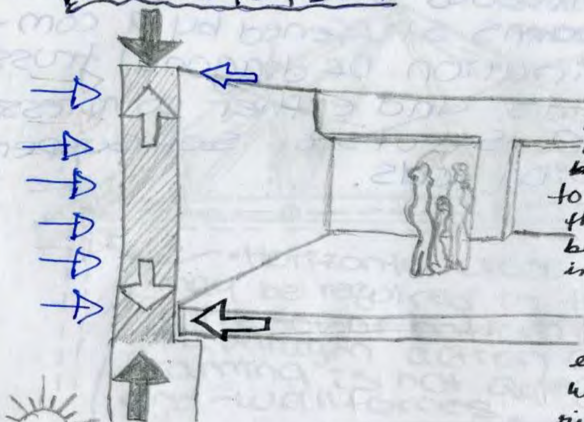
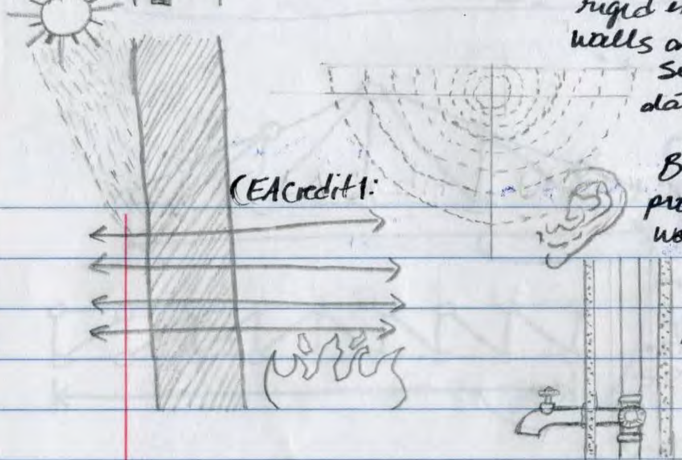
WALL SYSTEMS



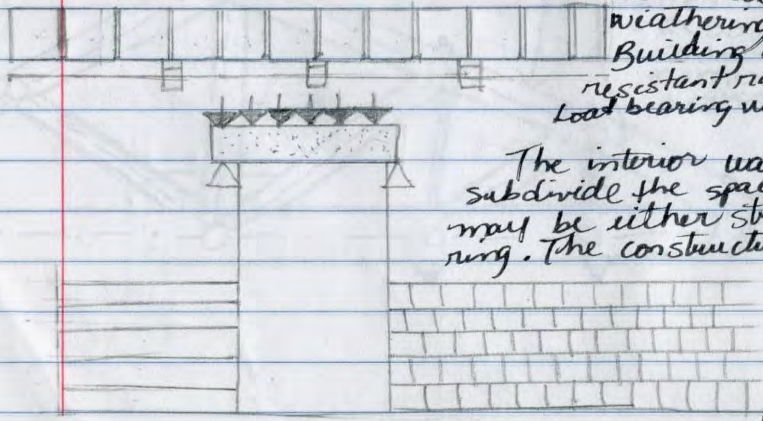
Walls are the vertical construction of a building that enclose, separate and protect its interior spaces.

They may be load bearing structures of homogeneous or composite construction designed to support imposed loads and beams with nonstructural panels attached to or filling in between them. The pattern of these loadbearing walls and columns should be coordinated with the layout of the interior spaces of a building.

In addition to supporting vertical loads, exterior wall constructions must be able to withstand horizontal wind loading. If rigid enough, they can serve as shear walls and transfer lateral wind and seismic forces to the ground foundation.

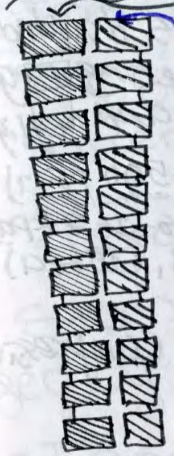


Because exterior walls serve as protective shield against the weather for the interior spaces of a building, their construction should control the passage of heat, infiltrating air, sound, moisture, and water vapor. The exterior skin, wich may be either applied to or integral with the wall structure, should be durable and resistant to the weathering efects of sun, wind and rain. Building codes specify the fire-resistant rating of exterior walls, load- Loadbearing walls, and interior partitions.



The interior walls of partitions, wich subdivide the space withing a building, may be either structural or nonloadbearing. The construction should be able to support the desired finish material, provide the required degree of acoustical separation, and accomodate when necessary the distribution and outlet of mechanical and elect

Masonry



Common brick, also called building brick is made for general building ~~proce~~ purposes and not specially treated for color and texture.

Face brick is made of special clay for facing a wall, often treated to produce the desired color and surface texture.

Brick types:

- FBX
- FBS
- FBA
- Efflorescence

Brick unit	Nominal Dimensions thickness x height x length (inches)	(mm)	modular Coursing (Inches)	(mm)
Modular	4 x 2-2/3 x 8	100 x 68 x 205	3C = 8	205
Norman	4 x 2-2/3 x 12	100 x 68 x 305	3C = 8	205
Engineer	4 x 3-1/5 x 8	100 x 81 x 205	5C = 16	405
Norwegian	4 x 3-1/5 x 12	100 x 81 x 305	5C = 16	405
Roman	4 x 2 x 12	100 x 51 x 305	2C = 4	100
Utility	4 x 4 x 12	100 x 100 x 305	1C = 4	100

The actual dimensions of brick units vary due to shrinkage during the manufacturing process. The nominal dimensions given in the table include the thickness of the mortar joints which vary from 1/4" to 1/2" (6 to 13)

PRIMARY FUNCTIONS OF THE EXTERIOR WALL

• The exterior wall enclosure (also called the building envelope) is the part of a building that must defend the interior spaces against invasion by water, wind, sunlight, heat and cold, and all the other forces of nature.

Functions of the Exterior wall

• The exterior wall is to separate the indoor environment of a building from the outdoors.

Preventing Air Leakage

• The exterior wall of a building must prevent the unintended passage of air between indoors and outdoors.

Controlling the radiation of heat

Beyond its role in regulating the flow of radiant heat from the sun, the exterior wall of a building should also present interior surfaces at temperatures that will not cause radiant discomfort.

Keeping water out

• The exterior wall must prevent the entry of rain, snow, and ice into a building.

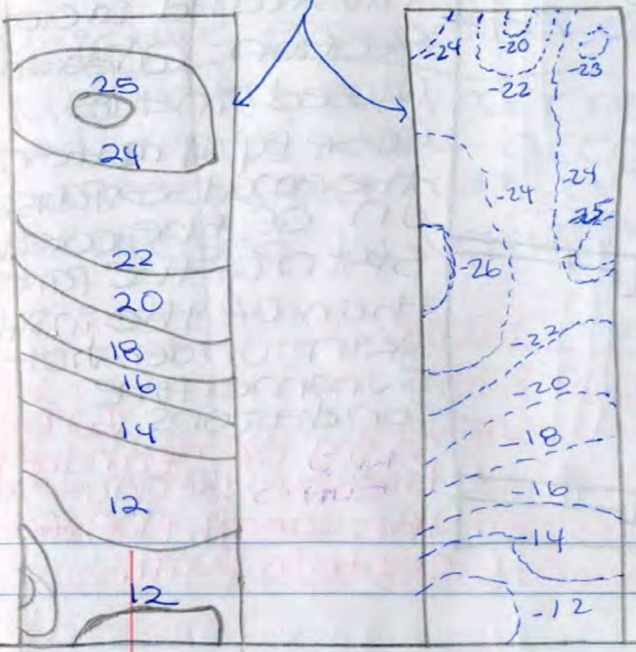
Controlling light

• The exterior wall of a building must control the passage of light, especially sunlight.

