Introduction

Low-E Buildings: Why and What

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Outline

- 1. Intro – Scope and problem definition
- 2. Human Comfort – brief intro
- 3. Building Enclosures
- 4. Mechanical Systems

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What is Green/Sustainable?

- Definitions
  - "Green"
  - Sustainable
  - Net Zero Energy
  - Net Zero Carbon

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Measuring Green Building

- Resource Use - in construction and operation
  - Depletion of limited resources
  - Renewable? Recyclable
- Energy Use - in construction and operation
  - Embodied in materials and construction
  - Operational
- Ecological Damage
  - Pollutant Production
  - Habitat destruction

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Sustainable buildings

- "Can keep doing what we are doing indefinitely"
  - *Sustainable development is development which meets the needs of the present without compromising the ability of future generations to meet their own needs.*
    Bruntland Commission Report – the source and inspiration for the popularization of the concept of sustainability
  - A sustainable society, process, or product is one that can be sustained or continue to be produced over the long term, without adversely affecting the natural conditions (e.g, soil, ecosystem, water quality, climate, etc) necessary to support those same activities in the future.
  - Even the greenest buildings today are not sustainable

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Green Building & Durability

- Green Buildings are very efficient
- Green Buildings are Durable
  - For two buildings otherwise the same a 25 yr life span will use twice the resources of a 50 yr lifespan
- If we use fewer resources it is greener
- Green buildings work well for users
  - Likely to be used longer and more

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Is it Green? Learning to count

- Depends on answers to:
  - Does it use less non renewable energy to operate?
  - Will it last longer? (less life-cycle resources)
  - Does it use fewer non renewable resources to build?
  - Does it pollute less?
- Compared to what?:
  - Zero (sustainable)
  - Better than average (move forward, "green")
    - What is average?
- LEED counts points, not resources/pollution

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Green Buildings require Change

- Must make them the new normal
- Need to use different thinking and process
- Different materials and systems secondary

"To achieve results never before accomplished, we must employ methods never before attempted."
- Sir Francis Bacon

"Great spirits have always been met with violent opposition from mediocre minds."
- Albert Einstein

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Measuring Green Building

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Damage Components

- Resource Extraction
  - Cutting trees, mining, drilling oil, etc.
- Processing
  - Refining, melting, etc. Pollutants and energy
- Transportation
  - Mass and Mode (ship/truck) and Mileage
- Construction
  - Energy, worker transport
- Operational Energy

The Majority of Impact

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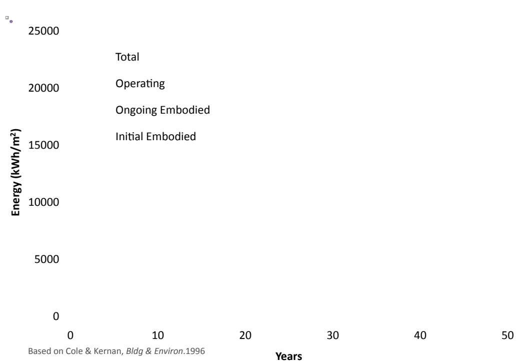
Office Example



Based on Cole & Kernan, *Bldg & Environ*.1996

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Embodied Energy

- *The energy used to mine, process, and manufacture a material & install in building*
  - Units usually Btu/lb or MJ/kg
- On-going repair and maintenance required for life of building
- Published values vary widely
  - Some research results available

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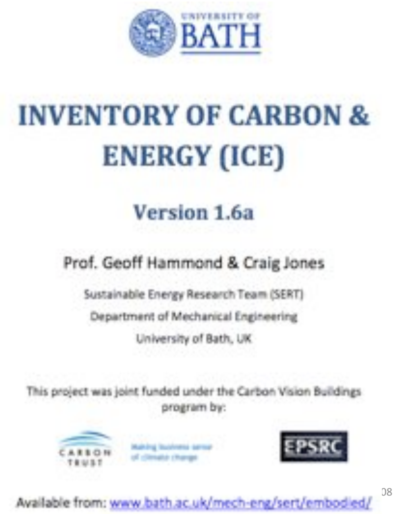

Source: *Canadian Architect*

MATERIAL	EMBODIED ENERGY MJ/kg	EMBODIED ENERGY MJ/m3
Aggregate	0.10	150
Straw bale	0.24	31
Soil-cement	0.42	819
Stone (local)	0.79	2030
Concrete block	0.94	2350
Concrete (30 Mpa)	1.3	3180
Concrete precast	2.0	2780
Lumber	2.5	1380
Brick	2.5	5170
Cellulose insulation	3.3	112
Gypsum wallboard	6.1	5890
Particle board	8.0	4400
Aluminum (recycled)	8.1	21870
Steel (recycled)	8.9	37210
Shingles (asphalt)	9.0	4930
Plywood	10.4	5720
Mineral wool insulation	14.6	139
Glass	15.9	37550
Fiberglass insulation	30.3	970
Steel	32.0	251200
Zinc	51.0	371280
Brass	62.0	519560
PVC	70.0	93620
Copper	70.6	631164
Paint	93.3	117500
Linoleum	116	150930
Polystyrene Insulation	117	3770
Carpet (synthetic)	148	84900
Aluminum	227	515700

NOTE: Embodied energy values based on several international sources - local values may vary.

Embodied Environmental Damage

- Pollution (air, water, etc)
- dangerous waste (end of life),
- habitat destruction,
- resource depletion

- Not well researched (Athena Institute)

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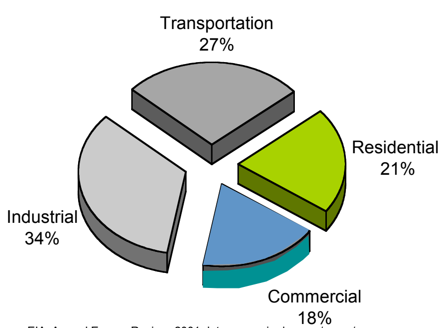
Building Energy Use

Primary Energy Consumption by Sector, 2001



Source: EIA, Annual Energy Review, 2001 data: www.eia.doe.gov/emeu/aer

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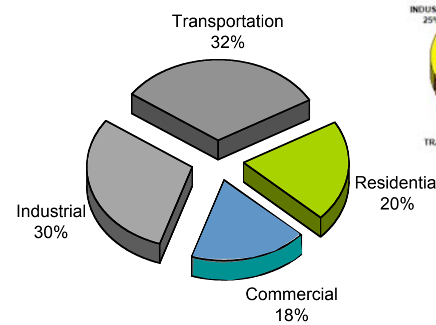
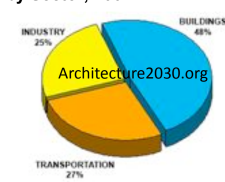
Building Carbon Emissions

Carbon Dioxide Emissions from Energy Consumption by Sector, 2001





Source: EIA, Annual Energy Review, 2001 data: www.eia.doe.gov/emeu/aer

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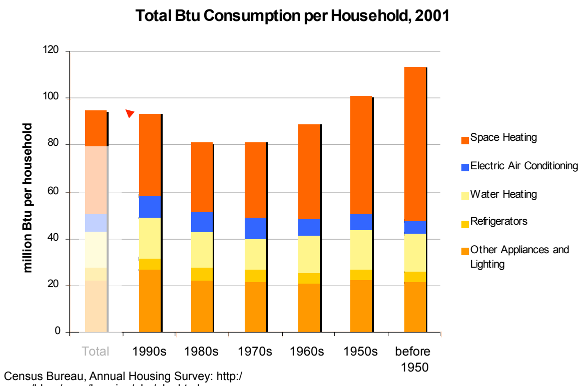
Old & New Houses Energy Use



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

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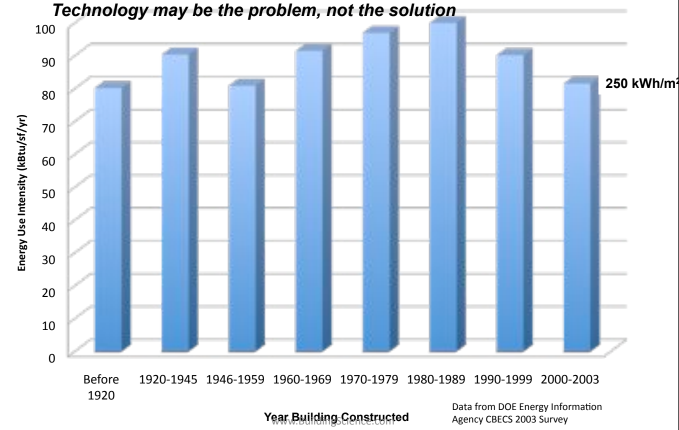
Commercial Buildings Energy Use

Technology may be the problem, not the solution



Data from DOE Energy Information Agency CBECS 2003 Survey

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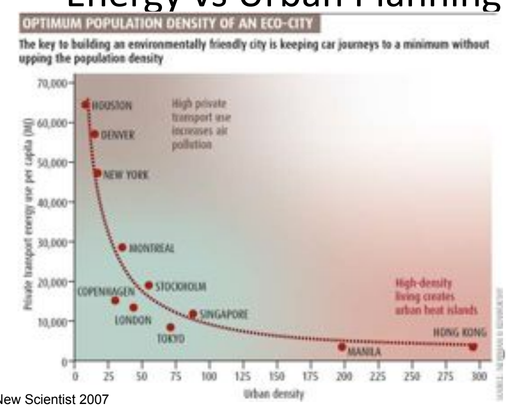
Energy vs Urban Planning



Source: New Scientist 2007

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How?

To reduce operational energy use

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Process and Philosophy

- Decide to value low energy consumption
- Set *measurable* targets, predict usage, measure performance
- Stamp out waste everywhere
- Ensure safety, comfort, health and durability are sacrificed

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Energy Intensity

- Energy use per area
  - kBtu/sf/yr
  - $kWh_e/m^2/yr$
  - 100 $kWh_e/m^2/yr$ = 33 kBtu/sf/yr
- Energy use per person
  - Person = bedrooms+1
  - Design occ. Vs actual occ.

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Low E Targets

- Ed Mazria Architecture 2030
  - Website www.architecture2030.org
- PassivHaus
  - 120 $kWh/m^2/yr$ (37 kBtu/sf/yr)
- Net Zero
- Aspirations
  - 30%? 50%? 75%? Of what?
- Occupancy and Climate matters
  - Cold climates, 24/7 facilities use more

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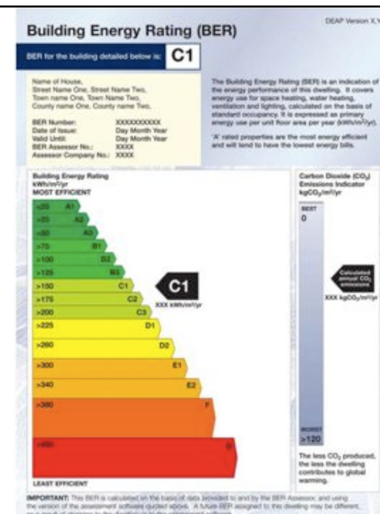


Electricity is Dirty

- BSD-151 Site vs Source

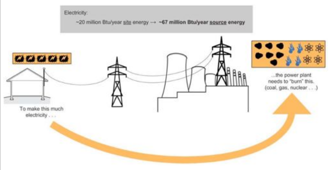
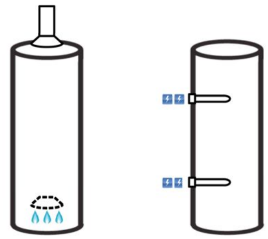


Figure 1: Source energy from power plant to electric service entrance



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Comparison different performance standards

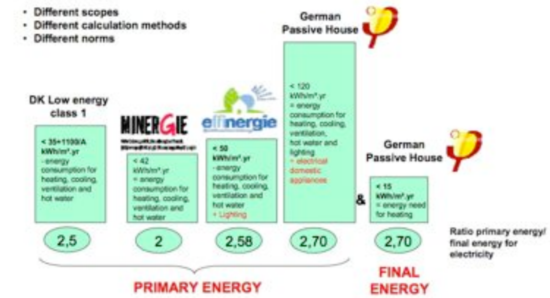

Figure 3. Comparison of the Danish low energy class 1, the Swiss energy calculation method (Minergie), French energy calculation methods (Effinergie), with the two energy frames as defined in the Passive House standard (total energy consumption and heating consumption per year). Source: Pascal Eveillard,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

[1] Energy used for lightning in a 150 m^2 house with traditional technology is approx. 1000 kWh/y (approx. 6 kWh/m^2) while the energy used for appliances is approx. 3000 kWh/y, (approx. 20 kWh/m^2).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/m^2) and to 1500 kWh/y (10 kWh/m^2) for appliances.

Commercial

- 1. Limit window-to-wall ratio (WWR) to 40% (more if TG)
- 2. Separate ventilation air supply from heating and cooling;
  - Use low temperature hydronic heating and cooling;
- 3. Increase window performance (lowest U-value affordable in cold climates, SHGC more important in hot climates);
- 4. Increase wall/roof insulation (thermal bridging), airtighten
- 5. Reduce equipment/plug & lighting power densities
  - Occupancy and daylighting dimming controls (Off= efficient)
- 6. Use heat recovery on exhaust and "relief" air
- 7. Don't over ventilate, then demand controlled ventilation
- 8. Improve chiller efficiency & recover heat (eg from IT rooms!)
- 9. Use condensing space heating boilers (low temp heating)
- 10. Consider source of energy

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Residential, single family

1. Comfortable, durable, healthy, safe
2. Insulate wall, roof basement, airtighten
3. Limit window-to-wall ratio (WWR) to <30%
4. Control ventilation, use energy recovery ventilation
5. Upgrade windows (control SHGC and R-value)
6. Use efficient lighting, right-sized
7. Use efficient appliances
8. Use efficient heating and domestic hotwater equip.
9. Consider source of energy
10. Add renewables to push toward zero

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Low-energy Design

- Reduce the demand. Examples:
  - Reduce size of building
  - Reduce the enclosure area exposed to the environment
  - Reduce the heat loss and gain
  - Reduce the need for lighting
  - Increase efficiency / stop waste
- Provide a clean energy supply (RE)

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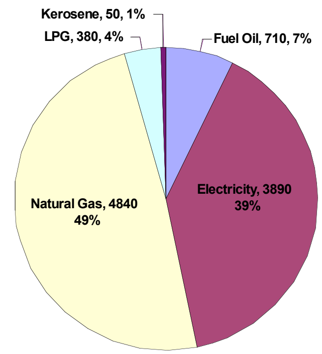
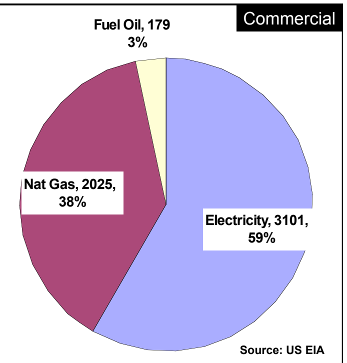
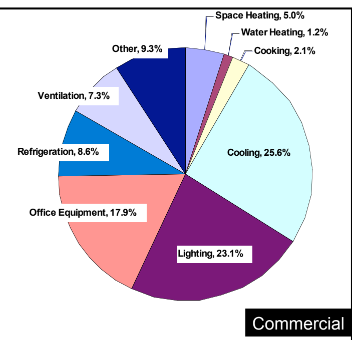
Building Energy Use

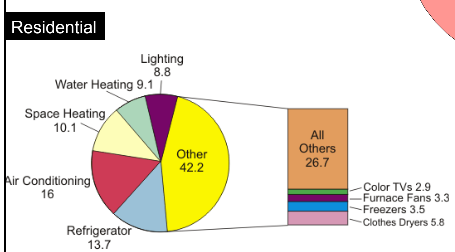




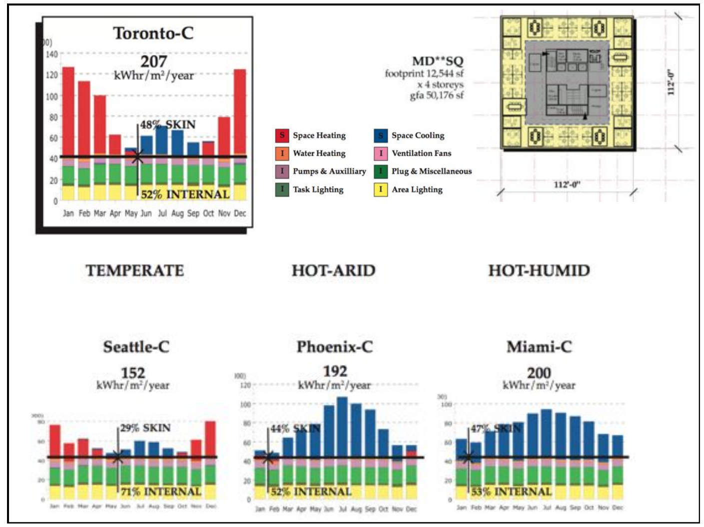
Mostly NG (heating, hotwater) and electricity (cooling, lighting, etc)

US Building *Electrical* Use





Source: Energy Information Administration, Form EIA-457A, B, C, E, and H of the 2001

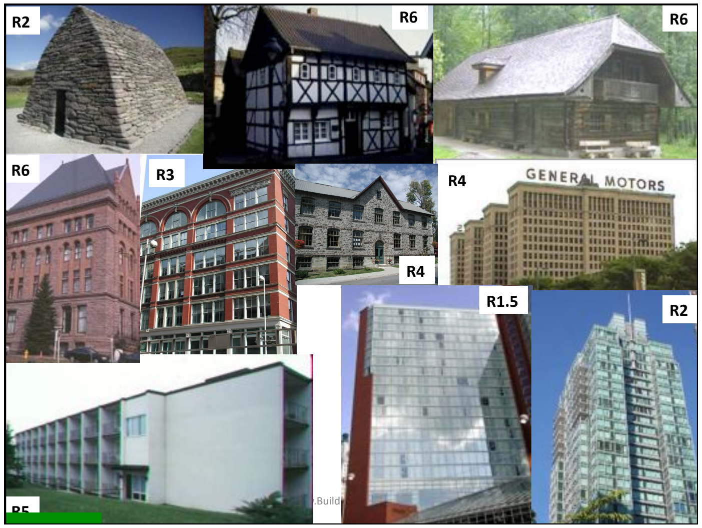


Strategies

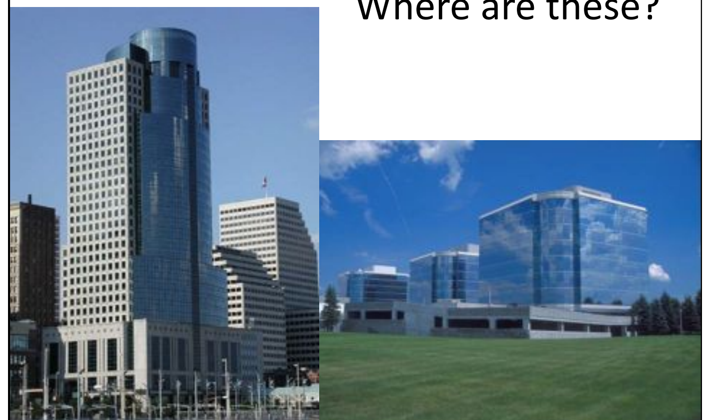
- Siting (small impact)
  - Orient with sun, wind, rain, earth shelter?
- Shape and Form (small to moderate impact)
  - Small, Compact, simple
- Exceptional building enclosure (mod to large impact)
  - Insulated, airtight, durable, solar control
- Efficient Equipment (mod impact)
  - Not there or off is best, controls help
- Renewable Energy Generation (impact varies)

Building Energy Determinants

Requirements	**Client**	Temperature, humidity ranges, lighting type, views, air changes, size
Loads	**Architecture**	Massing, window area, enclosure details, selection of HVAC type
Systems/ Equipment	**Mech Eng**	System design, controls, equipment selection
Demand	**Occupant**	Behavior, desires
Energy Source	**Utility**	Generation technology, pricing structure, efficiency of operations



Where are these?



