CAE 463/524
Building Enclosure Design

Fall 2012

Lecture 12: Applications
November 19, 2012

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Built Environment Research Group

www.built-envi.com

Housekeeping

- Campus projects grading

- Final projects
  - Some of you will present next Monday 11/26

Team	Member	Member	Topic	11/26 or 12/3?
1	Russo	Foley	Green roofs	12/3
2	Vagner	Diaz	Electrochromic windows	12/3
3	Espinoza	Wright	Cool roofs	12/3
4	Angulo	Huo	Double skin facades	12/3
5	Sebastian	Morris	Phase change materials	11/26
6	Kayo	Gonzalez, Alv	Building integrated photovoltaics	11/26
7	Zwang	Gomez Soriano	Exterior insulated finish systems	11/26
8	El Orch	Gonzalez, Ar	Strawbale construction	11/26
9	Mcgreal	Diaz	Conventional construction	12/3
10	Daras Ballester	Zylstra	High performance glass	11/26
11	Mejia	n/a	Sun shading and thermal mass	12/3

Housekeeping

- Final project due date
  - Originally due 11/26
    - Monday after Thanksgiving
  - Although many of you will present that day, I am extending the deadline for your report to Monday 12/3 at 7:30 PM
    - Just send me a PDF copy before 7:30 PM on 12/3
- Course evaluations (extremely important)
  - Unrelated to the deadline extension, I swear
  - Survey open until Sunday, December 2, 2012
  - Academics tab in MyIIT portal
    - Please complete ASAP

Last lecture

- Discussed how all of our modes of heat transfer combine together to impact energy use in an actual building

- Described energy simulation software
  - And how to use it in design phase

- Described IECC and ASHRAE Standard 90.1
  - Not very academic, but important to know requirements for compliance

Today's lecture

- Focus on applications in building enclosure design and construction
  - Insulation materials
  - Fire ratings of materials
  - Roofing materials
  - Vapor and air barriers
  - Glazing and wind loads

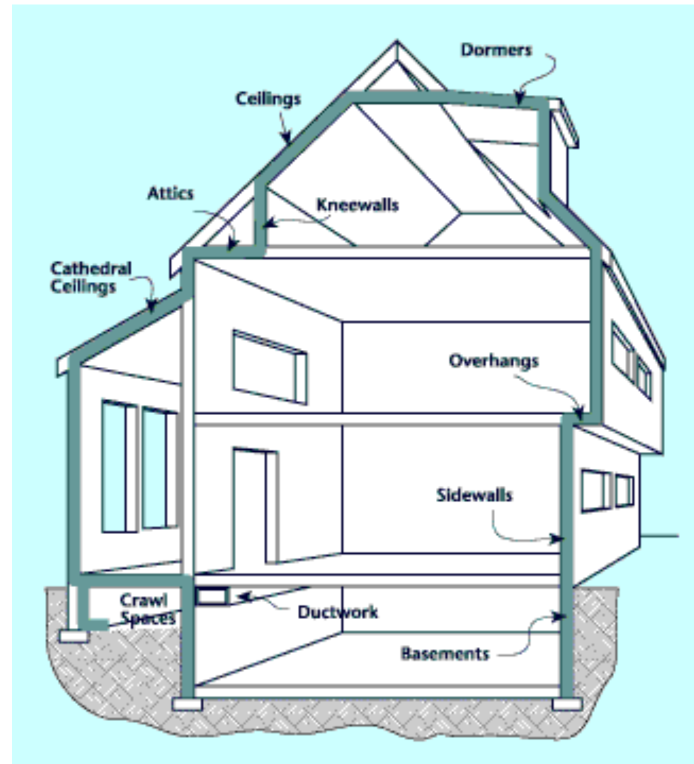
- Note: this is our last full lecture
  - I will have no more than ~1.5 hours worth of material next class

INSULATION MATERIALS

Applications

Building insulation

- Insulation is necessary to control heat flow through enclosure
- All opaque external surfaces should have insulation
  - Walls
  - Ceilings
  - Roof
  - Basements
- We've discussed insulation in terms of thermal conductivity, U-values, and R-values
  - ***A lot***



Important properties of insulation

- Thermal Resistance
  - Important for controlling heat flow
- Vapor Resistance
  - Important for controlling condensation
- Fire/Smoke Resistance
  - Important for fire and life safety considerations
- Sound Absorption
  - Important for noise control
- Structural Integrity
  - Important for use in certain applications (roofing)
- Chemical Composition
  - Important for knowledge of environmental considerations
- Cost
- Sustainability

Thermal resistance measures (IP units)

- R = R-Value [(h ft^2 °F)/Btu]
  - Thermal resistance per unit area
  - Larger R-Value is better
- U = U Value [Btu/(h ft^2 °F)]
  - $U = 1/R$ = Thermal conductance per unit area
  - Often used for doors and windows
- r = thermal resistivity [(h ft^2 °F)/Btu in]
  - $r = R/L$ = R-Value per inch of thickness
  - Larger r value is better
- k = thermal conductivity [Btu/(hr ft^2 °F in)]
  - $k = 1/r = L/R$
  - Smaller k factor is better

- Thermal resistance is measured using ASTM C1114-00 and C1363-05

Notes for construction documents

- Conductivity of types of insulations can change from manufacturer to manufacturer
  - It is best to denote a required R value on the building drawings and in the specifications
  - Ensures that the required insulating value is installed

- When comparing insulations, it is better to compare r or k values because they are basic material properties
  - Not dependent on thickness

Vapor resistance measures (IP units)

- M_v = vapor permeance [IP perms] ≈ [57.2 ng/(s·m^2·Pa)]

  - $M_v < 0.1$ is a vapor barrier
  - $0.1 < M_v < 1$ is a vapor retarder
  - $1 < M_v < 10$ is vapor semi-permeable

- $Z = 1/M_v$ = vapor resistance [IP reps, inverse of M]
  - $Z > 10$ is a vapor barrier
  - $1 < Z < 10$ is a vapor retarder
  - $0.1 < Z < 1$ is a vapor semi-permeable

- Vapor resistance is tested using ASTM E96

Primary types of insulation

- Fiberglass
- Mineral Fibers
- Cellulose
- Natural Fibers
  - Cotton
  - Wool
- Spray on Foams
- Rigid Foams
- Structure-integrated insulations
  - EIFS, ICFS, SIPS

ASTM insulation standards

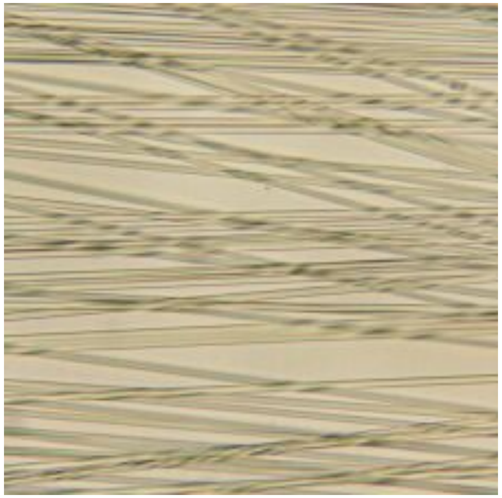
- C168-05 Standard Terminology for Thermal Insulation
- C165-05 Standard Test Method for Measuring Compressive Properties of Thermal Insulations
- C520-04 Standard Test Methods for Density of Granular Loose Fill Insulations
- C1058-03 Standard Practice for Selecting Temperatures for Evaluating and Reporting Thermal Properties of Thermal Insulation
- C1114-00 Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Thin-Heater Apparatus
- C1155-95(2001) Standard Practice for Determining Thermal Resistance of Building Envelope Components from the In-Situ Data
- C1158-01 Standard Practice for Installation and Use of Radiant Barrier Systems (RBS) in Building Construction
- C1363-05 Standard Test Method for Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus
- ASTM E96 / E96M - 05 Standard Test Methods for Water Vapor Transmission of Materials

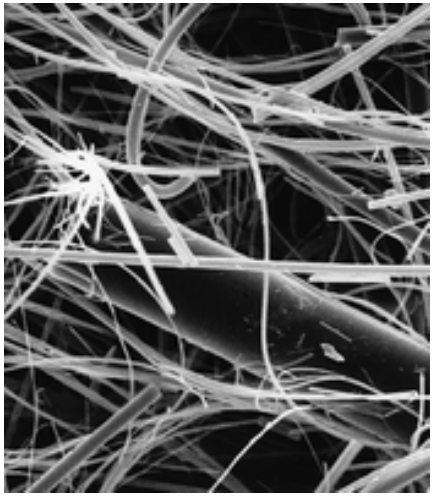
ASTM insulation specifications

- C578-05 Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation
- C552-03 Standard Specification for Cellular Glass Thermal Insulation
- C553-02 Standard Specification for Mineral Fiber Blanket Thermal Insulation for Commercial and Industrial Applications
- C610-05 Standard Specification for Molded Expanded Perlite Block and Pipe Thermal Insulation
- C764-04 Standard Specification for Mineral Fiber Loose-Fill Thermal Insulation
- C1014-03 Standard Specification for Spray-Applied Mineral Fiber Thermal and Sound Absorbing Insulation
- C1126-04 Standard Specification for Faced or Unfaced Rigid Cellular Phenolic Thermal Insulation
- C1289-05 Standard Specification for Faced Rigid Cellular Polyisocyanurate Thermal Insulation Board

Fiberglass or glass wool insulation

- Fiberglass is made from thin filaments of glass
  - Also known as glass wool
- Fiberglass acts as an insulator by reducing internal convection and radiation
  - Glass fibers conduct heat better than still air, but the closely spaced fibers resist air motion and nearly eliminate convection
  - Radiation is absorbed and reradiated by fibers but each absorption and re-radiation reduces the energy transmission





Forms of fiberglass insulation

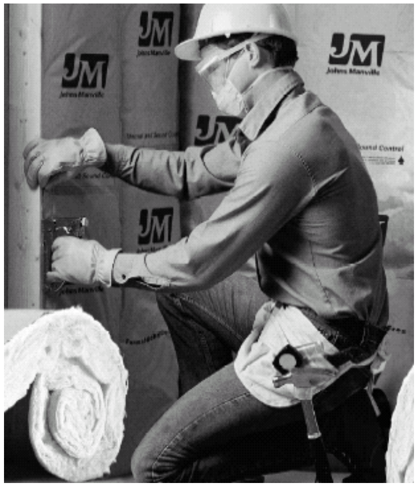
- Blankets
  - Faced or Unfaced Rolls and Batts
    - Kraft Paper Facing provides variable vapor resistance but reduces fire resistance
    - Foil Facing provides vapor resistance, fire resistance, and a radiative reflective barrier
    - MR Facing: Mold Resistant facing
  - Encapsulated batts
    - Poly-encapsulation acts as a vapor barrier and makes it easier to install without contacting fibers
- Loose-Fill
  - Blown in to place
  - Fits into nooks and crannies
- Rigid Boards
  - Used for acoustic panels and external insulation boards

Properties of fiberglass insulation

- $r \approx 3$ h ft^2 °F /Btu in with $2 < r < 3.7$
  - Starts a bit higher but usually drops as fiberglass settles
  - Must avoid compression to keep R-value high
    - A 6 inch fiberglass batt compressed to fit in a 2x6 stud has a lower R value than a 5 inch fiberglass batt undisturbed
- Usually sold according to its R-Value
  - R-11, R-13, R-19, etc. (or R per inch)
- Vapor Resistance (IP)
  - 0.001 rep (bare), ~0.1-5 rep (Kraft faced), 20 rep (foil faced)
- Density ≈ 1 pcf (pound per cubic foot)
- Compressive strength
  - 10-20 PSI for rigid fiberglass, 0 PSI for batting
- Costs: R-11 installed costs are as low as \$0.50/ft^2
  - More typically \$0.75-1/ft^2

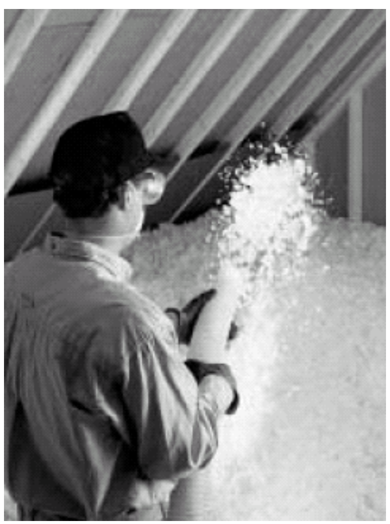
Types of fiberglass insulation

Kraft Faced



Poly Encapsulated

Rigid



Blown In

Foil Backed

Advantages and disadvantages of fiberglass

- Advantages
  - Low density
    - Easy storage and transport
  - Inexpensive (both material and installation costs)
  - Inorganic – fiberglass itself is fire and mold/bacteria growth resistant
- Disadvantages
  - Low density means surprisingly poor fire resistance
    - Material very difficult to ignite, but flame travels through air space fairly well
  - Fiberglass is a carcinogen
    - Very hazardous installation - must wear gloves, masks and goggles
    - Must keep fibers from getting airborne after installation
  - Can absorb moisture since there are no closed cells
    - R-value can drop when wet

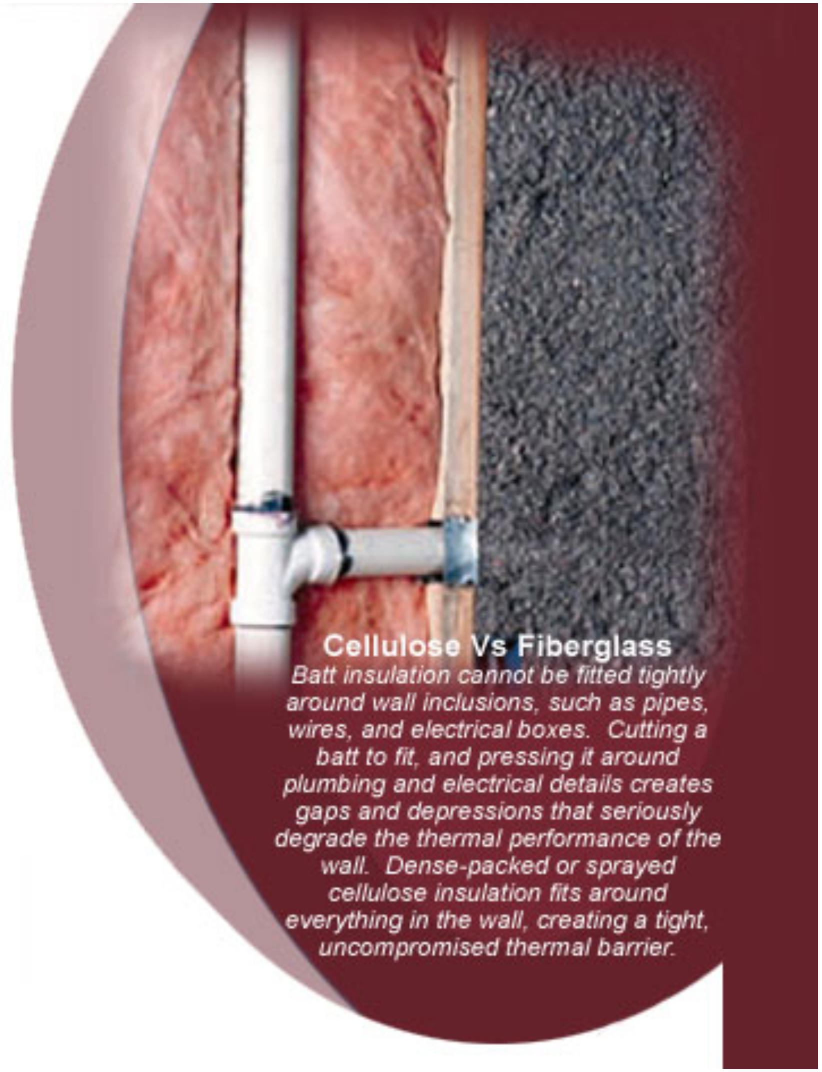
Rock and slag wool insulation (aka mineral wool)

- Rockwool
  - Made from basalt (a volcanic rock) and limestone
- Slagwool
  - Made from recycled blast furnace slag (byproduct of iron/steel)
- Density of 2.5 to 4.0 lb/ft^3
- r usually a bit higher than fiberglass
  - r is 3.7 h ft^2 °F/(Btu in) for 2.5 pcf rock wool
  - r is 3.9 h ft^2 °F/)Btu in) for 4 pcf rock wool
- Higher fire resistance than fiberglass
- Does not absorb moisture well
- Installed costs a bit higher than fiberglass

Mineral wool insulation

Cellulose insulation

- Made from shredded newspaper and wood pulp
  - Chemically treated to increase fire resistance
  - Noncarcinogenic
- r ≈ 3.6 h-ft$^{2°}$-F/(Btu in)
- Density ≈ 1.6 pcf
- Cellulose is applied wet and sticks to wall and fills gaps
- Installed costs a bit higher than blanket fiberglass
  - \$1-1.5/ft^2



Advantages and disadvantages of cellulose

- Advantages
  - A very ‘green’ building product
    - 6x less energy than fiberglass to manufacture
    - 25 to 50x less embodied energy than other mineral fibers
  - Higher density than fiberglass reduces air flow
    - May reduce heat transfer even with a lower R value
    - Less air space means flame spread characteristics can be better than fiberglass
- Disadvantages
  - Absorbs and retains moisture, which reduces R-Value
  - More susceptible to mold/fungus growth than mineral fibers
  - Lower innate fire resistance than mineral fibers
    - Wet applied clings to walls which means quicker ignition
  - Wet Applied Cellulose must dry before walls are closed – slows down construction time