Controlling the conduction of heat

This requires not merely satisfactory overall resistance of the wall to the passage of heat, but also avoidance of thermal bridges, wall components such as metal framing members that are highly conductive of heat and therefore likely to cause localized condensation on interior surfaces.

Same wall under different wind Directions



Maximum Positive Pressure | Maximum negative pressures

(units on isobars are pounds per square foot)

Controlling water vapor

The exterior wall of a building must retard the passage of water vapor. In the heat of summer or the cold of winter, vapor moving through a wall assembly may condense inside the assembly and cause staining, loss of insulating value, corrosion of metals, and decay of wood.

An example of expected positive and negative wind pressures on the cladding of a tall building, shown here in elevation, as predicted by wind tunnel testing.

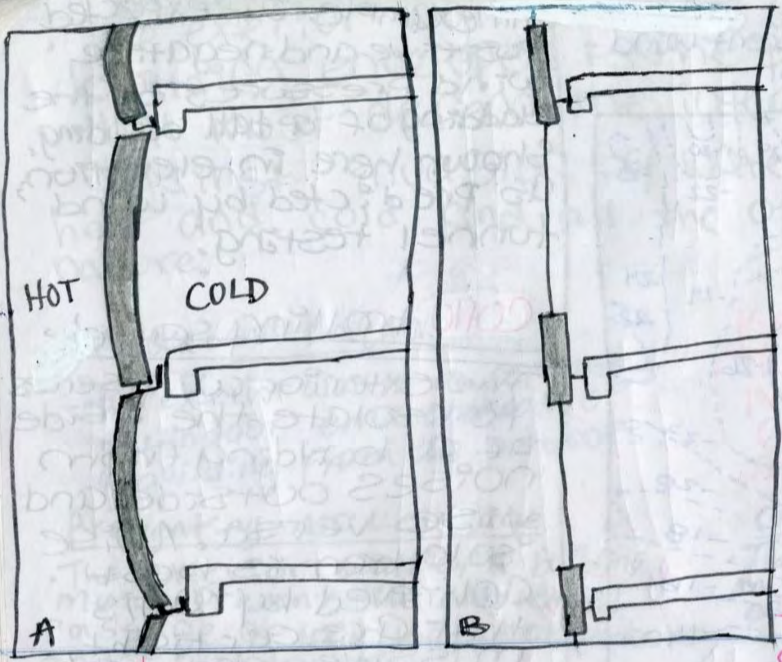
Controlling sound

The exterior wall serves to isolate the inside of a building from noises outside and vice versa. Noise isolation is best achieved by walls that are airtight, massive, and resilient.

SECONDARY FUNCTIONS OF THE EXTERIOR WALL

Resisting wind forces

The exterior wall of a building must be adequately strong and stiff to sustain the pressures and suctions that will be placed upon it by wind.



Distortions of Curtain wall panels, illustrated in cross Section. (a) Bowing caused in this case by greater thermal expansion of the outside skin of the panels than of the inside skin under hot summertime conditions. (b) Twisting of spandrel beams because of the weight of the curtain wall.

Adjusting to movement

Several different kinds of forces are always at work throughout a building, tugging and pushing both the frame and the exterior wall: Thermal expansion and contraction, moisture expansion and contraction, and structural deflections. These forces must be anticipated and allowed for in designing a system of building enclosure.

Thermal Expansion and contraction

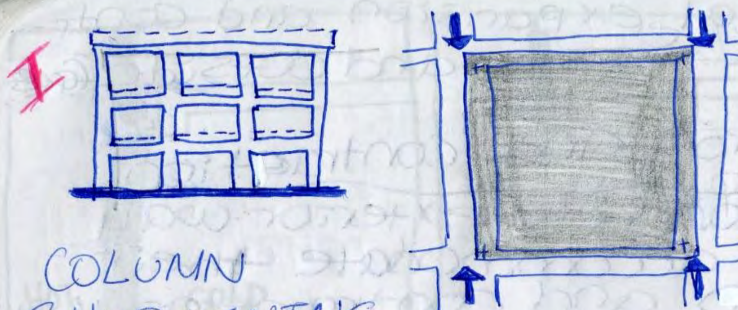
The exterior wall of a building has to accommodate movements due to changes in temperature at several levels: Indoor/outdoor temperature differences can cause warping of cladding panels due to differential expansion and contraction of their inside and outside faces.

Moisture expansion and contraction

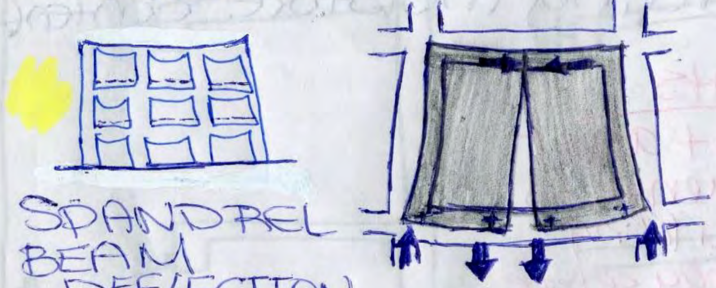
Masonry and concrete exterior wall materials must accommodate ~~their~~ own expansion and contraction that is caused by varying moisture content.

Structural movements

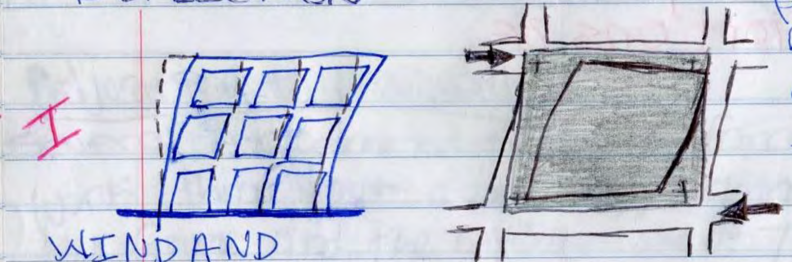
The exterior wall must adjust to structural movements in the frame of the building. Building foundations may settle unevenly, causing distortions of the frame.



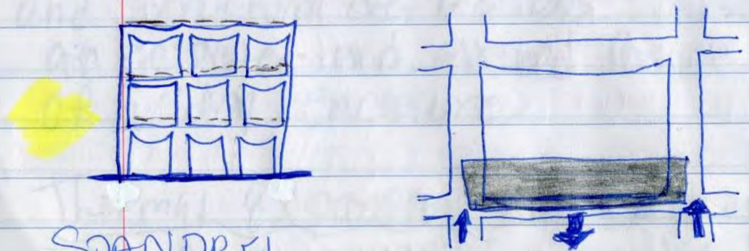
COLUMN SHORTENING



SPANDREL BEAM DEFLECTION

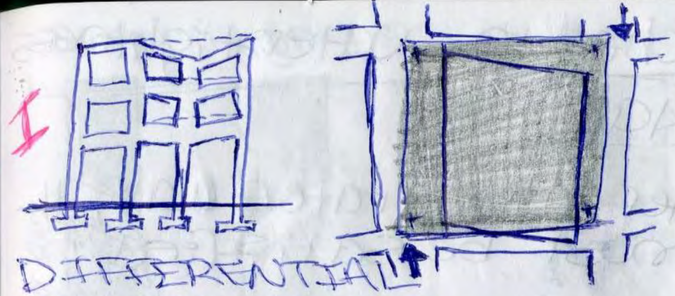


WIND AND EARTHQUAKE DEFORMATIONS



SPANDREL BEAM DEFLECTION

Forces on curtain wall panels caused by movements in the frame of the building, illustrated in elevation. In each of the six examples, the drawing in the pink shows the movement in the overall frame of the building and the larger-scale drawing in yellow shows its consequences on the curtain wall panels (shaded in gray) covering one bay of the building. Points of attachment between the panels and the frame are shown as crosses. The black arrows indicate forces on the wall panels caused by the movement in the structure. The magnitude of the structural movements is exaggerated for clarity, and some inadvisable attachment schemes are shown to demonstrate their consequences. Forces such as these, if not taken into account in the design of the frame and cladding, can result in glass breakage, panel failures, and failure of the attachments between the panels and the frame.