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Enclosure Design

Defining the Energy Load

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Size: Surface Area to Floor Area

- Size matters

10 - 12' storeys

SA: = 72 000
FA: 120 x120 = 144000

Ratio 0.5: 1

1 - 12' storey (mall)

FA: 100 x 250 = 25000
SA: = 33400

Ratio 1.5:1

The higher the ratio, the more enclosure design & climate impact performance

1 - 10' storey (house)

FA: 30x 50 = 1500
SA: = 3100

Ratio 2:1

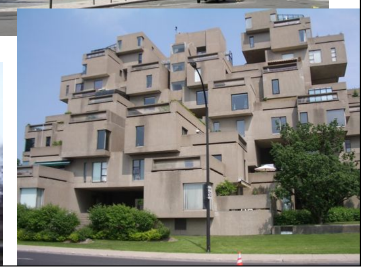
Small, Compact Form

- Fewer resources
- Less heat loss and gain

Form & Massing

- Keep it simple
- Cheaper, easier, faster
- Fewer
  - thermal bridges, air leaks
  - Material volumes
  - construction challenges





Enclosure Area

- Heat Loss: Surface Area / R_{avg} + air leakage
- House SA: FA = 2:1
  - If R_{avg} = 20, and SA= 1000 sf then 1000/20:
    - = 50 Btu/sf enclosure/F
    - = 100 Btu/sf floor/F
- Office SA:FA = 0.5:1
  - If R_{avg} = 10, and SA= 1000 sf then 1000/10:
    - = 100 Btu/sf enclosure/F
    - = 50 Btu/sf floor/F

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Daylighting

Adding enjoyment while saving electricity

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Daylighting

- Natural light can offset artificial lights
- Natural light almost always preferred
- BUT,
  - **Must** use daylight controls and sensors to capture energy savings
  - Need to control glare and solar heating caused by too much glass on sunny days

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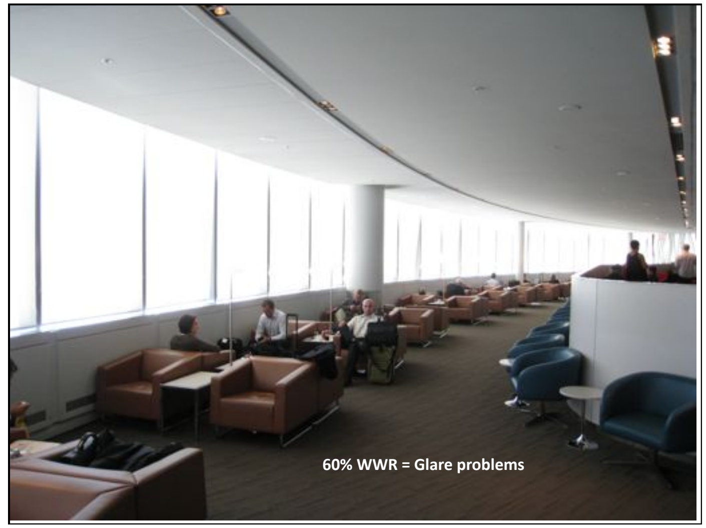

Daylight Penetration

- Many simple design tools available
  - Work well for standard shapes
- Effective Aperture
  - Visual transmittance x Glass area
  - Recommended: (window ht/ ceiling ht) * VT > 0.20
- Daylight zone depends on window head height
  - Eg penetration 1.5 – 2.5 window head height
- Software such as Ecotect Radiance DaySim quantify complex shapes

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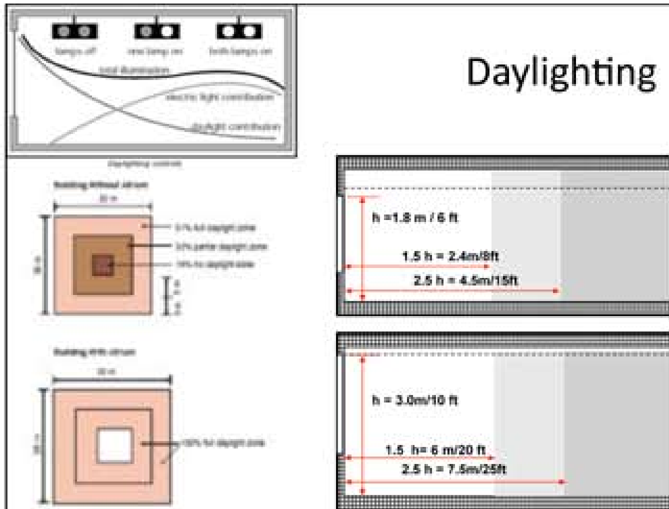
Daylighting



Daylighting

- Direct solar penetration is NOT desirable
  - Creates glare and discomfort.
  - MAY be useful for free solar heating if desired
  - High on south in winter, W/E in summer
- Design for *diffuse* light
  - Almost the same on all four orientations
  - Bright sky is about 10 000 lux on horizontal

Lighting Goals

- 300 lux on desktop (500 for special apps)
  - Often this means a Daylight Factor of 2%
- Lighting power density has dropped tremendously (3X) in last 30 yrs
- Now possible to do 0.8 W/ft^2 (10 W/m^2)
  - Future LED offer even lower lighting
  - Smarter task and general lighting
- **Energy Benefit of daylighting is decreasing**

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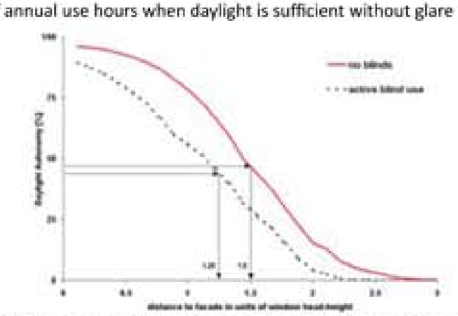
Daylight Autonomy

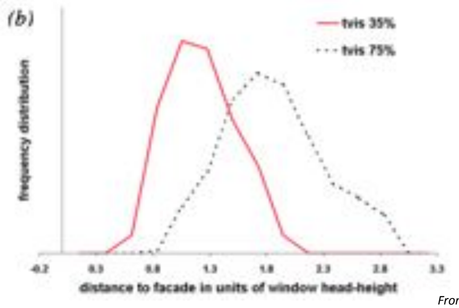
- % of annual use hours when daylight is sufficient without glare



From: C Reinhart, 2005

Daylight Design

- Next to head height and window area, window transmittance (T_{vis} or VT)



From: C Reinhart, 2005

Daylight Design

- Head height, not ceiling height. Low glass is essentially useless for daylighting.

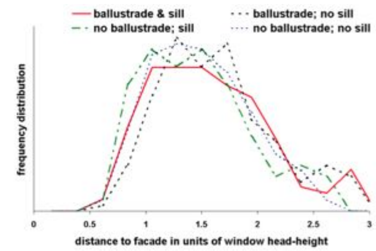
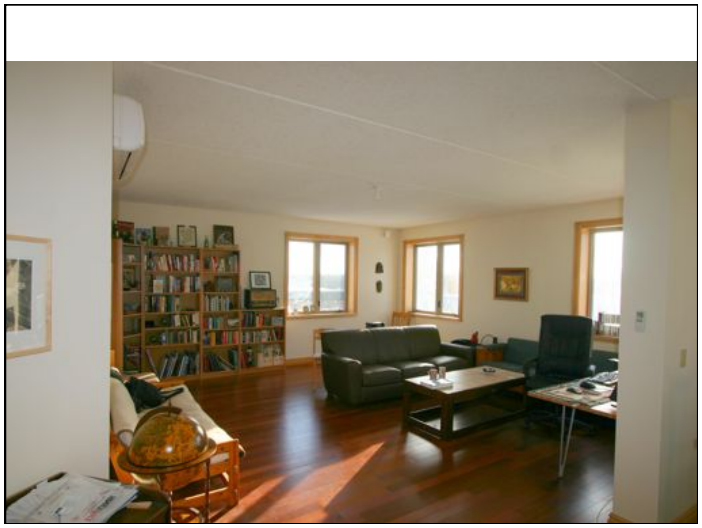
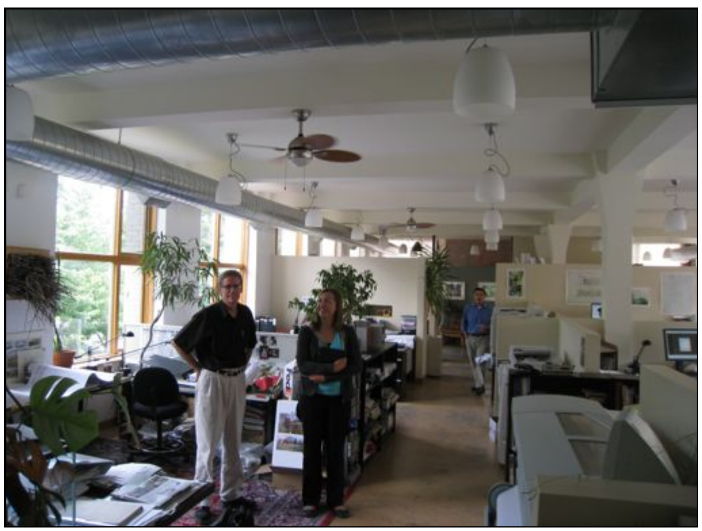


Figure 6: Frequency distributions of predicted daylit zone depths with blinds for varying facade

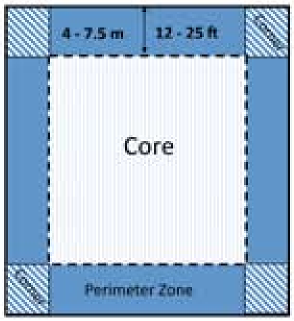
From: C Reinhart, 2005



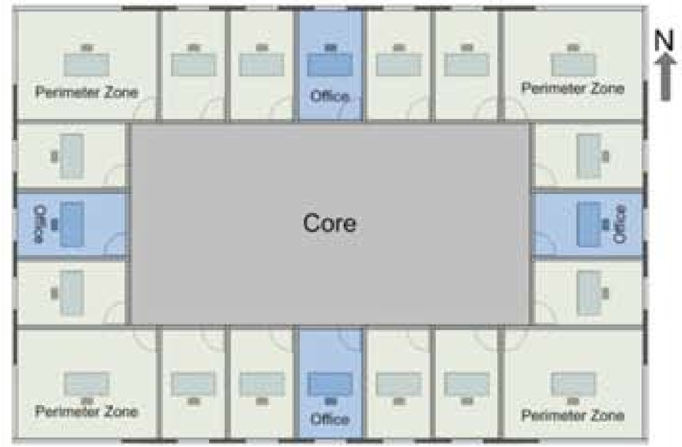



Building Shape
• Alphabet Soup
– H I A B E

Core / Perimeter



- Perimeter Zone
  - performance dominated by climate and enclosure
- Core Zone
  - dominated by interior use. Climate/enclosure almost irrelevant
- In most occupancies, core needs cooling and lighting all year long, all day



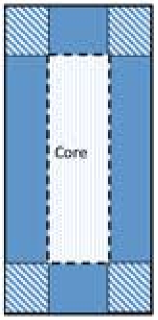
Large Buildings

Many buildings with sizeable core areas require cooling in winter while heating the perimeter

Define "perimeter"

- Maximum distance about 25 ft/ 7.5 m
  - Classrooms often 25-30 ft, open plan office
- Minimum often set by walls/partitions of exterior offices
  - Cellular offices often 15 ft/ 4.5m deep

Skin Dominated Building



- Perimeter Zone over most of building area
- Excellent daylighting and cross ventilation opportunities
- Termed "Skin Dominated"
- Demands good building enclosure

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Skin dominated

Double loaded corridor school, with one side for daylighting, roof over each class
one of thousands

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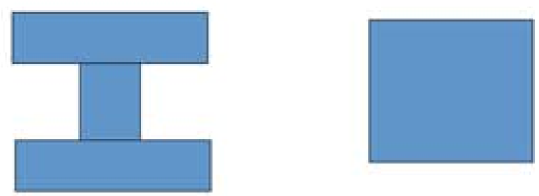
Expanded Plans

- Better daylight, easier ventilation but more enclosure heat loss and gain and air leaks



E. Gratia, A. De Herde / Energy and Buildings 35 (2003) 473–491

Shape and Orientation: Heating Energy for cold climate

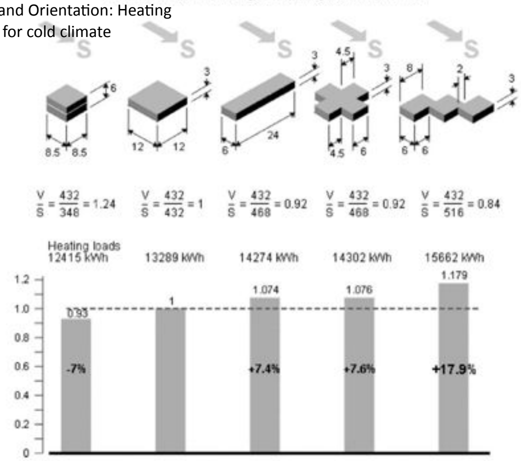


Fig. 4. Impact of the building shape on the heating loads.

Trade offs

- Large rectangular buildings have a reduced surface to volume ratio
  - Equals lower heat loss and gain
- Complex building shapes increase surface area
  - Heat loss and gain increase
  - Require better insulation and solar control

Grouping buildings

- Grouping units reduces heat loss/gain through shared walls
- Reduces resource use per unit

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Grouping housing

Enclosure Details

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Enclosure & Low Energy Buildings

- Enclosure defines the load
  - Architecture defines massing, orientation, enclosure
- Enclosure critical for skin-dominated
  - Heat flow, Solar control, air tightness
- Lighting, ventilation critical for deep plan
- Enclosure Durability / Performance problems are common

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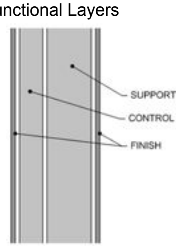
Basic Functions of the Enclosure

- 1. Support
  - Resist and transfer physical forces from inside and out
- 2. Control
  - Control mass and energy flows
- 3. Finish
  - Interior and exterior surfaces for people

- Distribution – a building function

Functional Layers



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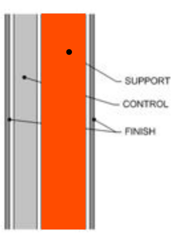
Enclosures No. 39 /

Basic Enclosure Functions

- **Support**
  - **Resist & transfer physical forces from inside and out**
    - Lateral (wind, earthquake)
    - Gravity (snow, dead, use)
    - Rheological (shrink, swell)
    - Impact, wear, abrasion
- Control
  - Control mass and energy flows
- Finish
  - Interior and exterior surfaces for people

Functional Layers



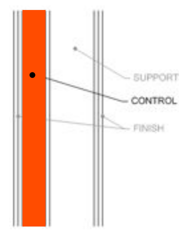
Building Science

Enclosures No. 40 /

Basic Enclosure Functions

- Support
  - Resist & transfer physical forces from inside and out
- **Control**
  - **Control mass and energy flows**
    - **Rain** (and soil moisture)
      - Drainage plane, capillary break, etc.
    - **Air**
      - Continuous air barrier
    - **Heat**
      - Continuous layer of insulation
    - **Vapor**
      - Balance of wetting/drying
- Finish
  - Interior and exterior surfaces for people

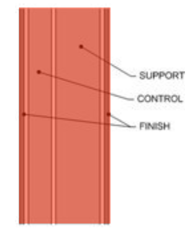
Functional Layers



Other Control Functions . . .

