Part I: Building Systems

- Introduction
- Definitions and Performance
  - i. Foundation
  - ii. Superstructure
  - iii. Exterior Envelope
  - iv. Mechanical Services
  - v. Interior Partitions

Part II: Superstructure and Exterior Envelopes

- History
- Morphology
- Materials and Systems

Reading

Daniels, Klaus.

Low Tech, Light Tech, High Tech

Chapter 9, pages 146-173

Building Systems: Definitions

1. Foundation/Subgrade *(SITE)*
2. Superstructure *(STRUCTURE)*
3. Exterior Envelope *(SKIN)*
4. Interior Partitions *(SPACE PLAN)*
5. Mechanical Systems *(SERVICES)*
6. Furnishings *(STUFF)*

Sources:

Brand, Howard, *How Buildings Learn.*

Turner, *Construction Economics.*

Building Systems: Definitions

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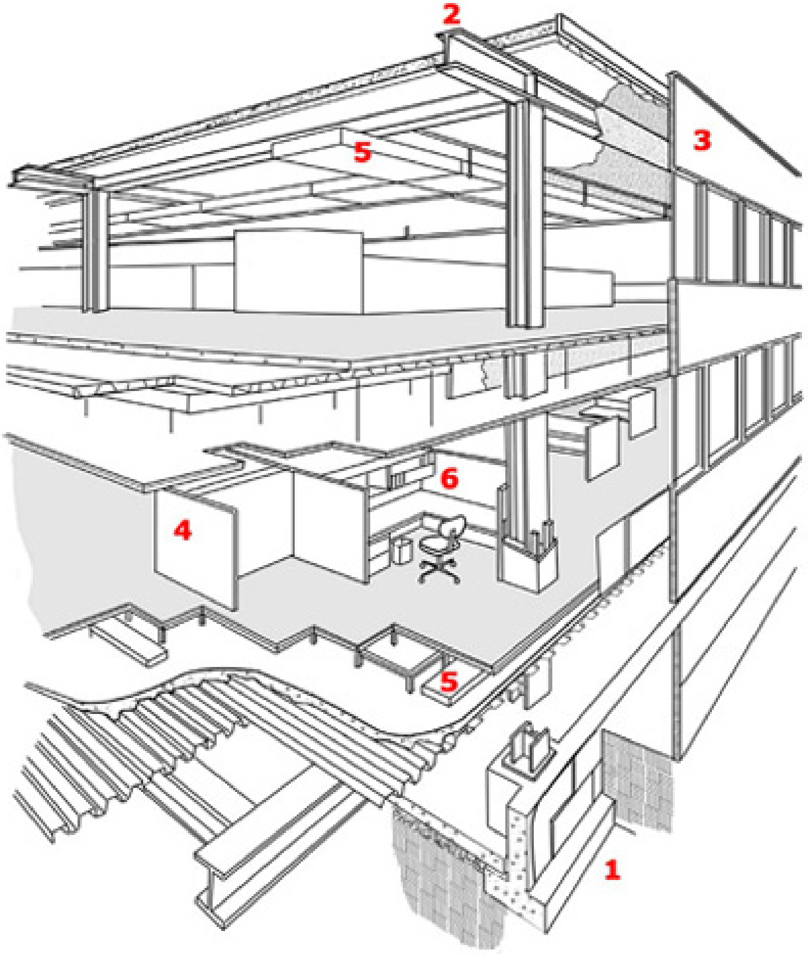

Image by MIT OCW.

Source: Rush, Richard

The Building Systems Integration Handbook.

Curtainwall and raised floor construction.

Building Systems: Definitions

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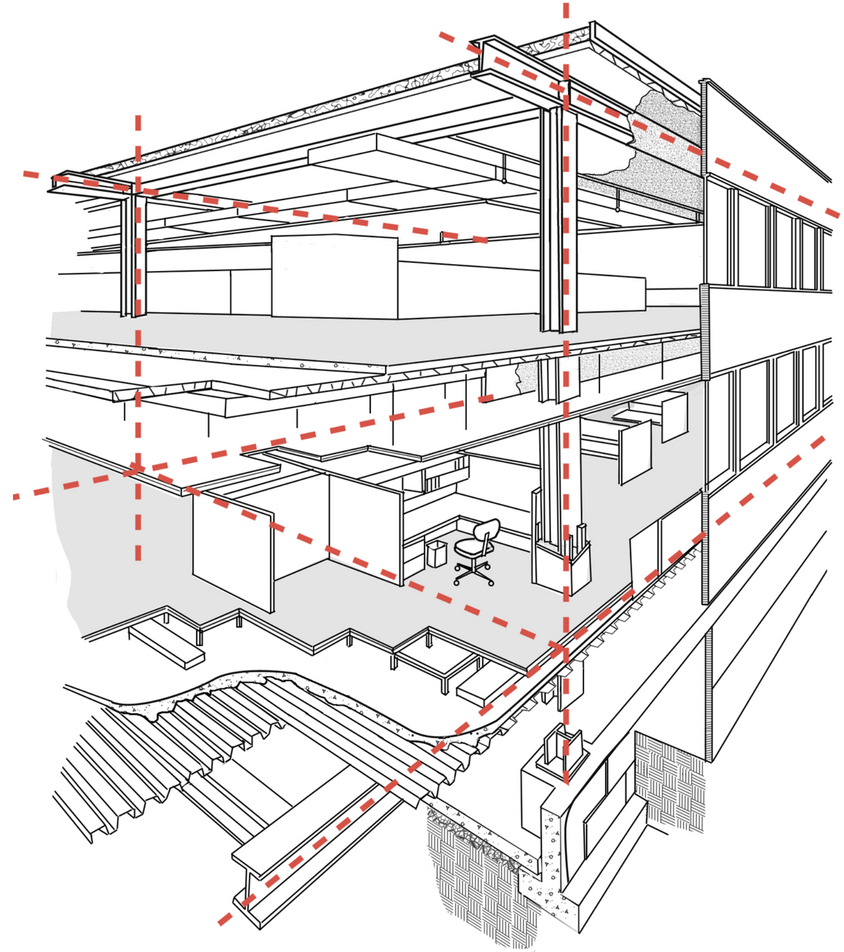

Image by MIT OCW.

Curtainwall and raised floor construction.

Building Systems: Performance

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Foundation

1. Transfer superstructure loads to subgrade condition
2. Act as subgrade exterior envelope
3. Resist lateral loading from below and above

Building Systems: Performance

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Superstructure

1. Transfer vertical dead and live loads
2. Transfer lateral loading on exterior surfaces of building
3. Provide rigidity and limit deflection
4. Provide armature for the suspension and support of secondary structure and other building systems such as the exterior envelope, mechanical systems, interior partitions etc.

Building Systems: Performance

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Exterior Envelope

1. Mediate between interior and exterior environments *means:*
   - Control of mass flux
   - Control of thermal flux
   - Control of light energy
   - Transfer of loads (primarily self weight and lateral)
   - Control of acoustic flux

2. Provide delineation of interior space for programmatic activities
3. Define character of building on urban and architectural scales

Building Systems: Performance

1. Foundation/Subgrade *(SITE)*
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Interior Partitions

1. Delineate interior spatial conditions
2. Control acoustical energy
3. Provide conduit for services
4. Provide rated fire barriers
5. Define the character of the interior space

Building Systems: Performance

1. Foundation/Subgrade *(SITE)*
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Mechanical Systems

1. Maintain interior environment through service to the space with:
   - Air distribution systems (ventilation)
   - Water distribution systems (plumbing)
   - Heating and cooling systems
   - Electrical distribution systems
   - Artificial lighting
   - Data distribution systems
   - Fire detection, suppression and alarm systems
   - Vertical circulation systems (elevators)

Building Systems: Performance

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Furnishings

1. Accommodate occupation of space
2. Provide devices for storage, surfaces for working
3. Accommodate all other interior furnishings needs

Part II: Superstructure and Exterior Envelopes

- History
- Morphology
- Materials and Systems

Images:

Wright, Millard House
Pasadena, CA, 1923

Part II: Superstructure and Exterior Envelopes

- History
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Historical Development of the Superstructure frame

- ca. 300 B.C. Estruscan houses of timber
- ca. 100 A.D. Concrete used in many Roman buildings
- ca. 100 Pantheon built of concrete
- ca. 300 Adobe block used worldwide (many earlier examples)
- 1100 Gothic style begins and dominates western Europe for 400 years
- 1100 Iron clamps used in masonry construction of medieval period
- 1500 Introduction of blast furnace industrializes the melting and casting of iron
- 1622 Bricks commercially made in New World
- 1700s First steam-powered saw mills enables mass production of standardized lumber
- 1824 First artificial cement patented in England (Portland cement)
- 1830s Inexpensive machine-made nails makes balloon frame possible
- 1851 Crystal Palace built in London – first major prefabricated and site-assembled iron structure
- 1856 Modern steel production (Bessemer process) invented
- 1868 Prefabricated concrete blocks first made
- 1877 Reinforced concrete beams patented
- 1881 Produce Exchange Building in New York is first building in US to carry full loads on an iron frame
- 1900 Maillart patents flat slab reinforced concrete
- 1950 Welding adopted for high-rise construction