DIFFERENTIAL FOUNDATION SETTLEMENT

DIFFERENTIAL SPANDREL BEAM DEFLECTION

Resisting Fire

The exterior wall of a building can interact in several ways with building fires.

Weathering Gracefully

Functional provisions must be made for maintenance operations such as glass and sealant replacement and for periodic cleaning, including scaffolding supports and safety equipment attachment points for window washers.

Conceptual Approaches to Watertightness in the Exterior Wall

In order for water to penetrate a wall, three conditions must be satisfied simultaneously:

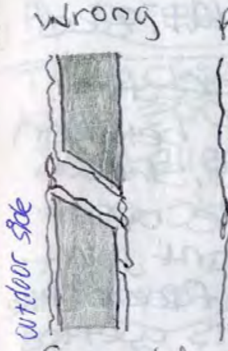
1. There must be water present at the outer face of the wall.
2. There must be an opening through which the water can move.
3. There must be a force to move the water through the opening.

Gravity is a factor in pulling water through a wall only if the wall contains an inclined plane that slopes into, rather than out of, the building.

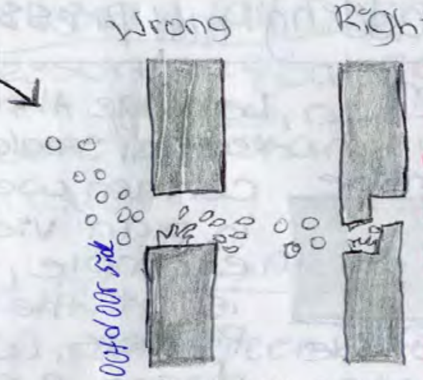
The momentum of falling raindrops can drive water through a wall only if there is a suitably oriented slot or hole that goes completely through the wall.

The surface tension of water, which causes it to adhere to the underside of a cladding component, allows water to be drawn into the building.

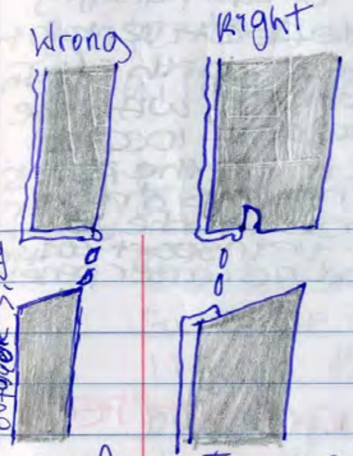
Capillary action is the surface tension effect that pulls water through any opening that can be bridged by a water drop.



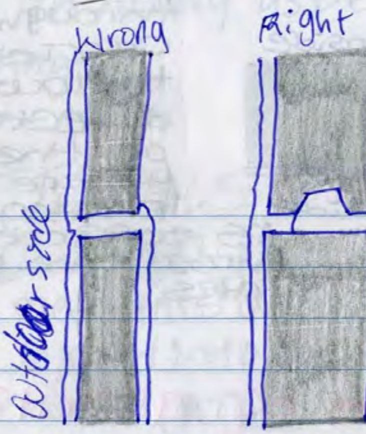
Gravity



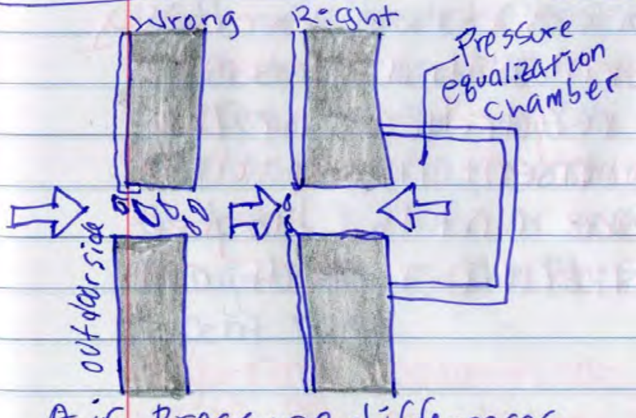
Momentum



Surface Tension



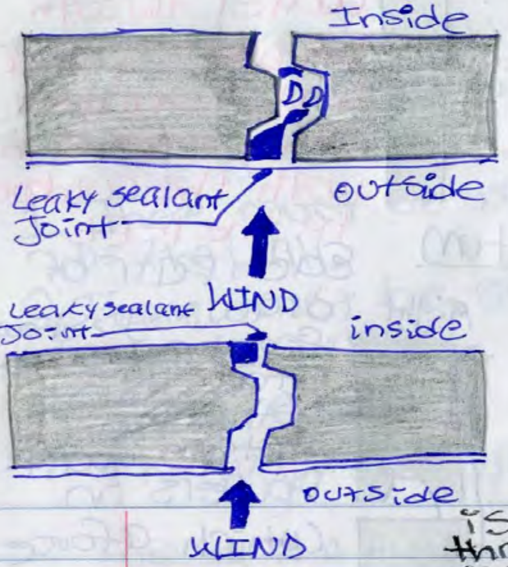
Capillary action



Air Pressure differences (Wind currents)

Five forces that can move water through an opening in a wall, illustrated in cross section with the outdoors to the left. Each pair of drawings shows first a horizontal joint between curtain wall panels in which a force is causing water leakage through the wall, then an alternative design for the joint that neutralizes this force.

Rainscreen Cladding and Pressure-Equalized Wall Design



Leakage through a defective vertical sealant joint between curtain wall panels, shown in plan view. In the upper example, the sealant joint is at the outside face of the panels, where it is wetted during a storm. Even a small current of air passing through the defective joint carries water with it. In the lower example, with the defective sealant located on the inside of the panels where it remains dry, air leakage through the joint is sufficient to transport water through the joint, and no water penetrates.

- Pressure equalization Chamber (PEC)
- The term rainscreen cladding has come to be applied more broadly to any cladding system with a system of internal drainage, regardless of the extent of compartmentalization of the drainage space and the degree of pressure equalization that can be achieved.

A Pressure-Equalized Wall Design

To achieve a pressure-equalized design, horizontal metal angles, not shown, are installed between the channels at one- or two-story intervals.

Pressure Equalization at Smaller Scale

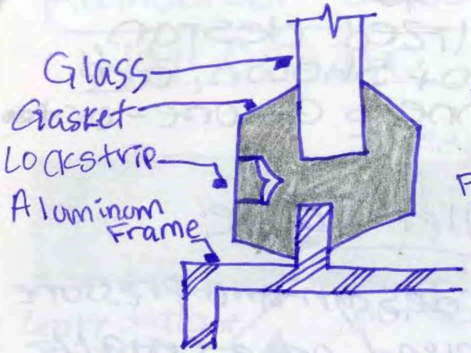
The principles of rainscreen design and pressure equalization may also be applied on a small scale to guide us in many aspects of exterior detailing of buildings.