- Support
- **Control**
  - **Fire**
    - **Penetration**
    - **Propagation**
  - **Sound**
    - **Penetration**
    - **Reflection**
  - **Light**
    - **Diffuse/glare**
    - **View**
- Finish

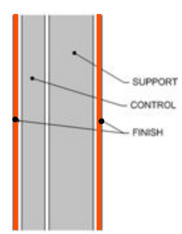
Functional Layers



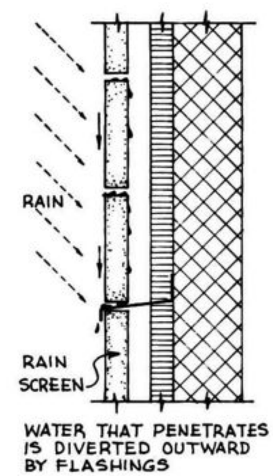
Basic Enclosure Functions

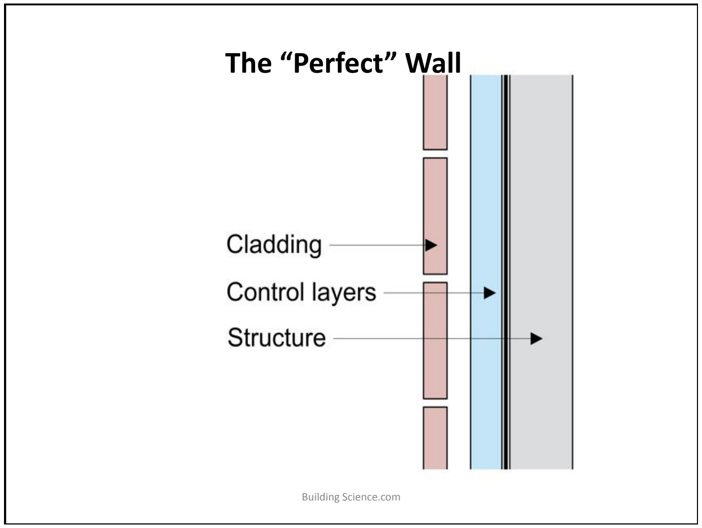
- Support
  - Resist & transfer physical forces from inside and out
- Control
  - Control mass and energy flows
- **Finish**
  - **Interior & exterior surfaces for people**
    - Color, speculance
    - Pattern, texture

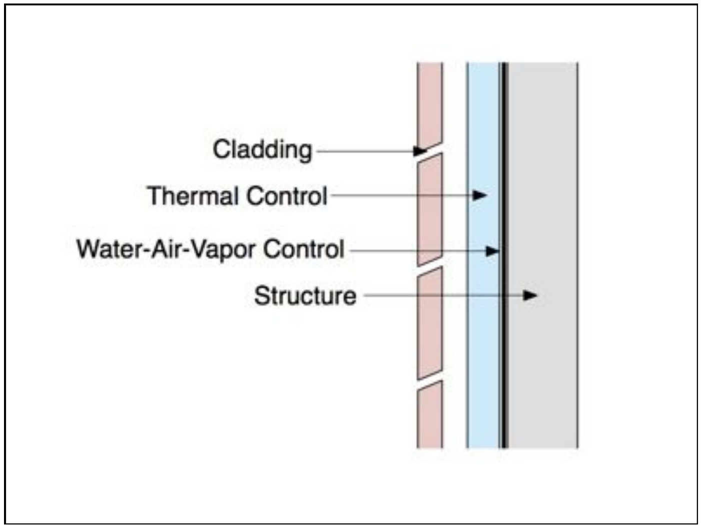
Functional Layers

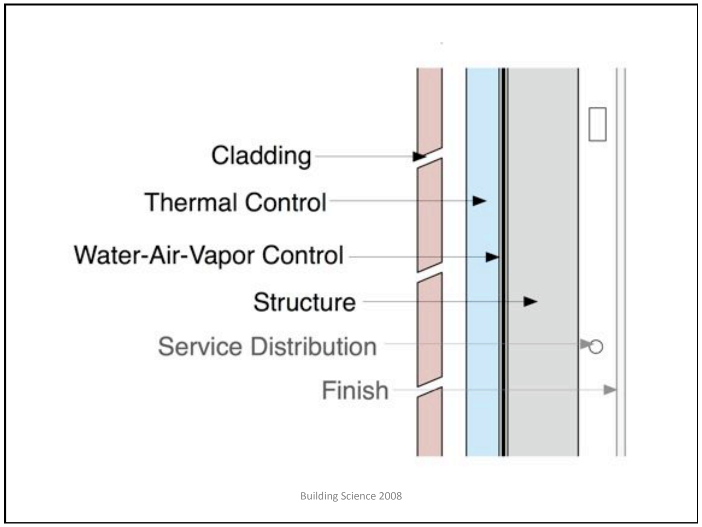


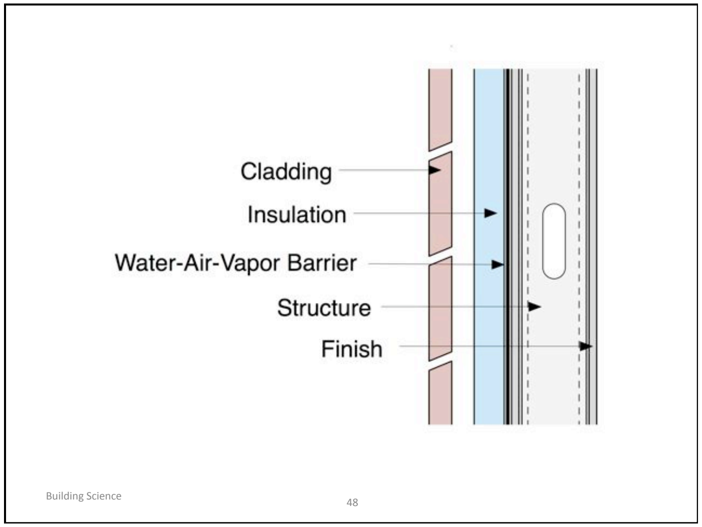
- Follow the rules
- Bleeding edge research from 1960's

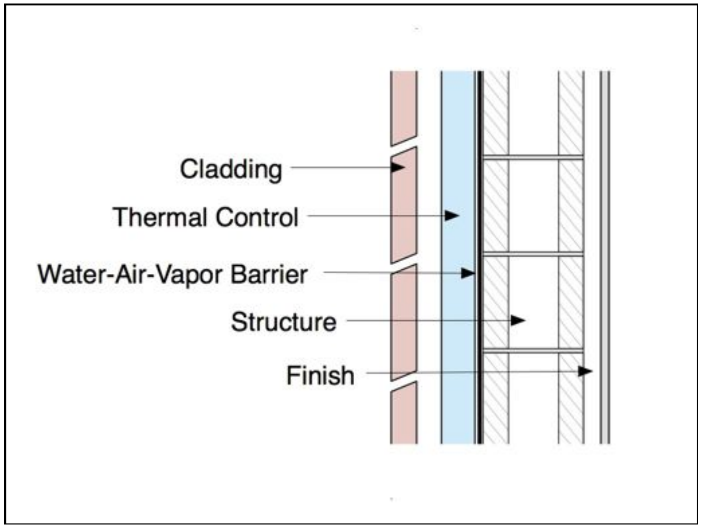


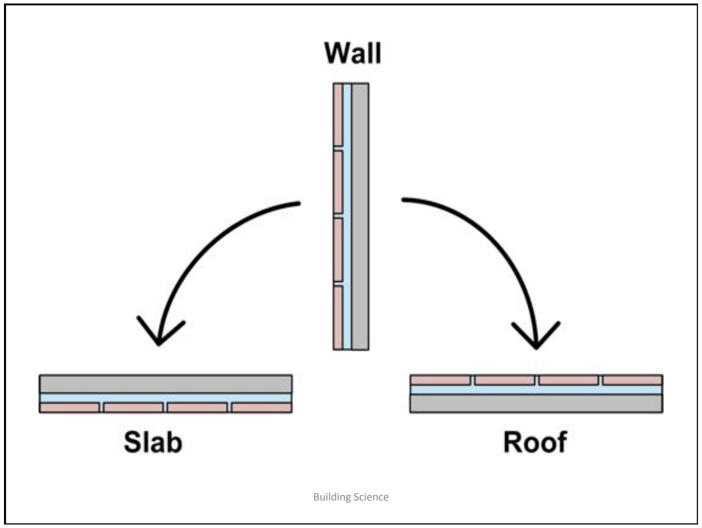

The "Perfect" Wall
Cladding
Control layers
Structure
Building Science.com

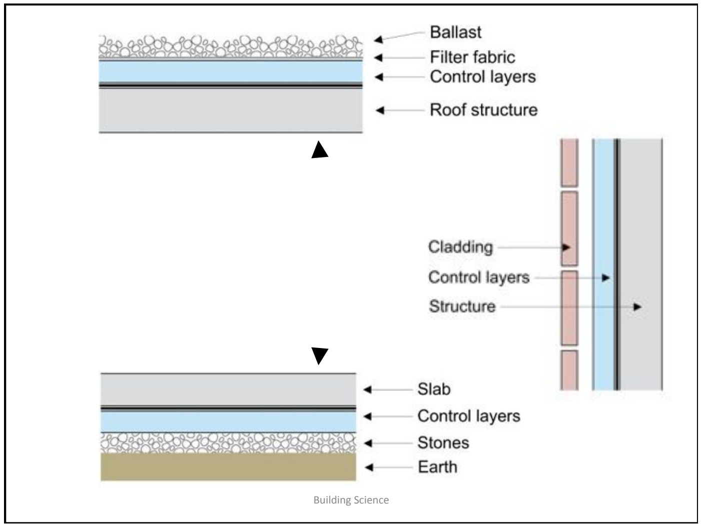

Cladding
Thermal Control
Water-Air-Vapor Control
Structure

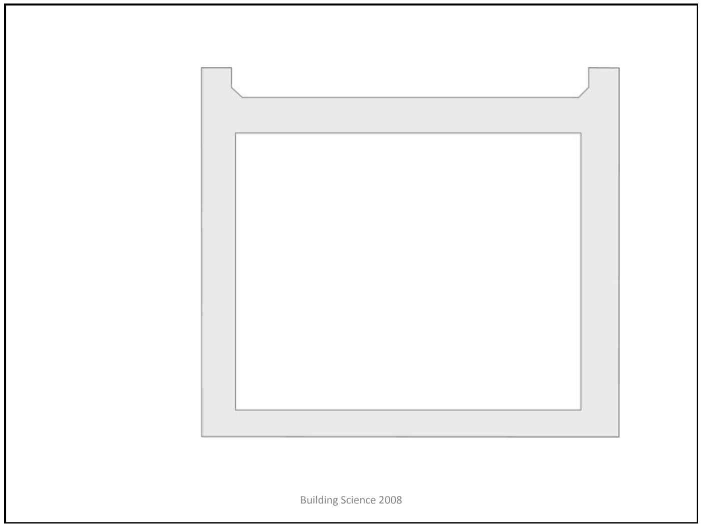

Cladding
Thermal Control
Water-Air-Vapor Control
Structure
Service Distribution
Finish
Building Science 2008

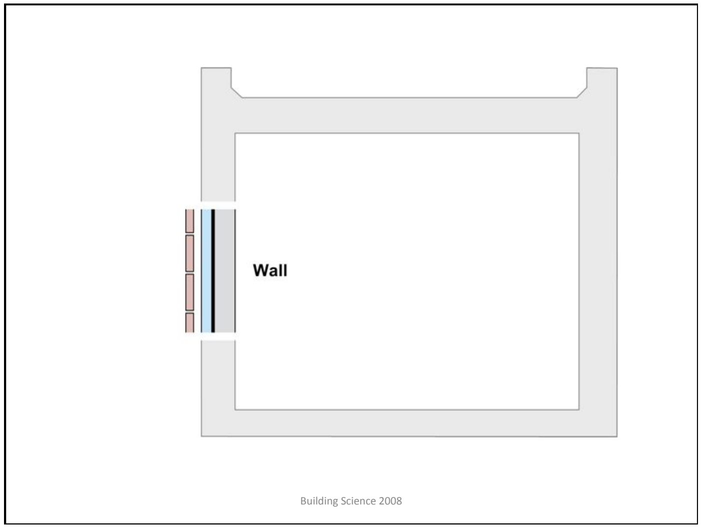

Cladding
Insulation
Water-Air-Vapor Barrier
Structure
Finish
Building Science
48

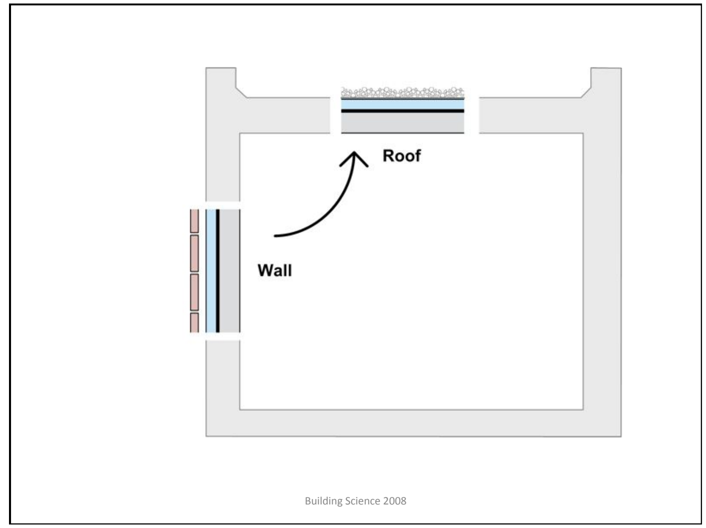

Cladding
Thermal Control
Water-Air-Vapor Barrier
Structure
Finish

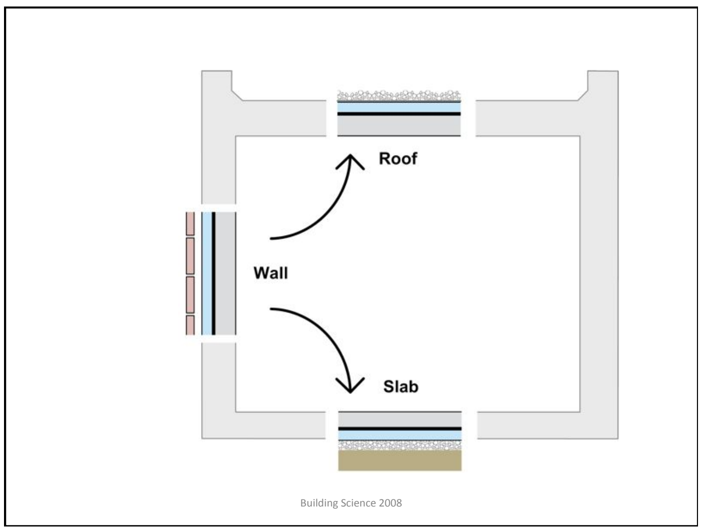

Wall
Slab
Roof
Building Science

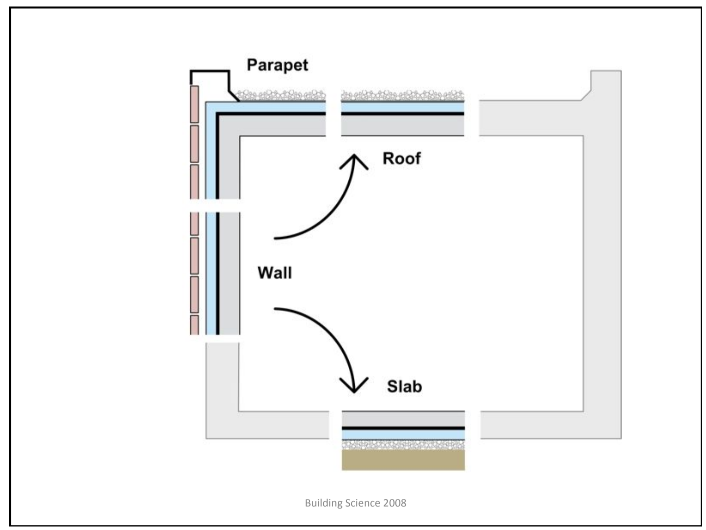

Ballast
Filter fabric
Control layers
Roof structure
Cladding
Control layers
Structure
Slab
Control layers
Stones
Earth
Building Science