Part II: Superstructure and Exterior Envelopes

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Historical Development of the Exterior Envelope

- ca. 0 Very early examples of the use of glass in Roman villas
- ca. 100 B.C. Terra cotta tiles used for roofing in Rome
- ca. 100 A.D. Slabs of cork used for thermal insulation
- ca. 100 A.D. Copper used extensively in Rome: Pantheon covered in gold-plated copper tiles
- ca. 700 A.D. Small panes of cast glass widely used
- 1100 Roofs formed of wood trusses bearing skin of lead
- 1100 Roofs formed of wood trusses bearing skin of shingles or thatch
- 1200s Timer-frame roofs are common, whether with a false ceiling, stone vaults, exposed roof
- 1400s Glass now in general use
- 1750s Glass polishing mechanized
- 1750 Industrial Revolution marks greater use of brick
- 1773 Cast plate glass made in England
- 1776 Glass company at Ravenshead, England manufacturers cast plate glass up to 160 inches by 80 inches, an increase of 250 percent over blown plate glass

Part II: Superstructure and Exterior Envelopes

- History
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Historical Development of the Exterior Envelope (continued)

- 1800s Walls continue to be built of solid masonry
- 1800s Sullivan uses terra cotta tiles in Chicago
- 1840 Mineral wool first produced in Wales – full century before it becomes popular as a building insulation
- 1851 Crystal Palace demonstrates first large-scale, prefabricated, site assembled envelope completely divorced from load-bearing functions
- 1884 First applications of aluminum in architecture
- 1904 Fourcault and Libby-Owens develop process for drawing sheet glass directly from molten glass
- 1905 Plywood patented by Hetzer
- 1923 Phenolic resins enable mineral, and later glass, fibers to be bound into batts
- 1925 Ford Motor Co. and Pilkington Bros. develop continuous strip method to make plate glass
- 1931 Neoprene developed by DuPont
- 1935 Owens-Corning formed to make and sell fiberglass wool insulation batts
- 1938 First glass-fiber reinforced polyester (fiberglass)

Part II: Superstructure and Exterior Envelopes

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Historical Development of the Exterior Envelope (continued)

- 1940 Terra cotta industry is almost extinct
- 1943 Dow Chemical produces silicone
- 1945 Dow Chemical produces styrene foam
- 1945 Polyethylene developed; later used for vapor barriers
- 1945 and after Pre-cast concrete gains widespread favor in Europe
- 1946 Fiberglass is strengthened by addition of epoxy resins
- 1947 Fuller patents geodesic dome
- 1950s Foamed plastics developed for insulation
- 1950s Sealed curtainwall developed
- 1952 Pilkington Bros. Invent float glass process
- 1953 Aluminum now 25% of curtainwalls, versus 5% in 1949
- 1956 Aluminum production now 10 times greater than in 1939
- 1950s Tempered glass invented
- 1960s Building industry incorporates numerous plastics into standardized assemblies
- 1962 Kynar introduced
- 1970s Composition board used for exterior sheathing
- 1970s Vinyl siding introduced
- 1990s High performance double-leaf wall systems introduced in Europe

Part II: Superstructure and Exterior Envelopes

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System Design Decisions

Exterior Envelope

1. Systems type definition: bearing, suspended, laterally braced, strongbacks, insulated, vapro and air barriers, rainwall etc.
2. Module size
3. Window and opening configurations
4. Control systems: air and vapor barriers and other internal assembly materials, sun shading, security privacy etc.
5. Exterior surface materials: color, texture
6. Interior surface materials: color, texture

Structure

1. Systems type definition: frame, bearing wall, tensile, pneumatic etc.
2. System materials: steel, concrete, wood, composite etc.
3. Spans and floor to floor heights
4. Cross section of structural elements
5. Lateral bracing
6. Building form
7. Expansion capabilities

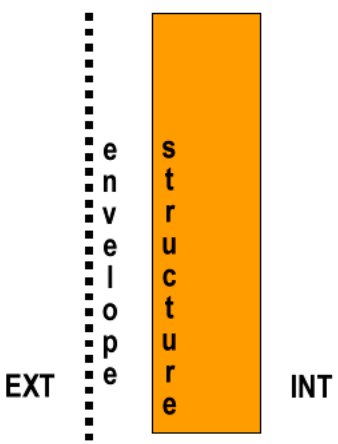
Part II: Superstructure and Exterior Envelopes

- History
- Morphology
- Materials and Systems

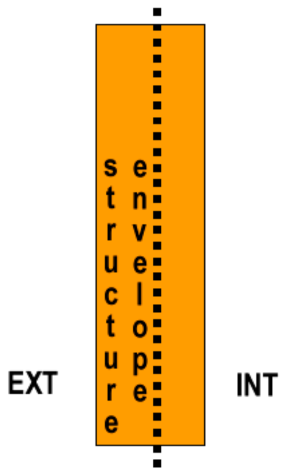
Morphology

Exterior Envelope – Structure: Wall Assembly

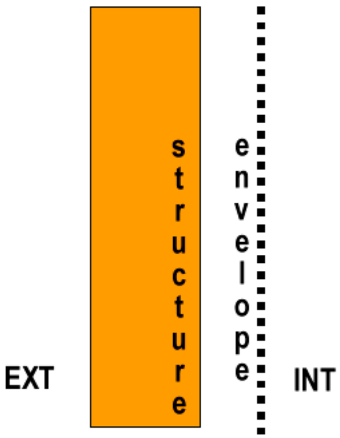
1. Skin Envelope: envelope outside, structure fully inside
2. Structural Envelope: exterior envelope and structure coincident
3. Exoskeleton: structure substantially outside, envelope within



Skin Envelope



Structural Envelope



Exoskeleton

Part II: Superstructure and Exterior Envelopes

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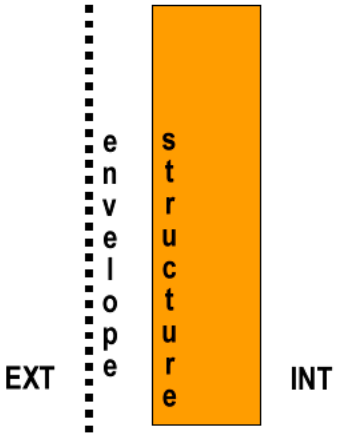

Issues

Positive

1. Structure protected from weather
2. Structure protected from temperature differentials
3. Clearly established solution for structure/exterior envelope relationship
4. Interface with roof is easy

Negative

1. Thermal bridges difficult to completely eliminate
2. Differential movement between superstructure and envelope

Systems

Glass curtainwall and structural frame

Tensile fabric buildings

Structural glass and frame

Non-structural masonry/pre-cast concrete/metal panel over structural CMU

Part II: Superstructure and Exterior Envelopes

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- Morphology
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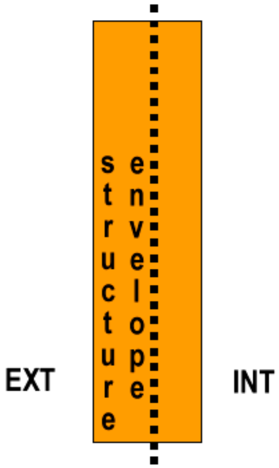

Issues

Positive

1. Structure (in some cases) protected from weather
2. Clearly established solution for structure/exterior envelope relationship
3. Relatively heavy construction (masonry and stone buildings)
4. Relatively light construction (pneumatic buildings)

Negative

1. Systemic thermal bridging
2. Structure and interior wall assembly subject to vapor condensation
3. Structural movement may cause discontinuities in exterior envelope membrane
4. Structural frame requires great deal of secondary framing

Systems

Balloon and platform framing

In-situ concrete, pre-cast concrete, cmu walls, brick walls

Tube structures

Monocoque systems

Part II: Superstructure and Exterior Envelopes

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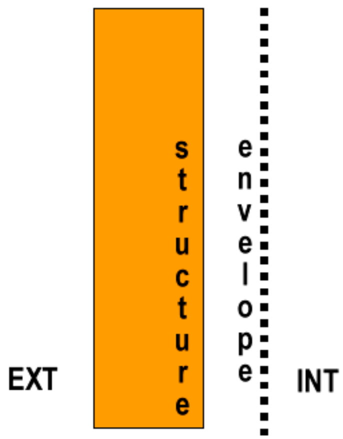

Issues

Positive

1. Structure does not obstruct interior space
2. Coordination between mechanical and other delivery systems and the superstructure is no longer an issue
3. Possible protection from fire

Negative

1. Structure not protected from weather
2. Structure not protected from temperature differentials
3. Unorthodox solution for structure/exterior envelope relationship
4. Interface with roof is difficult
5. Systemic thermal bridging
6. Differential movement between superstructure and envelope causing problems