Cotton fiber insulation

- Made mostly from recycled cotton fibers
- r value ≈ 3-4 h ft^2 °F/(Btu in)
- Organic
  - Possible problems with mold/fire
  - Fire ratings are pretty good
- No problems with chemical emissions
  - Possible problems with allergies
- 'Green' manufacturing
  - 100% recyclable
  - Low energy to manufacture
- Installed cost is comparable to mineral fibers and cellulose

  ~\$1.20-1.50/ft^2

Insulation made from recycled denim

Actual wool fiber insulation

- Made from Sheep's wool
- r-factor ≈ 3.5 to 3.8 h ft^2 °F /(Btu in)
- Organic
  - Possible problems with mold/fire
  - Fire ratings are pretty good
- No problems with chemical emissions
  - Possible problems with allergies
- Somewhat 'green' manufacture
  - 100% recyclable
  - You can eat the production device
- Installed cost is much higher than mineral fibers

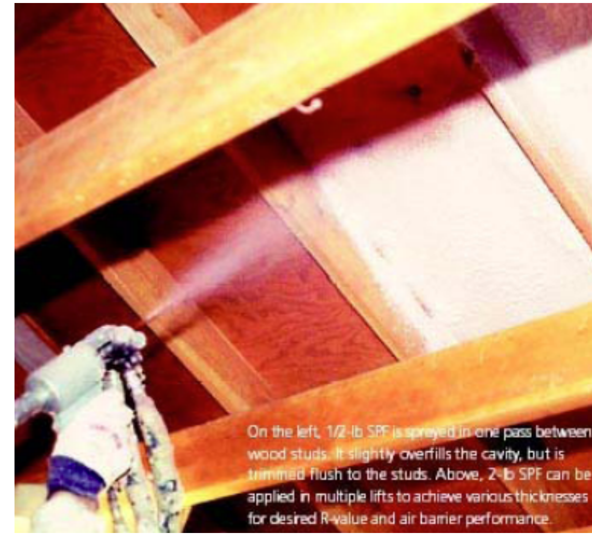
  ~\$2-2.50/ft^2

Foam insulations

- Foam building insulations offer an alternative to fibrous materials
- Liquid Foams are sprayed in and expand to fill cavities
  – Use in place of spray in fiberglass or cellulose
- Foam board is rigid and self supporting
  – Use in place of blanket, batt or rigid fiberglass insulation
  – Very useful for external and roof insulation

Spray-on expanding foam

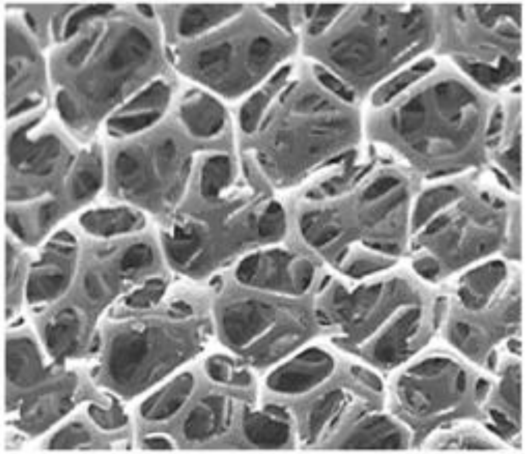
- Spray-on polyurethane material
- r ≈ 3-7 (h ft2 °F)/(Btu in)
- Density ≈ 2.0 pcf
- Spray in expanding foam fills cracks and gaps
- Closed cell completely eliminates the need for taping/sealing and air barrier material
  - This is great for trying to insulate existing construction where it is hard to cut around framing and piping
    - Spray in foam can be sprayed around it
- Installed costs are about $1.5-2/ft^2
  - But you eliminate the cost to install an air barrier for closed cell foam

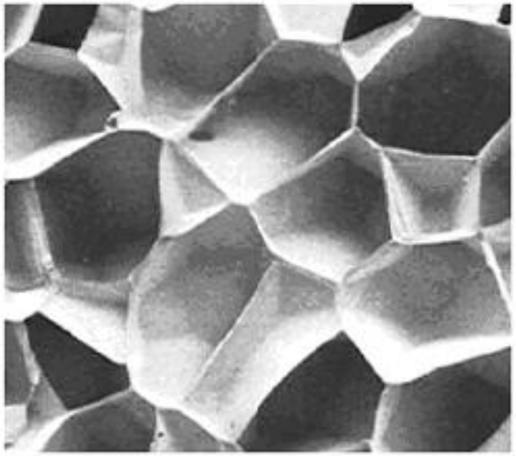


Open-cell:
r ~ 3.6 per inch

Closed-cell:
r ~ 6.5 per inch

Open-cell and closed-cell foams





Expanded polystyrene (EPS)

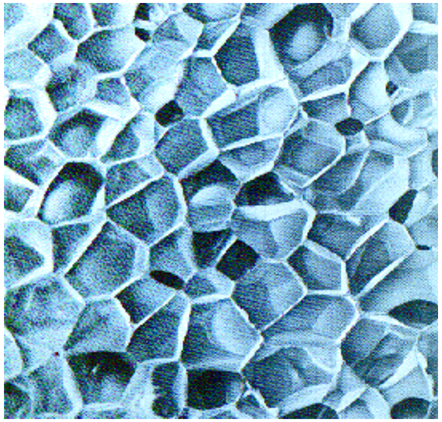
- Denoted EPS or MEPS (M = molded)
  - Commonly called styrofoam
- Polystyrene beads are heated in molds
  - Expands pentane within (C_5H_{12})
  - Resulting structure is touching spheres with gaps between
- More easily molded to different thicknesses than XPS

EPS properties

- r ≈ 4 ft^2 °F /Btu in
- Density ≈ 1 - 5 pcf
- Vapor Resistance ≈ 0.3-3 rep/in
- Compressive Strength: 10 - 20 PSI
  - Much higher than non-rigid fiberglass
- Up to 4% or 5% water absorption
- Flame Spread: 20
- Smoke Developed: 150-300
- Material itself is usually 100% recyclable
  - But note that EPS cannot be made completely from recycled material, some virgin materials are necessary

Extruded expanded polystyrene

- XEPS or XPS
- Polystyrene is melted and injected with a blowing agent forming gas bubbles
- Resulting structure is more like a honeycomb with closed or open cells
- Often used as structural insulating panels (SIPs) or insulating concrete forms (ICF)
  - More on these later
- Because the cells are closed, it stores less moisture and is suitable for foundation insulation



XPS properties

- r-factor ≈ 5.5 h ft^2 °F /Btu in
  - A bit higher than EPS
- Density ≈ 1.5 - 5 pcf
- Vapor Resistance ≈ 0.4 – 2.2 rep/in
  - Compressive Strength: 20 – 100 PSI
- Flame Spread: 5
  - Closed cells reduce flame spread
- Smoke Developed: 175
- Material itself 100% recyclable
  - But XPS cannot be made completely from recycled material

Polyisocyanurate (“polyiso” or “PIR”)

- Low conductivity gas is injected to form bubbles
  - Decreases thermal conductivity
  - Increases thermal resistance
- Available in rigid board or as a spray on foam
- Foil backed boards repel water and reflect radiant energy

http://www.polyiso.org/

Polyiso insulation properties

- r-factor ≈ 8-10 h ft^2 °F /Btu in
  - Highest of all common building materials
  - Starts at 10 but stabilizes at 7-8 as gas escapes
- Vapor Resistance ≈ 0.5 reps/in
- Density ≈ 1.5 – 2 pcf
- Compressive Strength: 16 – 40 PSI
- Flame Spread: 5
- Smoke Development: 165

Advantages and disadvantages of foams

- Advantages
  - Highest r-factors = best insulating capabilities
  - Easy storage, transport, and installation
  - Easily shaped and tapered
    - Important for designing drainage in roofs
- Disadvantages
  - Least environmentally friendly to manufacture
    - Made from plastics (oil and natural gas inputs)
    - Blowing agents in XPS and polyiso are still usually HCFCs or HFCs
  - Foams generally have lower fire resistances and are toxic when ignited
  - Does have some water absorption properties (especially EPS)
  - Possible VOC off-gassing problems

Structural requirements of insulations

- On rooftops, the insulation must be able to support some load
  - Rain, snow, occasional people
- Fibrous materials need a supporting shell or need to be used interior only
- Rigid fiberglass is strong but expensive
- Foam insulations are self supporting and are used almost ubiquitously for external roofing insulation

Acoustic uses

- For acoustic uses, the insulation must allow sound into the porous structure and have minimal contact with walls
  - Fibrous materials like fiberglass, rockwool, cotton, and wool are good
  - Blown-in materials like cellulose are okay, but they have contact with both sides of walls
- Rigid foams are usually closed cell and do not provide any acoustic benefit
  - Rigid foams (either open or closed) in touch with two walls transmits vibration directly which will decrease sound isolation
    - Properly installed (i.e., only touching one wall) open cell foams can act similarly to a fiberglass batt

Applicability of insulations

- Fibrous, cellulose, and expanding foams are really only useful as cavity insulation
- Rigid foams are mostly used as exterior insulations
  - Even thin pieces of external insulation can reduce thermal bridging of structural elements

Comparing “greenness”

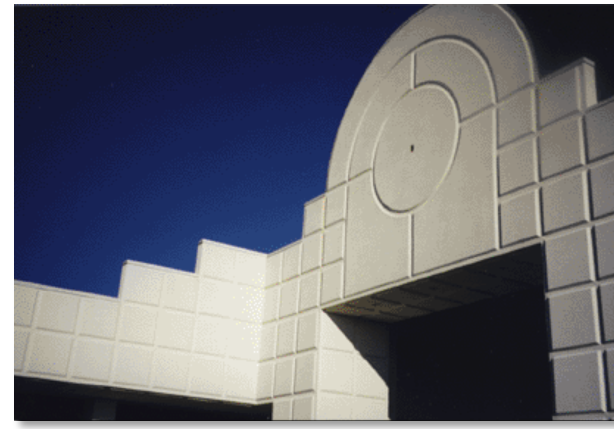
- Some man-made and natural fiber dealers claim theirs is the “greenest” insulation
  - Wool and cellulose in particular
- A proper comparison includes entire cost to manufacture, transport and install (embodied energy), as well as expected energy savings over the lifetime of the material
  - On an energy only basis, XPS and polyiso win out as the increased R value is so much higher than other insulations
- Sustainability should be included too
  - Wool and cellulose come from sustainable materials, but the growth and harvesting require the use of non-sustainable materials (namely fossil fuels)
  - Natural fibers are biodegradable, something that poly’s are not

Structure-integrated insulation systems

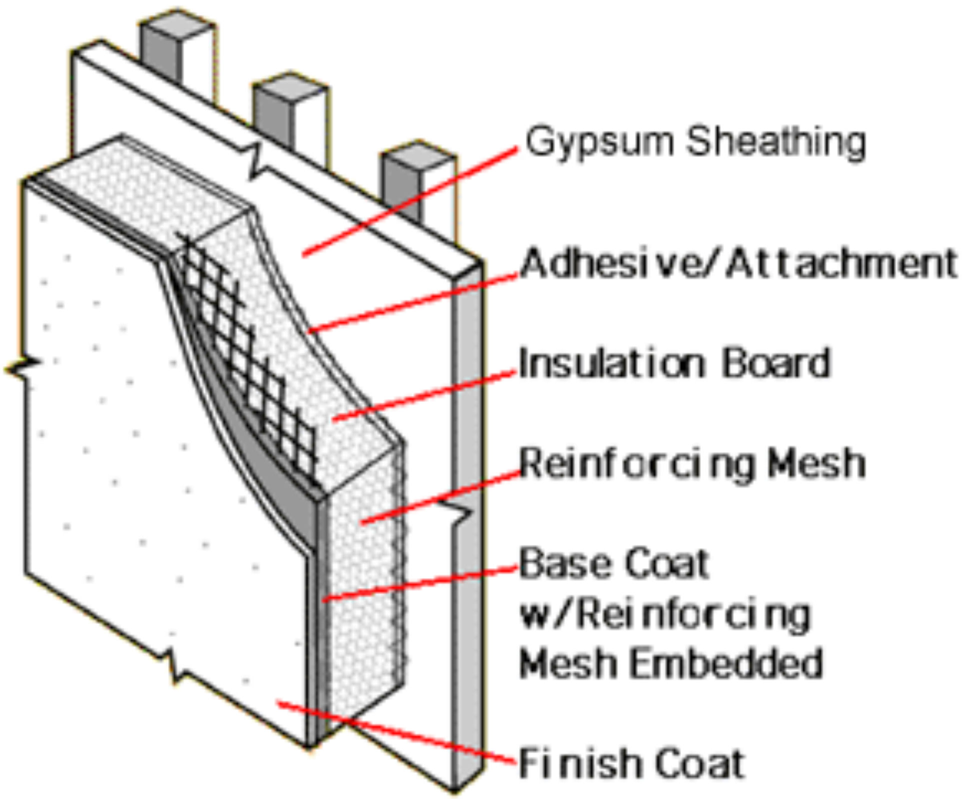
- EIFS
  - Externally Insulated Finish Systems
- ICFs
  - Insulated Concrete Forms
- SIPs
  - Structural Insulated Panels

EIFS

- Exterior Insulation and Finish Systems (EIFS) are insulated, multilayered exterior wall systems
  - Essentially this is synthetic stucco
  - Introduced into US in the 1970s to improve energy efficiency
  - First used on commercial buildings
    - Then used in homes as well
  - 30% of the commercial building exterior wall market



EIFS construction

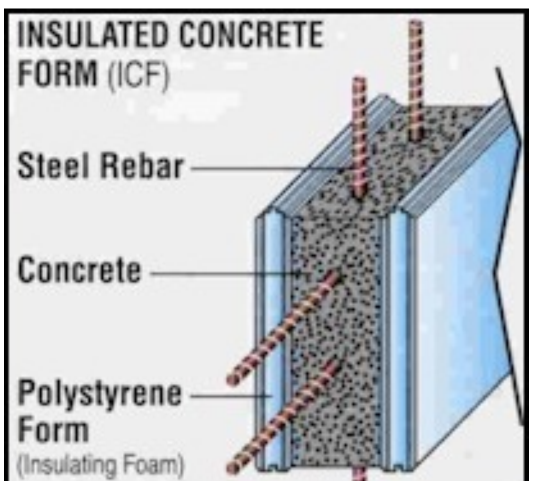


- OSB or plywood substrate
- Polystyrene or polyisocyanurate insulation
- Multi-coat acrylic polymer with fiberglass reinforcement
  - Basically, synthetic stucco

No more information because Stuart and Maria will tell us all about EIFS in their final project presentation!