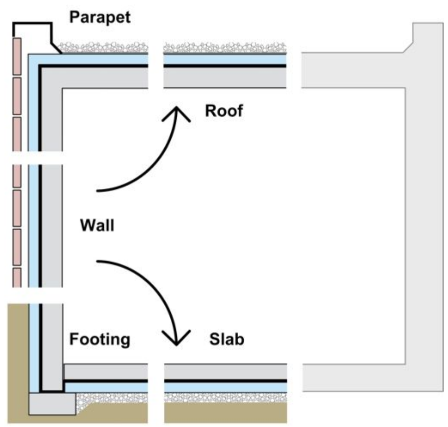

Building Science 2008

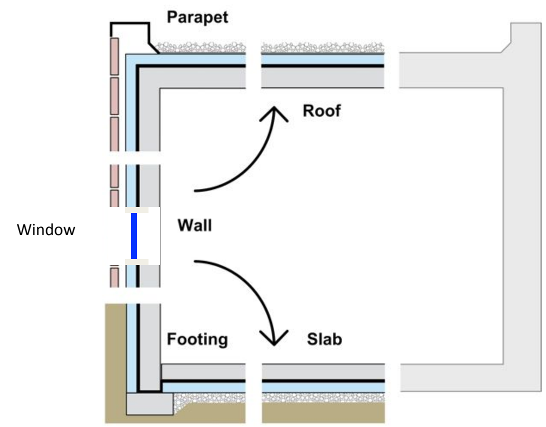

Wall
Building Science 2008


Roof
Wall
Building Science 2008


Roof
Wall
Slab
Building Science 2008


Parapet
Roof
Wall
Slab
Building Science 2008





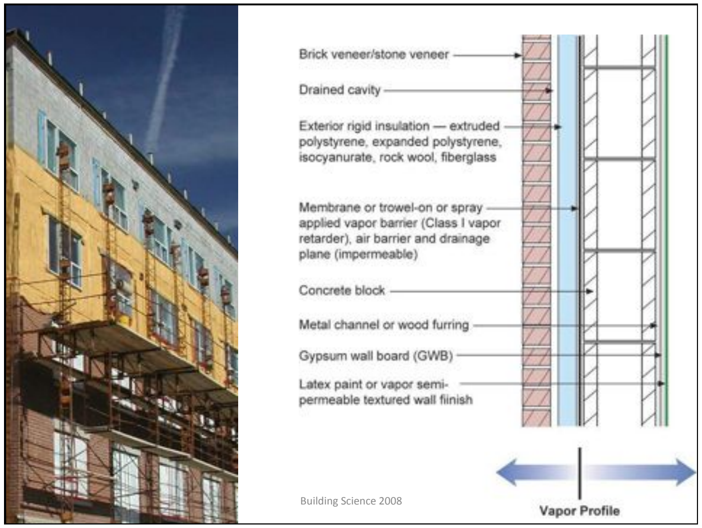
The Enclosure: Adding the Layers

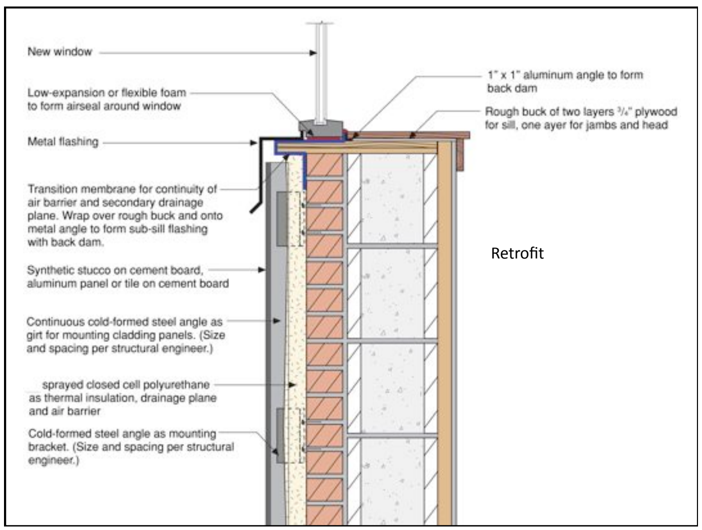
- Structure
- Air Barrier
- Rain Control
- Insulation
- Finish

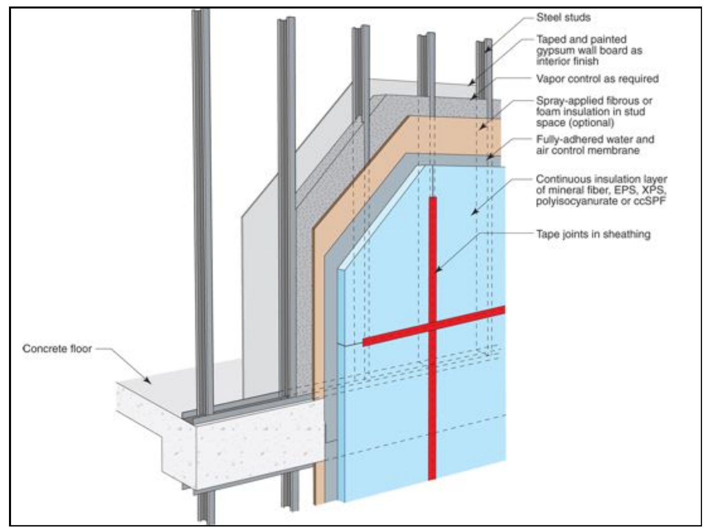
Basic Enclosure Practice

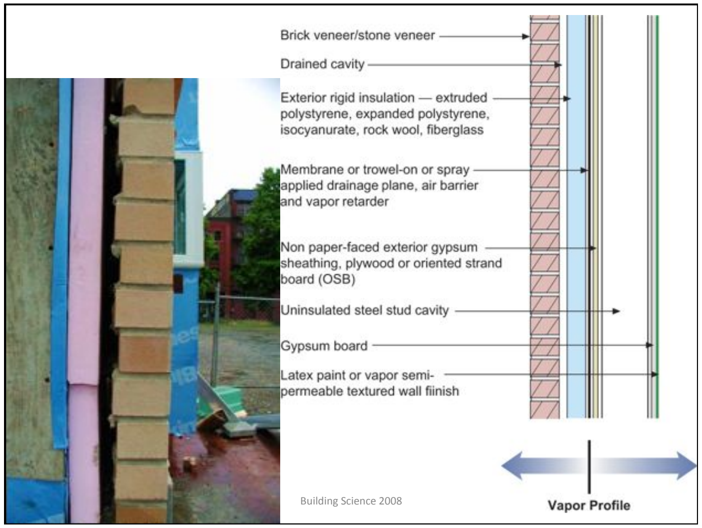
- Structure
  - connect all parts together to foundation
- Continuous Rain Control
  - Drainage plane, gap, flashing, weeps needed
- Air barrier
  - Continuous air barrier to control air flow
  - Vapor retarder less important, may have holes
- Continuous Insulation
  - Exterior insulation layer to slow heat flow, blunt cold spots (R>5-10)+

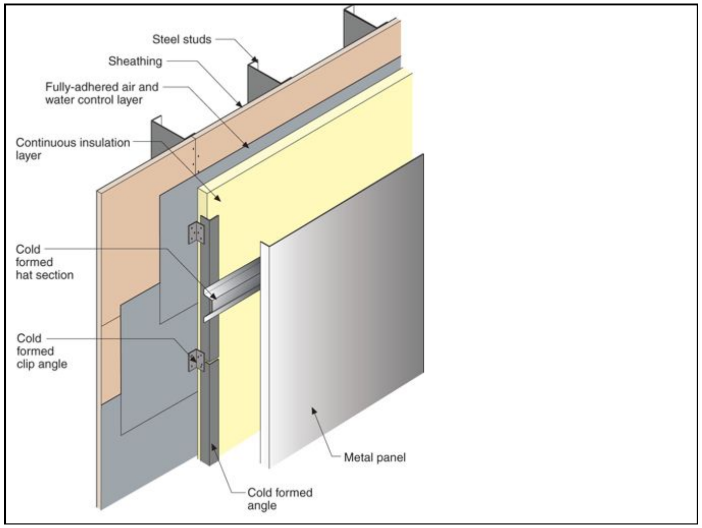
60/175 9/29/10

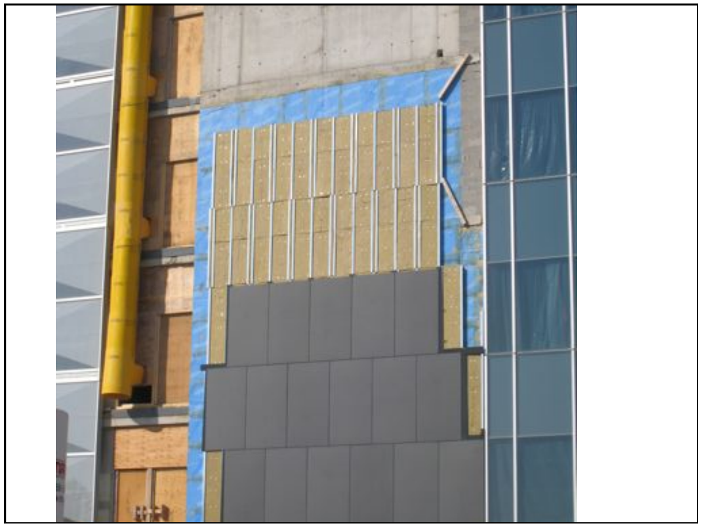

Brick veneer/stone veneer
Drained cavity
Exterior rigid insulation — extruded polystyrene, expanded polystyrene, isocyanurate, rock wool, fiberglass
Membrane or trowel-on or spray applied vapor barrier (Class I vapor retarder), air barrier and drainage plane (impermeable)
Concrete block
Metal channel or wood furring
Gypsum wall board (GWB)
Latex paint or vapor semi-permeable textured wall finish
Building Science 2008
Vapor Profile

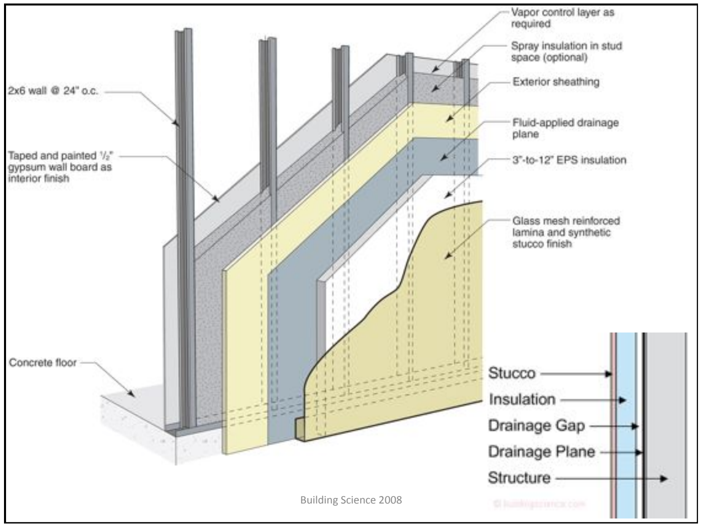

New window
Low-expansion or flexible foam to form airseal around window
Metal flashing
Transition membrane for continuity of air barrier and secondary drainage plane. Wrap over rough buck and onto metal angle to form sub-sill flashing with back dam.
Synthetic stucco on cement board, aluminum panel or tile on cement board
Continuous cold-formed steel angle as girt for mounting cladding panels. (Size and spacing per structural engineer.)
sprayed closed cell polyurethane as thermal insulation, drainage plane and air barrier
Cold-formed steel angle as mounting bracket. (Size and spacing per structural engineer.)
1" x 1" aluminum angle to form back dam
Rough buck of two layers ³/₄" plywood for sill, one ayer for jambs and head
Retrofit


Steel studs
Taped and painted gypsum wall board as interior finish
Vapor control as required
Spray-applied fibrous or foam insulation in stud space (optional)
Fully-adhered water and air control membrane
Continuous insulation layer of mineral fiber, EPS, XPS, polyisocyanurate or ccSPF
Tape joints in sheathing
Concrete floor

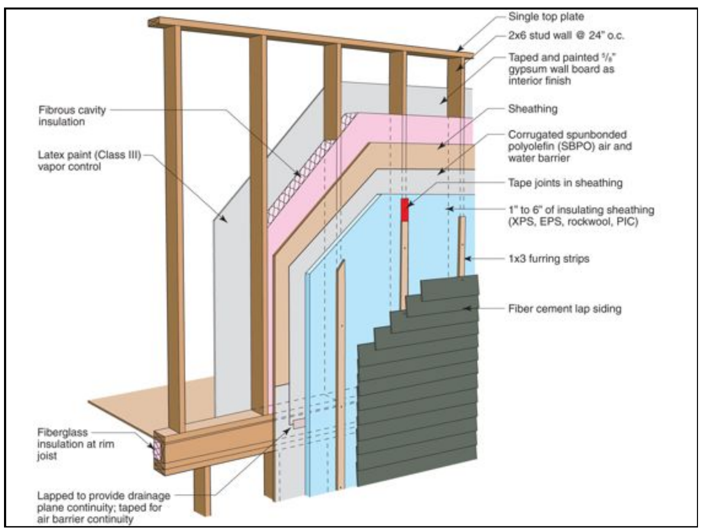

Brick veneer/stone veneer
Drained cavity
Exterior rigid insulation — extruded polystyrene, expanded polystyrene, isocyanurate, rock wool, fiberglass
Membrane or trowel-on or spray applied drainage plane, air barrier and vapor retarder
Non paper-faced exterior gypsum sheathing, plywood or oriented strand board (OSB)
Uninsulated steel stud cavity
Gypsum board
Latex paint or vapor semi-permeable textured wall finish
Building Science 2008
Vapor Profile

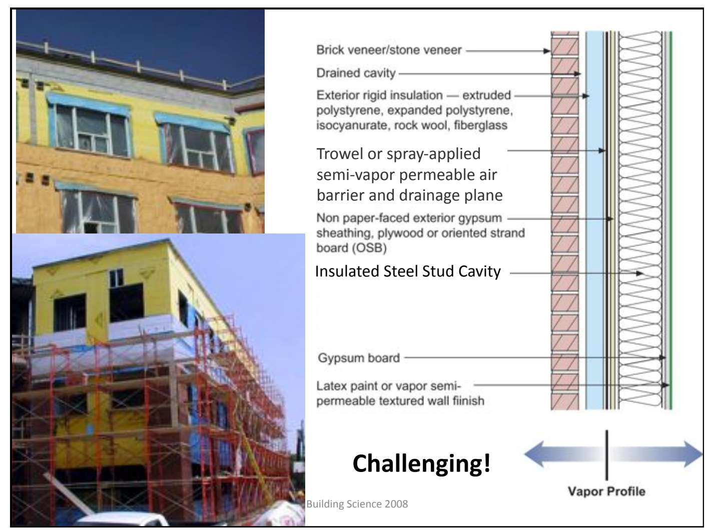

Steel studs
Sheathing
Fully-adhered air and water control layer
Continuous insulation layer
Cold formed hat section
Cold formed clip angle
Metal panel
Cold formed angle



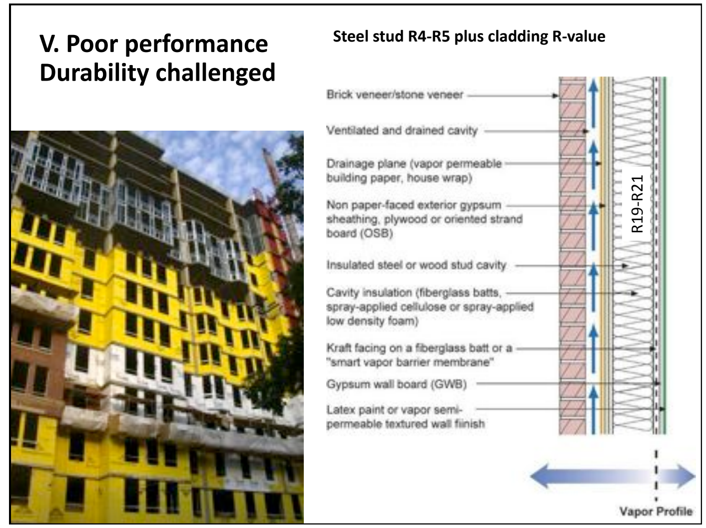

Vapor control layer as required
Spray insulation in stud space (optional)
Exterior sheathing
Fluid-applied drainage plane
3"-to-12" EPS insulation
Glass mesh reinforced lamina and synthetic stucco finish
2x6 wall @ 24" o.c.
Taped and painted ½" gypsum wall board as interior finish
Concrete floor
Stucco
Insulation
Drainage Gap
Drainage Plane
Structure
Building Science 2008


Building Science 2008

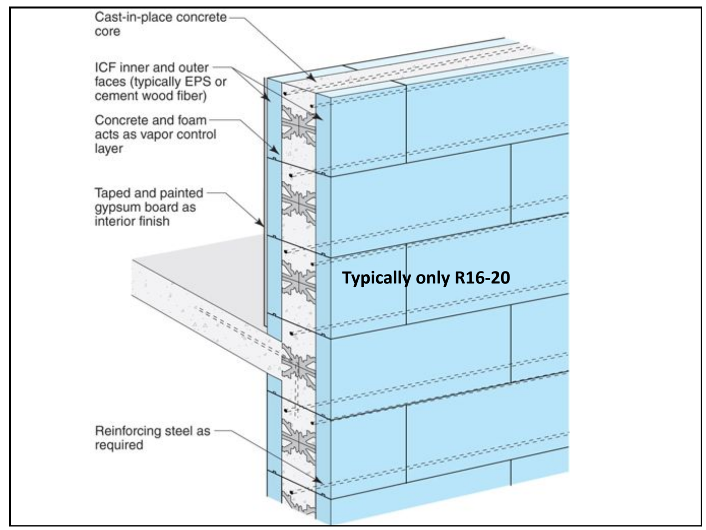

Single top plate
2x6 stud wall @ 24" o.c.
Taped and painted 5/8" gypsum wall board as interior finish
Sheathing
Corrugated spunbonded polyolefin (SBPO) air and water barrier
Tape joints in sheathing
1" to 6" of insulating sheathing (XPS, EPS, rockwool, PIC)
1x3 furring strips
Fiber cement lap siding
Fibrous cavity insulation
Latex paint (Class III) vapor control
Fiberglass insulation at rim joist
Lapped to provide drainage plane continuity; taped for air barrier continuity