Systems

Gothic stone

Exterior steel frame

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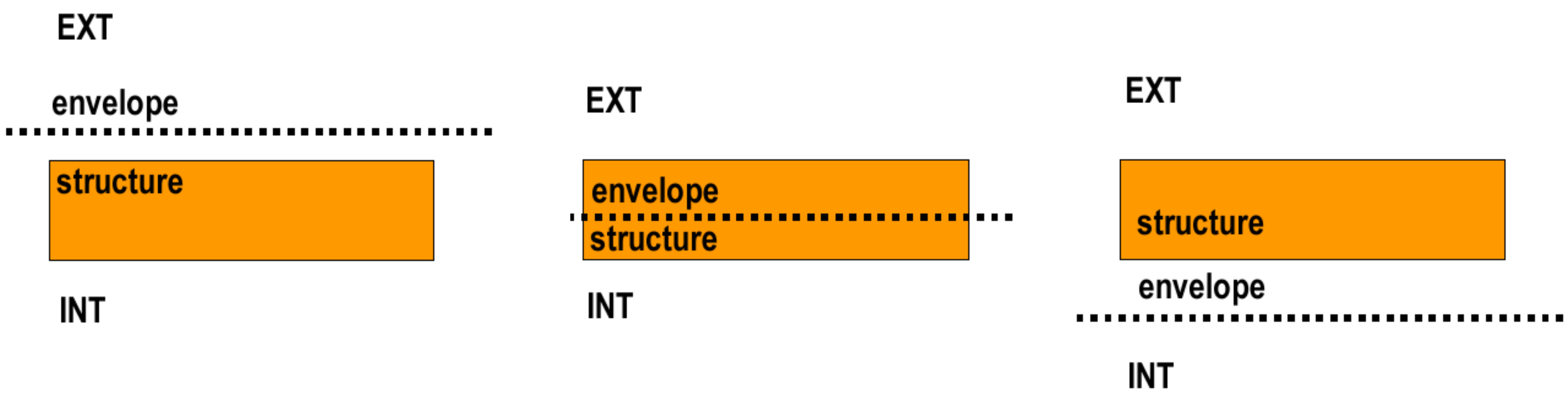
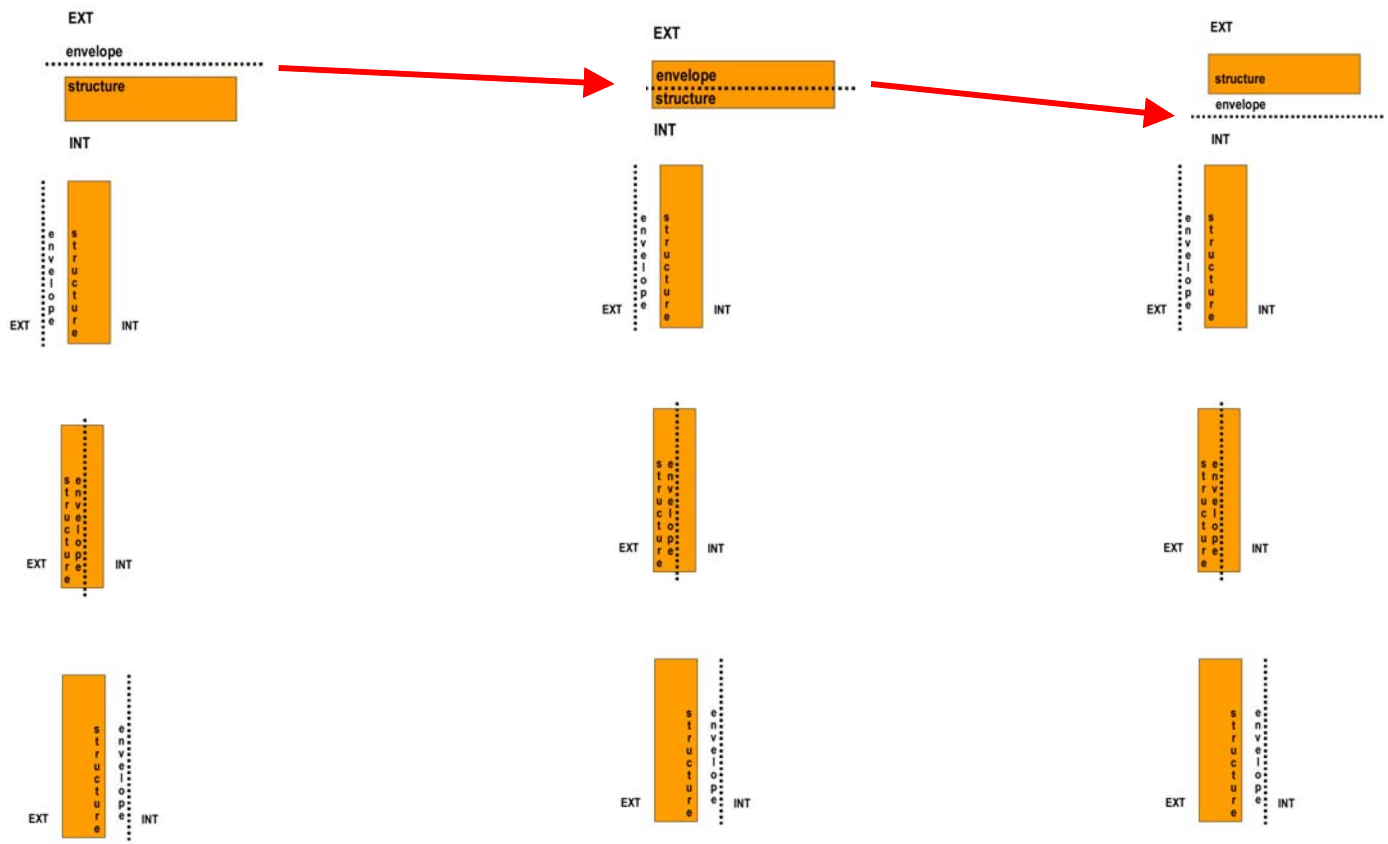


Skin Envelope

Structural Envelope

Exoskeleton

Morphology: Combinations

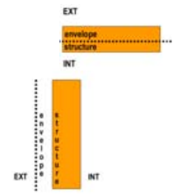
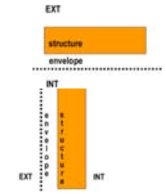
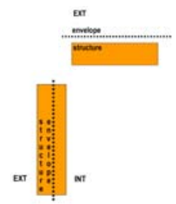
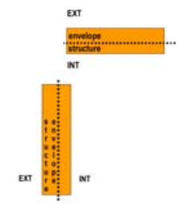
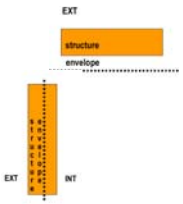
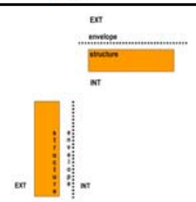
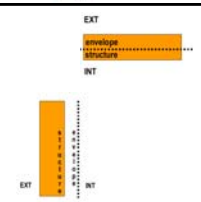
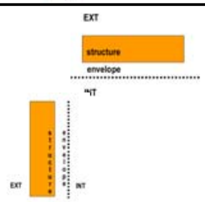


Skin Envelope

Structural Envelope

Exoskeleton

Morphology: Combinations

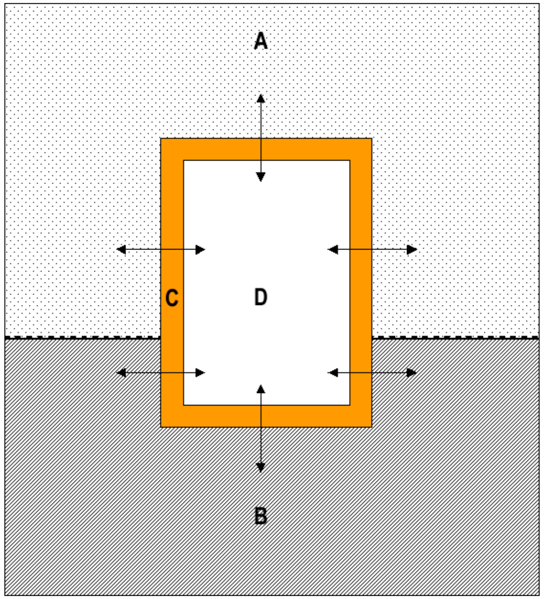
Roof / Wall	Skin Envelope	Structural Envelope	Exoskeleton
Skin Envelope			
Structural Envelope			
Exoskeleton			

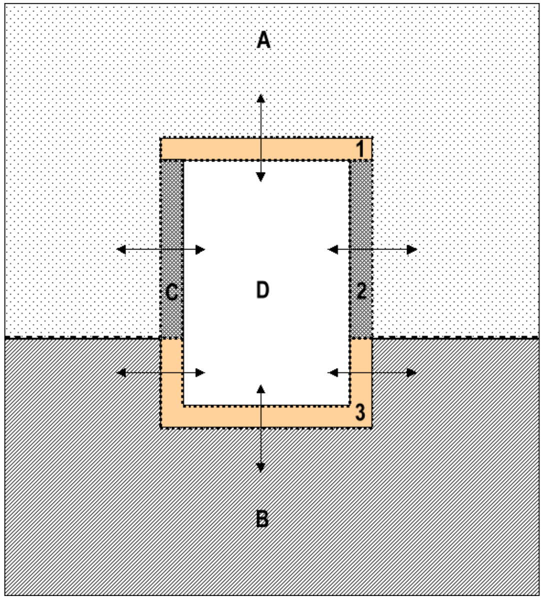
Part I: Exterior Envelopes

- Performance
- Environments
- Assemblies

Part II: Analysis and Detailing

- Assembly Principles
- Details
- Integration
- Analysis Tools





Benisch, Assembly Building, Bonn, Germany, 1999.