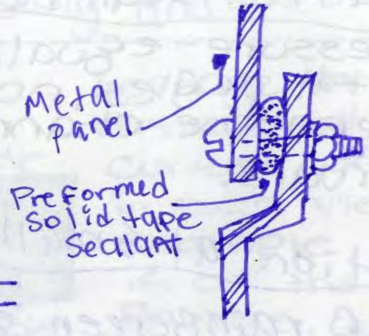
SEALANT MATERIALS

Gunnable Sealant Materials

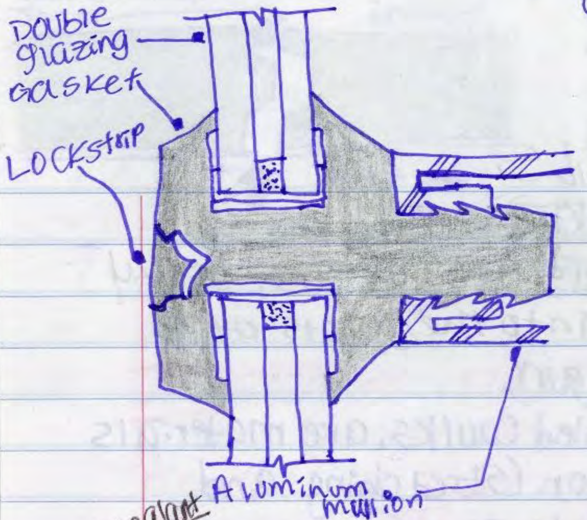
Gunnable sealant materials are viscous, sticky liquids that are injected into the joints of a building with a sealant gun.

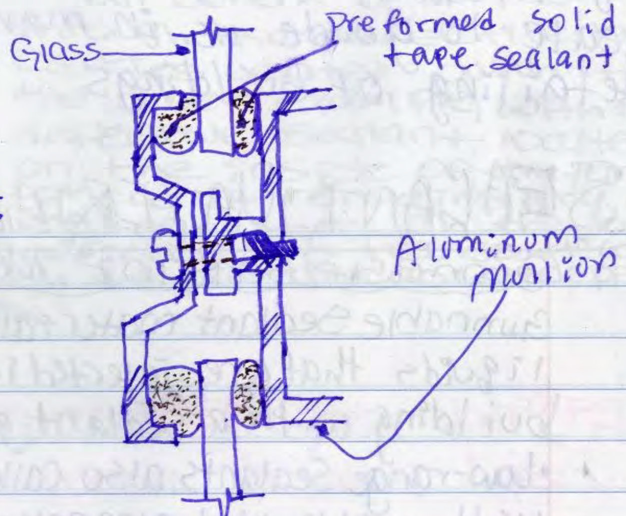
- Low-range sealants, also called caulks, are materials with very limited elongation (stretching and squeezing) capabilities, up to plus or minus 5 percent of the width of the joint.
- Medium-range sealants are materials such as butyl rubber or acrylic that have safe elongations in the plus or minus 5 to 10 percent range.
- High-range sealants can safely sustain elongations up to plus or minus 50 to 100 percent.





Some solid sealant materials. At the left two examples of lockstrip gaskets. At the right, preformed solid tape sealants.

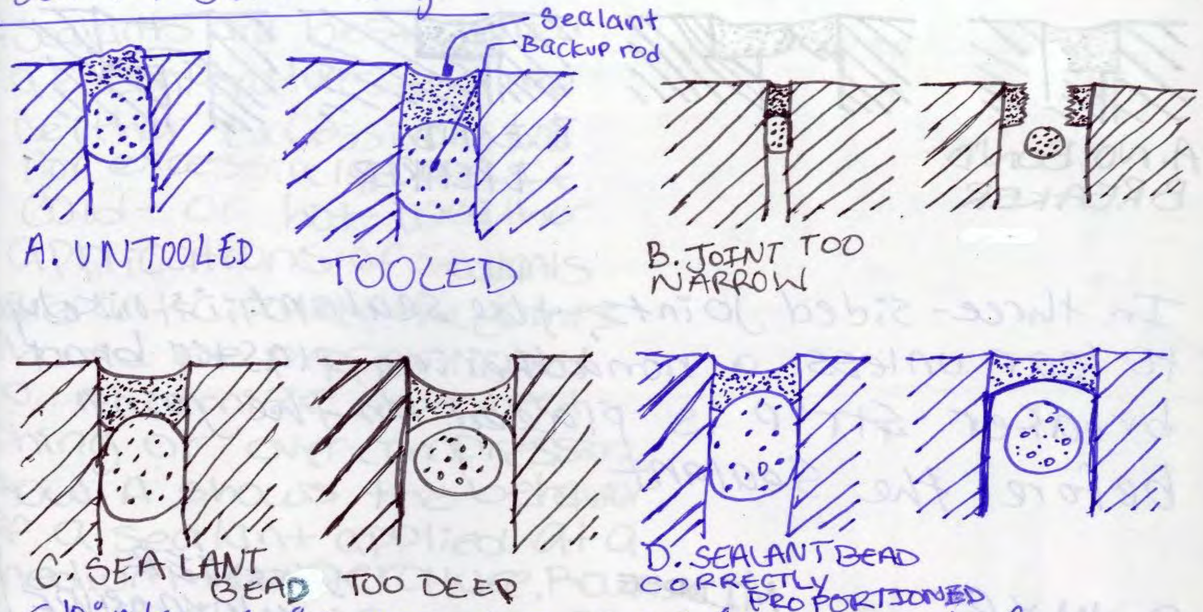


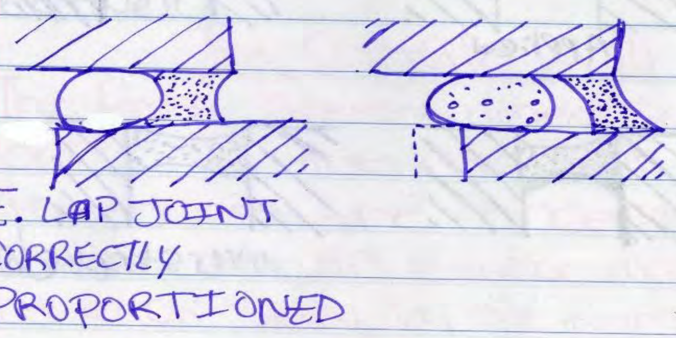


Solid sealant Materials

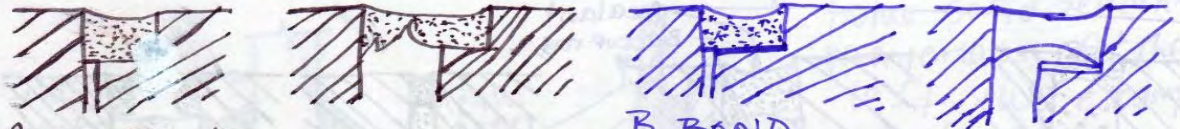
- Gaskets are strips of various fully cured elastomeric (rubberlike) materials manufactured in several different configurations and sizes for different purposes.
- Preformed cellular tape sealant is a strip of polyurethane sponge material that has been impregnated with a mastic sealant.
- Preformed solid tape sealants are used only in lap joints, as in mounting glass in a metal frame or overlapping two thin sheets of metal at a cladding seam.