ICFs: Insulated Concrete Forms

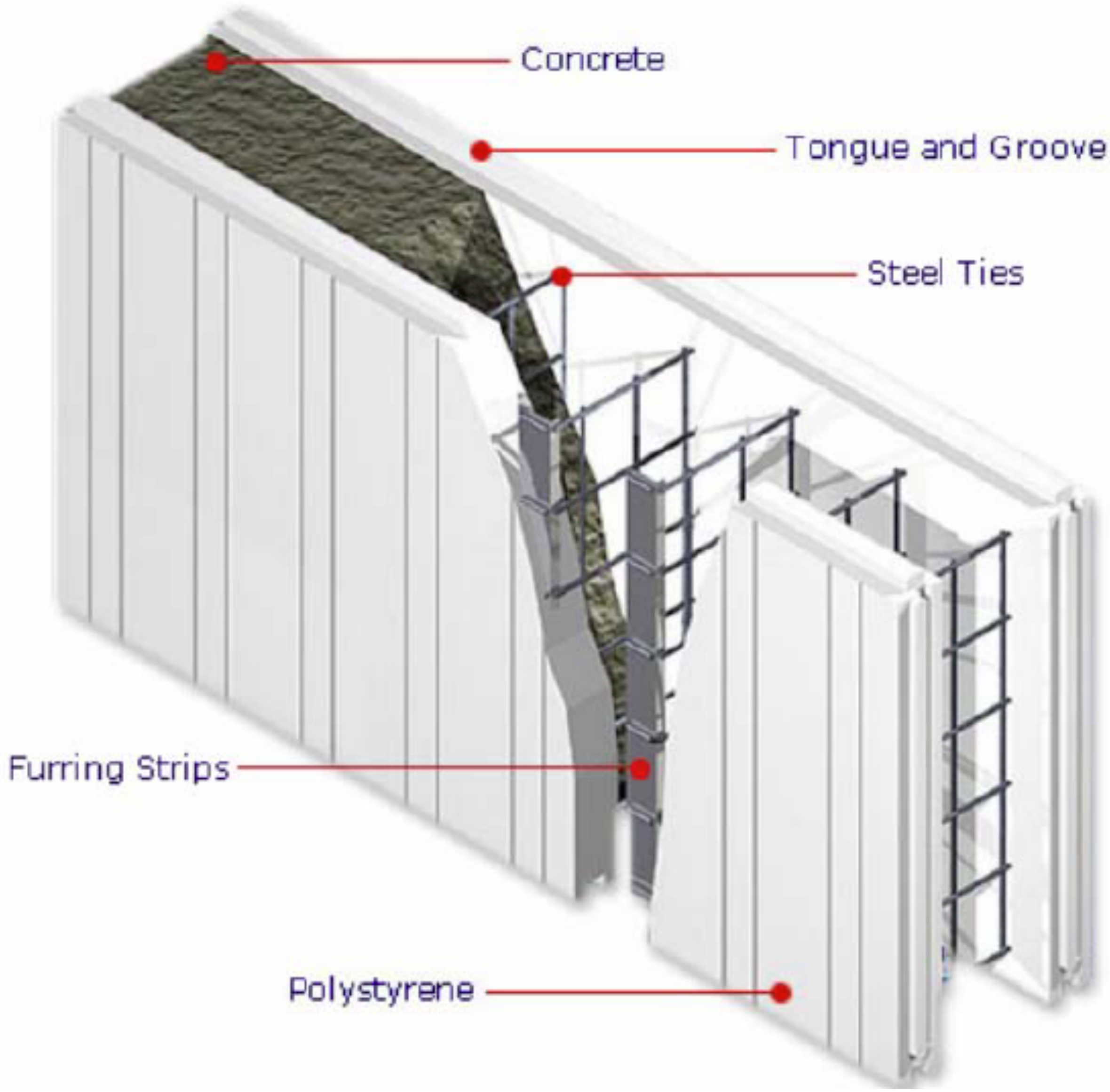
- Forms or molds that have made insulation for accepting reinforced concrete
- These forms are stacked and tied together, rebar is added, then filled with concrete
- Forms remain in place after concrete cures
  - It's like formwork you don't remove



Components

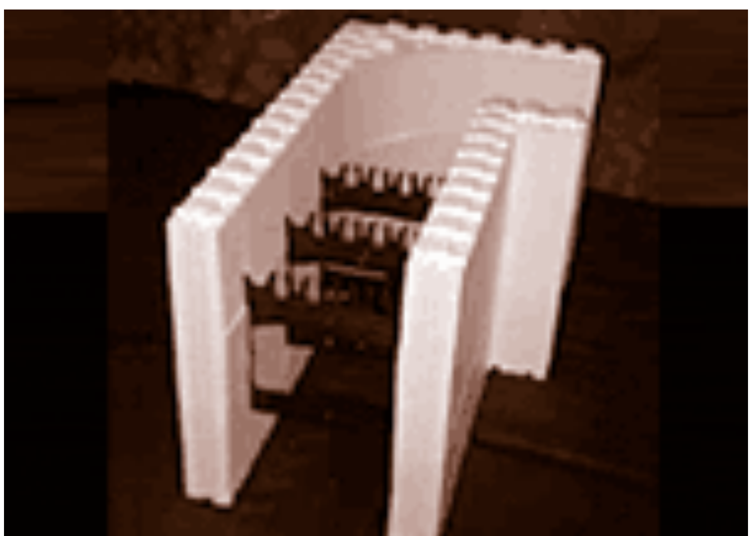
- 2 Pieces of EPS or XPS 2-4 inches thick
- 4, 6, 8, or 12 inch thick concrete fill
- Steel rebar

ICFs



Concrete
Tongue and Groove
Steel Ties
Furring Strips
Polystyrene

ICFs

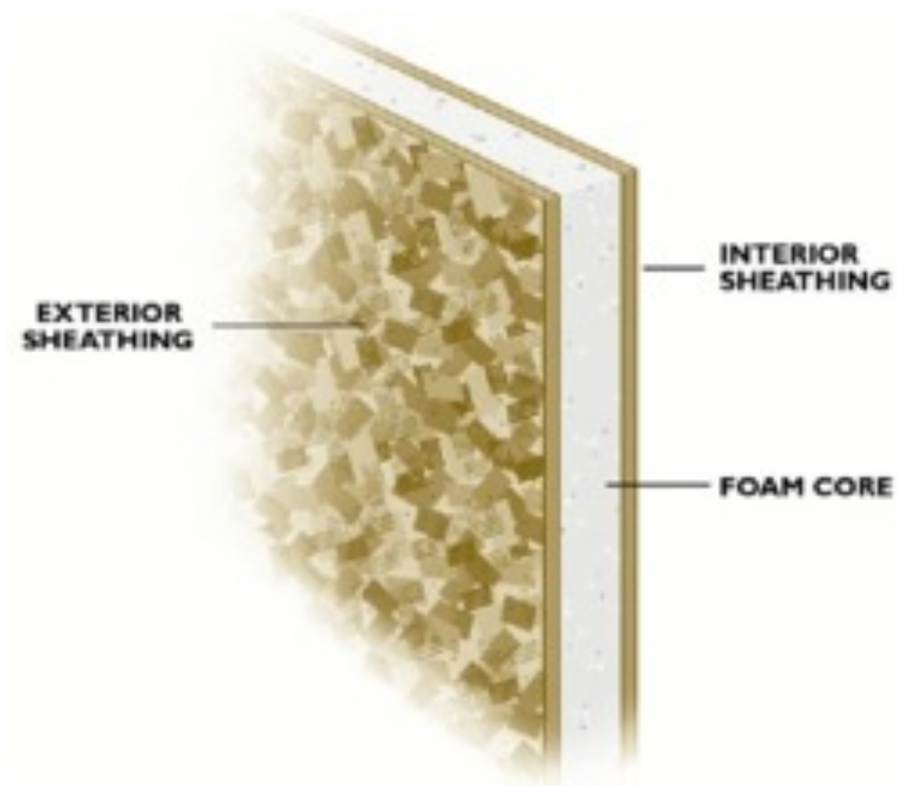


Advantages of ICFs

- Benefits of both thermal mass and high R value
  - R-20 to R-40 (IP) are commonly available
  - Peak energy reductions of 20-50% over frame buildings
- ICFs create a structural concrete wall that is up to 10 times stronger than wood framed structures
- High sound isolation
- Good protection against fire, water, insects
- Construction methods are easy to learn
- Flexibility in design
  - Can be externally cladded with EIFS to make virtually any shape

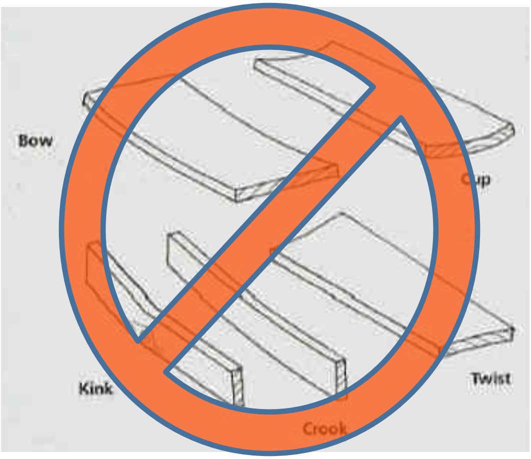
Structural Insulated Panels (SIPs)

- SIPs are a manufactured wall panel system usually constructed of two wood panels that sandwich a foam core
  - Usually OSB around EPS
  - Sometimes foam is XPS or polyiso



SIP construction benefits

- Panels can be pre-cut at the factory
- No framing = fewer workers
  - Retains very high structural strength
- Easier to hang drywall
  - No studs to mark and find
- Walls will be straighter
  - No cups, warps, etc., as found in most lumber
- Results
  - Faster construction
  - Up to 30%-40% reduction in labor costs



Disadvantages of SIPs

- Less flexibility for wires and pipes
  - Locations must be set before manufacture
  - Conduit not possible
- On the job design changes are difficult
- Cranes are needed for large panels

Structural strength of SIPs

- Structural sandwich provides very high strength
  - Handles higher axial and transverse loads than standard wood stud wall construction
- Can be used for almost any part of the enclosure
  - 4x8 foot sections typically used for walls
  - 8x24 foot sections typically used for roofs and floors

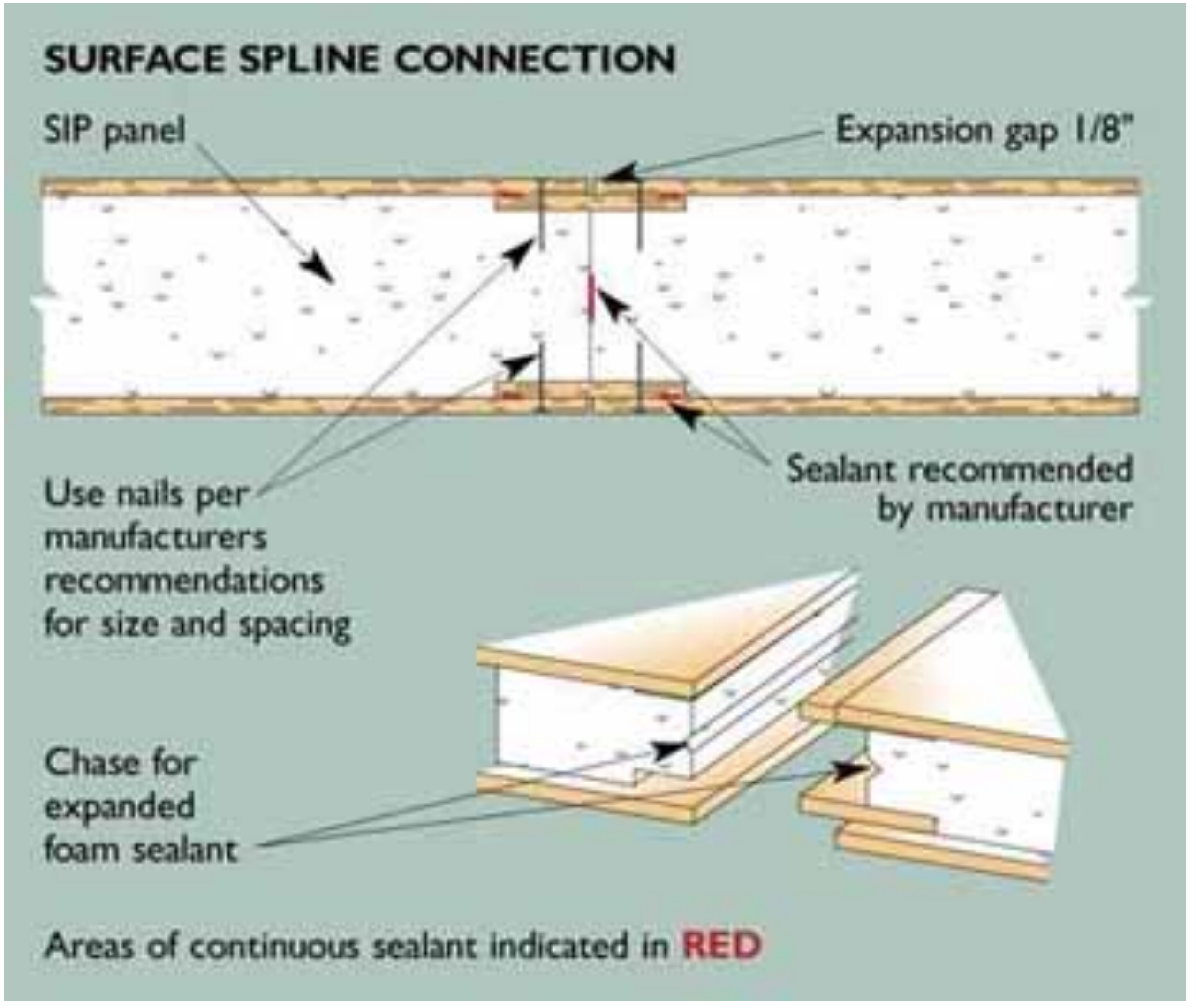
SIP thermal benefits

- Little framing means few thermal bridges
- Use of EPS/XPS/Polyiso foam insulation provides high inherent R-Value
  - A high R-Value maintained even when wet
- Lack of air gaps reduces air leakage considerably
  - Less chance for moisture to get to insulation
- Inherently high vapor resistance
  - Vapor barrier not needed in most climates

- Result: installed R-Value is near theoretical R-Value
  - A SIP wall is usually 25-50% more energy efficient than a wood frame wall of same thickness with fiberglass insulation

SIP connection details

- Surface spline connection eliminates thermal bridging
- Put together like puzzle pieces



SIPs

FIRE RATINGS

Flame and smoke ratings

- Flame Spread Index is a relative measure of the speed of flame spread
  - 100 is the speed at which flames spread on red oak wood
    - 0 is asbestos-cement board
  - A flame spread rating of 20 means the flame spread speed is 20/100 = 1/5 (20%) that of red oak
  - Class A fire ratings (the best) have flame spreads of 0-25
  - Class B is 26-75
  - Class C is 76-200
  - Flame spread ratings are not the same as fire resistance ratings

- Smoke-developed-index is a relative measure smoke emissions of a material as it burns
  - 100 is the amount of smoke developed by red oak when burned
    - 0 is asbestos-cement board

Flame and smoke ratings of some materials

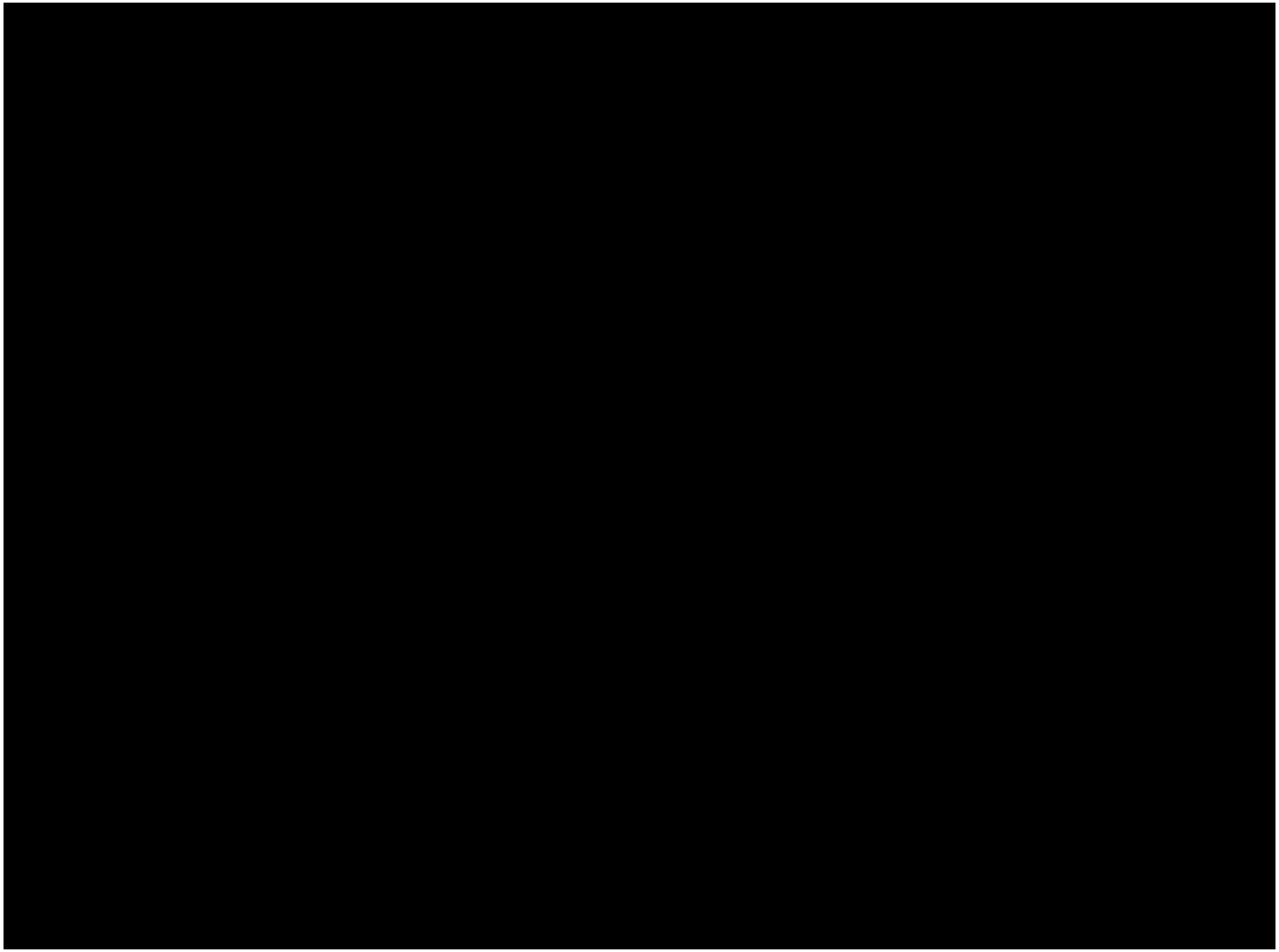
Material	Flame Spread Index	Class
Brick	0	A
Plywood • Fire-retardant-treated	0-25	A
Gypsum wallboard	10-20	A
Cedar	69	B
Spruce	55	B
Plywood	120-180	C
OSB	150	C
Particle board	116-178	C

http://sfm.dps.louisiana.gov/doc_flamespread.html

Fire-resistance ratings

- Determined by ASTM E 119 and/or UL 72
- Duration of time for which a passive fire protection system can withstand a standard fire resistance test
  - “Passive fire protection” just means without active measures (e.g., water spraying)
  - Strategies include fire stops, fire doors, and particular wall and floor assemblies that utilize fire-resistant materials to prevent fire from spreading
    - Or at least increase the time it takes to spread)
    - Compartmentalization is often utilized