Performance

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Exterior Envelope

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    - Control of mass flux
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    - Control of light energy
    - Transfer of loads (primarily self weight and lateral)
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2. Provide delineation of interior space for programmatic activities
3. Define character of building on urban and architectural scales

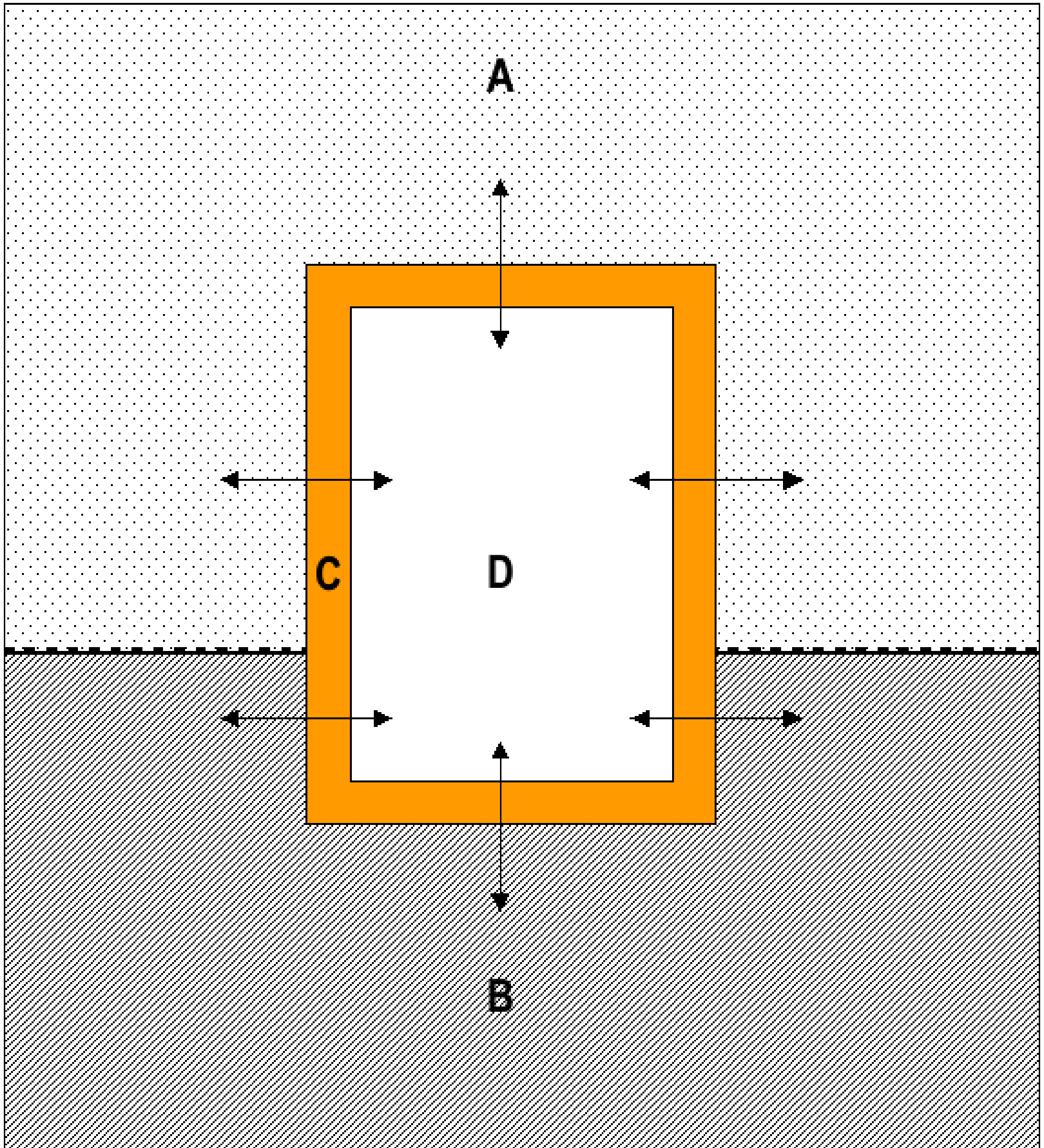
Environments

A. Exterior
- Air
- Water
- Heat
- Radiation

B. Subgrade
- Water
- Heat
- Soil

C. Exterior Wall Assembly
- Air
- Water
- Heat
- Radiation

D. Interior
- Air
- Water
- Heat
- Radiation



Environmental Forces

Air: A,C,D

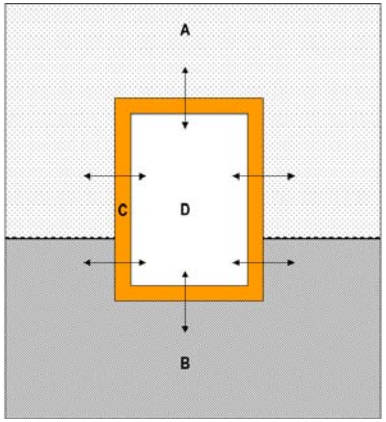
Water

Heat

Radiation

Soil

Air



Two conditions are required for air movement:

1. A thru-wall opening
2. Pressure differential

A thru-wall opening is the consequence of:

1. Improper detailing
2. Permeable materials
3. Separation of components due to building aging

A pressure differential is the consequence of:

1. Wind
2. Stack effect (temperature differential)
3. Mechanical ventilation

Environmental Forces

Air

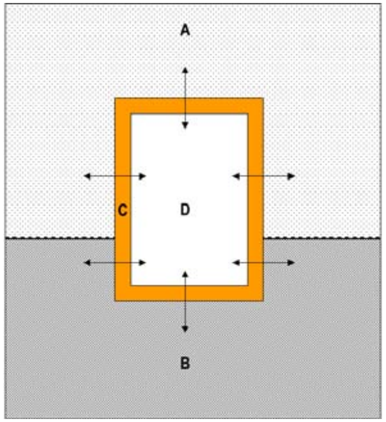
Water, A,B,C,D

Heat

Radiation

Soil

Water



Five forces draw water into an exterior envelope assembly:

1. Momentum (kinetic energy)
2. Gravity
3. Surface tension
4. Capillary action
5. Air pressure differential

There are six principle water sources:

1. Atmosphere and condensation
2. Precipitation
3. Ground water
4. Construction water
5. Rising damp
6. Leaks from services
7. Cleaning and maintenance

Environmental Forces

Air

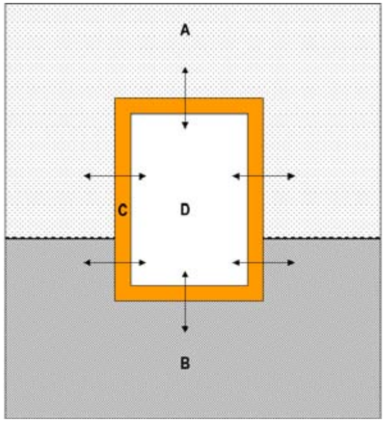
Water

Heat, A,B,C,D

Radiation

Soil

Heat



Heat is transferred through three mechanisms

1. Radiation
2. Convection
3. Conduction

Rate of heat flow through the exterior envelope is proportional to:

1. The air temperature differential (between D and [A or B])
2. Wall area
3. Thermal resistance of wall assembly

Environmental Forces

Air

Water

Heat

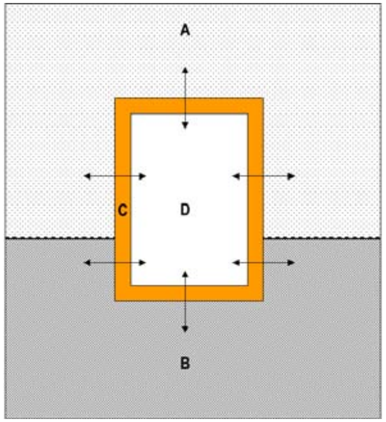
Radiation

Soil

Soil

Two primary issues result from the foundation wall's adjacency to soil:

1. Soil pressure
2. Moisture diffusion from moist soil



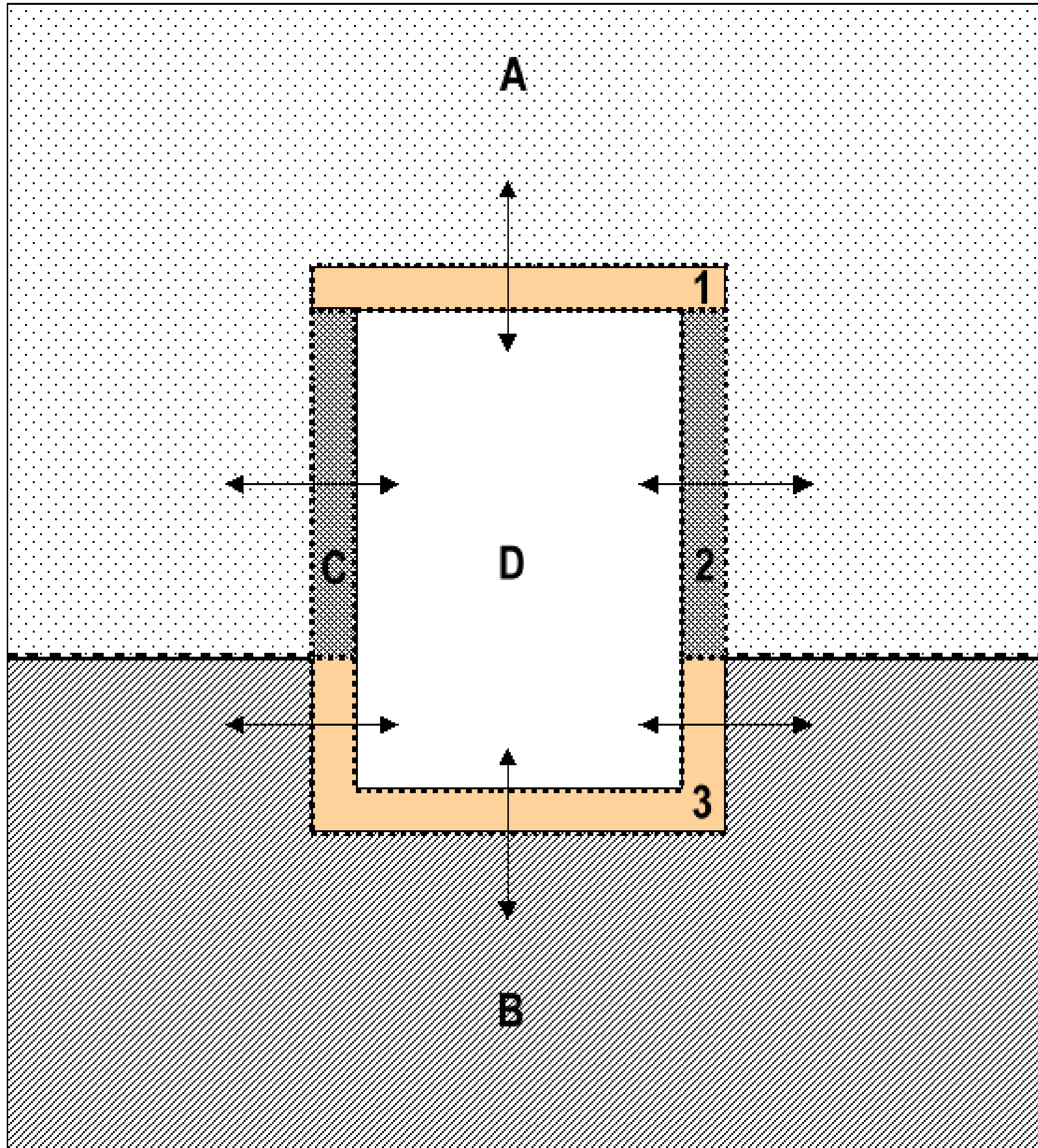
Assemblies

1. Roof Assembly
2. Exterior Wall Assembly
3. Foundation Assembly

Three distinct assemblies are defined as a result of the forces that act on each.

Primary issues relating to the interface between each assembly are:

1. Mechanical connection and separation between each
2. Continuity of common membrane and structural elements (e.g. the vapor barrier)
3. Discontinuity of elements not in common (e.g. roofing membrane, ballast)
4. Total behavior of all systems toward satisfaction of the making of an interior environment



Assemblies

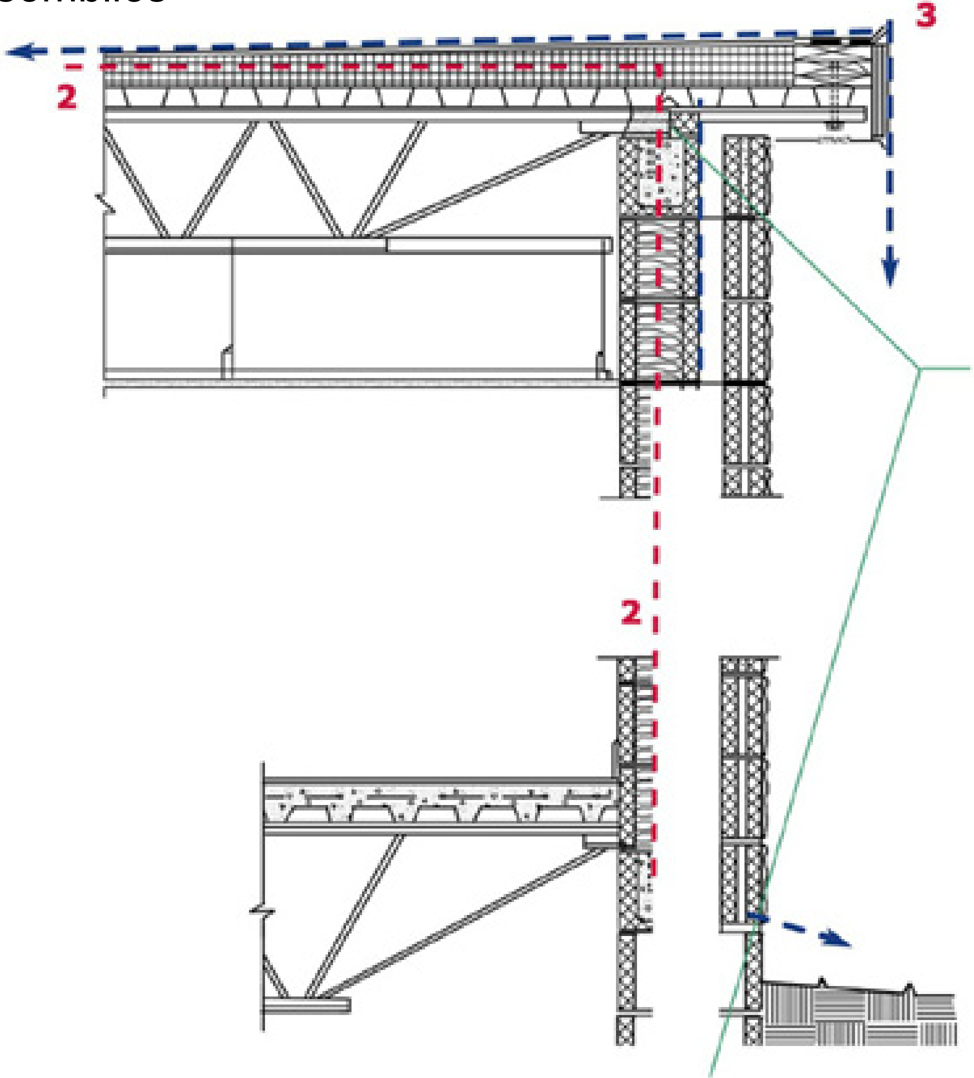


Image by MIT OCW.

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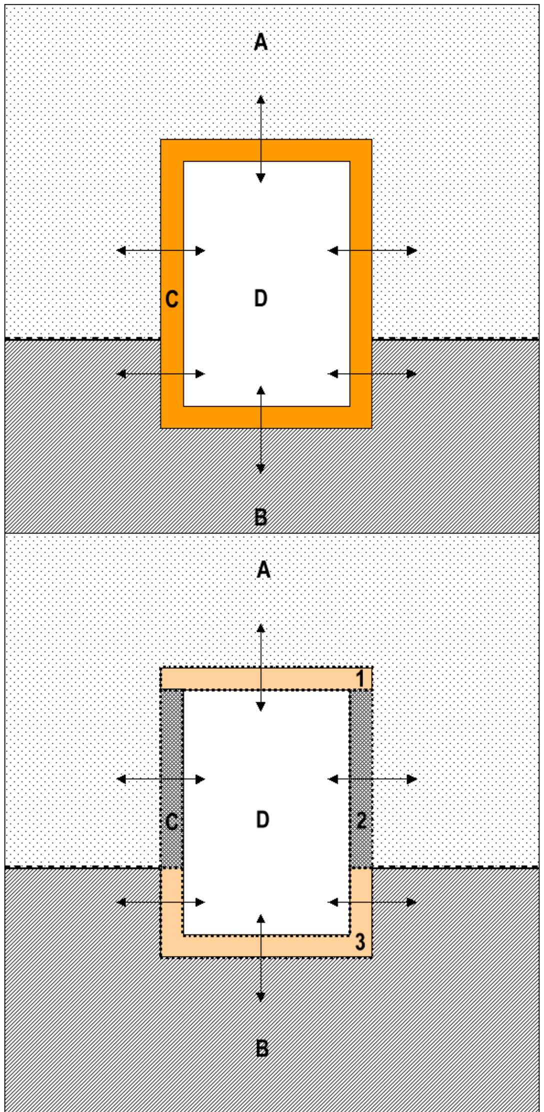
4.461 BT1	Exterior Envelopes II

Assemblies and Environments Matrix



Systems Check List

Assembly / Environment	1. Roof	2. Wall	3. Foundation
A. Exterior			na
B. Ext. subgrade	na		
C. Exterior envelope assembly			
D. Interior			

Part II: Analysis and Detailing

- Assembly Principles
- Thermal Analysis

Images:

Foster, Sainsbury Gallery, England.