Sealant Joint Design





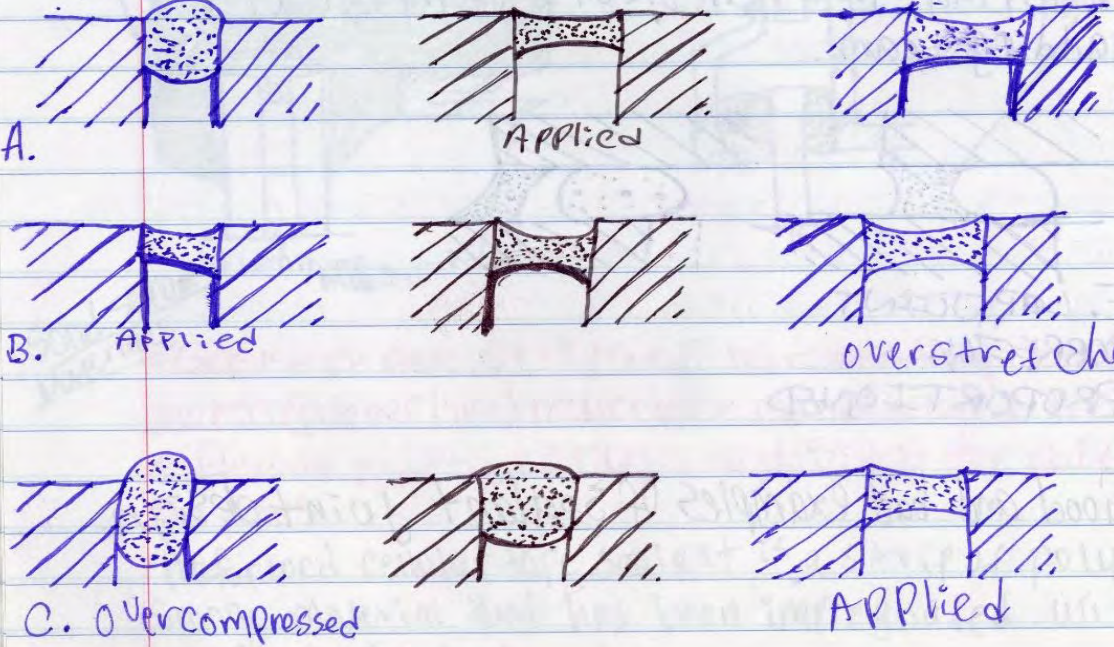
Good and bad examples of sealant joint design.



A. NO BOND BREAKER   B. BOND BREAKER

In three-sided joints, the sealant is likely to tear unless a nonadhering plastic bond breaker strip is placed in the joint before the sealant.

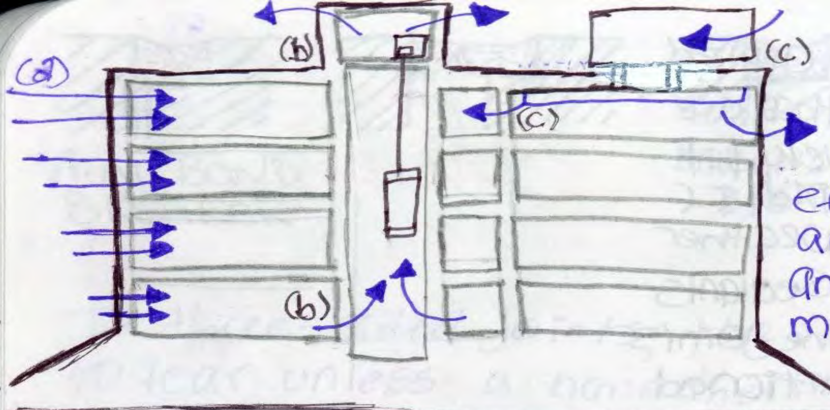
SUMMER TEMPERATURE   MIDDLE TEMPERATURE   WINTER TEMPERATURE



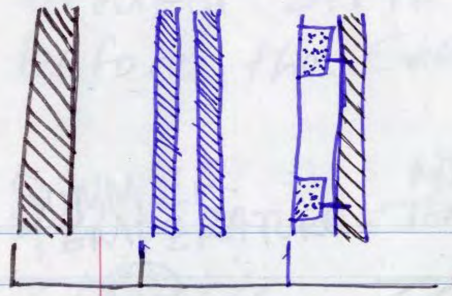
Sealants are best applied at temperatures that are neither excessively hot nor excessively cold. If cold- or hot-weather applications of sealants are anticipated, the joints should be proportioned to minimize overstretching or overcompression. Row A shows the behavior of a sealant applied at a medium temperature. Rows B and C show sealant applied at summer and winter temperatures, respectively.

The Curtain Wall

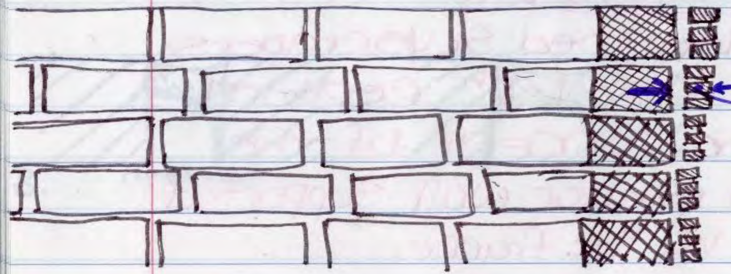
- The first steel-framed skyscrapers, built in the late 19th century, introduced the concept of the curtain wall, an exterior wall supported at each story by the frame.
- Curtain walls may be constructed of any noncombustible material that is suitable for exposure to the weather.



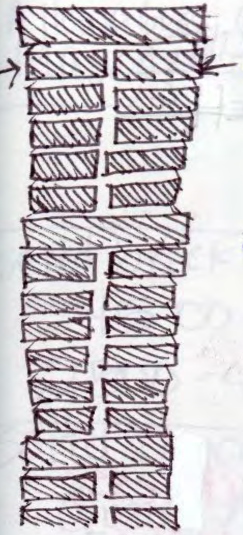
Air pressure differences in a building can be caused by (a) wind, (b) the stack effect, such as within an elevator shaft, and (c) building mechanical systems.



- Masonry walls may be constructed as solid walls, cavity walls, or veneered walls.

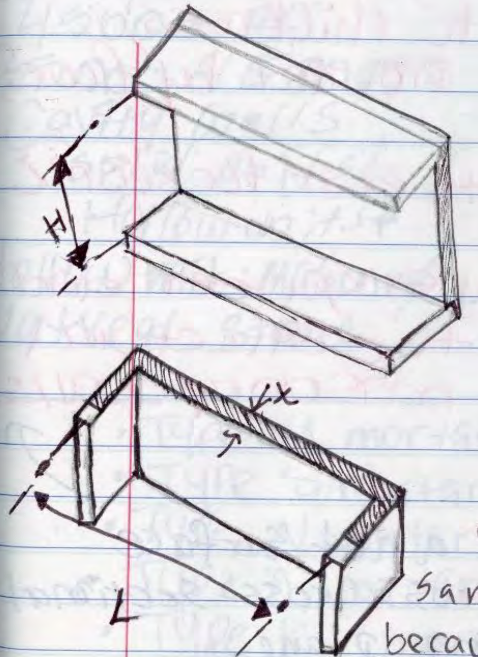


A Wythe refers to a continuous vertical section of a wall that is one masonry unit in thickness.



