low density (< 3pcf)
- Built in moisture concerns (MC? at close in)
- Provides moisture storage
- Controls mold with borate salts (avoid ammonia)
- Is not part of an air barrier system!

Blown Cellulose

Can act as thermal (fire) control layer over foam
Spray Foam

- Primarily polyurethane foam
- Open cell (CO₂ blown) e.g., Icynene
  - About R3.7/inch (R13/3.5", R20/5.5")
  - Moderate to high vapour permeance (≥10 perms)
  - Airtight <0.01 lps/m² @ 75 Pa
- Closed cell (gas blown)
  - R6+/inch
  - 1 - 2 US perms (don’t need vapour barrier)
  - Airtight <0.01 lps/m² @ 75 Pa

Spray Foam

- Open cell
  - Most high vapor permeance
  - Controls convection / wind washing
- Closed cell
  - Air barrier and part vapor barrier
  - Excellent air seal in difficult areas!
  - Beware: adhesion and movement/shrinkage cracks
- Both expensive
- Neither solve air leakage outside of stud cavity

Great for sealing/insulating difficult complex details

- Complete air-vapour-water barrier solution
- Requires transition membranes
**Residential – Air Sealing, Attics, Basements**

**Hybrid: Air, thermal**
- 2" HD spray foam
- 3.5" spray cellulose/fiberglass
- 2x6 wood frame
- 4" (R25) or 6" (R38) HD spray foam

**R40+ roof, fire protection**
- Roof cladding
- Roof underlayment
- 3" CC spray foam (R-19.6)
- 6½" spray fiberglass (R-21)

**Cold Climate (Zone 5/6) Solution**

**Air Sealing Framed Walls with Foam: the details!**
- Most air leakage at
  - rim joist
  - windows
  - penetrations
  - bath rooms
Rigid Boards (sheathing)

- Expanded Polystyrene (EPS)
  - R-value of 3.6 to 4.2
- Extruded Polystyrene (XPS)
  - Higher R-value, usually 5/inch or higher
  - Usually more strength
- Polyisocyanurate (PIC)
  - Highest temp resistance. Long term R6
- All have fire "issues"

Mineral Fiber Sheathing

- Semi-rigid MFI (mineral fiber insulation)
- Rockwool and Fiberglass
  - Air permeable
  - Vapor permeable
  - Allows drainage (provides gap)
- R values of 4 to 4.4/inch
Structural Insulated Panels

- Advantages
  - Superior blanket of insulation (3.5”=R12, 5.5”=R20)
  - 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
Insulated Concrete Forms

- Excellent enclosure system
- Concrete acts as air barrier
- No vapor barrier needed
- Expensive, but high performance (R20)

Future products

- Vacuum panels: Depends on vacuum
  - R20-30/inch
  - VacuPor
    (Porextherm)
- Nanogel/aerogel
  - R12-20/inch
  - Aspen Aerogel

Radiant barriers

- Often misunderstood
- Must have an air space!! (below slabs?)
- Performance depends on temperature difference
  - better at high temperatures, e.g., roof, South
- Can be useful (R5 or so) if low cost
- Most effective at high temperatures (radiation $\propto T^4$)
  How reflective is the material over time?
  Are dust and corrosion avoided?
**How much insulation?**

- Regardless of type, use *more*
- Comfort & moisture –
  - *True* R5-10 is usually enough, but …..
- For energy / environment
  - As much as practical
- Practical constraints likely the limit
  - How much space available in studs?
  - Exterior sheathing of 1.5”/4”
- Increased insulation should reduce HVAC capital as well as operating!

**But there are Complications**

- Add up the R-values of the layers to get the total R-value of the assembly

- **BUT** the actual thermal resistance of an assembly is affected by
  - Air Leakage
  - Thermal Bridges
  - Thermal Mass
The Meaning of R-value

- **Thermal Resistance**
  - R-value (material property, not system)
  - Thermal Bridging

- **Airtightness and Air Looping**
  - About 10-40% of energy loss

- **Mass**
  - Smooths peaks and valleys
  - Takes advantage of heat within (sun, equipment)

- **Buildability / Inspectability**
  - Do you get what you spec/design?

Internal Stack Effect & Insulation

- Gaps in batt insulation on both sides
  - Wrinkles inevitable
  - Closed circuit
  - Energy cost
  - Cold surfaces

**Cold or Hot Weather**

- Hot air = light
- Cold air = heavy
- Result: Air Flow

Common problem

- Batt
- Air gaps
Steel studs provide conduits

- Hard to fill steel studs
- Results in gaps in batt insulation on both sides

Hot air = light

Cold air = heavy

It’s More Than Insulation!

- 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
Thermal Bridging

- Steel is 400 times more conductive than wood
- Steel studs are about 40 times thinner

R<0.3
Cold
Batt
3.5” wall
R=4+
Hot

Wood vs Steel

ASHRAE 90.1 “Clear Wall” best case

Wood Studs
Simple framing
ASHRAE 90.1 “Clear Wall” best case

R-value Comparison

Impact of Insulating Sheathing

Adding studspace insulation is not helpful!
Cold surfaces where R<5

Plot of temperature along wall mid-height:

- Thermal bridging heat flow
- Cold exterior: -10°C / 15°F
- Siding sheathing
- Framing: drywall
- Warm interior: +23°C / 75°F

High RH / Low R

- Poorly insulated window frames and glass
- Behind furniture: poor airflow and insulating material
- Condensation in walls and ceilings

Thermal Bridging: Common Problems
Thermal Bridge Examples

- Balcony, etc
- Exposed slab edge,

Solving Thermal Bridging

- Exterior insulation can solve most thermal bridges
  - Inside works, but hard to cover structural penetrations
- Lower interior RH to stop condensation

All on the exterior
Small metal clips dramatically reduce thermal bridging.
Precast balcony supported on knife edge supports to limit thermal losses.
Summary: Heat flow control

- A *continuous* layer of only R5-10 is key
  - Exterior is easiest to get continuous
  - Should provide much more for energy efficiency
- Heat flow control is not just about R-value!
  - Control of airflow
  - Thermal bridging must be managed
  - Thermal mass can play a role
  - Solar Gain can dominate
    - Window area, shading, low SHGC windows
    - Overhangs, light colors for walls and roofs