Part II: Analysis and Detailing

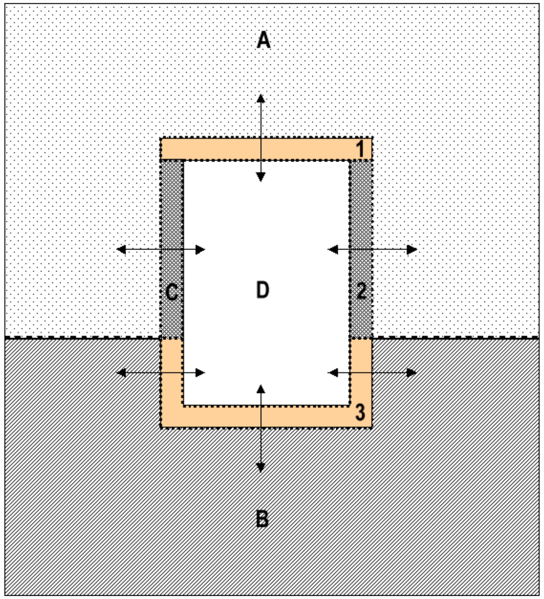
- Assembly Principles
- Thermal Analysis

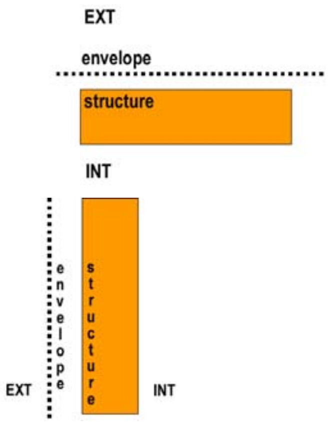
Anatomy of an Exterior Envelope: Essential Component Types

The exterior envelope consists of the following six essential components (from interior to exterior*):

1. Supporting frame (superstructure)
2. Interior surface finish
3. Mass and thermal flux control materials (insulation and air/vapor barriers)
4. Joint materials and mechanisms
5. Exterior surface finish

*Assuming a skin envelope





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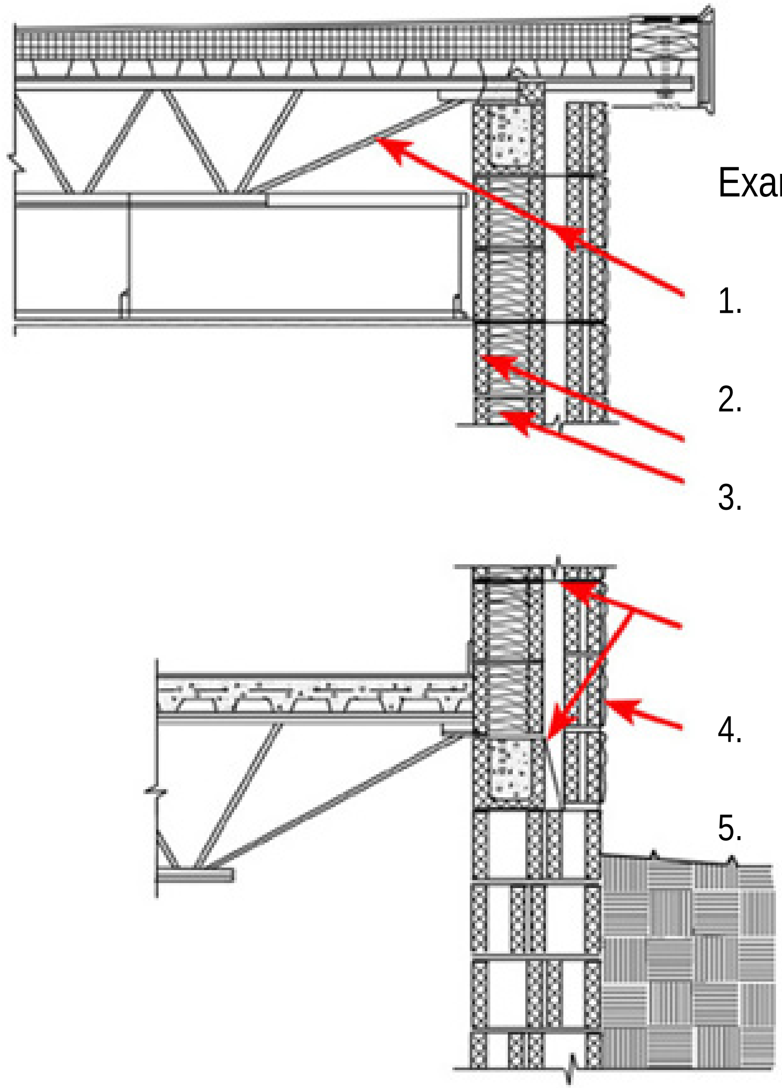


Image by MIT OCW.

Example

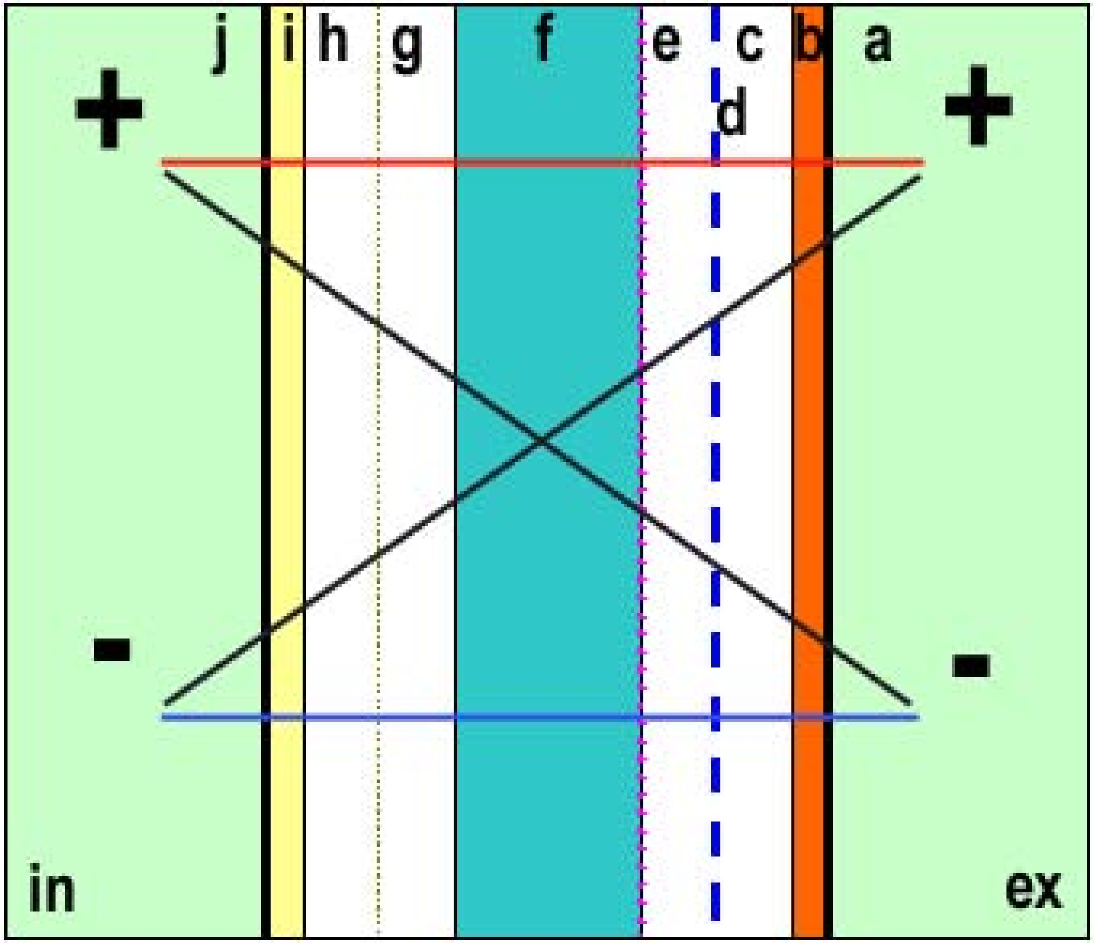
1. Supporting frame (superstructure)
2. Interior surface finish
3. Mass and thermal flux control materials (insulation and air/vapor barriers)
4. Joint materials and mechanisms
5. Exterior surface finish

Part II: Analysis and Detailing

- Assembly Principles
- Thermal Analysis

Assembly layers refinement

a. Exterior finish
b. Exterior barrier
c. Air space
d. Air barrier
e. Radiation barrier
f. Insulation
g. Vapor barrier
h. Air space
i. Interior barrier
j. Interior finish