Minimum Wall Thickness

- 8" (205) minimum nominal thickness for:
  - Masonry bearing walls
  - Masonry shear walls
  - Masonry parapets; height of parapet not to exceed 3x parapet thickness
- 6" (150) minimum nominal thickness for:
  - Reinforced masonry bearing walls
  - Solid masonry walls in one-story buildings not more than 9' (2745) high
  - Masonry walls relied upon for resistance to lateral loading are limited to 35' (10m) in height.



Mortar

Mortar is a plastic mixture of cement or lime, or a combination of both, with sand and water, used as a bonding agent in masonry construction.

- CSI MasterFormat 04 05 13 Masonry mortaring.
- Cement mortar is made by mixing portland cement, sand, and water.
- Lime mortar is a mixture of lime, sand, and water that is rarely used because of its slow rate of hardening and low compressive strength.
- Cement-lime mortar is a cement mortar to which lime is added to increase its plasticity and water-retentivity.

Lateral Support for Masonry Walls

Type of Masonry	Maximum L/t or H/t
Bearing Walls	
Solid or grouted	20
All other	18
Nonbearing Walls	
Exterior	18
Interior	36

- L/t = ratio of wall length to thickness; lateral support may be provided by cross walls, columns, or pilasters.
- H/t = ratio of wall height to thickness; lateral support may be provided by floors, beams, or roofs.
- More stringent requirements exist for seismic zones 3 and 4.
- Consult a professional engineer and the building code for the structural requirements of all masonry walls.

* 1 psi = 6.89 kpa.

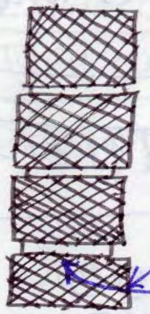
† Solid masonry units have a net surface area at least 75% of the gross cross-sectional area parallel to the bedding plane.

‡ Hollow masonry units have a net surface area less than 75% of the gross cross-sectional area parallel to the bedding plane.

Allowable Compressive Stresses (psi)* in Unreinforced Masonry Walls

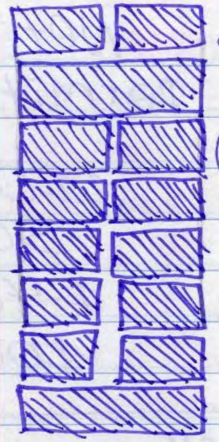
	Mortar type		
	Type M	Type S	Type N
Solid brick masonry			
4500 + psi	250	225	200
2500-4500 psi	175	160	140
Solid Concrete masonry			
Grade N	175	160	140
Grade S	125	115	100
Grouted Masonry			
4500 + psi	350	275	Not permitted
2500-4500 psi	275	215	
Cavity walls			
Solid units†	140	130	110
Hollow units‡	70	60	50
Hollow unit masonry	170	150	140
Natural stone	140	120	100

- Type M mortar is a high-strength mortar
- Type S mortar is a medium-high-strength mortar
- Type N mortar is a medium-strength mortar
- Type O mortar is a low-strength mortar
- Type K mortar is a very-low-strength mortar

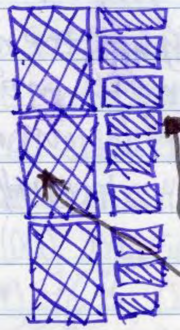


- Concrete masonry units (CMUs)
- Horizontal joint reinforcement is fully embedded in bed joint mortar.

- Vertical cells of the concrete blocks may be reinforced with steel bars embedded in grout.



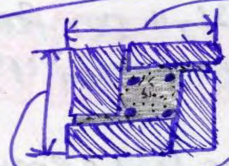
Solid masonry walls may also consist of multiple wythes bonded by grout, corrosion-resistant metal wall ties, or horizontal joint reinforcement.



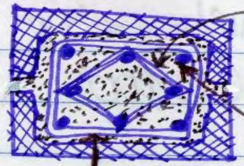
- Composite walls are solid masonry walls having a facing wythe and a backup wythe of different solid or hollow masonry units.
- Facing wythe
- Backup wythe

- 5/8" (16) minimum mortar cover between ties or joint reinforcement and any exposed face.
- 1/4" (6) minimum mortar thickness between masonry and ties or joint reinforcement.

Masonry columns & pilasters

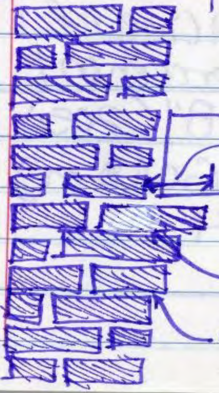


- Minimum nominal width = 12" (305)
- Minimum nominal length = 12" (305); maximum = 3x column width



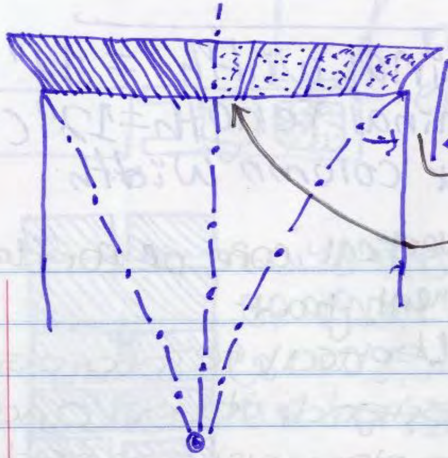
- Vertical core of portland cement grout
- Vertical reinforcement bars extend down and are tied to dowels embedded in colum footing
- Lateral ties

Masonry wall sections



- Corbels are permitted only in solid walls at least 12" (305) thick.
- Maximum total projection = 1/4 wall thickness
- Header top course
- 1" (25) maximum projection @ each course

• Spandrel refers to the triangular-shaped area between the extrados of two adjoining arches, or between the left or right extrados of an arch and the rectangular framework surrounding it.

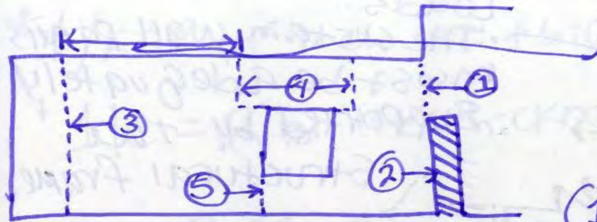


• Skewback 1/2" per foot of span (1:24) for each 4" (100) of arch depth

• Camber = 1/8" per foot of span (1:100)

Expansion & control joints

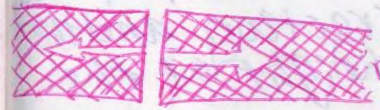
Control joint spacing	Vertical spacing of joint reinforcement	
	16" (405)	8" (205)
Wall Length (L)	50' (15m)	60' (18 m)
L/H ratio	3	4



Movement joints should be spaced every 100' to 125' (30 to 38m) along unbroken wall lengths, and:

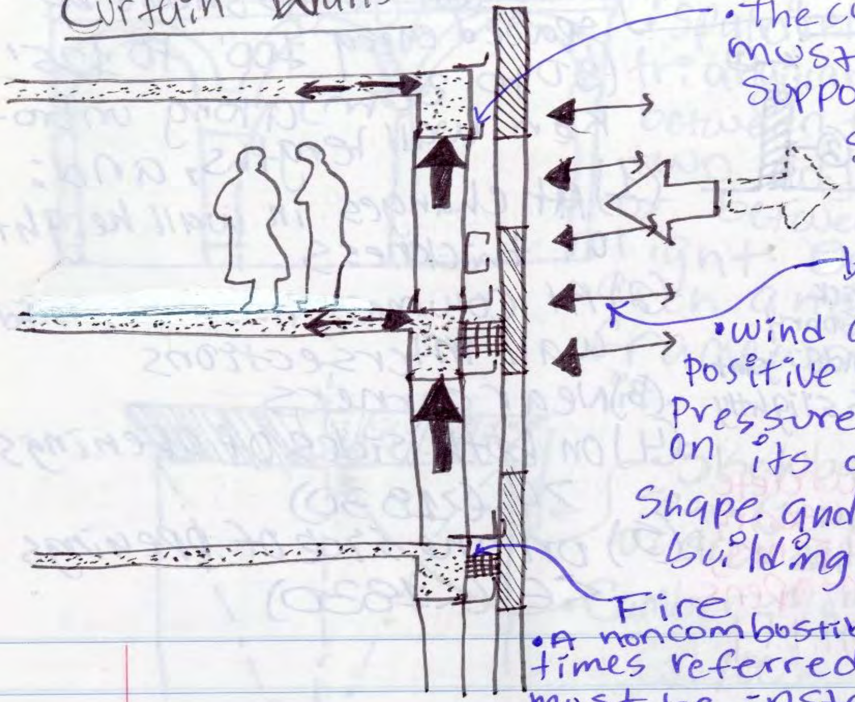
(1) At changes in wall height or thickness
(2) At columns, pilasters, and wall intersections
(3) Near corners
(4) on both sides of openings >6' (>1830)
(5) on one side of openings <6' (<1830)

• Brick masonry expands; joint closes slightly



• Concrete masonry shrinks; joint opens slightly

Curtain Walls



Loads
- The curtain wall panels must be adequately supported by the structural frame.

Wind
- Wind can create both positive and negative pressure on a wall, depending on its direction and the shape and height of the building.

Fire
- A noncombustible material, sometimes referred to as safing, must be installed to prevent the spread of fire at each floor within column covers and between the wall panels and the slab edge or spandrel beam.

Thermal resistance of building materials

* $1/k = R$ per inch of thickness

† $1/C = R$ for the thickness indicated

- R is a measure of thermal resistance of a given material. It is expressed as the temperature difference required to cause heat to flow through a unit area of material at the rate of one heat unit per hour.

$R = F° / Btu/hr \cdot sf$

- R_t is the total thermal resistance for a construction assembly and is simply the sum of the individual R-values of the component materials of an assembly.

- U is a measure of the thermal transmittance of a building component or assembly. It is expressed as the rate of heat transfer through a unit area of a building component or assembly caused by a difference of one degree between the air temperatures on the two sides of the component or assembly. The U-value for a component or assembly is the reciprocal of its R-value.

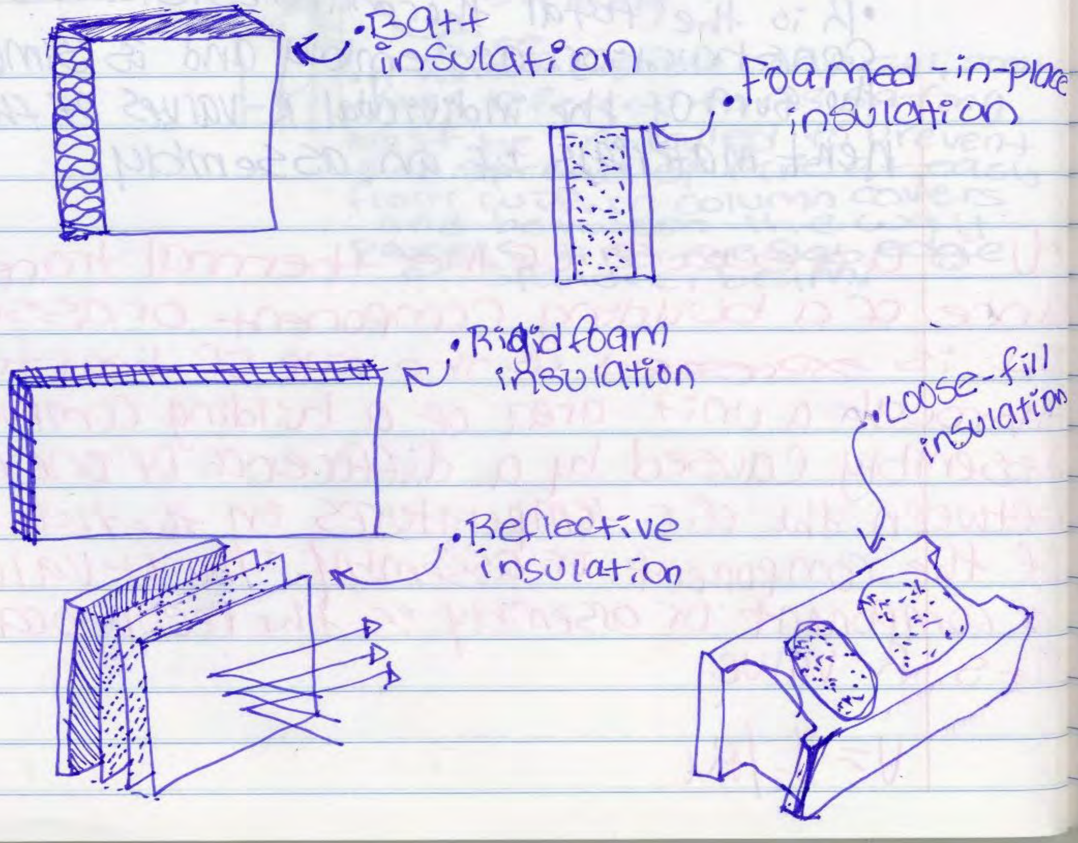
$U = 1/R_t$

- Q is the rate of heat flow through a construction assembly and is equal to:

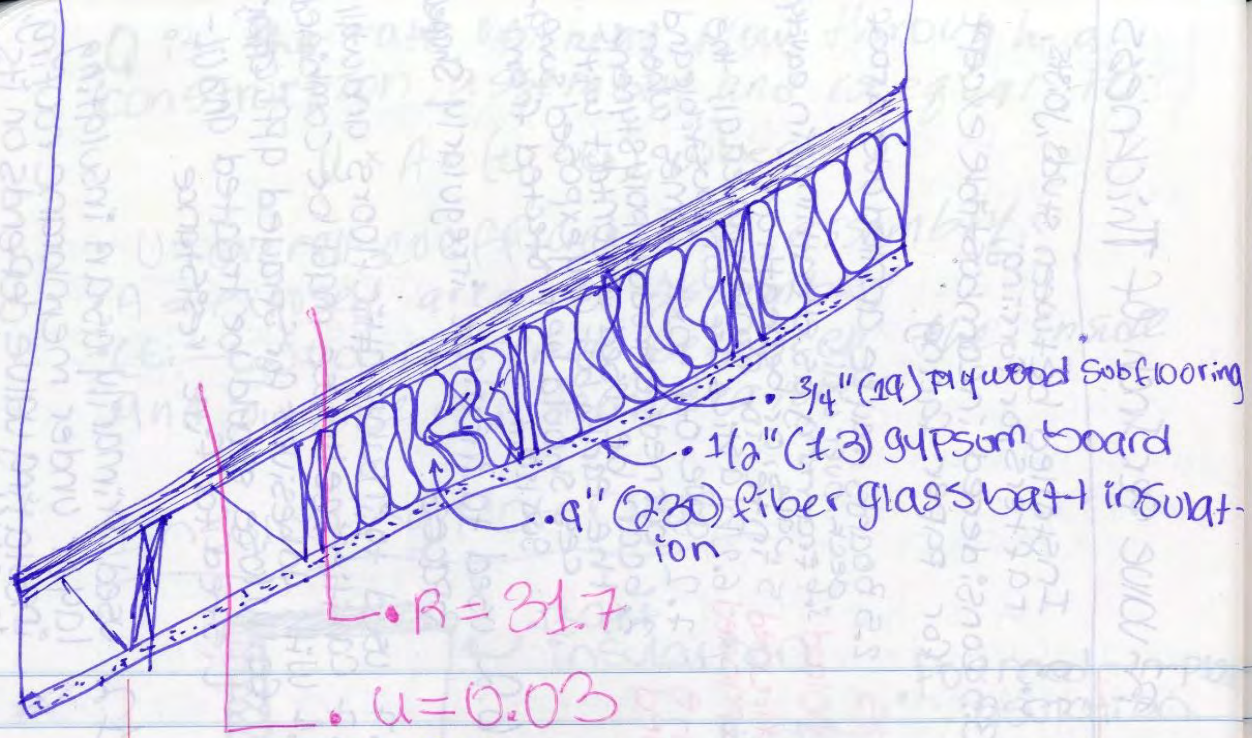
$$U \times A \times (t_i - t_o), \text{ where:}$$