Fire resistance testing



Fire-resistance ratings of materials

TABLE 721.2.1.4(2)
TIME ASSIGNED TO FINISH MATERIALS ON FIRE-EXPOSED SIDE OF WALL

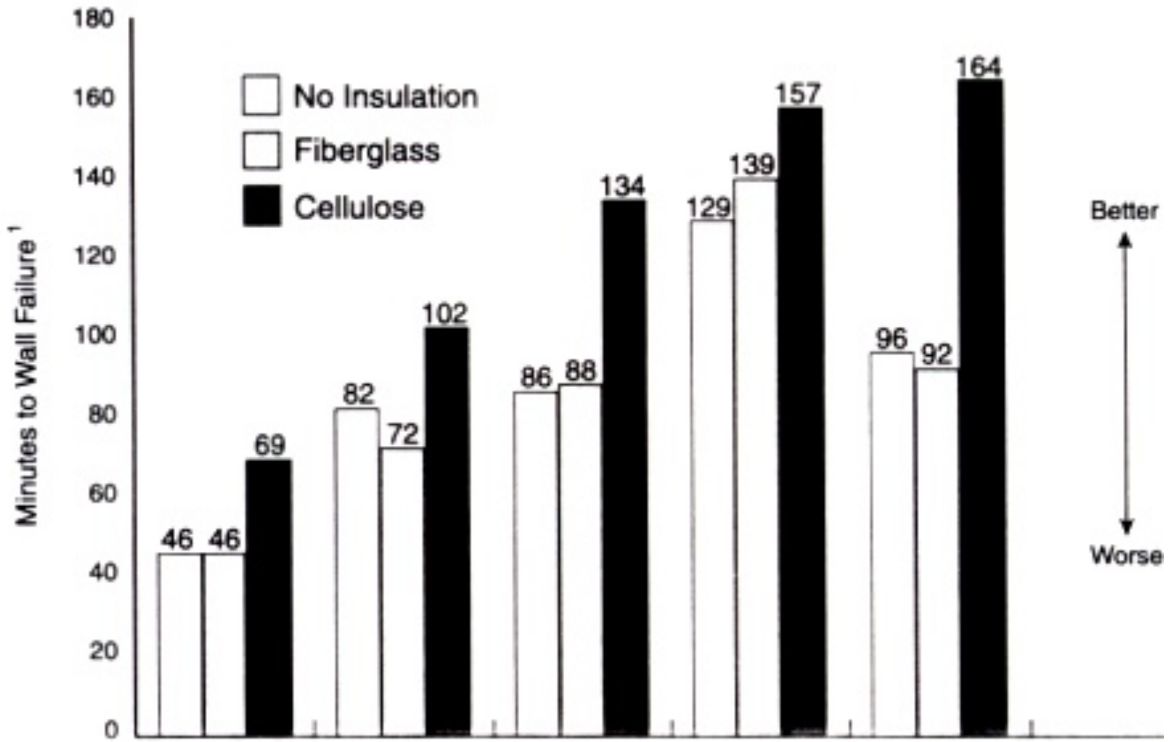
FINISH DESCRIPTION	TIME (minute)
Gypsum wallboard	
$^3/_8$ inch	10
$^1/_2$ inch	15
$^5/_8$ inch	20
2 layers of $^3/_8$ inch	25
1 layer $^3/_8$ inch, 1 layer $^1/_2$ inch	35
2 layers $^1/_2$ inch	40
Type X gypsum wallboard	
$^1/_2$ inch	25
$^5/_8$ inch	40
Portland cement-sand plaster applied directly to concrete masonry	See Note a
Portland cement-sand plaster on metal lath	
$^3/_4$ inch	20
$^7/_8$ inch	25
1 inch	30
Gypsum sand plaster on $^3/_8$-inch gypsum lath	
$^1/_2$ inch	35
$^5/_8$ inch	40
$^3/_4$ inch	50
Gypsum sand plaster on metal lath	
$^3/_4$ inch	50
$^7/_8$ inch	60
1 inch	80

For SI: 1 inch = 25.4 mm.

a. The actual thickness of portland cement-sand plaster, provided it is $^5/_8$ inch or less in thickness, shall be permitted to be included in determining the equivalent thickness of the masonry for use in Table 721.3.2.

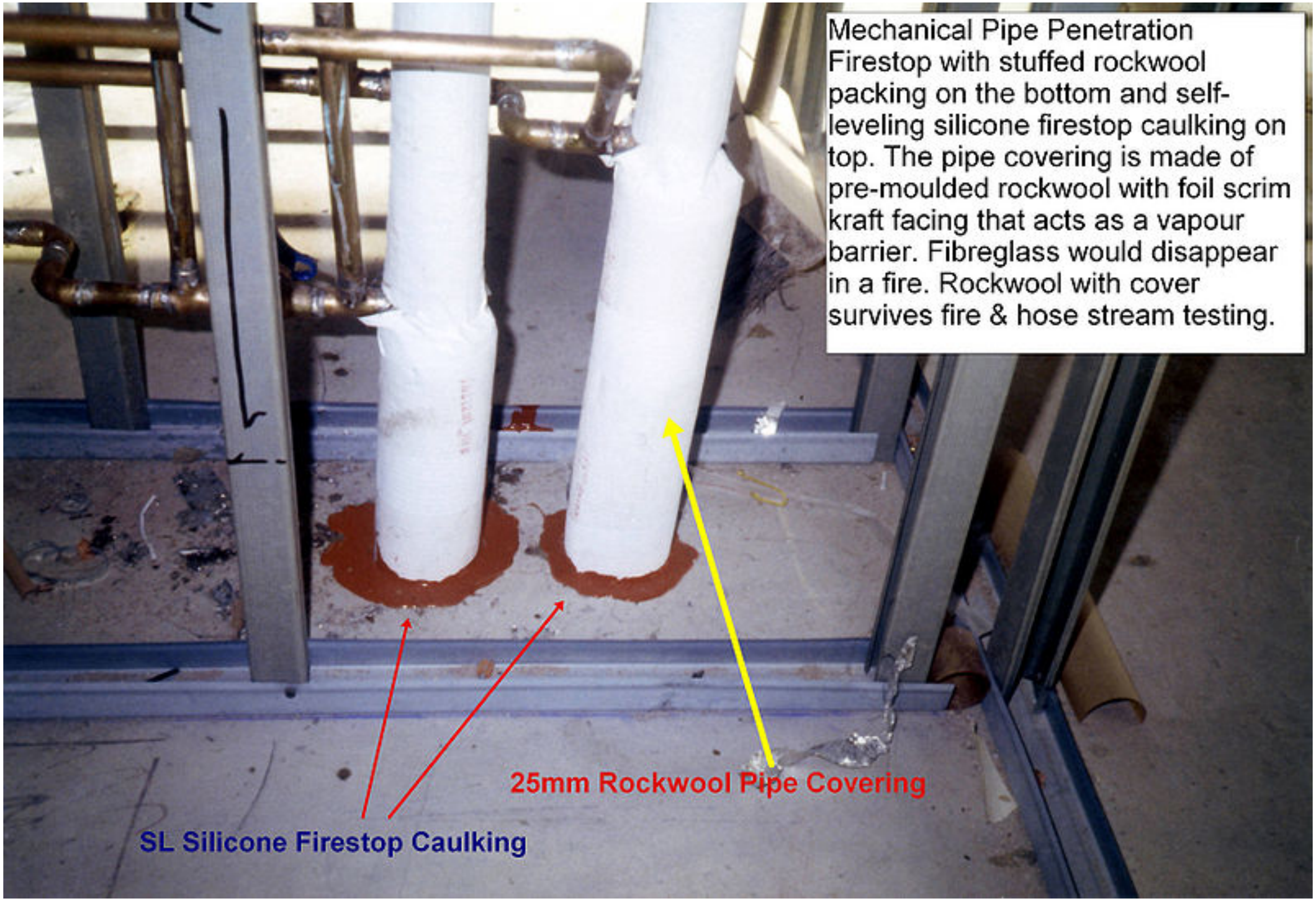
Fire-resistance ratings of assemblies

Figure 2. Wood and Steel Framed Wall Tests



Stud type	Steel	Steel	Steel	Steel	Wood
Stud size	2" x 4"	2" x 4"	2" x 4"	2" x 4"	2" x 4"
Stud spacing	24" OC	24" OC	24" OC	24" OC	16" OC
Gypsum type	½" X	½" Reg.	½" X	½" X	½" X
Gypsum layers (exposed x unexposed)[2]	1 x 1	2 x 2	1 x 2	2 x 2	1 x 2
Resilient channel	no	no	no	no	yes

Passive fire protection: fire-stopping plumbing penetrations



ROOFING

Applications

Roofing

- First line of weather defense
  - Precipitation (rain, snow)
  - Sun
  - Thermal Transmission
- Subjected to extreme heat and cold
  - Surface can have wide temperature swings

Notes on roofing

- The roof receives the most severe physical and chemical degradation of any building component
  - Extreme temperature swings
  - Extreme UV exposure
  - High wind and rain exposure
- Good roofing is hard to design
  - Roofing the subject of nearly 65% of the lawsuits against architects and builders[1]
  - Low-slope roofing has the shortest lifespan of any component – typically 12-15 years[1]

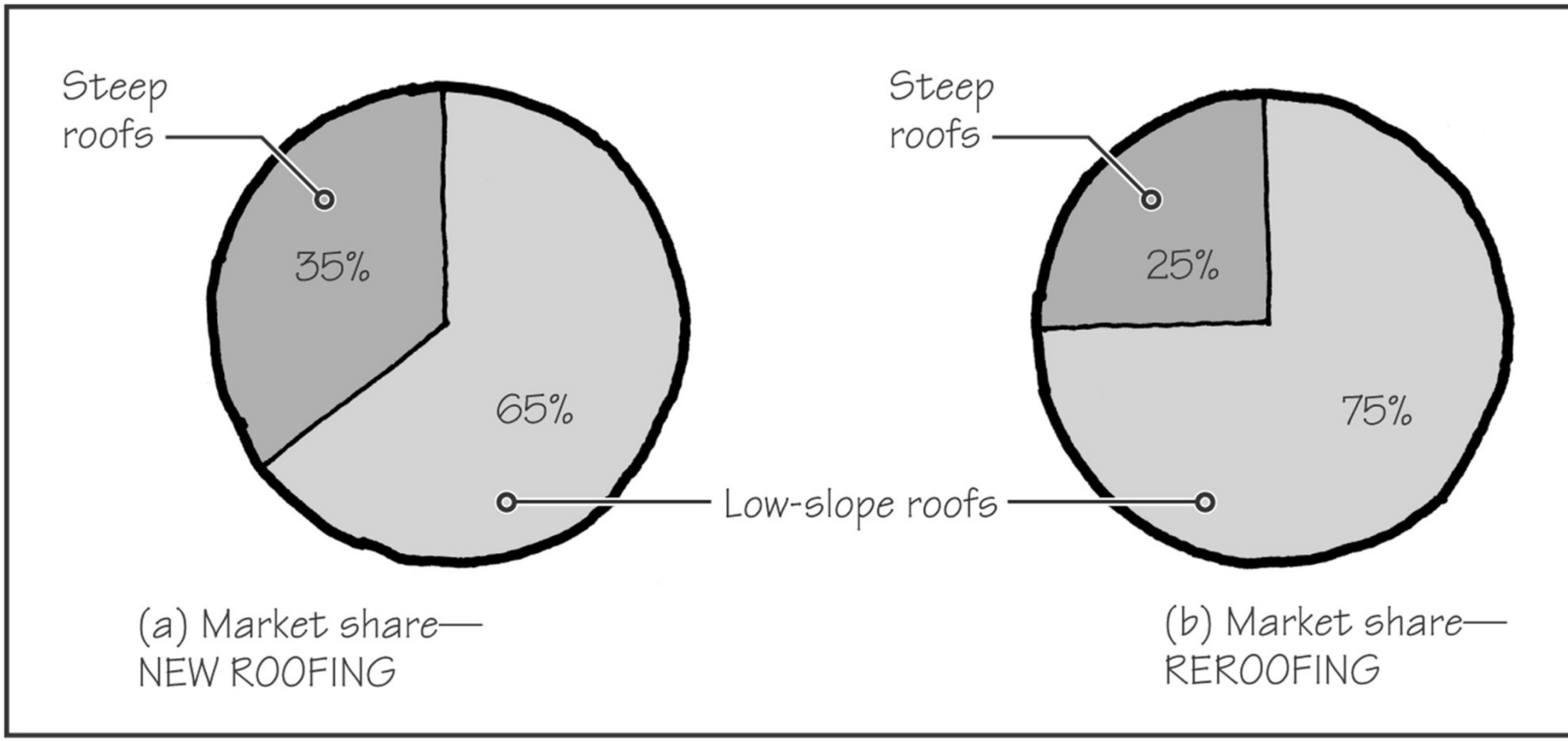
[1]Mehta, *Building Construction,* Pearson, 2008

Two principle types of roofs

- Steep Roofs
  - Used primarily on small buildings

- Low-Slope Roofs
  - Used on larger buildings

Market share: Low-slope and steep slope roofs



Design considerations

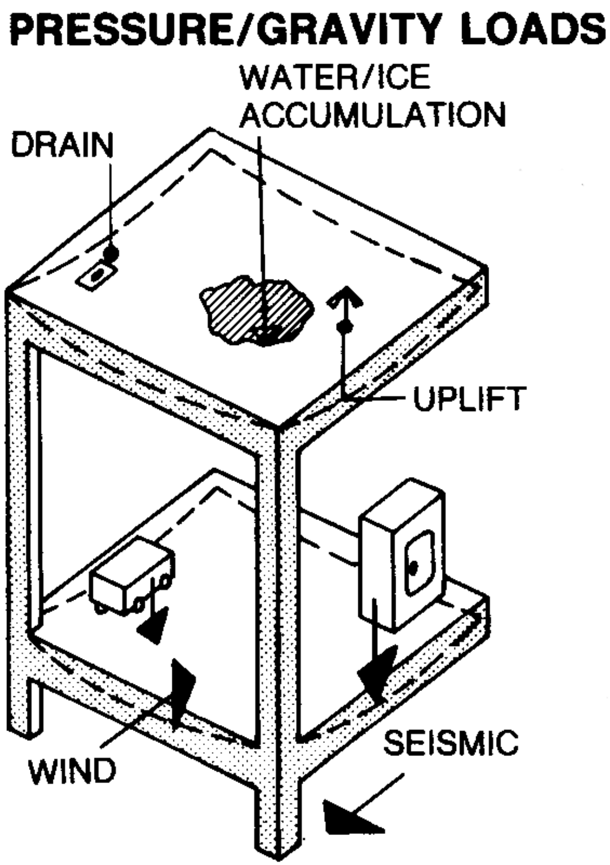
- Locally available technology and labor
- Suitability to local climate
  - Wind uplift and hail impact resistance
  - Drainage requirements
- Roof shape
- Chemical environment
- Roof warranty
- Long-term cost, including sustainability
- Life safety
- Fire safety

Principal elements of a roof system

- Substrate – support for roofing
  - Framing
  - Framing + Deck
  - Framing + Deck + Insulation or Concrete fill

- Roofing
  - Barrier formed to protect substrate from elements
  - Continuous membrane or overlapping units

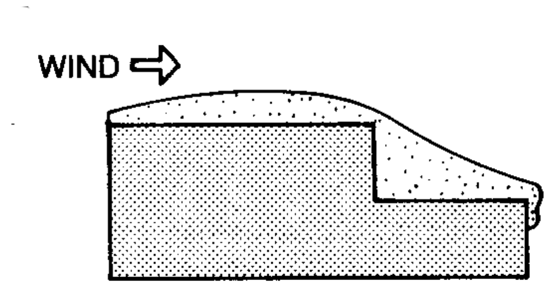
Structural loads



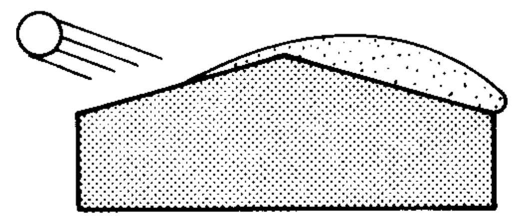
- Live loads
  - Water, snow, and ice accumulation
- Dead loads
  - Roof assembly
  - Rooftop equipment
- Shear loads
  - Wind
  - Seismic

Uneven live loads

- Wind loads are uneven
  - Negative for low slope
  - Positive for steep slope

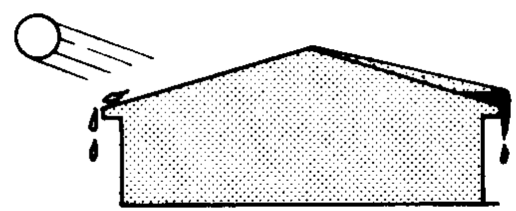


- Water/snow accumulation is uneven



SNOW ACCUMULATION

- Ice forms unevenly in cracks and low spots splitting roof membrane



ICE FORMATION

Low-slope Roofs

- Advantages
  - Can cover large horizontal surfaces
  - Simpler geometry, often less expensive
  - Roof can have other functions
    - patio, decks, parking, etc.