Exterior Envelope Assembly
Gradients +,-

a. Temperature
b. Air Pressure
c. Vapor Pressure
d. Humidity

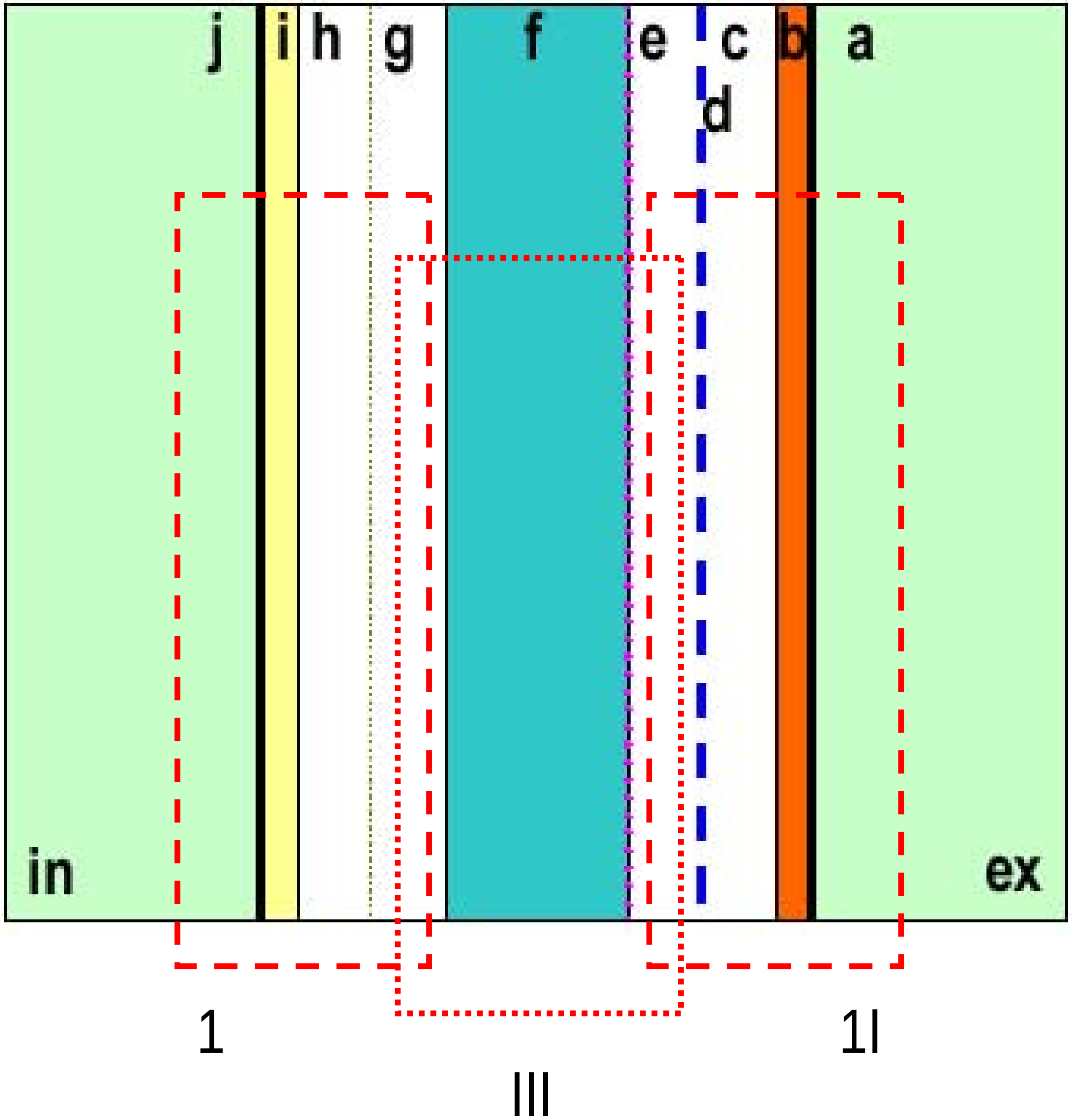
Part II: Analysis and Detailing

- Assembly Principles
- Thermal Analysis

Assembly Zones

I. Vapor/Air to the interior
II. Vapor/Air to the exterior
III. Insulating zone

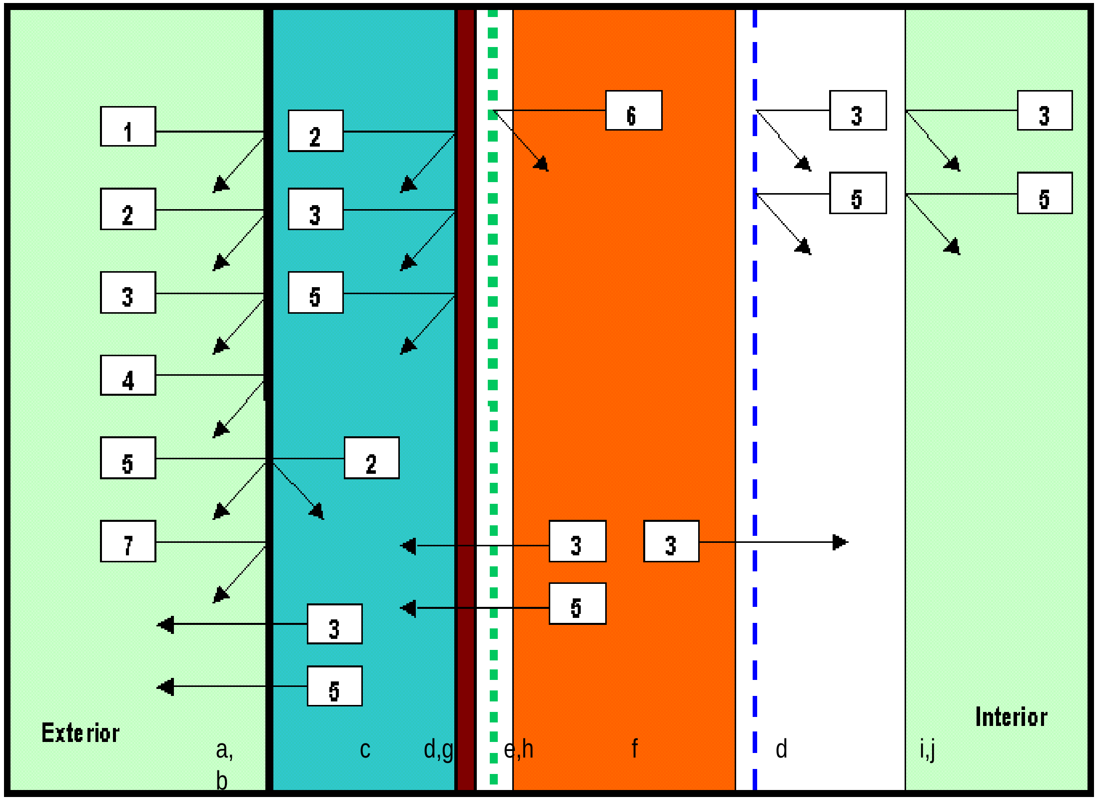
a. Exterior finish
b. Exterior barrier
c. Air space
d. Air barrier
e. Radiation barrier
f. Insulation
g. Vapor barrier
h. Air space
i. Interior barrier
j. Interior finish



Part II: Analysis and Detailing

- Assembly Principles
- Thermal Analysis

a. Exterior finish
b. Exterior barrier
c. Air space
d. Air barrier
e. Radiation barrier
f. Insulation
g. Vapor barrier
h. Air space
i. Interior barrier
j. Interior finish