Brick veneer/stone veneer
Drained cavity
Exterior rigid insulation — extruded polystyrene, expanded polystyrene, isocyanurate, rock wool, fiberglass
Trowel or spray-applied semi-vapor permeable air barrier and drainage plane
Non paper-faced exterior gypsum sheathing, plywood or oriented strand board (OSB)
Insulated Steel Stud Cavity
Gypsum board
Latex paint or vapor semi-permeable textured wall finish
Challenging!
Vapor Profile
Building Science 2008


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
DOW

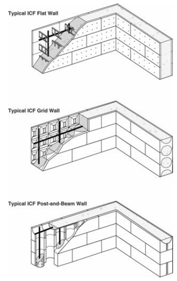

V. Poor performance
Durability challenged
Steel stud R4-R5 plus cladding R-value
Brick veneer/stone veneer
Ventilated and drained cavity
Drainage plane (vapor permeable building paper, house wrap)
Non paper-faced exterior gypsum sheathing, plywood or oriented strand board (OSB)
Insulated steel or wood stud cavity
Cavity insulation (fiberglass batts, spray-applied cellulose or spray-applied low density foam)
Kraft facing on a fiberglass batt or a "smart vapor barrier membrane"
Gypsum wall board (GWB)
Latex paint or vapor semi-permeable textured wall finish
R19-R21
Vapor Profile

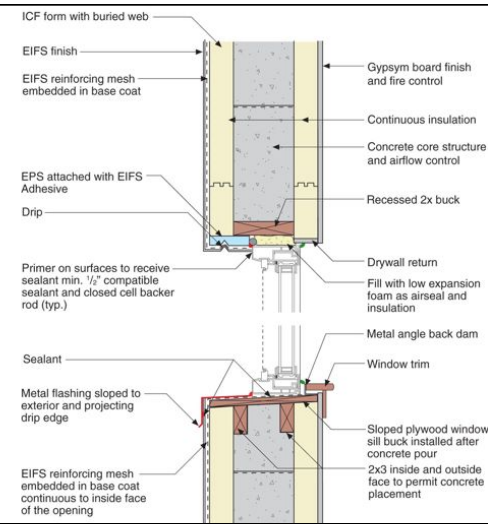

Continuity?
• Rain
• Air
• Heat
75


Cast-in-place concrete core
ICF inner and outer faces (typically EPS or cement wood fiber)
Concrete and foam acts as vapor control layer
Taped and painted gypsum board as interior finish
Reinforcing steel as required
Typically only R16-20

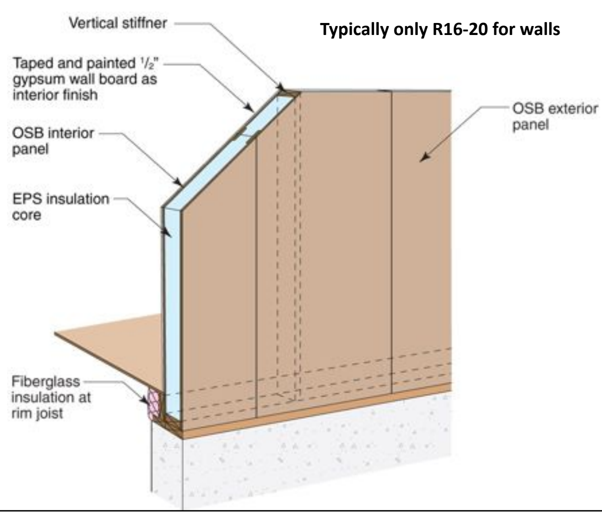
Insulated Concrete Forms: ICF

- Excellent enclosure system + structure
- Concrete acts as air barrier
- No vapor barrier needed
- High performance mid-rise system





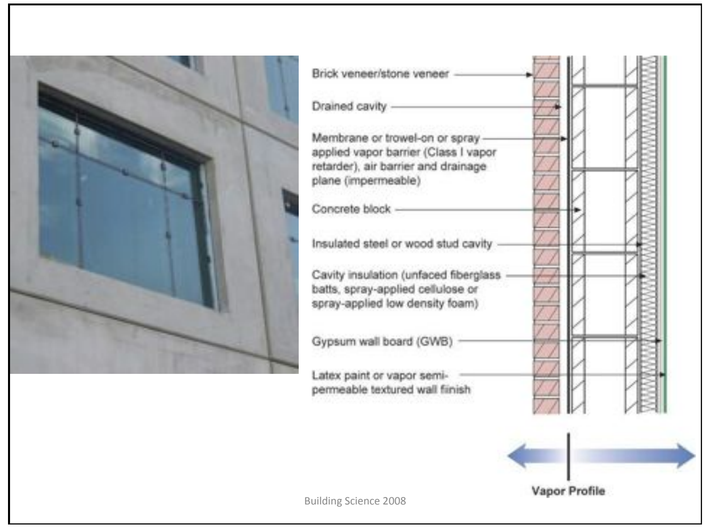
Typically only R16-20 for walls

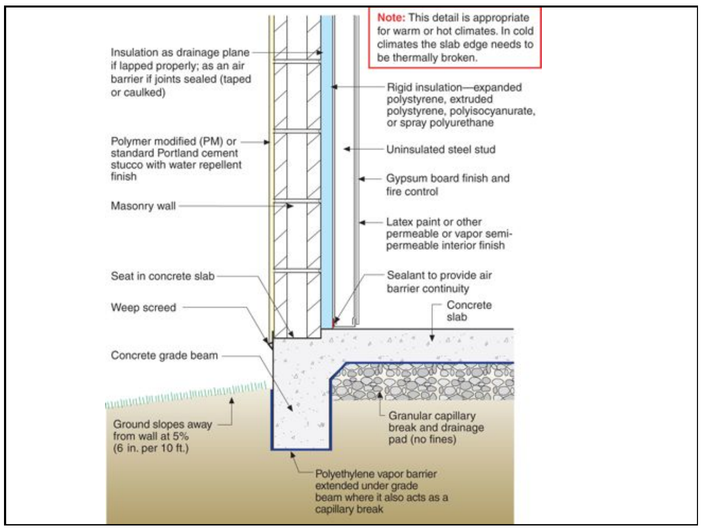


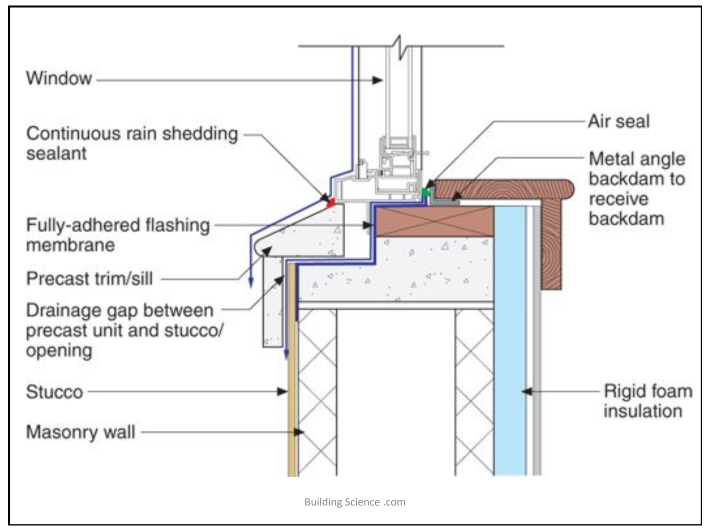
Structural Insulated Panels

- 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


Beware Joints
No vapor barriers


Brick veneer/stone veneer
Drained cavity
Membrane or trowel-on or spray applied vapor barrier (Class I vapor retarder), air barrier and drainage plane (impermeable)
Concrete block
Insulated steel or wood stud cavity
Cavity insulation (unfaced fiberglass batts, spray-applied cellulose or spray-applied low density foam)
Gypsum wall board (GWB)
Latex paint or vapor semi-permeable textured wall fiinish
Vapor Profile
Building Science 2008

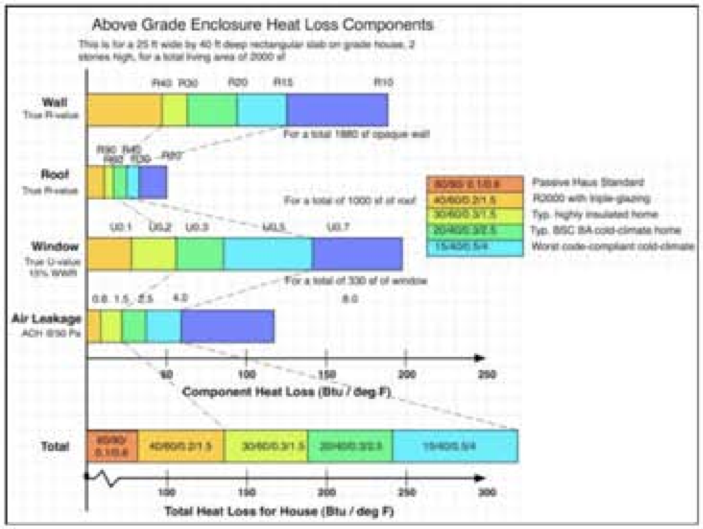

Note: This detail is appropriate for warm or hot climates. In cold climates the slab edge needs to be thermally broken.
Insulation as drainage plane if lapped properly; as an air barrier if joints sealed (taped or caulked)
Rigid insulation—expanded polystyrene, extruded polystyrene, polyisocyanurate, or spray polyurethane
Polymer modified (PM) or standard Portland cement stucco with water repellent finish
Uninsulated steel stud
Gypsum board finish and fire control
Masonry wall
Latex paint or other permeable or vapor semi-permeable interior finish
Seat in concrete slab
Sealant to provide air barrier continuity
Weep screed
Concrete slab
Concrete grade beam
Ground slopes away from wall at 5% (6 in. per 10 ft.)
Granular capillary break and drainage pad (no fines)
Polyethylene vapor barrier extended under grade beam where it also acts as a capillary break

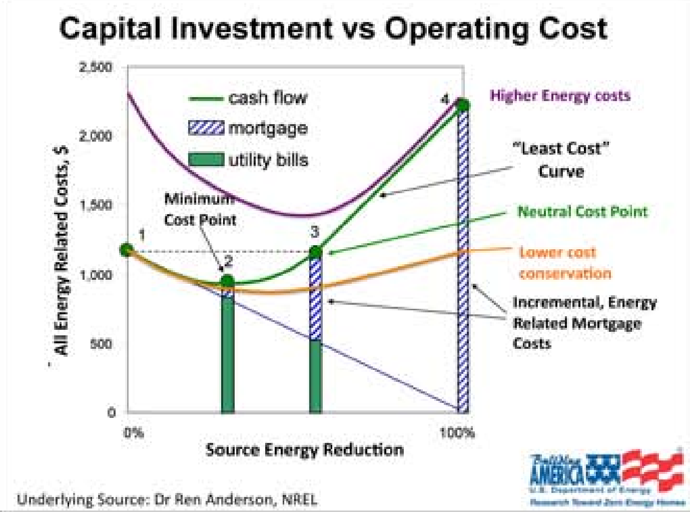

Window
Continuous rain shedding sealant
Air seal
Metal angle backdam to receive backdam
Fully-adhered flashing membrane
Precast trim/sill
Drainage gap between precast unit and stucco/opening
Stucco
Rigid foam insulation
Masonry wall
Building Science .com

Spreadsheet Interactive

Insulation?

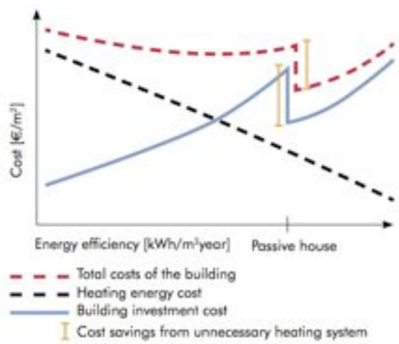
- How much? Use much *more than normal practise*
- Comfort & moisture –
  - **True** R5-10 is usually enough, but .....
- For energy / environment
  - As much as "practical"
  - How much space available in studs?
  - Fastening, windows: exterior sheathing of 1.5"/4"
- Increased insulation should reduce HVAC capital as well as operating!





Passive House Economic Theory

But . . . furnaces are just not that expensive in North America

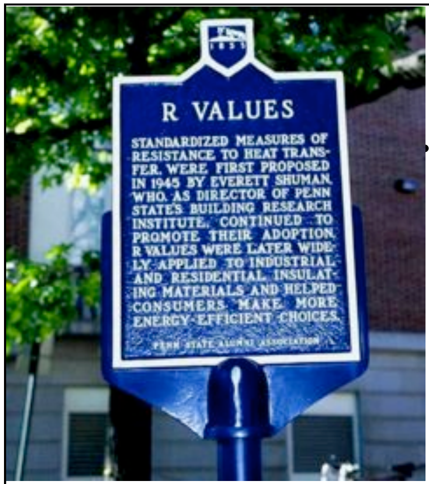


Building Science

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
  - **Thermal Bridges**
  - **Thermal Mass**
  - **Air Leakage**

Building Science 2008 Insulation and Thermal Bridges No. 90/65



R Values

- An effective property including all heat flow modes

Building Science Insulation and Thermal Bridges No. 91/65

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?

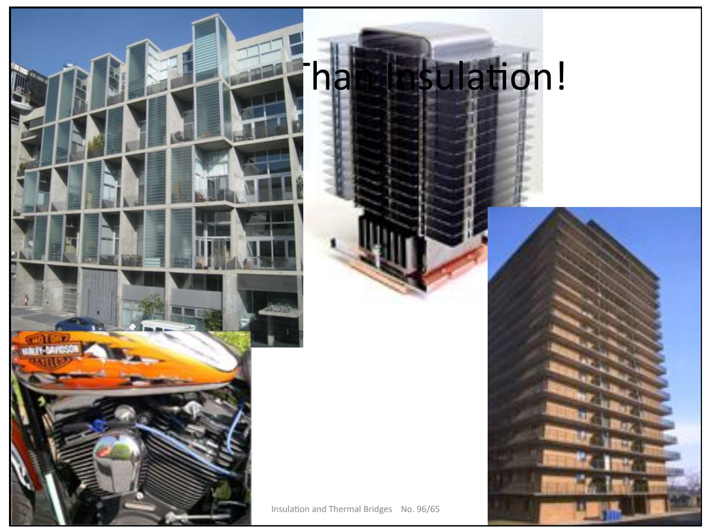
Building Science 2008 Insulation and Thermal Bridges No. 92/65

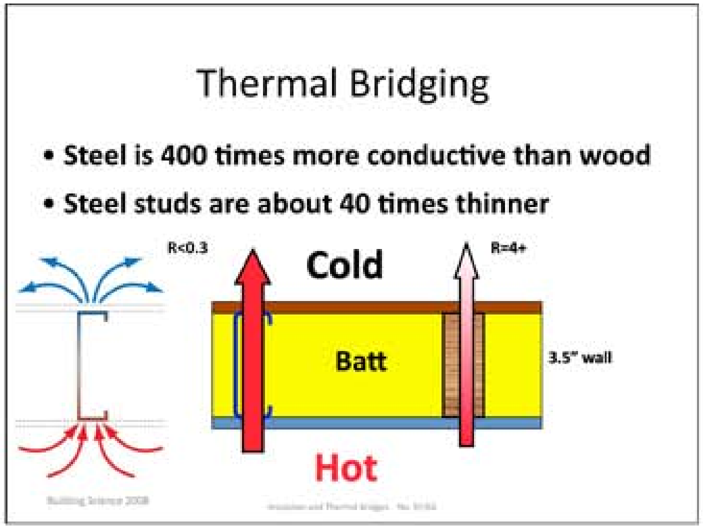
It’s More Than Insulation!