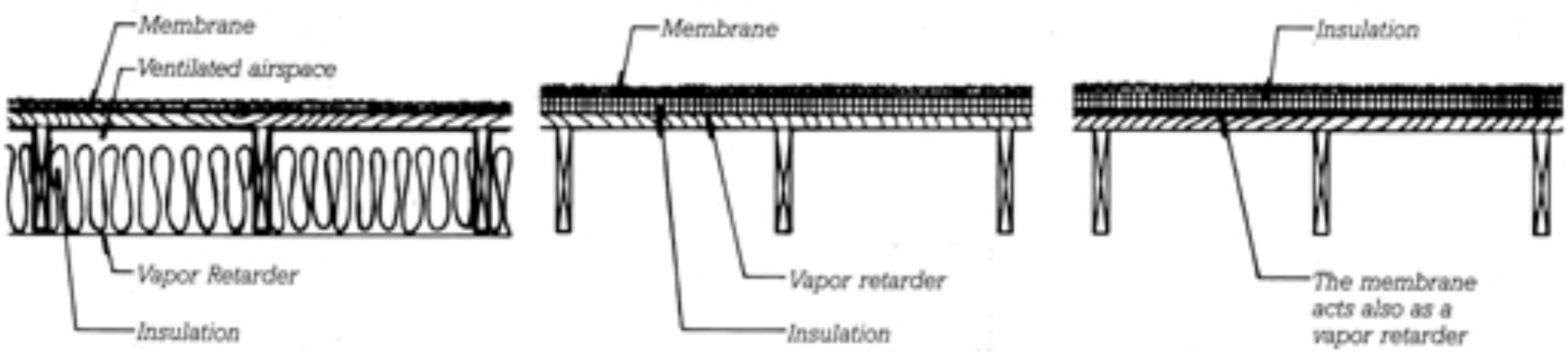
- Disadvantages
  - Water drains slowly
  - Slight structural movements can tear the membrane
  - Water vapor pressure can blister & rupture the membrane
  - Increased structural load from wind and accumulation

Low-slope roof components

- Structural Support: Deck on frame
- Thermal Insulation
- Roof Membrane
- Roof Ballast
- Drainage
- Flashing

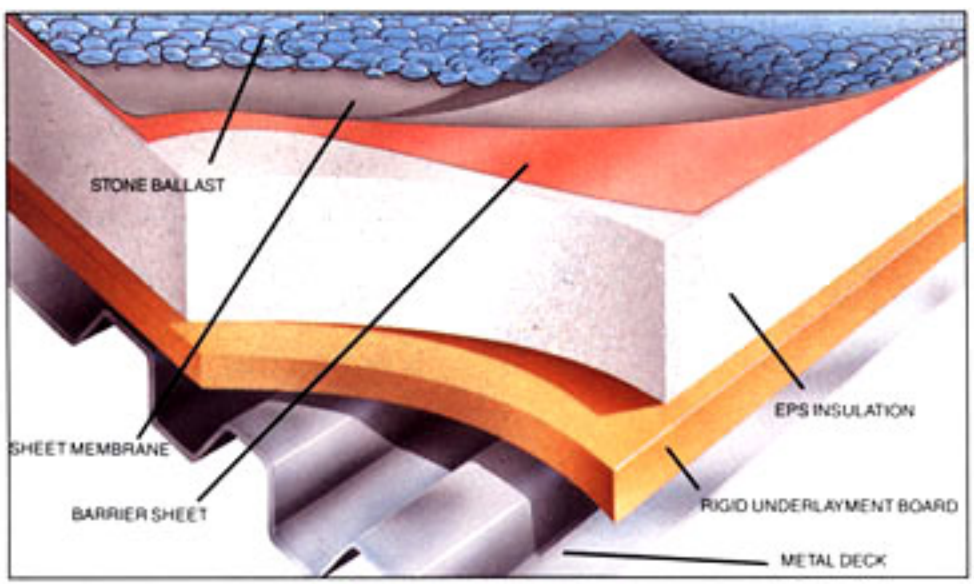
Roof thermal insulation

- Insulation is required to meet ASHRAE 90.1
- Location and placement
  - Below the deck: Thermal bridging is a problem
  - Between the deck and membrane: membrane exposed
  - Above the membrane: helps protect membrane
- Rigid insulation attachment
  - Adhered or mechanically attached



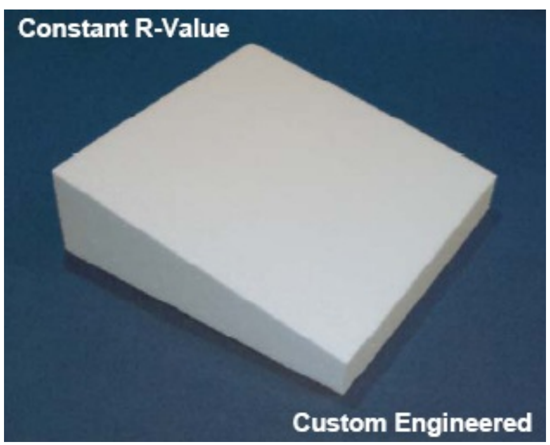
Typical roof insulation

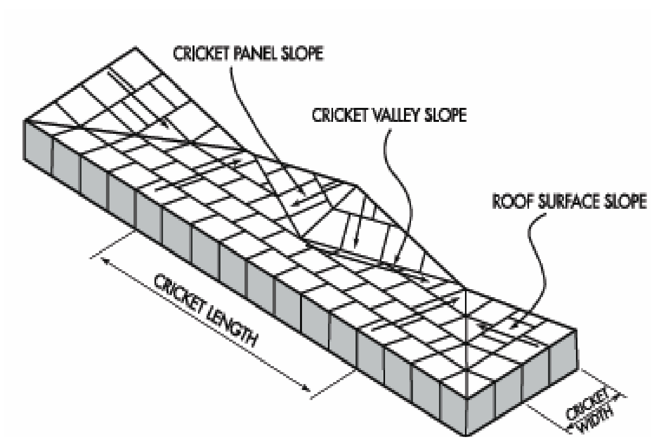
- Over-deck insulation is usually EPS, XEPS, polyiso, or rigid fiberglass
  - These are the only insulation materials that can handle the wind/snow/roofing loads and still provide high insulating capabilities
  - High inherent R values of EPS and polyiso gives good insulating capabilities with only a few inches of insulation

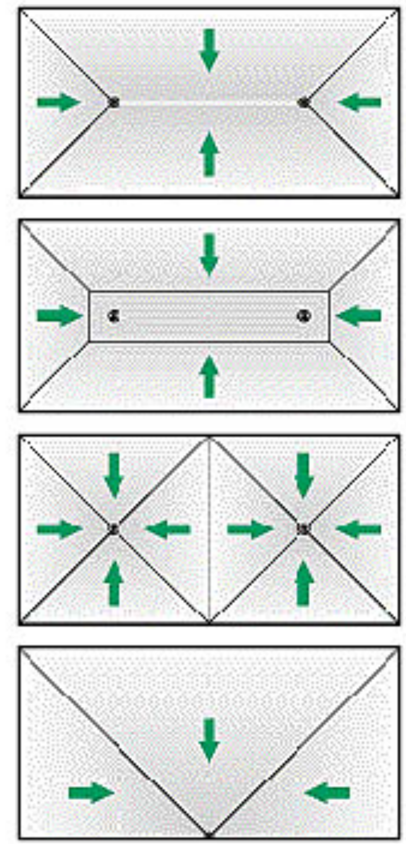


Tapered insulation

- To promote proper drainage roof should have a ¼” slope for every 12”
- This can be achieved through the use of tapered roof insulation







Typical Drainage Pattern

Insulating and foamed concrete

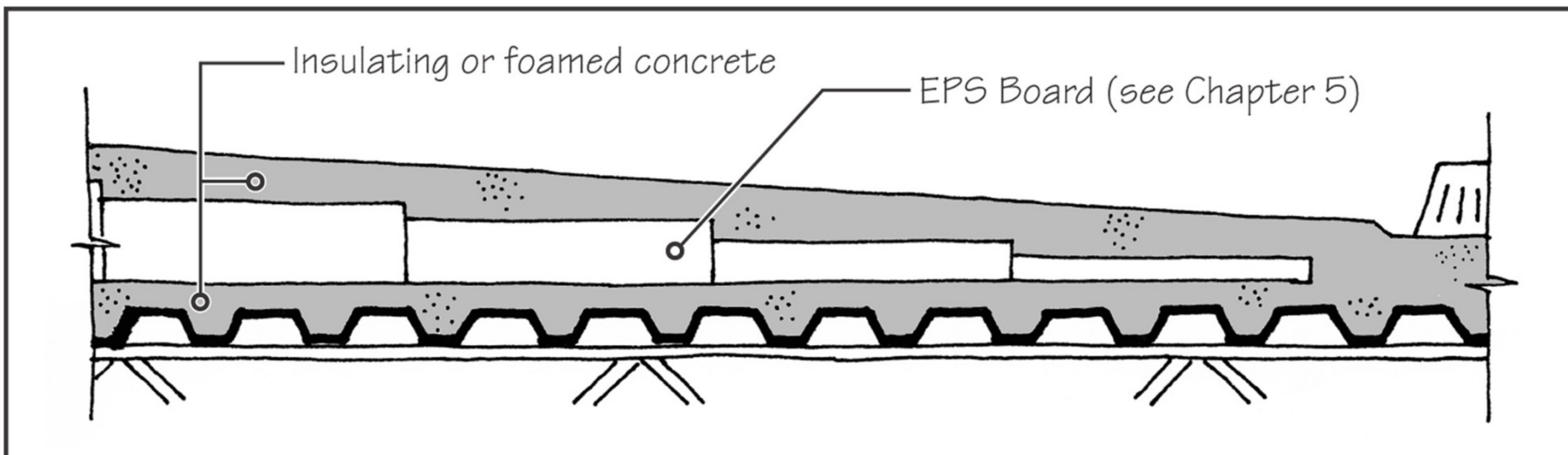
- *Insulating concrete* is a very lightweight concrete that with perlite or vermiculite as a high insulating granular additive
  – 0.8 < R per inch < 1.2 (normal concrete is about 0.2)

- *Foamed concrete* (also called cellular or aerated concrete) has a foaming concentrate that creates tiny air bubbles within the concrete
  – Increases thermal resistance
  – 0.5 < R per inch < 2

- Both of these are popular for use on roofs where the strength requirements are lower than for floors or walls

Embedded insulation

- EPS or Polyiso insulation can be embedded within the concrete itself
- This is commonly done with foamed or insulating concrete



Roof membranes

- Membrane roofing systems are used to prevent leaks and move water off of roofs

- Three main categories:
  - Built-up Roof (BUR) Membrane
  - Single-Ply Roof Membrane
  - Fluid Applied Roof Membrane

Built-up roofs (BUR)

- Standard Built-up Roof Membrane
  - A BUR is 3-5 layers of felts + bitumen (asphalt)
  - Bitumen provides waterproofing
    - Semi-solid crude oil product
  - Felt provides the structural support needed
    - Because bitumen will soften (and can even melt) at high temperatures
- Modified Bitumen Sheets
  - Bitumen has polymers added to improve the UV protection and make it more cold resistant
  - Felt or fiberglass sheets are embedded with modified bitumen
    - 2 to 3 layers of the sheets are installed with more modified bitumen between

BUR membrane

- Multiple plies of asphalt-impregnated felt bedded in bitumen (hot asphalt or coal tar)
- Forms a “laminated” membrane typically 2-4 plies thick
- Stinks during install!

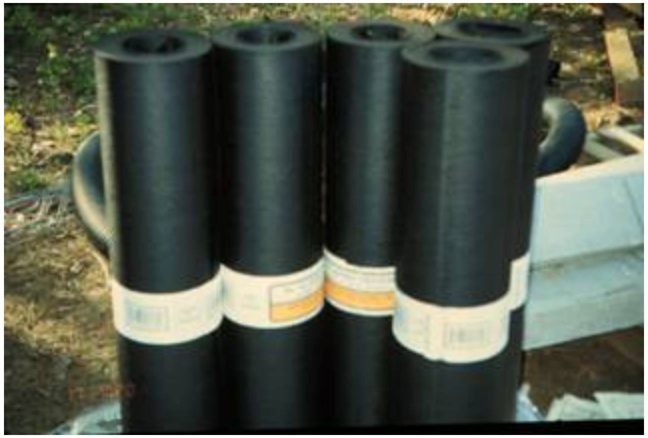
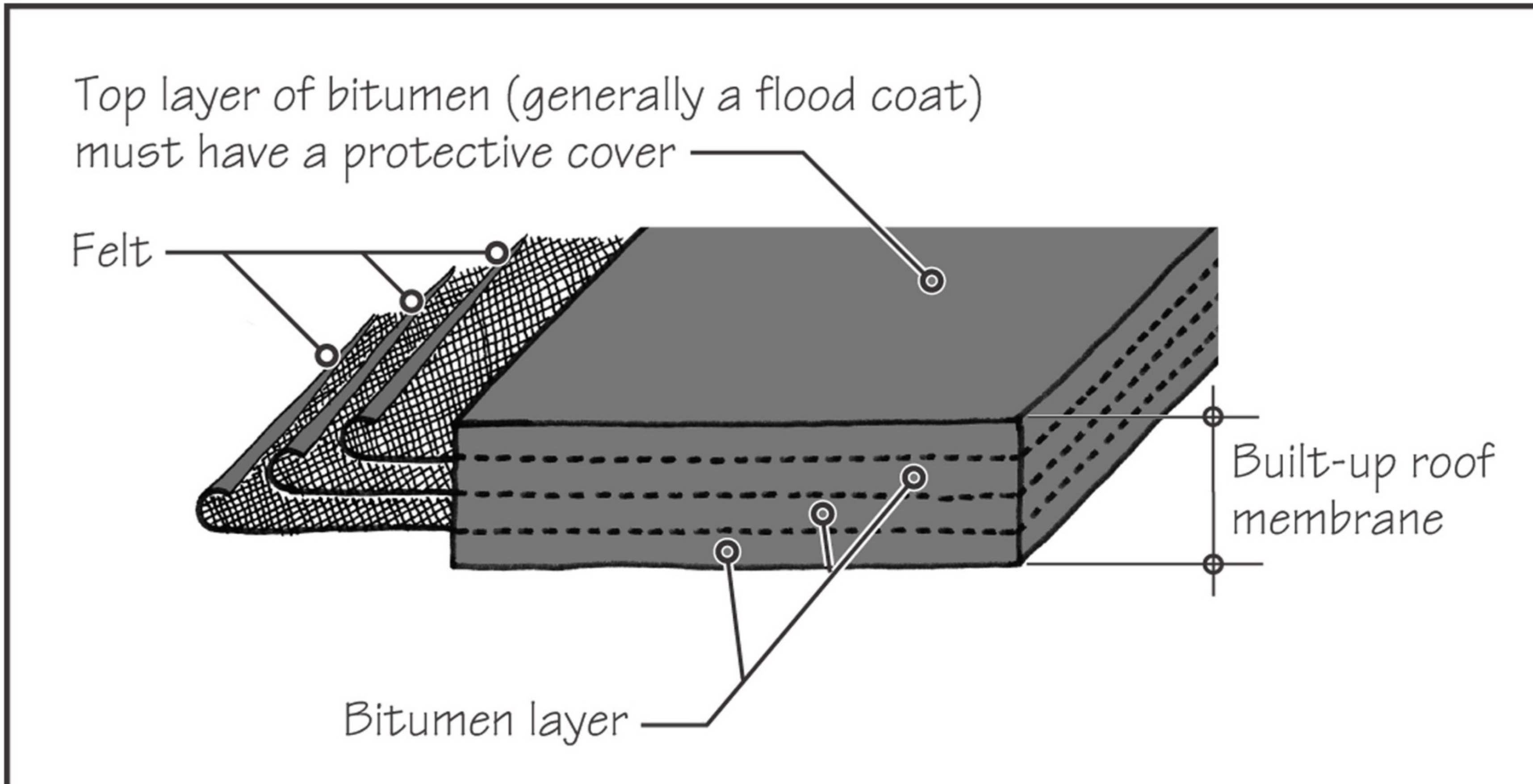
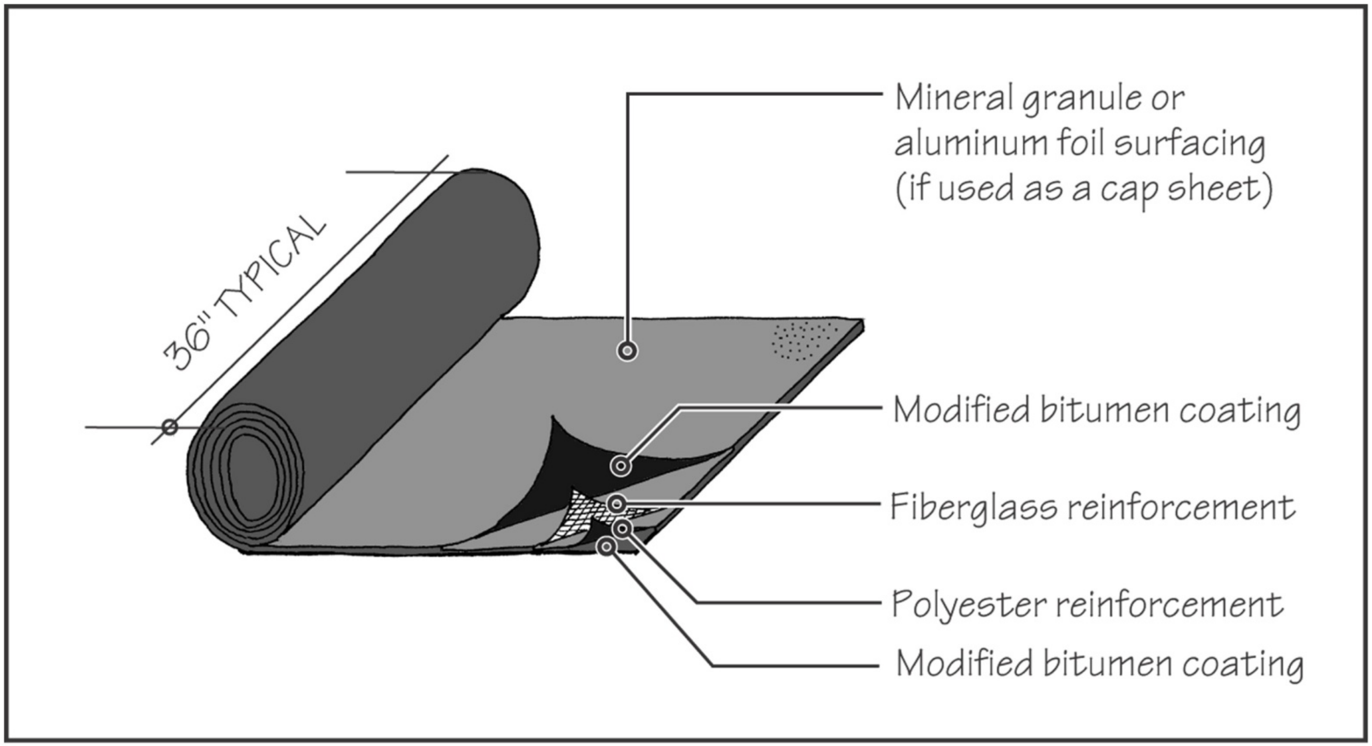