- U = overall coefficient of assembly
- A = exposed area of assembly
- $(t_i - t_o)$ = difference between the inside and outside air temperatures.

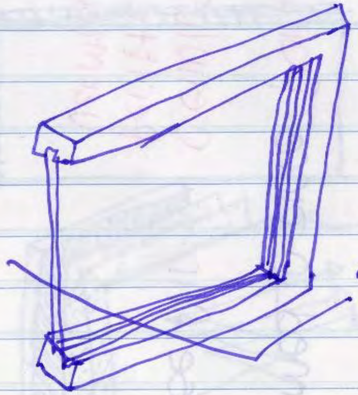
Insulating Materials



Form	Material	R-Value Per Inch Of Thickness	
Batt or blanket	Fiberglass	3.3	Installed between studs, joists, rafters, or forring;
	Rock wool	3.3	considered incombustible except for paper facing.
Rigid board	Cellular glass	2.5	Boards may be applied over a roof deck, over wall.
	Polystyrene, molded	3.6	framing as sheathing, in cavity
	Polystyrene, extruded	5	walls, or beneath an interior finish material; the
	Polyurethane, expanded	6.2	Plastics are combustible and
	Polyisocyanurate	7.2	give off toxic fumes when burned; extruded polystyrene
	Perlite, expanded	2.6	can be used in contact with the earth but any exposed surfaces should be protected from sun light.
Foamed in place	Polyurethane	6.2	Used to insulate irregularly shaped spaces.
Loose fill	Cellulose	3.7	Used to insulate attic floors and wall
	Perlite	2.7	cavities; cellulose may be combined
	Vermiculite	2.1	with adhesives for sprayed application; Cellulose should be treated and UL-listed for fire resistance.
Cast	Insulating concrete	1.12	Used primarily as an insulating layer under membrane roofing; insulating value depends on its density.

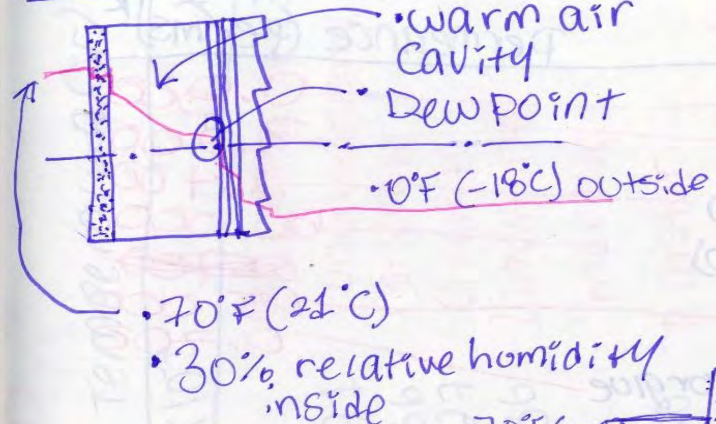


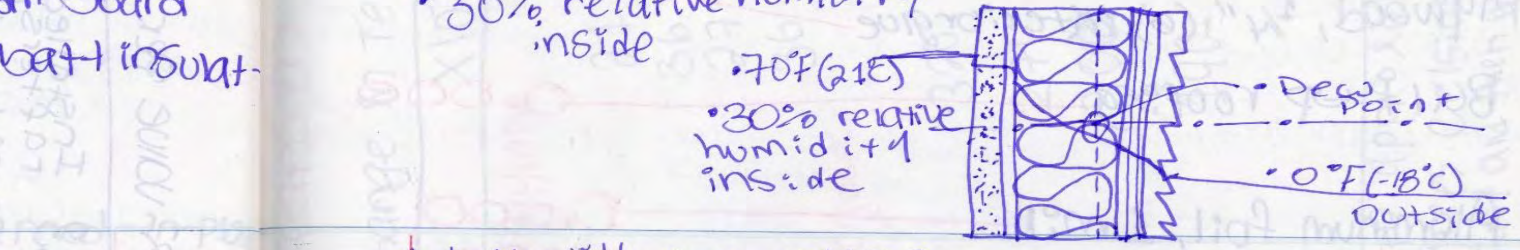
- R=2.0
- U=0.5
- R-value of inside air film=0.61.



- single glazing
- R= 0.88; U=1.13

Moisture control





Wall with insulation

- Wall requires a vapor retarder to prevent water vapor from condensing within the layer of insulation. A vapor retarder becomes more important as the level of thermal insulation increases.

*Perm is a unit of water vapor transmission, expressed in grains of vapor per one square foot per hour per inch of mercury pressure difference.

Permeability of some building Materials

Material	Permeance (perms)*
Brick, 4" (100)	0.800
Concrete, 1" (25)	3.200
Concrete block, 8" (205)	2.400
Gypsum board, 3/8" (10)	50.000
	~~[illegible]~~
Plaster, 3/4" (19)	15.000
Plywood, 1/4" (6), exterior glue	0.700
Built-up roofing	0.000
Aluminum foil, 1 mil	0.000
Polyethylene, 4 mil	0.080
Polyethylene, 6 mil	0.060
Duplex sheet, asphalt + foil	0.002
Asphalt-saturated + coated paper	0.200
Kraft paper, foil-faced	0.500
Blanket insulation, faced	0.400
Cellular glass	0.000
Polystyrene, molded	2.000
Polystyrene, extruded	1.200
Paint, two coats, exterior	0.900

Coefficients of linear expansion

Per unit length Per 1 Degree Change in Temperature (°F)*

	$\times 10^{-7}$		$\times 10^{-7}$		$\times 10^{-7}$
Aluminum	128	Parallel to wood grain:		Brick masonry	34
Brass	104	Fir	21	Concrete masonry	52
Bronze	101	Maple	36	Concrete	55
Copper	93	Oak	27	Granite	47
Iron, cast	59	Pine	36	Limestone	44
Iron, wrought	67	Perpendicular to grain:		Marble	73
Lead	159	Fir	320	Plaster	76
Nickel	70	Maple	270	Rubble masonry	35
Steel, carbon	65	Oak	300	Slate	44
Steel, stainless	99	Pine	190	Glass	50

*one degree Fahrenheit is equal to approximately 0.6 degree Celsius or Centigrade. To find degrees Celsius or centigrade, first subtract 32 from the degrees Fahrenheit and then multiply by 5/9.