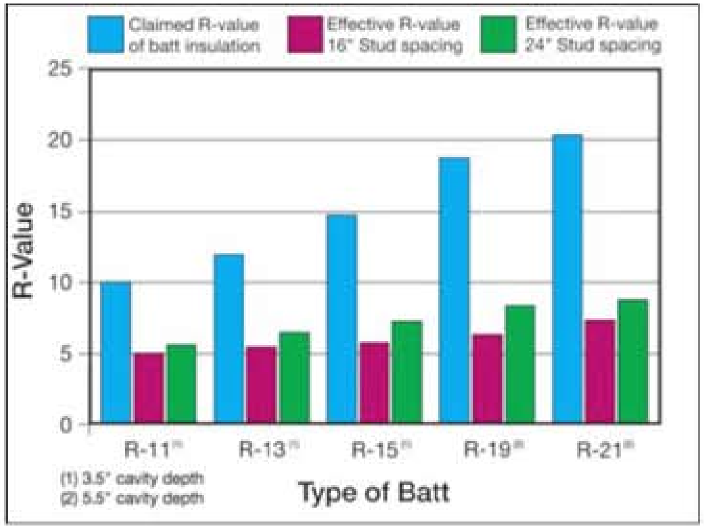
- Thermal bridges provide shortcut for heat through insulation
- Heat passes through the structural members
- Common offenders
  - Floor and balcony slabs
  - Shear walls
  - Window frames
  - Steel studs

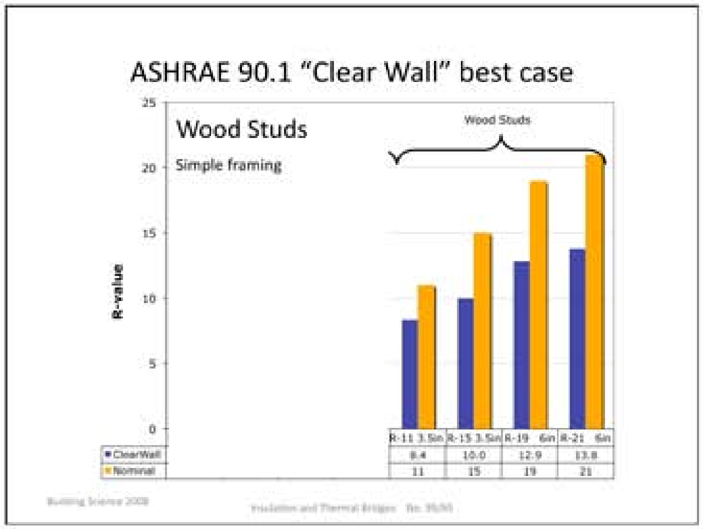
Building Science 2008 Insulation and Thermal Bridges No. 93/65

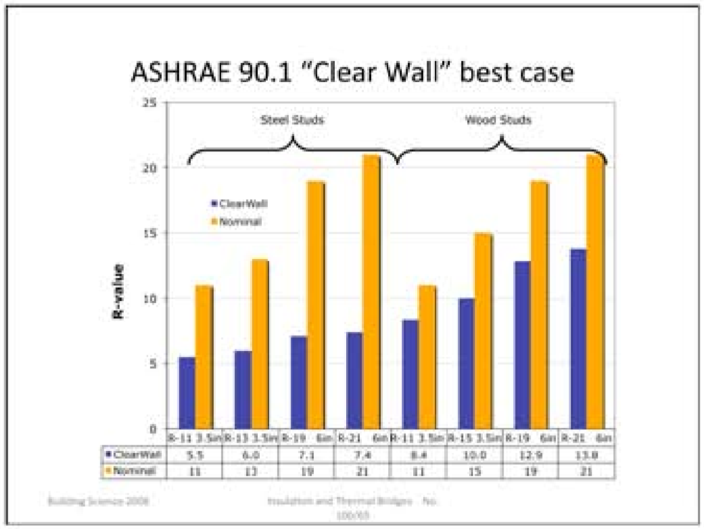
Building Science 2008 Insulation and Thermal Bridges No. 95/65




Thermal Bridging
• Steel is 400 times more conductive than wood
• Steel studs are about 40 times thinner
R<0.3
Cold
R=4+
Batt
3.5" wall
Hot


Claimed R-value of batt insulation
Effective R-value 16" Stud spacing
Effective R-value 24" Stud spacing
R-Value
25
20
15
10
5
0
R-11(1)
R-13(1)
R-15(1)
R-19(2)
R-21(2)
(1) 3.5" cavity depth
(2) 5.5" cavity depth
Type of Batt


ASHRAE 90.1 "Clear Wall" best case
Wood Studs
Simple framing
Wood Studs
R-value
25
20
15
10
5
0
R-11 3.5in
R-15 3.5in
R-19 6in
R-21 6in
ClearWall
8.4
10.0
12.9
13.8
Nominal
11
15
19
21


ASHRAE 90.1 "Clear Wall" best case
Steel Studs
Wood Studs
ClearWall
Nominal
R-value
25
20
15
10
5
0
R-11 3.5in
R-13 3.5in
R-19 6in
R-21 6in
R-11 3.5in
R-15 3.5in
R-19 6in
R-21 6in
ClearWall
5.5
6.0
7.1
7.4
8.4
10.0
12.9
13.8
Nominal
11
13
19
21
11
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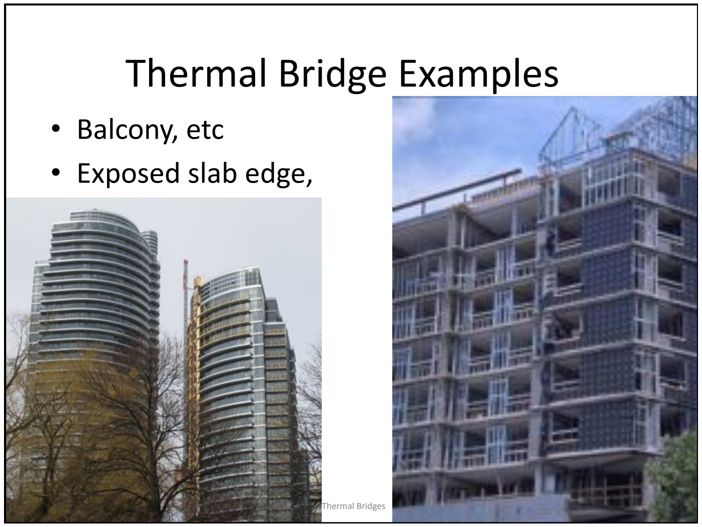
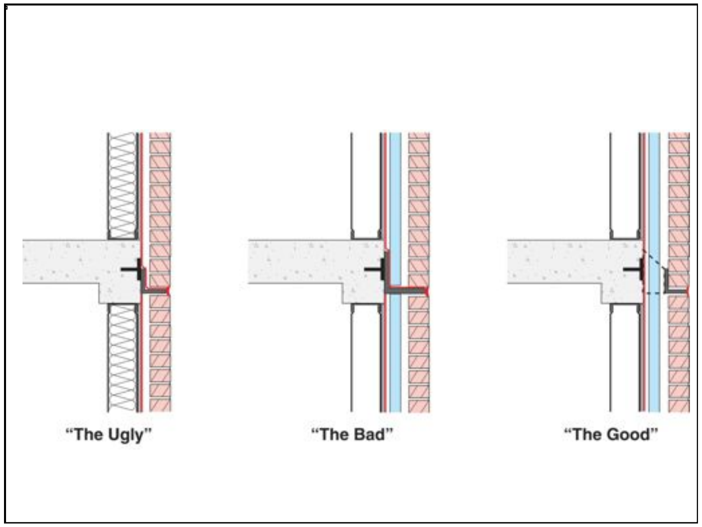
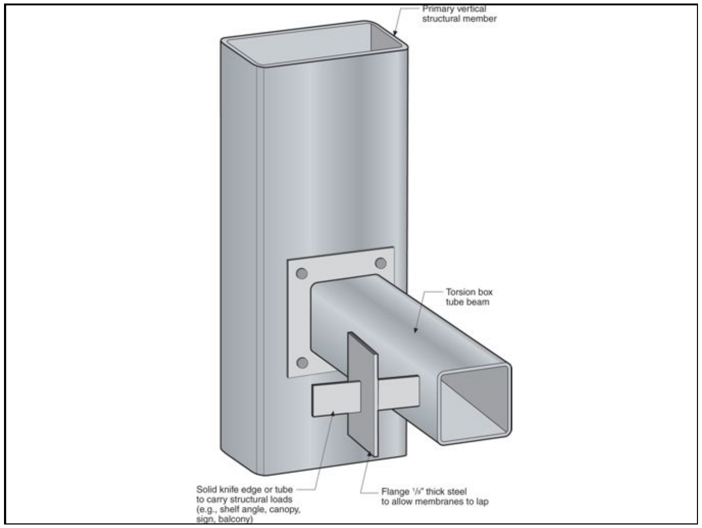
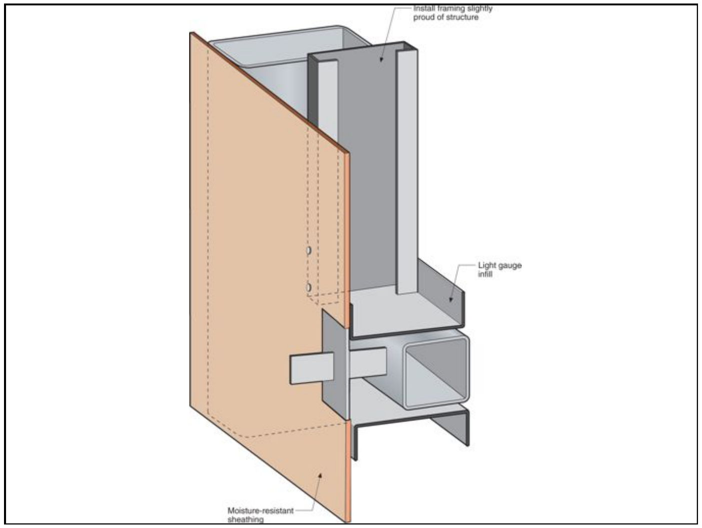
Building Science 2008
Insulation and Thermal Bridges No. 101/65

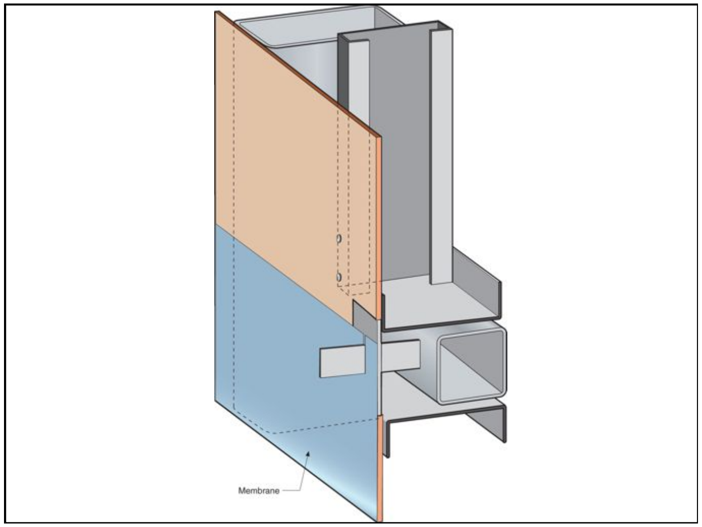

Building Science 2008
Insulation and Thermal Bridges No. 102/65

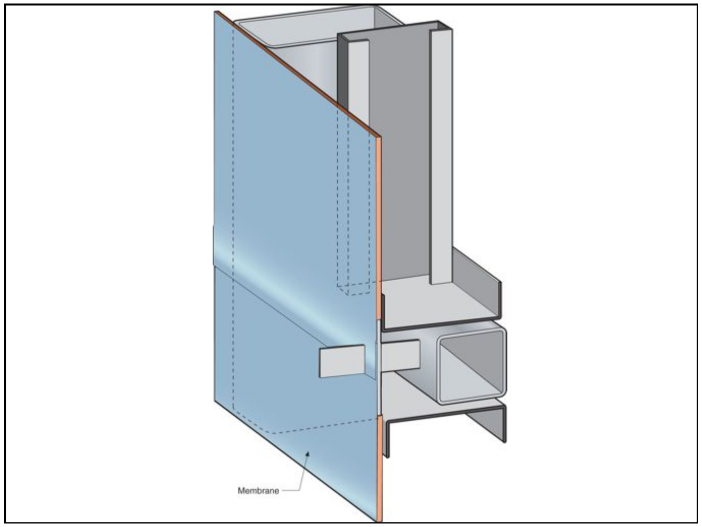

Thermal Bridge Examples
• Balcony, etc
• Exposed slab edge,
Thermal Bridges

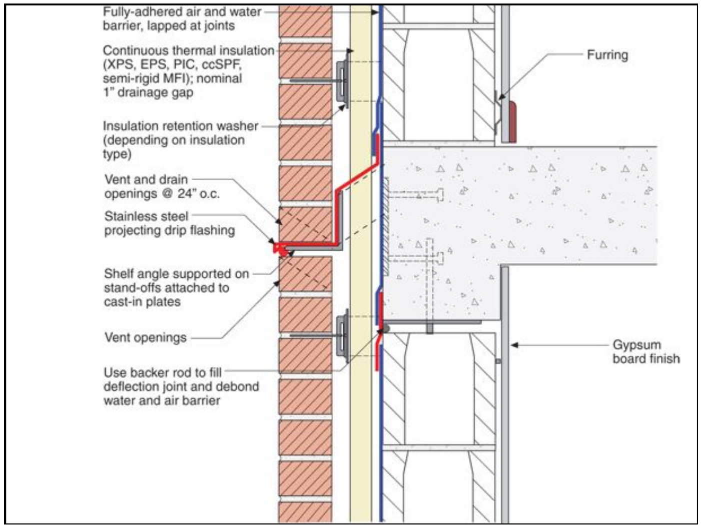

"The Ugly"
"The Bad"
"The Good"


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 1/8" thick steel
to allow membranes to lap

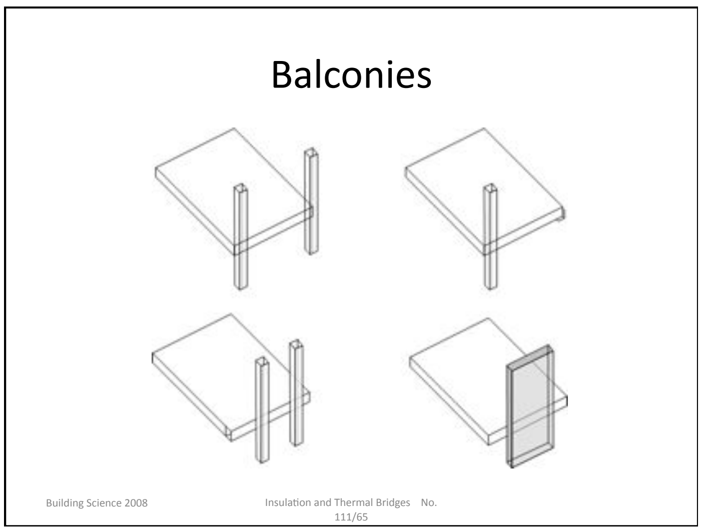

Install framing slightly
proud of structure
Light gauge
infill
Moisture-resistant
sheathing

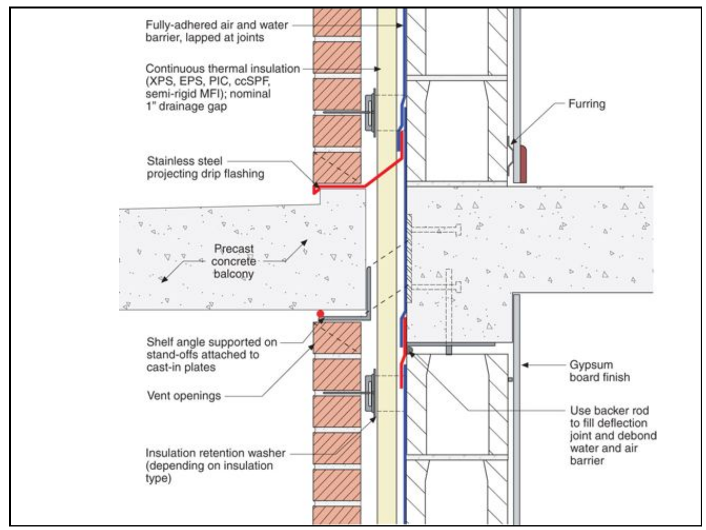

Membrane

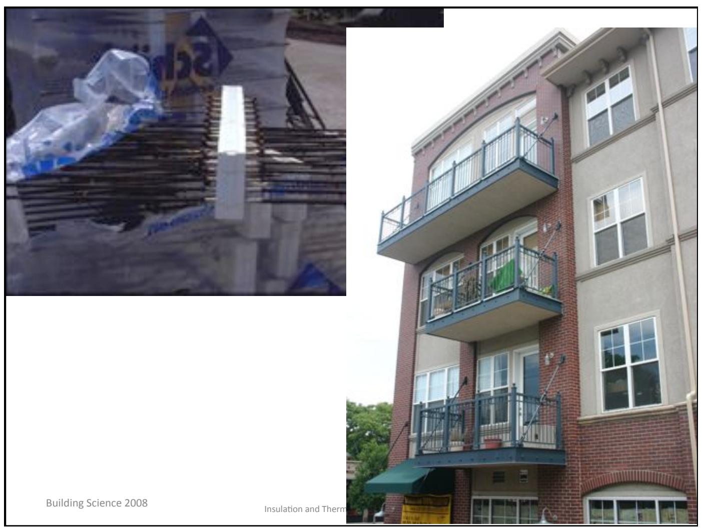

Membrane


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


Balconies
Building Science 2008
Insulation and Thermal Bridges No. 111/65


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



Air leakage & Ventilation

- Hard to save energy with the door open
- Buildings getting tighter, but . . .
  - Many still leak way too much
  - We can't identify the leakers
  - Need to test! Commission!
- Ventilation: Many try to improve air quality by increasing quantity
  - Target good air when and where needed

116/175 9/29/10

Air Barriers and Energy

- Require a strong, stiff, durable, and above all continuous barrier to airflow over the whole building
- Easily 1/3 of total heat loss is due to air leakage in well insulated building

117/175 9/29/10

Air Barriers vs Vapor Barriers

- ***Vapour Barriers Control Vapour Diffusion***
  – Why? 1. Moisture wetting and drying
- ***Air Barriers Control Air Leakage***
  – Why? ***Six*** reasons.
  – Heat (for 1. comfort &
  2. energy considerations)
  – 3. Moisture
  – 4. Sound
  – 5. Smoke &
  – 6. odours and dust

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Vapor barriers = drying retarders

- Vapor diffusion is a slow process
- Uniform action = small holes don't matter
- Use as needed, not more
  – Beware air conditioned buildings
  – Don't place peel & stick outside insulation!