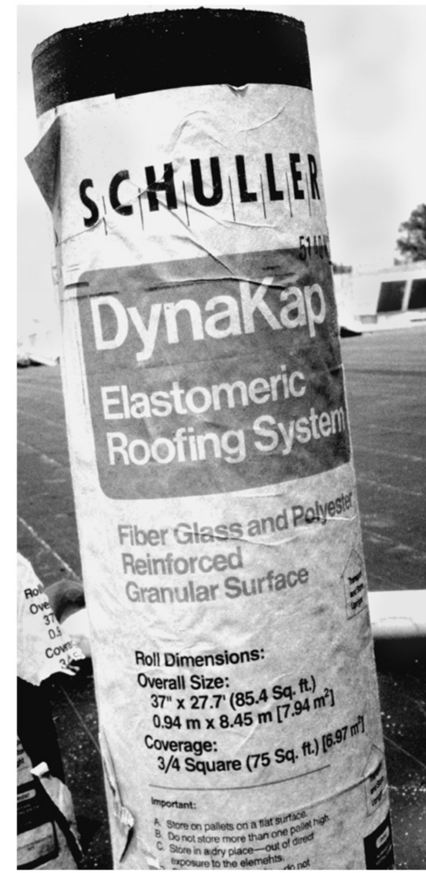
Diagram of BUR



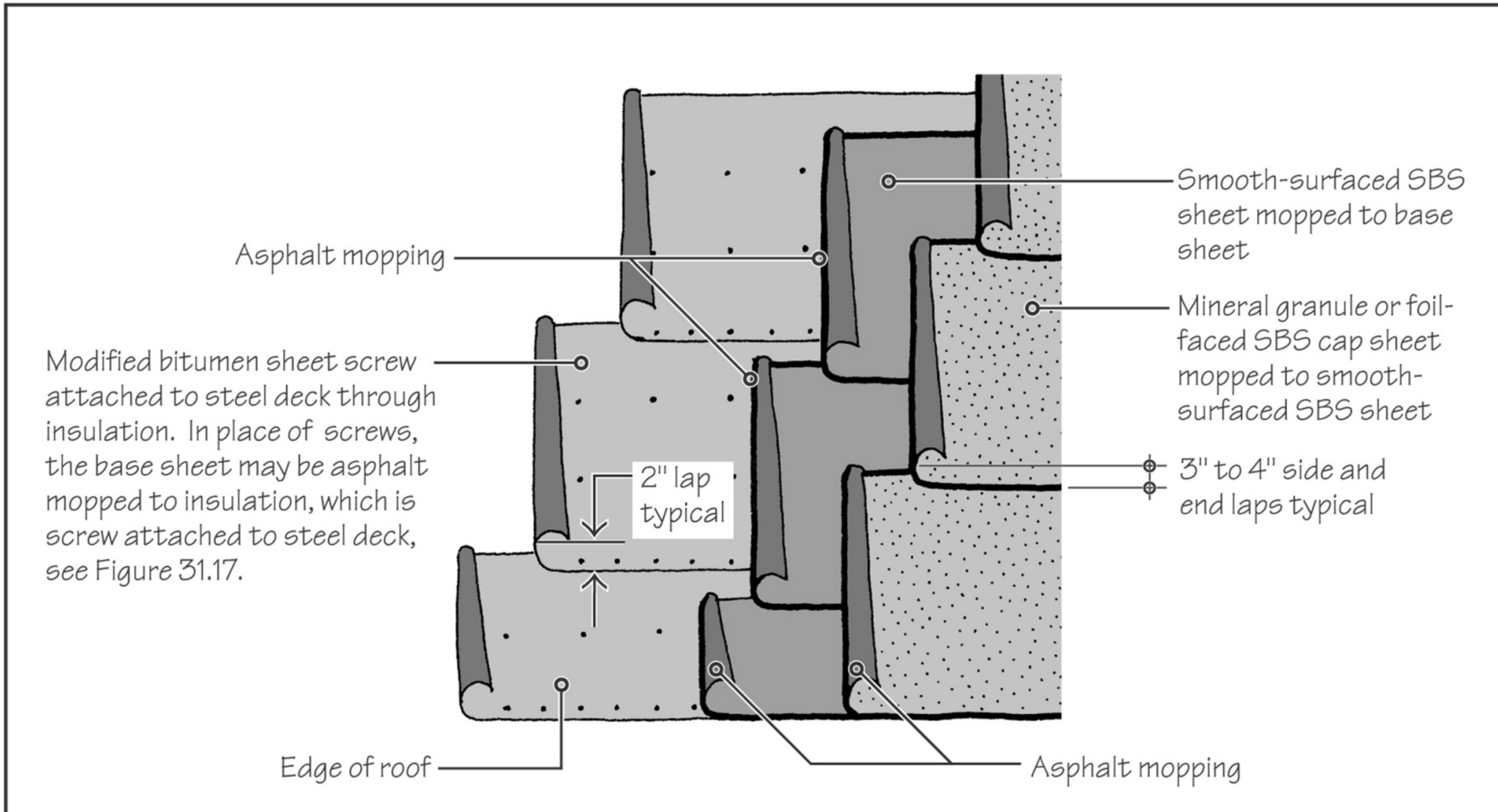
Kettle for heating the bitumen and pumping it to the roof

Modified bitumen membrane, cap sheet roll





3-ply SBS-modified bitumen roof membrane



Advantages and disadvantages of BUR

- Advantages
  - Can be easily repaired/patched in case of leaks
  - Can last longer than a single ply membrane roof
  - High tensile strength limits movement and reduces chances for fracturing
  - If structure does move, BUR can move with it

- Disadvantages
  - Not seamless, more locations for possible leaks
  - Higher cost (more materials, time and labor)
  - Less sustainable (uses much more raw materials and energy to install)
  - Fumes during installation

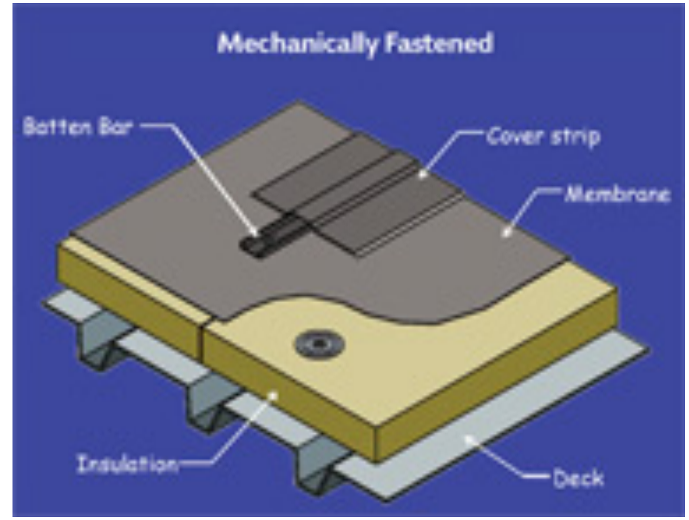
Single-ply roof membrane

- Sheet materials that are applied to the roof in a single layer

- Attached to the Roof:
  - Adhesives
  - Ballast Weight
  - Concealed fasteners

Single-ply materials

- Thermosetting
  - Compounded rubber polymer
  - Cannot be softened
  - Must be joined by adhesives or pressure sensitive tapes
  - EPDM
    - ethylene propylene diene monomer
    - Most widely used
    - Also Neoprene, CPE, etc.



- Thermoplastics
  - May be softened and joined by heat or solvent welding
  - Polyvinyl Chloride (PVC) – widely used, polymer-modified bitumens, PVC alloys, etc.

EPDM

- EPDM (ethylene propylene diene monomer) is a thermosetting polymer (a synthetic rubber) that does not soften once it has cured
  - This material can stretch, but cannot be heat welded
  - It must be adhered or taped
- EPDM can stretch 300-500% of its original length before tearing
- Typical thicknesses are 45 to 60 mm
- EPDM has poor inherent fire resistance
- EPDM is black and must be covered for high solar reflectivity

12 ft. wide EPDM membrane

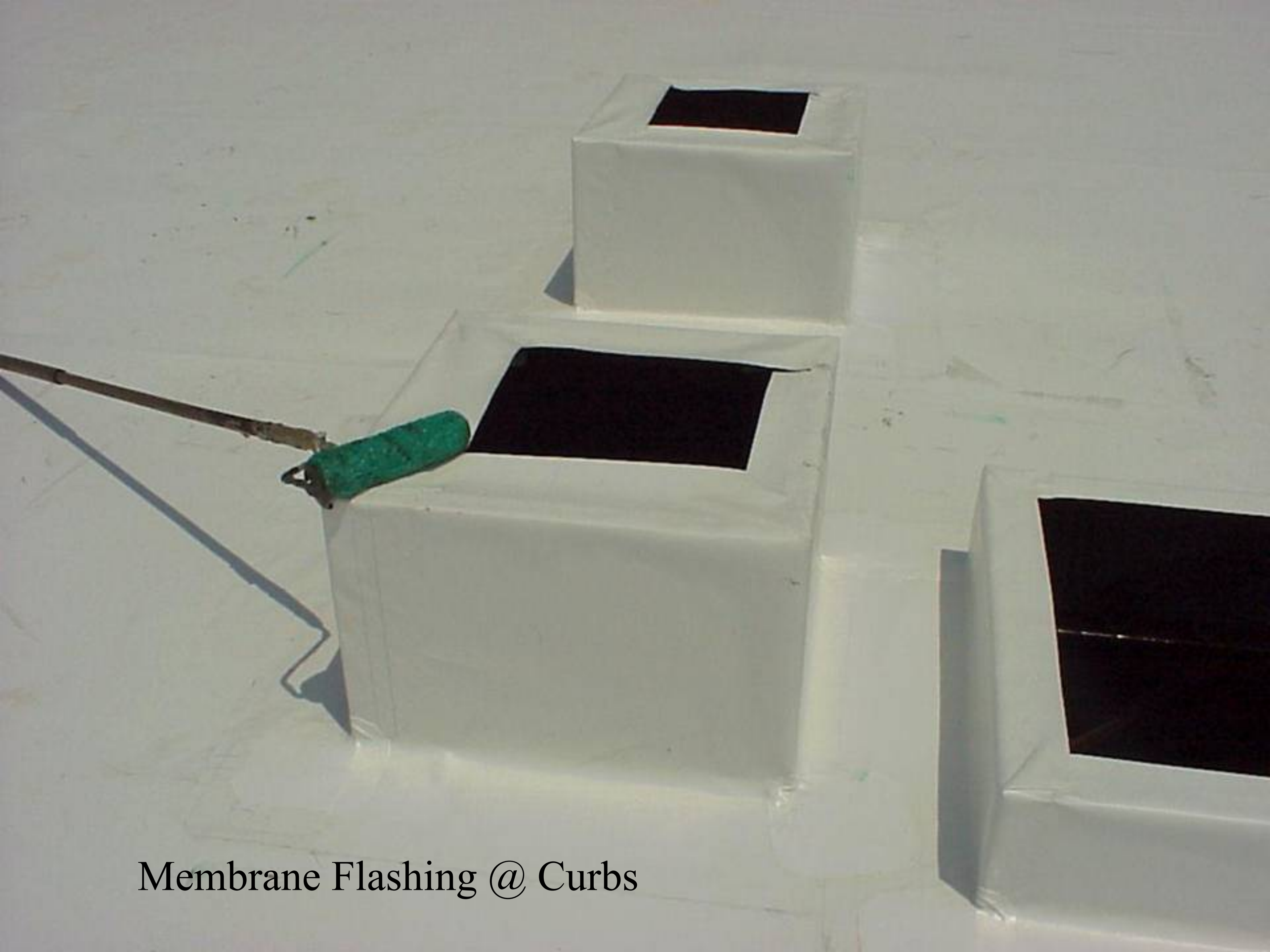
PVC and TPO

- PVC (polyvinyl chloride) is a soft and pliable form of the common plastic
  - PVC is very flexible, but is far less stretchable than EPDM
  - PVC membranes can be heat fused
- TPO (thermoplastic polyolefin) is also a thermoplastic
  - TPO is more flexible and stretchable than PVC but less than EPDM
  - TPO does not lose its flexibility over time like PVC
- These are easily used for cool roofing materials

Hand-held welding tool for PVC

Applying PVC or TPO

- Self-propelled hot air welding machine for PVC or TPO


Membrane Flashing @ Curbs

Fluid-applied membranes

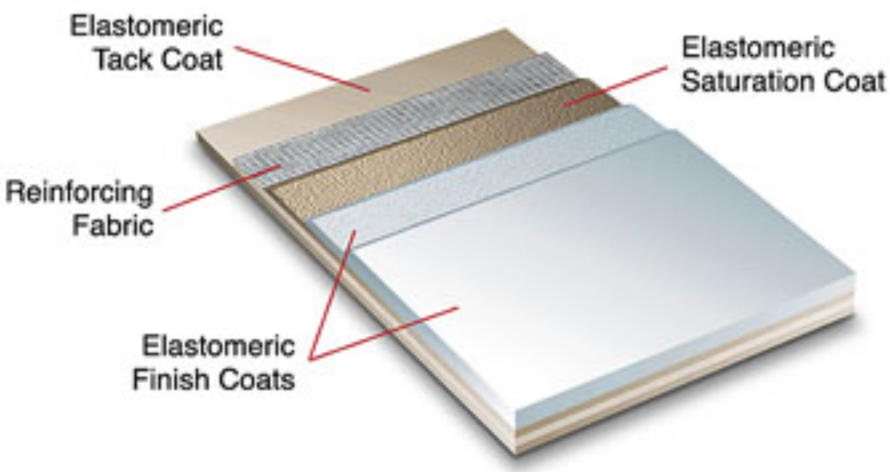
- Fluids applied with a roller or spray gun and cure to form a rubbery membrane

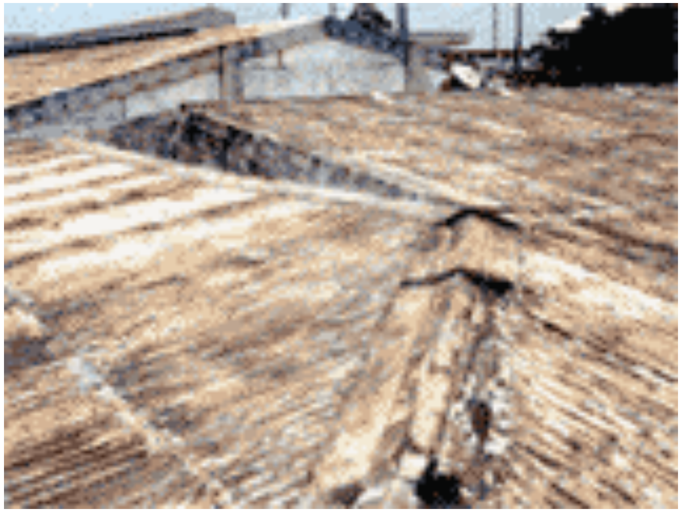
- Main Use: Complex shapes that are difficult to roof by conventional means such as domes and shells

– Fluid Applied Membranes can also be installed fairly quickly so when speed is more important than cost, consider these

Composite fluid membrane

- A typical composite fluid membrane is shown below
- The top 3 coats are fluid-applied membranes
- Fluid Applied Membranes can be used to replace standard membrane roofs too





Advantages and disadvantages of membranes

- Advantages
  - Lower cost
  - No seams (if properly installed)
  - Lighter weight
  - Can expand/contract much better than BUR
- Disadvantages
  - Any small puncture can cause leaks
  - Harder to repair small leaks
  - Must be completely (or near completely) replaced when repairs/modifications are made
  - Shorter lifetime than BUR