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Mechanical Basics

Outline

- functions of HVAC systems
- Role of temperature in system choice and efficiency
- Some common piece of equipment
- Generic systems

HVAC Objectives

- Health
- Safety
- Comfort
  - Temperature, humidity, air speed, noise, light
- Reliability
  - Long term performance, maintainable
- Efficiency
  - Meet the needs imposed by occupants and enclosure with a minimum of additional energy

Common Problems

- Poor comfort
  - Poor control of temperature and humidity,
  - Noise, drafts from high velocity air
- Health
  - Air based systems act as distribution for outdoor pollutants, mold grown in coils/ducts
  - Chilled water pipes collect condensation leading to mold
  - Insufficient ventilation/mixing common issue
- Energy
  - Systems are often very inefficient
- Maintainability / Controllability
  - Systems are complex, difficult to trouble shoot, maintain etc

Functions

Five Critical functions are needed

- Ventilation
  - "fresh air"
  - Dilute / flush pollutants
- Heating
- Cooling
- Humidity Control
- Air filtration / pollutant Removal
  - Remove particles from inside and outside air
  - Remove pollutants in special systems

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Physical Systems & Components

- Components
  - Heat production (including cooling)
  - Heat rejection / collection
  - Heat/Cold Distribution
  - Ventilation air supply/exhaust
  - Ventilation Air Distribution Air Filtration
  - Humidification/ Dehumidification
- Confusion arises when functions are combined across different components in different systems

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Thermodynamics 101

- Heat (Thermal energy) is measured by temperature
- Can produce heat by converting chemical, physical, electrical, radiation, or nuclear energy sources
  - Some heat can be produced at nearly 100%
- Cannot destroy heat, only move it around
  - Heat pumps move thermal energy from
- Cold is a relative term = "less heat"

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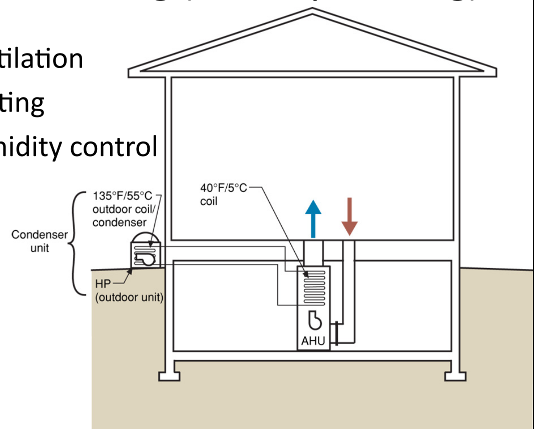
Systems

Heat Production
Rejection / Collection
Distribution

Air Conditioning (actually, cooling)

- No ventilation
- No heating
- No humidity control



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Small Residential HVAC

- Cooling DOES NOT mean humidity control
- Energy removal for lowering temperature:
  - Sensible energy
- Energy removal to condense water vapor:
  - Latent Energy
- Ratio of Sensible Heat Ratio =SHR
  - Normal cooling equipment 65% sensible
  - As enclosures become energy efficient the required SHR drops and latent becomes more important!

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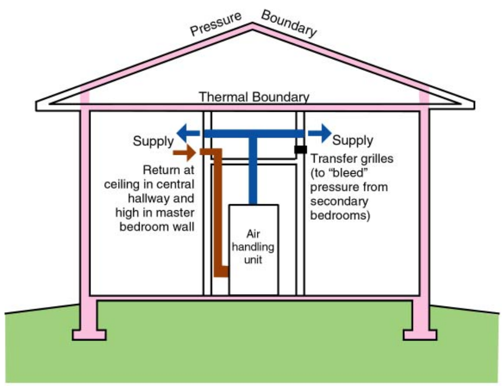
Heating Cooling (and mixing)



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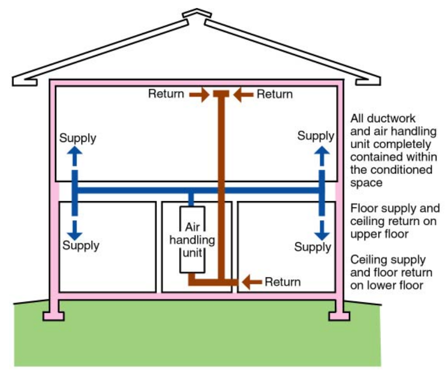
Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.

Two Storey Distribution



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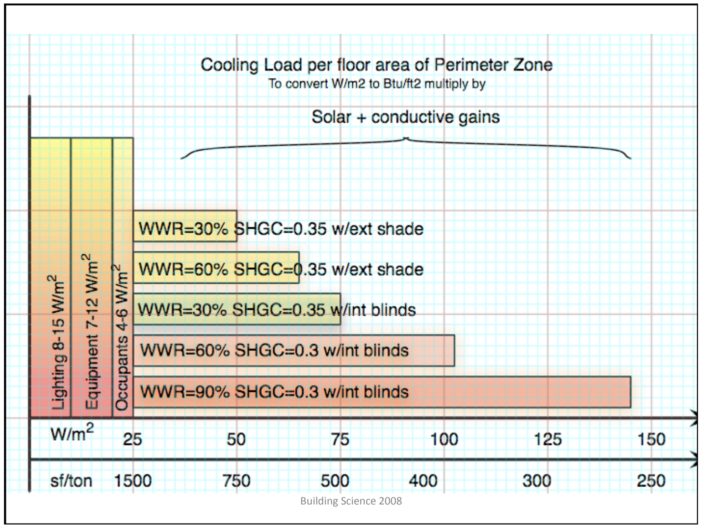
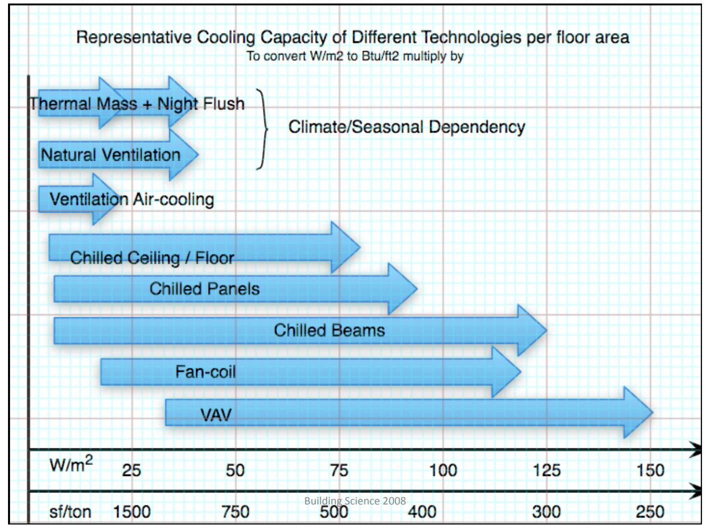
Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.





Size Effects

- Larger equipment
  - Often was more efficient
  - requires more distribution
  - Make central maintenance easier
  - Reduce redundancy
- Small equipment
  - Becoming equally efficient in some areas
  - Saves on distribution, adds redundancy

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Suite by Suite HVAC

Benefits of better control, simpler metering, fewer losses and problems with distribution

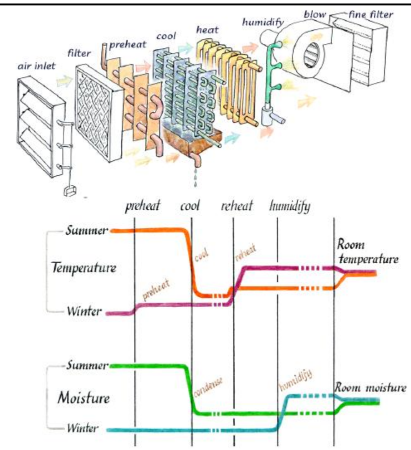

Figure 3. A large air conditioning system functions much like that described in figure 2, except that chilled water is used to cool the air. Outside air is drawn in, filtered and heated before it passes through the main air conditioning devices. The coloured lines in the lower part of the diagram show the changes of temperature and of water vapour concentration (not RH) as the air flows through the system.

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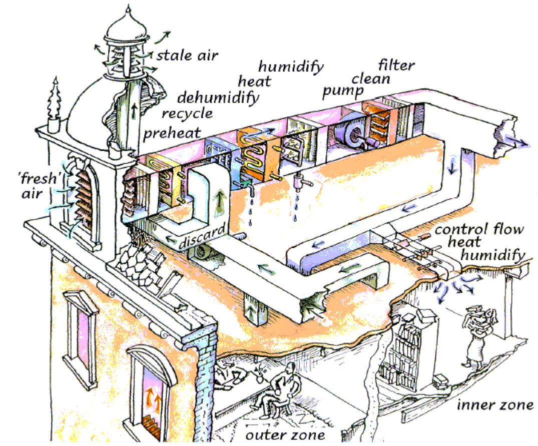

Figure 4. An air conditioning system with variable fresh air mixer and dust and pollutant filtration. Notice supplementary heating with radiators in the outer rooms and individual mini heater and humidifier in the air stream to each room.

9/29/

HVAC by the numbers

- Typical office AC required: 400 sf/ton (sensible+latent)
- Typical office AC airflow: 400 cfm/ton
  - Thus about 1 cfm/sf
- Office fresh air req't: 0.1-0.2 cfm/sf
  - Thus 5x to 10x less than cooling
- Classroom fresh air: 0.5 cfm/sf
- Coil velocity: 300-500 fpm
  - Thus, 400 fpm=400 cfm/sf coil, 1 sq ft coil/ton AC
- Typical duct velocity: 600-1500 fpm (noise!)
  - 0.30 to 0.70 sf duct per ton AC
- 200 cfm of hot-humid ventilation= 1 ton AC

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Indoor Air Quality

- Most HVAC re-circulates air
  - This takes pollutants from one space and moves to another
- HVAC can suck in pollutants from outdoors

- Filters and Interior Duct Insulation collect dirt
- If moisture (condensate) contacts, mold can grow
- Air flow distributes the problem smells and spores

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Common Air-based Sysems

- CAV systems
  - high energy consumers but provide outdoor air
- VAV
  - decent energy performance, but rarely supply desired ventilation (fresh) air rates
- DOAS: Dedicated Outdoor Air Systems
  - provide Ventilation (+ almost always dehumidification) only
  - separate terminal equipment does heating and cooling
  - Highest performance, easy to design & fix

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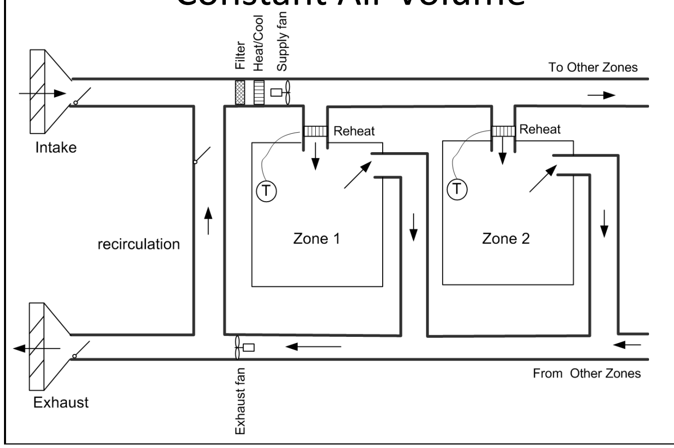
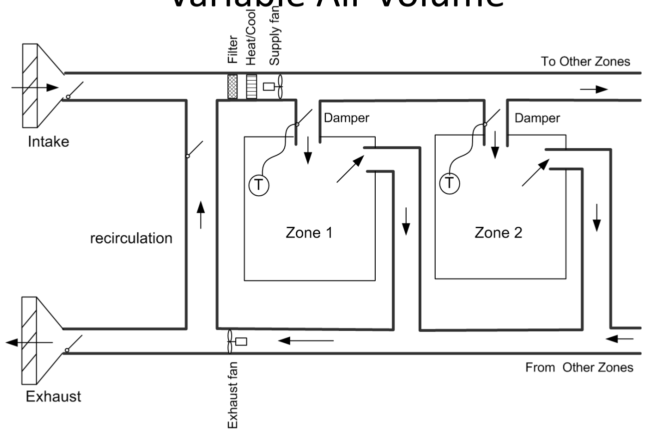
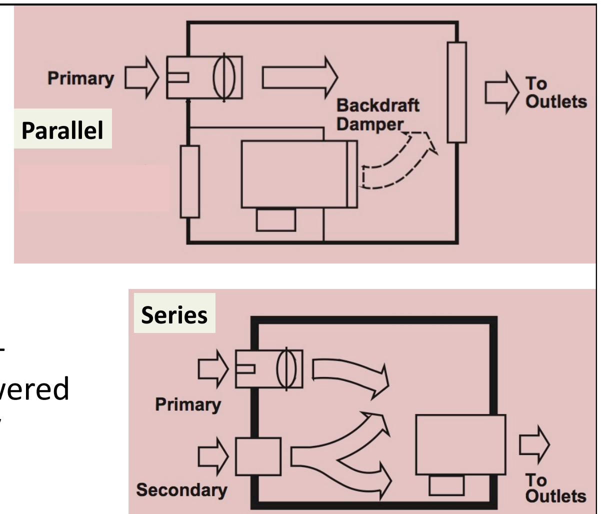
Constant Air Volume



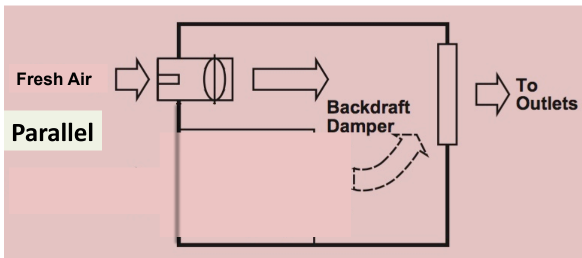
Variable Air Volume



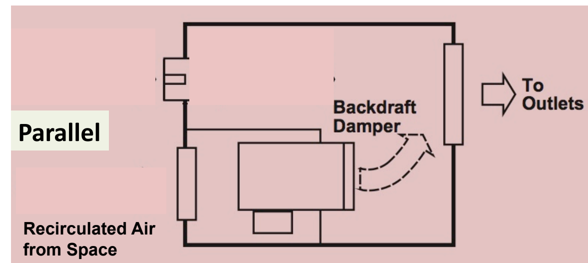


Fan-powered VAV

- Fan-powered parallel VAV
  acting as ventilation only from DOAS



- Fan-powered parallel VAV
  acting as sensible heating/cooling only



Variations on VAV

- Spaces with low cooling load often underventilated
- Minimum flow setting at box can be imposed by clock or CO2 and "reset" by temperature
- Reheat at box often needed, can be significant energy
- Outdoor air % can vary with return air CO2 or clock
- Supply fan can be operated to provide constant static pressure (VFD)
- Flow can be measured at each box, with reheat, to guarantee ventilation air (complex, $, works)

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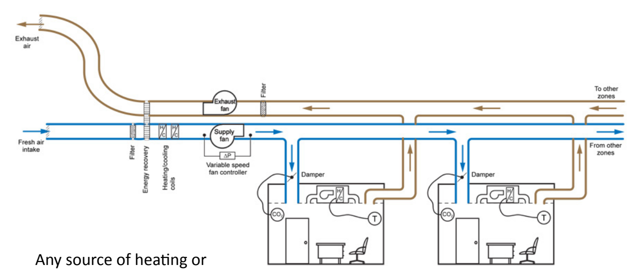
BSI-022 Perfect HVAC

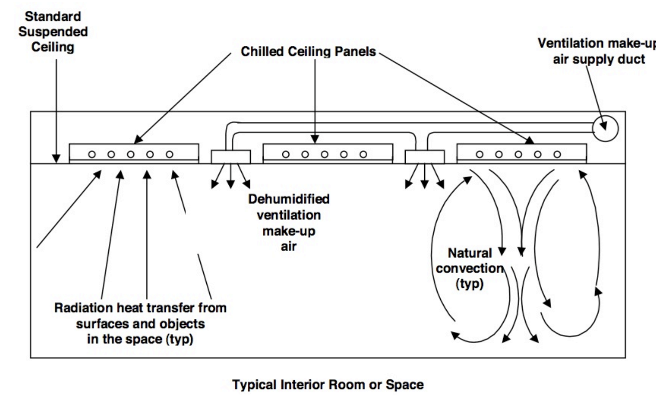


Any source of heating or cooling
Combined ventilation/ humdity control

DOAS

- Most reliable means of delivering ventilation air to people without over ventilating
- Excellent humidity control
- No cross-contaminated air from different zones
- Small ducts (ventilation only, no cooling)
- Works well with hybrid ventilation
- Disadvantage: economizer flow is limited, so free *air* cooling capacity is limited by 2-3X

DOAS + Radiant Terminal



Economizer aka "Free cooling"

- If it is cooler outside than inside and cooling is desired, blow some outdoor air into building
- This is called "air side economizer"
- Beware fan energy consumption- free cooling is not free, esp with long small ducts!
  - Small temperature differences (eg 5F) not enough to cool normally
  - larger temperature differences (eg >10F) work well
  - Cant use air if it is too humid (enthalpy control)
- Water-side may be more efficient in many cases

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Air-side Economizer

- Through-wall paddle fans can deliver air at very high efficiencies (10-25 cfm/Watt)
- E.g., If t_{out} = 65F & t_{in} = 74 F
  - @1.1 Btu/cfm/F & Δ9F = 10 Btu cooling / cfm
  - 15 cfm/Watt→ 150 Btu /Watt fan
  - EER of 150 = COP= 44!!
- If only 1 cfm/Watt VAV → COP= 2.9
  - AC or water side economizer will be better!!