Costs

- BUR
  - $8-10/ft^2 installed
    - Price includes EPS insulation and fiberboard overlay
  - Can be repaired or partially resurfaced without a complete tear-off and reinstall
  - 20-40 lifespan
    - Resurfacing every 10-15 years
- Modified Bitumen
  - $8-10/ft^2 installed
  - 10-15 year lifespan
  - Full tear-off required for replacement
- EPDM
  - $4-6/ft^2 installed
  - 10-15 year lifespan
  - Full tear-off required for replacement
- PVC
  - $6-8/ft^2 installed
  - 15-20 year lifespan
  - Full tear-off required for replacement
- TPO
  - $6-8/ft^2 installed
  - Lifetime unknown – it's too new
  - Full tear-off required for replacement

Ballast and traffic decks

- Ballast Material
  - Stone aggregate
  - Precast concrete blocks or Pavers

- Purpose
  - Hold down membrane
  - Protect membrane from ultraviolet light
  - Protect membrane from physical wear

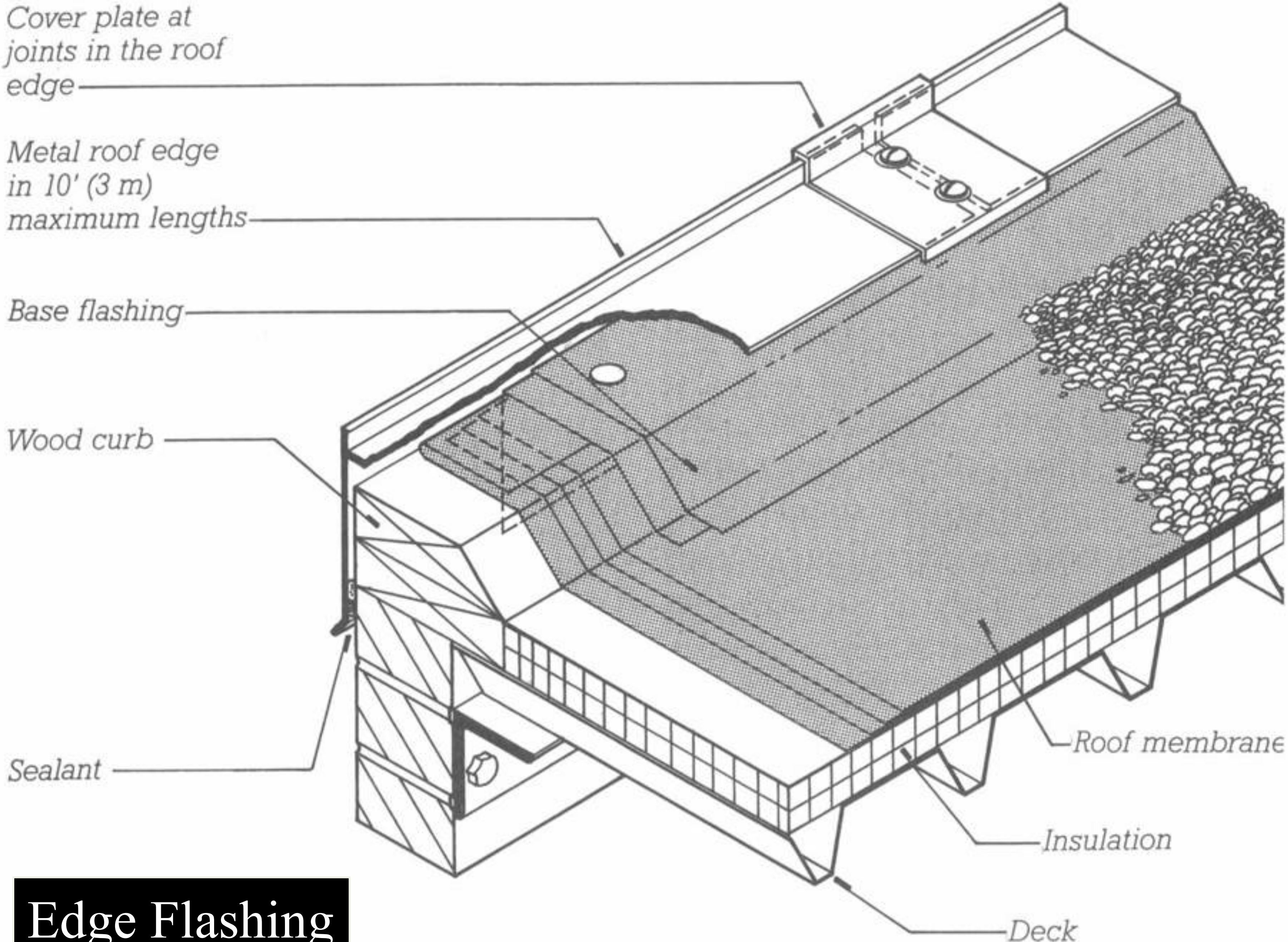
- Traffic Decks – installed over membranes for walks, terraces, drives, etc.

Flashing and joints

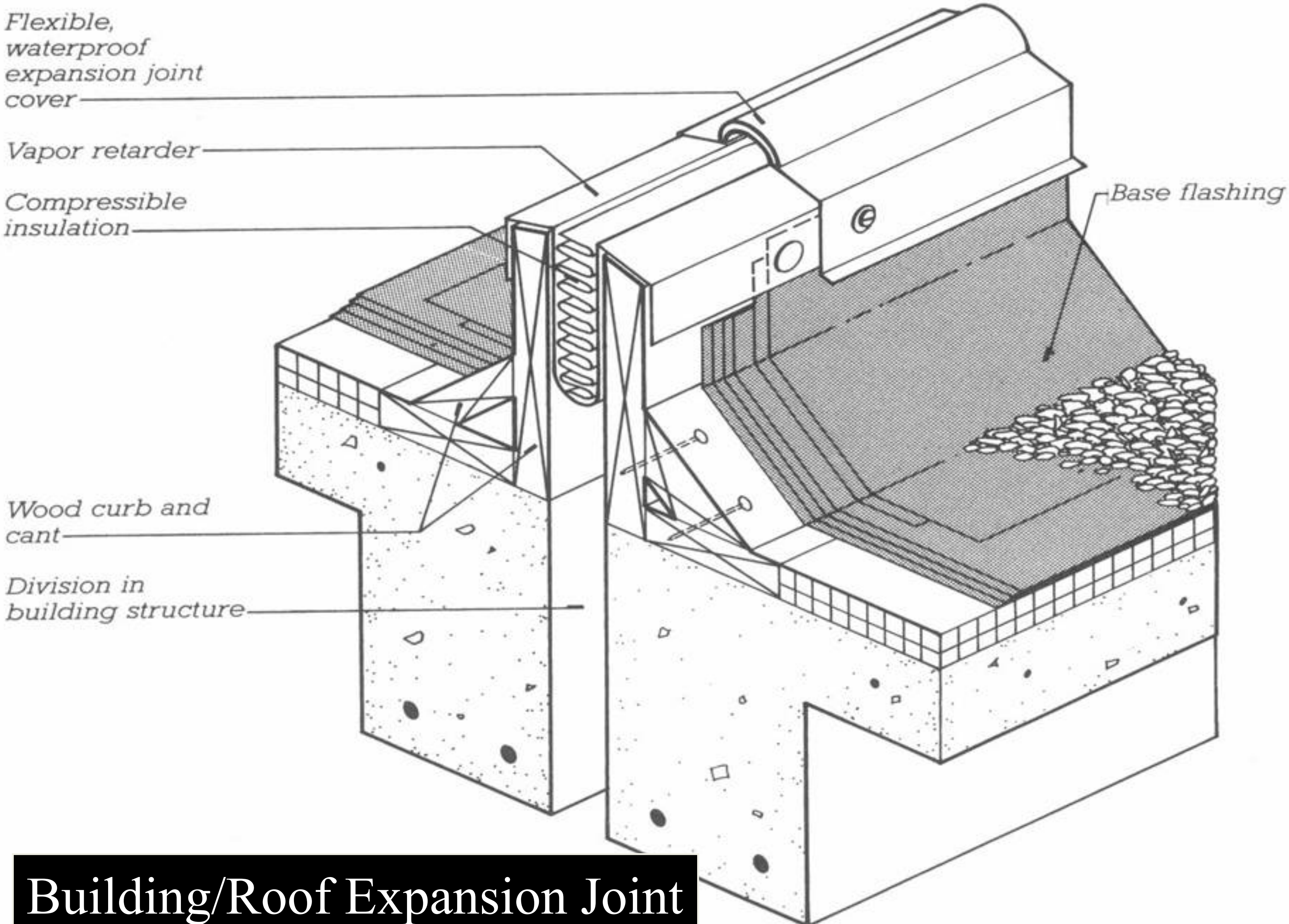
- Flashing needed to maintain seals
  - Building Edges and Parapets
  - Expansion Joints
  - Over top of cavity walls
  - Around Drains
  - Around Vents

- Usually metals or plastics over which membrane is fastened

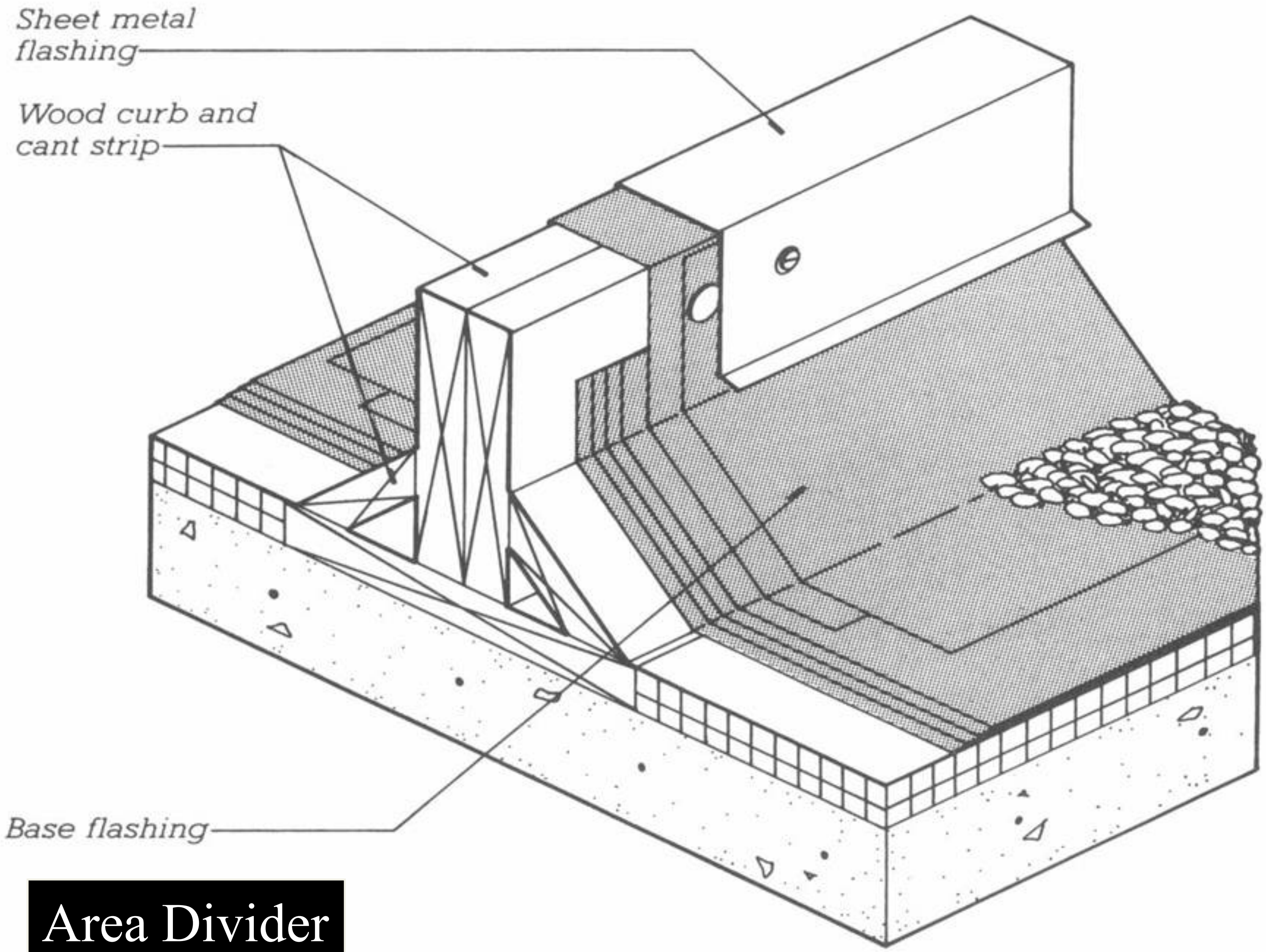
- Proper flashing is **absolutely essential** to avoid roof leaks



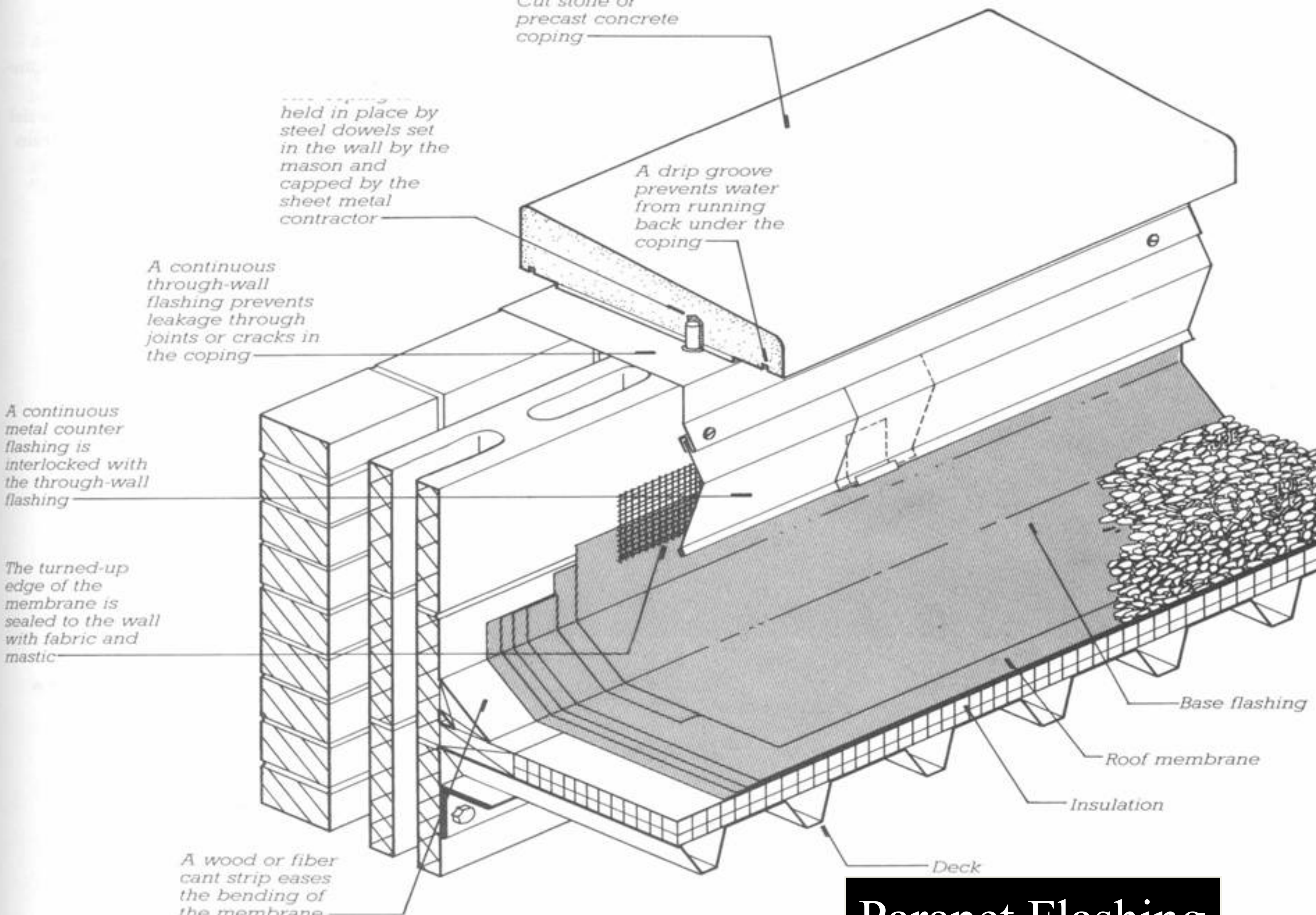
Edge Flashing



Building/Roof Expansion Joint



Area Divider



Parapet Flashing

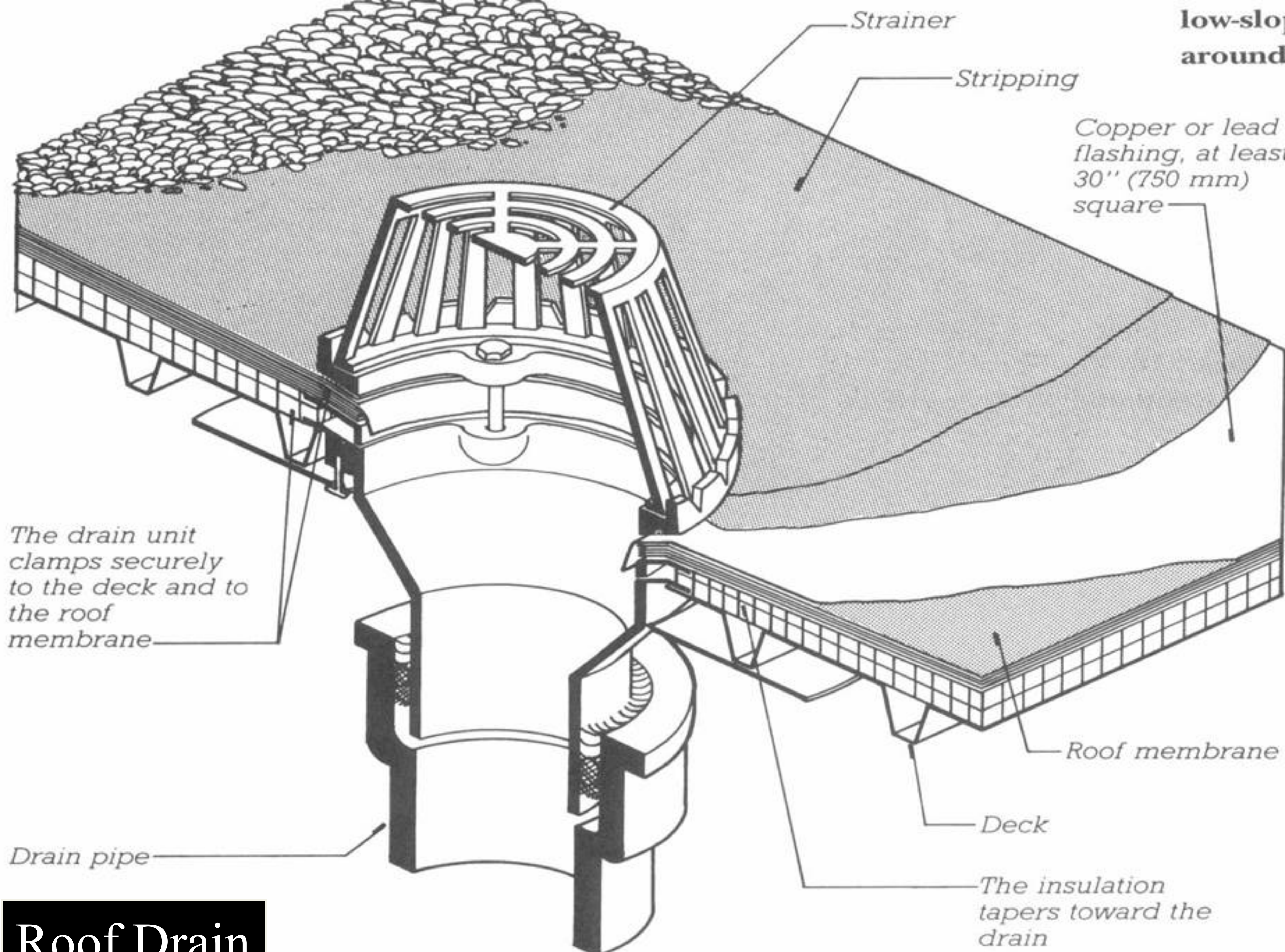
FIGURE 16.30
A conventional parapet design.

Roof drainage

- Drains need to be at low points of roofs to avoid water ponding
  - Drains near columns are at high points since there is no deflection

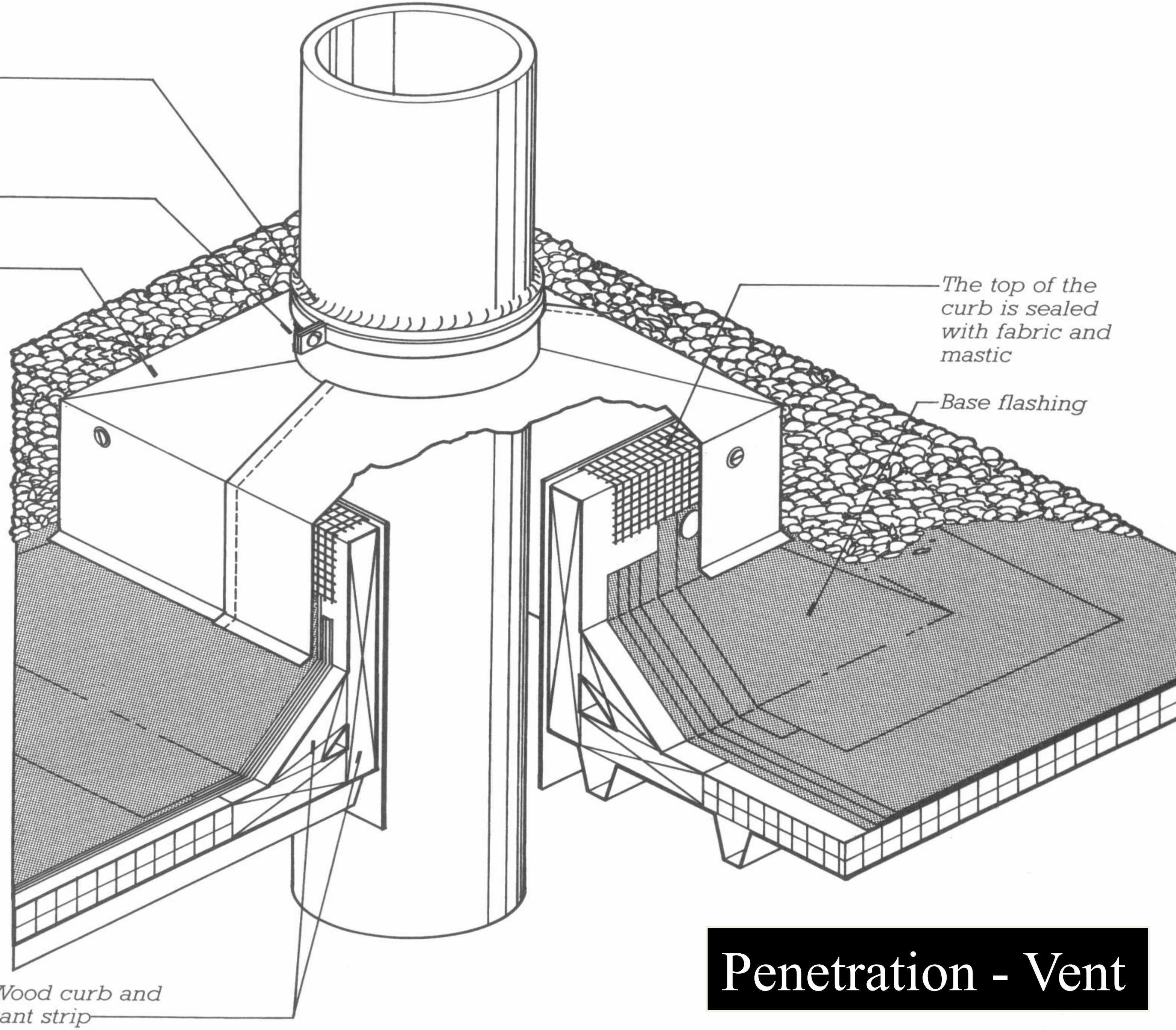
- Smaller and closer spaced drains preferred to larger but fewer

low-slo
around



Roof Drain

Penetration - Vent



VAPOR AND AIR BARRIERS

Applications

Vapor barriers or retarders

- Vapor barriers (or retarders) are materials with a low vapor permeance that resist vapor diffusion
  - A vapor **barrier** has a M_v < 1 US perm
    - < 57 SI perm, or 57 $ng/s \cdot m^2 \cdot Pa$
  - A vapor **retarder** has $1 < M_v < 10$ US perm
    - $57 < Mv < 570$ SI Perm ($ng/s \cdot m^2 \cdot Pa$)

- Vapor barriers are used in certain climates when condensation would be a regular occurrence
  - Hot-humid climates and very cold climates

- Vapor retarders are useful in many more climates
  - Cold and Mixed
  - Sealing is not as important with a pure vapor barrier

Vapor barriers: Good or bad?

- While vapor barriers/retarders can reduce vapor diffusion regardless of where they are placed
  - They must be placed carefully in order to ensure that the potential for condensation is minimized
- In hot and humid climates
  - Vapor barriers go toward the outside of the enclosure
- In very cold climates
  - Vapor barriers go toward the inside of the enclosure
- In mixed or cold environments
  - V*apor retarders* should be used (not barriers), or you may have problems in the opposite seasons
- Largely depends on climate and order of material installation

Interior vapor barriers

- Insulation with Kraft Paper
  - Kraft paper is a barrier at low humidity and a retarder at high humidity
  - Kraft paper also holds some moisture so light condensation is not a problem
  - Not an air barrier as commonly installed (stapled)

- Polyethelene sheet (discouraged)
  - This is a vapor barrier installed after insulation
  - Polyethelene holds no moisture so condensation results in standing water
  - Not an air barrier as commonly installed

Paints as vapor barriers/retarders

- Latex paints and primers are available in permeable, semi-permeable, or nearly impermeable forms
  - Typical latex paint has $5 < M < 10$ perm
  - Benjamin Moore Vapor Retardant Primer has $M \approx 0.43$ perm
  - These are especially useful when membrane vapor barriers cannot be installed
- Be careful to ensure that your paint is not acting as a vapor barrier or retarder unless you want it to act as a barrier or retarder

Liquid applied air barriers

- Air and vapor barriers can be installed as spray on liquid barriers
- These systems can be installed quickly and avoid the need for taping and sealing

Refer to Building Science Corp's website for more info

- "Enclosures that work"
  - http://www.buildingscience.com/doctypes/enclosures-that-work
- "Designs that work"
  - http://www.buildingscience.com/doctypes/designs-that-work
- "Understanding vapor barriers"
  - http://www.buildingscience.com/documents/digests/bsd-106-understanding-vapor-barriers

GLAZING AND WIND LOADS

Wind loads for exterior cladding

- In addition to the main building structure, the building enclosure (cladding) must also be able to handle the pressure variations and differentials that are created by the wind
  - Cladding elements include wall panels, fenestration, roof components and membranes

- We don't have time to discuss in detail, but will discuss the cladding wind load requirements in the Chicago Building Code (and the International Building Code)

Steps for wind load design

1. Determine the design wind pressures on the building enclosure elements
   – This will vary from code to code, but many refer back to ASCE 7 *Minimum Design Loads for Buildings and Other Structures*
2. Determine the allowable pressures of the cladding components
   – This can come from manufacturers data or using ASTM or other standards
3. Ensure that the allowable pressures exceed the design wind pressures

Chicago wind loads

- The City of Chicago has prescribed design wind loads in Table 13.52.310 of the Municipal Code:

Height (ft)	A: Main wind force resisting system (lb/ft^2)	B: Cladding Wind Pressure (other than corner) (lb/ft^2)	C: Cladding Wind Pressure (corner) (lb/ft^2)
200 or less	20	25	30
300	21	27	32
400	25	32	38
500	28	35	41
600	31	39	49
700	33	42	49
800	36	45	54
900	39	49	58
1000	42	53	63

- Column (A) applies to the main structure
- Column (B) applies to non-corner cladding (e.g., windows, curtain walls, exterior cavity walls, and wall panel units)
- The corner pressures in Column (C) apply at each corner of the building for a distance of 10% of building width or 50% of height above grade, whichever is smaller

Notes for Table 13.52.310

- Reductions in wind pressure due to neighboring structures and terrain are not to be considered
- The height is to be measured above the average level of the ground adjacent to the building or structure
- Wind pressures should be linearly interpolated between table values
- Example:
  - Q: What are the maximum cladding design wind loads for a 280 feet tall in Chicago?
  - A: We interpolate between the 200 feet and 300 feet and round up to be safe and find the design wind load is:
    - 32 lb/ft^2 (psf)

ASTM E 1300

- How do you tell if your cladding (e.g., glazing unit) can withstand that load?

INTERNATIONAL

Designation: E 1300 – 09a

Standard Practice for
Determining Load Resistance of Glass in Buildings[1]

This standard is issued under the fixed designation E 1300; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

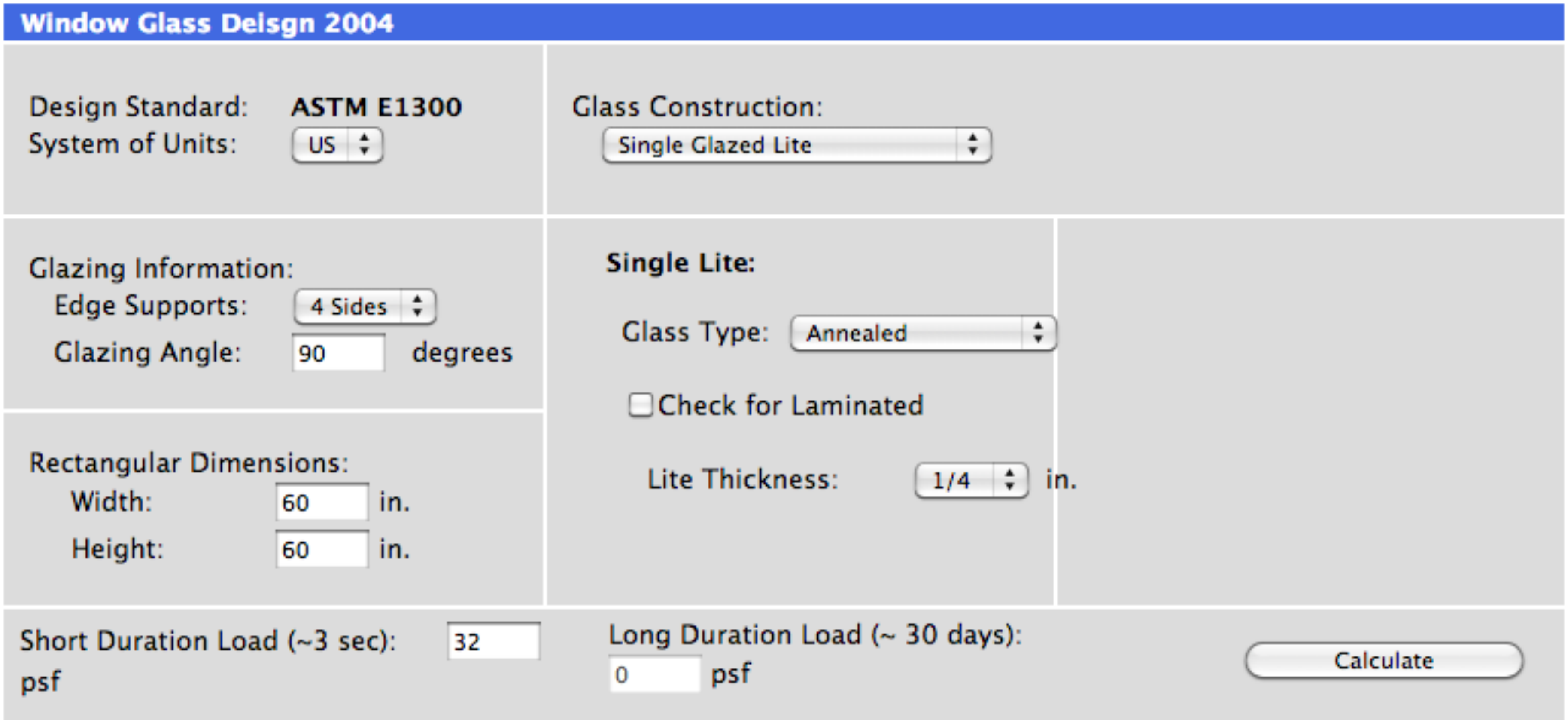
  - This standard describes procedures to determine the load resistance of specified glass types including combinations of glass types used in sealed insulating glass units

Short- and long-duration loads

- ASTM E1300 can be used for both short and long duration loads
  - Short duration loads are 3 sec or less (e.g., wind gusts)
  - Long duration loads are those lasting about 30 days
    - Snow loads are long duration loads

- The load calculation procedure is long and involved
  - But like most things, there's an online calculator!
    - http://www.standardsdesign.com/wgd/2004/demos/calculator/wgd2004calculator.aspx

Load calculator



http://www.standardsdesign.com/wgd/2004/demos/calculator/wgd2004calculator.aspx

Load calculator

Results – Single Glazed (Monolithic)

Short Duration Load, Resistance and Deflection Data

Load (~3 sec):	32.0	psf
Load Resistance:	45	psf
Approximate center of glass deflection under the applied load:	0.58	in.

Long Duration Load, Resistance and Deflection Data

Comments

Based on your design information, the load resistance is greater than or equal to the specified loading.

-- Approximate Probability of Breakage (Short Duration Load Only): 2/1000

http://www.standardsdesign.com/wgd/2004/demos/calculator/wgd2004calculator.aspx

Next time

- Approximately half of the next lecture (11/26) will be reserved for final presentations
  - The following 5 teams are presenting:

Team	Member	Member	Topic	11/26 or 12/3?
5	Sebastian	Morris	Phase change materials	11/26
6	Kayo	Gonzalez, Alv	Building integrated photovoltaics	11/26
7	Zwang	Gomez Soriano	Exterior insulated finish systems	11/26
8	El Orch	Gonzalez, Ar	Strawbale construction	11/26
10	Daras Ballester	Zylstra	High performance glass	11/26

- Plan for ~12 minute presentations
  - 3 minutes for Q&A
- I will then present a short lecture & summarize our class

- **Don't forget to do your course evaluations!**
  - **MyIIT/*Academics* tab**