Natural ventilation

- Airflow driven by natural forces
  - Wind
  - Buoyancy (hot air rises, cold air falls)
- Avoids fan energy
- Can be used for ventilation
  - Lower flows, risk of insufficient air= bad IAQ
- Cooling
  - Higher flows, only risk is occasional overheating

Natural ventilation cooling

- Airside Economizer using natural pressures
  - Large airflows needed as $T_{out} > 65$ F
- Must throttle airflow as $T_{out} < 60$ F for comfort
- Little airflow possible when $T_{out} < 40$F
  - Frost, comfort problems
- Most low energy buildings have low cooling loads, most internally generated

Human Comfort

And ventilation

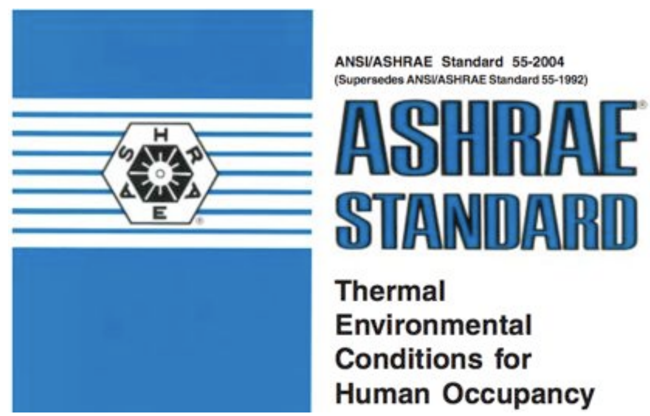
Comfort and Energy

- Purpose of a building
  - Provide the desired environment
- Comfort and health defines *what* that environment should be for people

Human comfort

- Energy balance, just like a building
- Interior heat generation – losses = zero
- Humans are very sensitive to in balances

- All space conditioning is not created equal
- Temperature is not a good measure



Human Heat Generation

- Heat produced, "standard" human
  - 58.2 W/m^2 or 18.4 Btu/hr/ft2
  - One "met" (metabolic rate)
- Standard human
  - Area: 1.8 m^2 = 19.4 ft^2
  - Varies from 1.3 to 2.2 m^2
- Standard heat production
  - 58.2 * 1.8 = 105 W (360 Btu)

Metabolic Rates

- Most commercial institutional occupancies, 1.2 met

Activity	Metabolic Rate (met)
Reclining	0.8
Seated quietly	1.0
Sedentary activity (school, office, residence)	1.2
Standing, relaxed	1.2
Light activity (shopping, light industry)	1.6
Medium activity standing (domestic)	2.0
High activity (working out, garage)	3.0

ACTIVITY	HOURLY METABOLIC RATE BTU/HR FOR AVERAGE ADULT @ 79°F-AMBIENT Total	Sensible	Latent	MOISTURE DISSIPATED IN LBS/HR/PERSON
Basal	290	145	145	0.140
Seated – reading aloud	420	225	195	0.183
Light work – standing	490	225	265	0.255
Pool player	680	230	450	0.434
Carpenter	954	307	647	0.623
Bowling	1500	490	1010	0.973
Walking upstairs	4365			

Maximum exertion for different people – 3000 to 4800

	Extreme Metabolic Rates	*Time to Reach Exhaustion*
Professional bicyclist	2,100 BTU/hr.	4.37 hrs.
Sculling boat race	4,900 BTU/hr.	0.37 hrs.
Max. effort – bicycle	15,600 BTU/hr.	0.006 hrs.

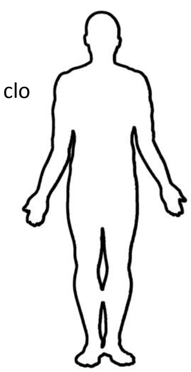
Heat Loss from Human Skin

Clothing Insulation I_{cl}

Unit: R (m²k/W) or clo

1 clo = 0.155 m²k/W

1 clo = 0.88 R-value



+

Insulation

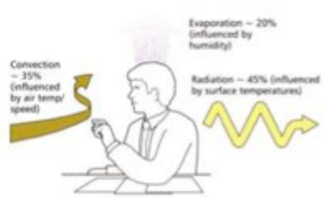
Clothing Description	Garments Included[b]	I_{cl} (clo)
Trousers	1) Trousers, short-sleeve shirt	0.57
	2) Trousers, long-sleeve shirt	0.61
	3) #2 plus suit jacket	0.96
	4) #2 plus suit jacket, vest, T-shirt	1.14
	5) #2 plus long-sleeve sweater, T-shirt	1.01
	6) #5 plus suit jacket, long underwear bottoms	1.30
Skirts/Dresses	7) Knee-length skirt, short-sleeve shirt (sandals)	0.54
	8) Knee-length skirt, long-sleeve shirt, full slip	0.67
	9) Knee-length skirt, long-sleeve shirt, half slip, long-sleeve sweater	1.10
	10) Knee-length skirt, long-sleeve shirt, half slip, suit jacket	1.04
	11) Ankle-length skirt, long-sleeve shirt, suit jacket	1.10
Shorts	12) Walking shorts, short-sleeve shirt	0.36
Overalls/Coveralls	13) Long-sleeve coveralls, T-shirt	0.72
	14) Overalls, long-sleeve shirt, T-shirt	0.89
	15) Insulated coveralls, long-sleeve thermal underwear tops and bottoms	1.37
Athletic	16) Sweat pants, long-sleeve sweatshirt	0.74
Sleepwear	17) Long-sleeve pajama tops, long pajama trousers, short 3/4 length robe (slippers, no socks)	0.96

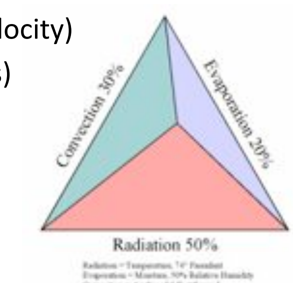
Evaporation

- 30-60 g/hr (1-2 ounce) normal conditions
- Evaporation rate depends on
  - Relative humidity
  - Airflow
- Increasing airflow rate and decreasing RH increases potential for evaporation

Human Cooling Modes

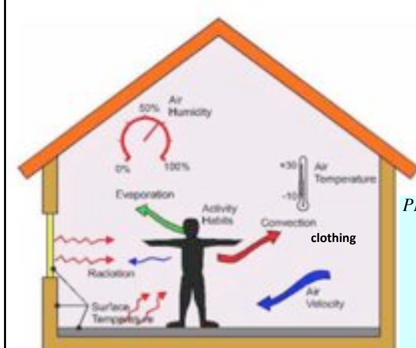
- Convection (air temp/Velocity)
- Radiation (surface temps)
- Evaporation (temp/ RH)



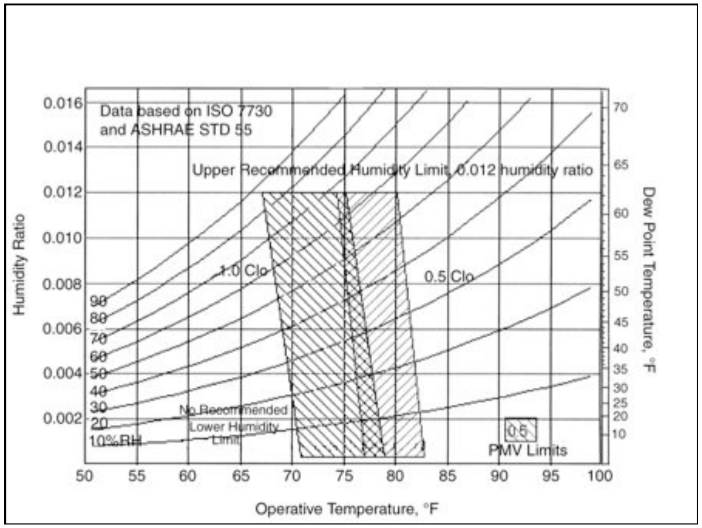


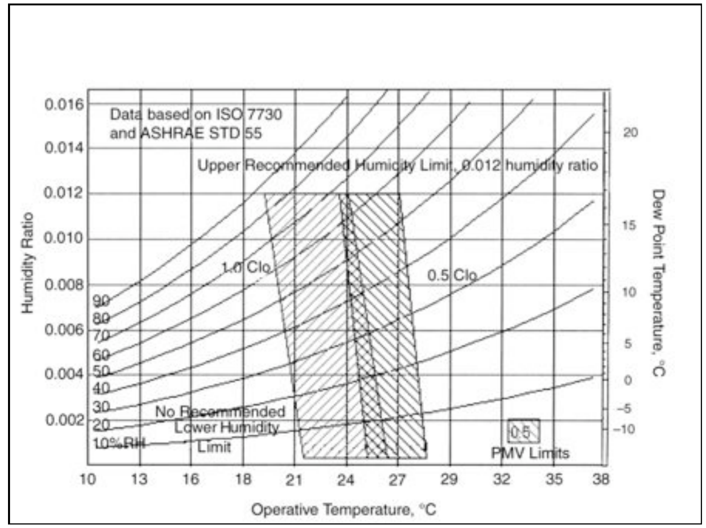
Thermal comfort

Six Primary Thermal Comfort Variables



$PMV = f($ Air temperature, Radiant temperature, Air flow velocity, Relative Humidity, Clothing Insulation, Physical activity$)$





Operative Temperature

$$t_{operative} = \frac{t_{ambient} + t_{radiative}}{2}$$

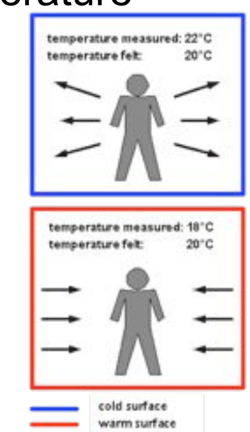
For low airspeeds

t_o = operative temperature [°C/F]

t_a = ambient temperature [°C/F]

t_r = radiative temperature [°C/F]

Ignores evaporation (RH)



Mean Radiant Temperature

- Area weighted average of all temperatures in the enclosing space seen by occupant
- Asymmetry is uncomfortable
  - Wall at 95F / 35C and ceiling at 68F/20C = bad

Source: ASHRAE 55-2004

"Adaptive" comfort

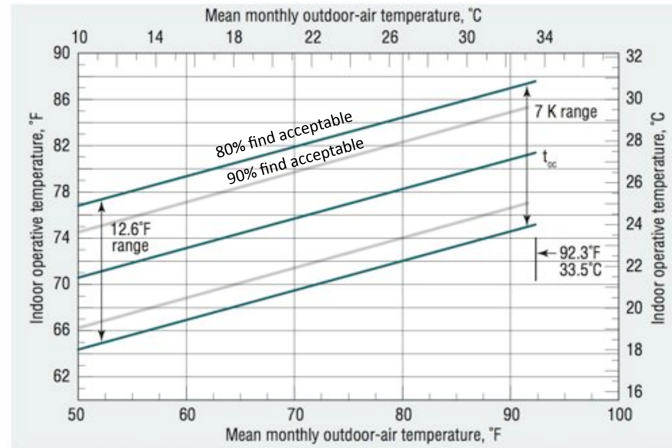
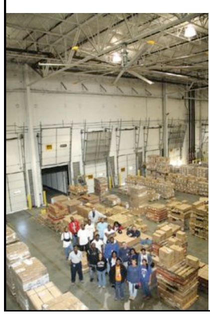


FIGURE 1. Adaptive-thermal-comfort zones vs. mean monthly outdoor-air temperature.

Air Movement

- Allows people to cool themselves Convectively/ evaporativel



Example Comfort Conditions

Temperature, °F	Humidity (RH)	Air velocity (fpm)
76	45	20
76	80	250
72	80	20
80	20	20
80	45	500

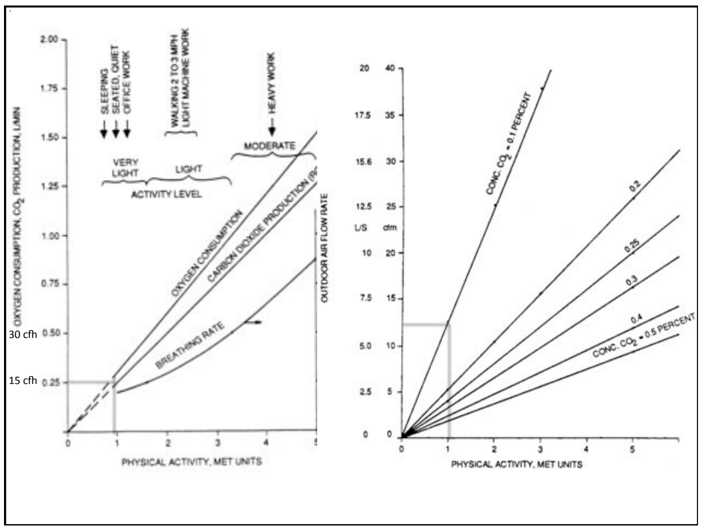
Run	Air Temp.		RH	Radiant Temp.		Air Speed			
#	°F	C	%	°F	C	FPM	m/s	Met.	CLO
1	67.3	19.6	86	67.3	19.6	20	0.10	1.1	1
2	75.0	23.9	66	75.0	23.9	20	0.10	1.1	1
3	78.2	25.7	15	78.2	25.7	20	0.10	1.1	1
4	70.2	21.2	20	70.2	21.2	20	0.10	1.1	1
5	74.5	23.6	67	74.5	23.6	20	0.10	1.1	0.5
6	80.2	26.8	56	80.2	26.8	20	0.10	1.1	0.5
7	82.2	27.9	13	82.2	27.9	20	0.10	1.1	0.5
8	76.5	24.7	16	76.5	24.7	20	0.10	1.1	0.5

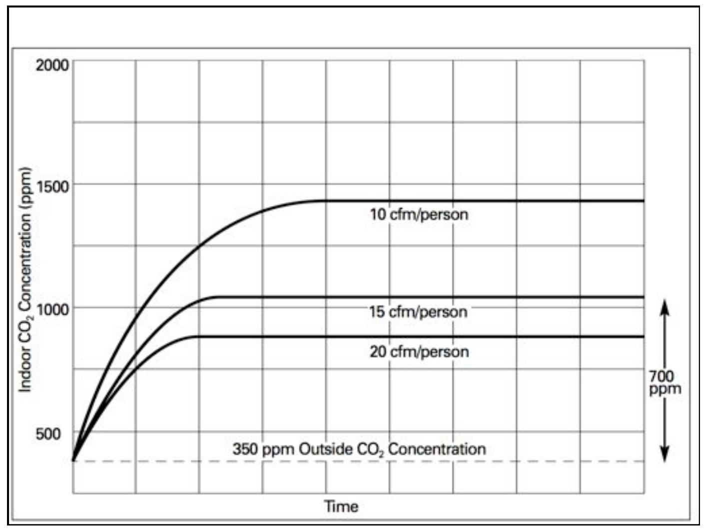
Ventilation

- Oxygen Replacement
  - Very little required (1 cf/h O_2/person) 0.02 cfm
- Pollution Dilution Removal
  - What pollution is in the space? (x cfm/sf)
- Odour and "stuffiness"
  - How smelly are you?
- ASHRAE 62 provides good guidance

CO_2

- Humans generate CO_2 depending on activity
  - Can be a tracer gas for ventilation
- Submarines: target 5 000 – 10 000 ppm
  - Limit is 30 000 ppm
- ASHRAE 62.1-2004 Section 6.2.7
  - Allows ventilation to vary with operating conditions
  - Target is about 1000 ppm, although up to 1500 ppm OK

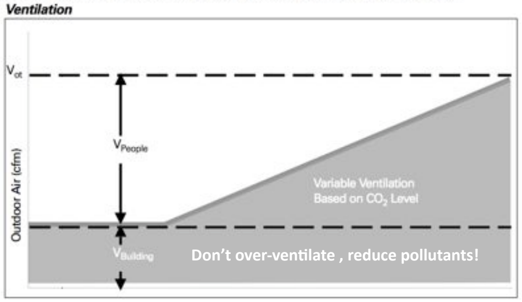




Building Pollution

- Base-level min. building ventilation always needed to remove other pollutants

Figure 10: Minimum Ventilation Rate with CO_2-Based Demand-Controlled Ventilation



ASHRAE 62.1

Zone Air Distribution Effectiveness

	Air Distribution Configuration	E_z
Typical office	Ceiling supply of cool air	1.0
	Ceiling supply of warm air and floor return	1.0
	Ceiling supply of warm air 15°F (8°C) or more above space temperature and ceiling return.	0.8
	Ceiling supply of warm air less than 15°F (8°C) above space temperature and ceiling return provided that the 150 fpm (0.8 m/s) supply air jet reaches to within 4.5 ft (1.4 m) of floor level. **Note**: For lower velocity supply air, E_z = 0.8.	1.0
Typical Underfloor Air	Floor supply of cool air and ceiling return provided that the 150 fpm (0.8 m/s) supply jet reaches 4.5 ft (1.4 m) or more above the floor. **Note**: Most underfloor air distribution systems comply with this proviso.	1.0
Displacement ventilation	Floor supply of cool air and ceiling return, provided low-velocity displacement ventilation achieves unidirectional flow and thermal stratification	1.2
Typical House htg	Floor supply of warm air and floor return	1.0
	Floor supply of warm air and ceiling return	0.7
	Makeup supply drawn in on the opposite side of the room from the exhaust and/or return	0.8
	Makeup supply drawn in near to the exhaust and/or return location	0.5

1. "Cool air" is air cooler than space temperature.
2. "Warm air" is air warmer than space temperature.
3. "Ceiling" includes any point above the *breathing zone*.
4. "Floor" includes any point below the *breathing zone*.
5. As an alternative to using the above values, E_z may be regarded as equal to air change effectiveness determined in accordance with ASHRAE Standard 129[15] for all air distribution configurations except unidirectional flow.

Conclusions

- Comfort is more complex than thermostat setting
- These complications affect choices of enclosures, distribution of air, etc.
- Ventilation is more than "fresh air"