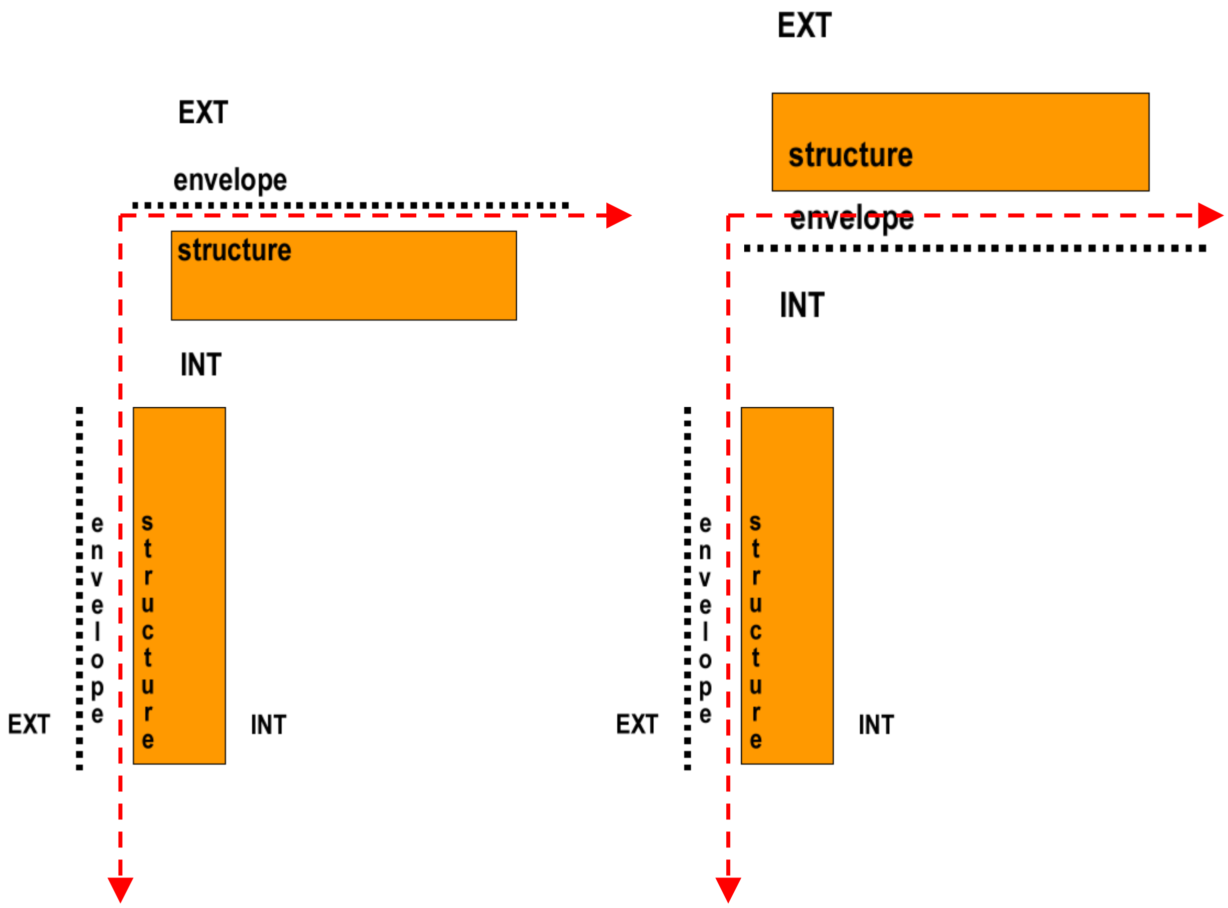
Water	Air	Heat Radiation	Solar Radiation
1. Wind-driven H_2O	4. Turbulent wind	6. Heat transfer through radiation	7. Heat from direct solar exposure
2. Surface H_2O	5. Pressure driven		
3. H_2O Vapor			

Part II: Analysis and Detailing

- Assembly Principles
- Thermal Analysis

Principles

1. Continuity of barrier/control systems
   - Insulation
   - Air barrier
   - Vapor retarder

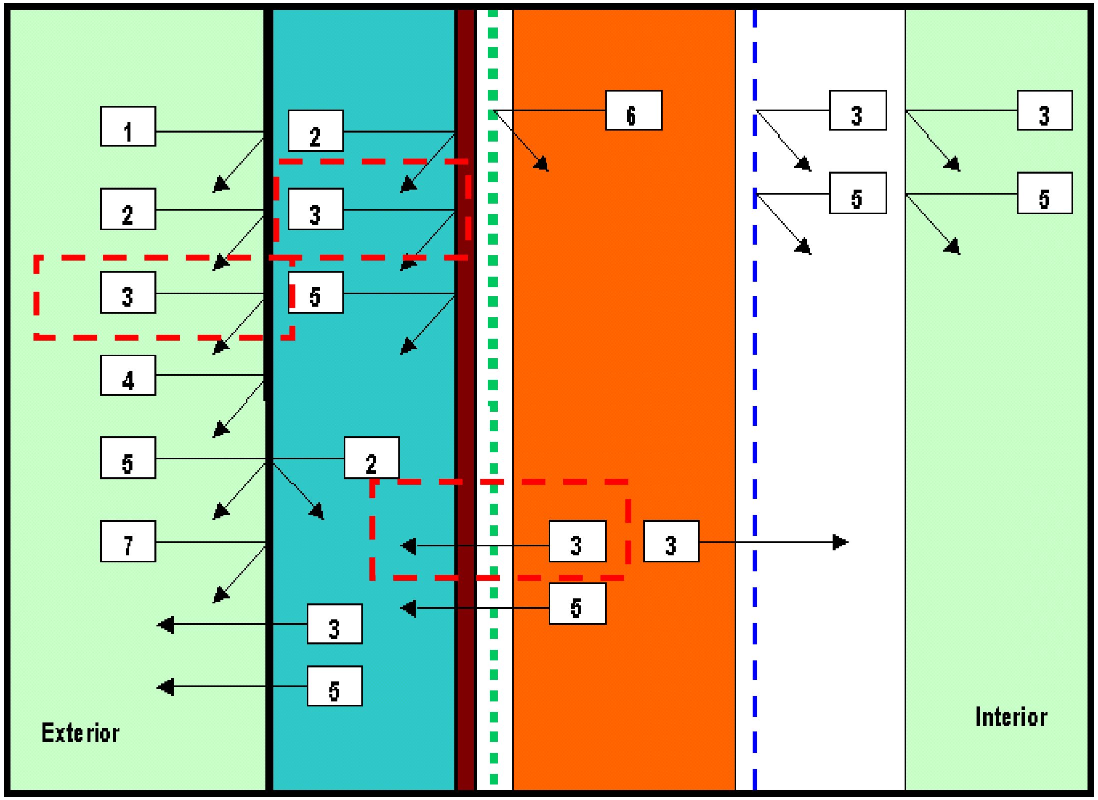


Part II: Analysis and Detailing

- Assembly Principles
- Thermal Analysis

Principles

2. Redundancy
   - Water management system (flashing)
   - Finishes as barriers (interior + exterior)



Water	Air	Heat Radiation	Solar Radiation
1. Wind-driven H_2O	4. Turbulent wind	6. Heat transfer through radiation	7. Heat from direct solar exposure
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Part II: Thermal Analysis

Domains for Analysis

1. Thermal flux →

Domains for Analysis

1. Temperature gradient calculations

$$\Delta T = \frac{R}{R_T} \times \Delta T_T$$

ΔT = temperature change across a component

R = thermal resistance of the component

R_T = total thermal resistance of all components

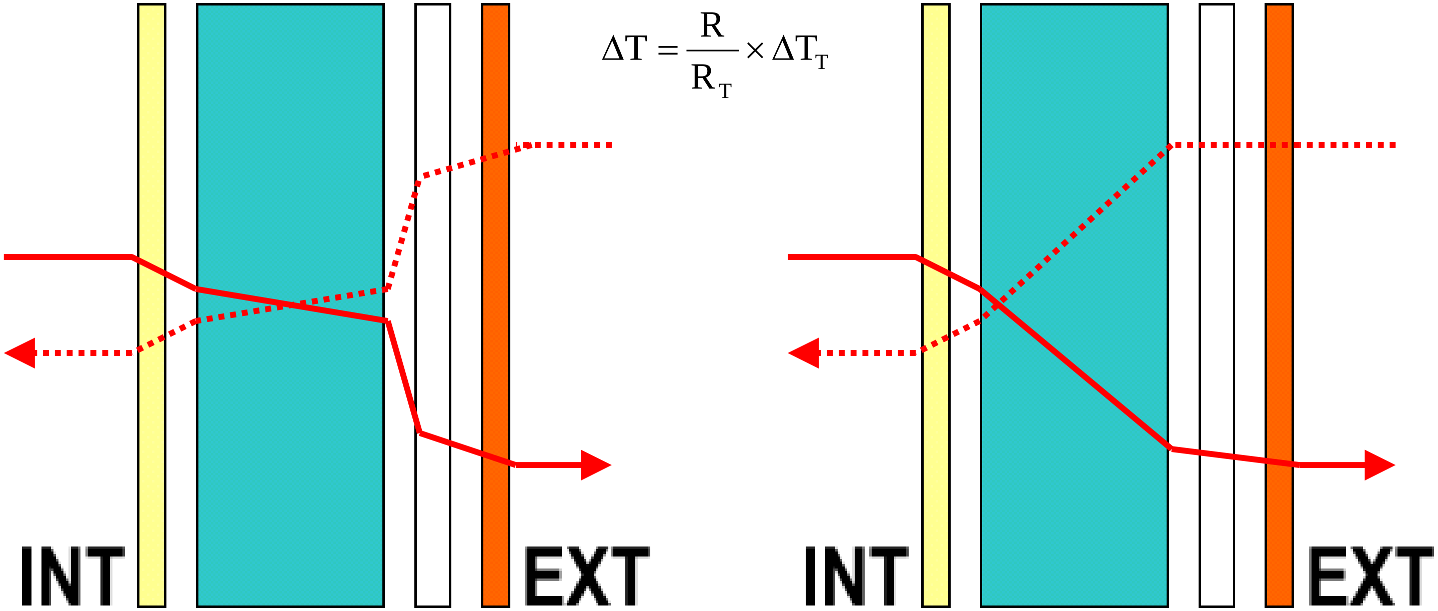
ΔT_T = total temperature change from interior to exterior

Under steady-state conditions, meaning that the calculation will be subject to errors, especially for rapidly changing outside air temperatures.

Domains for Analysis

Temperature gradient calculations

$$\Delta T = \frac{R}{R_T} \times \Delta T_T$$



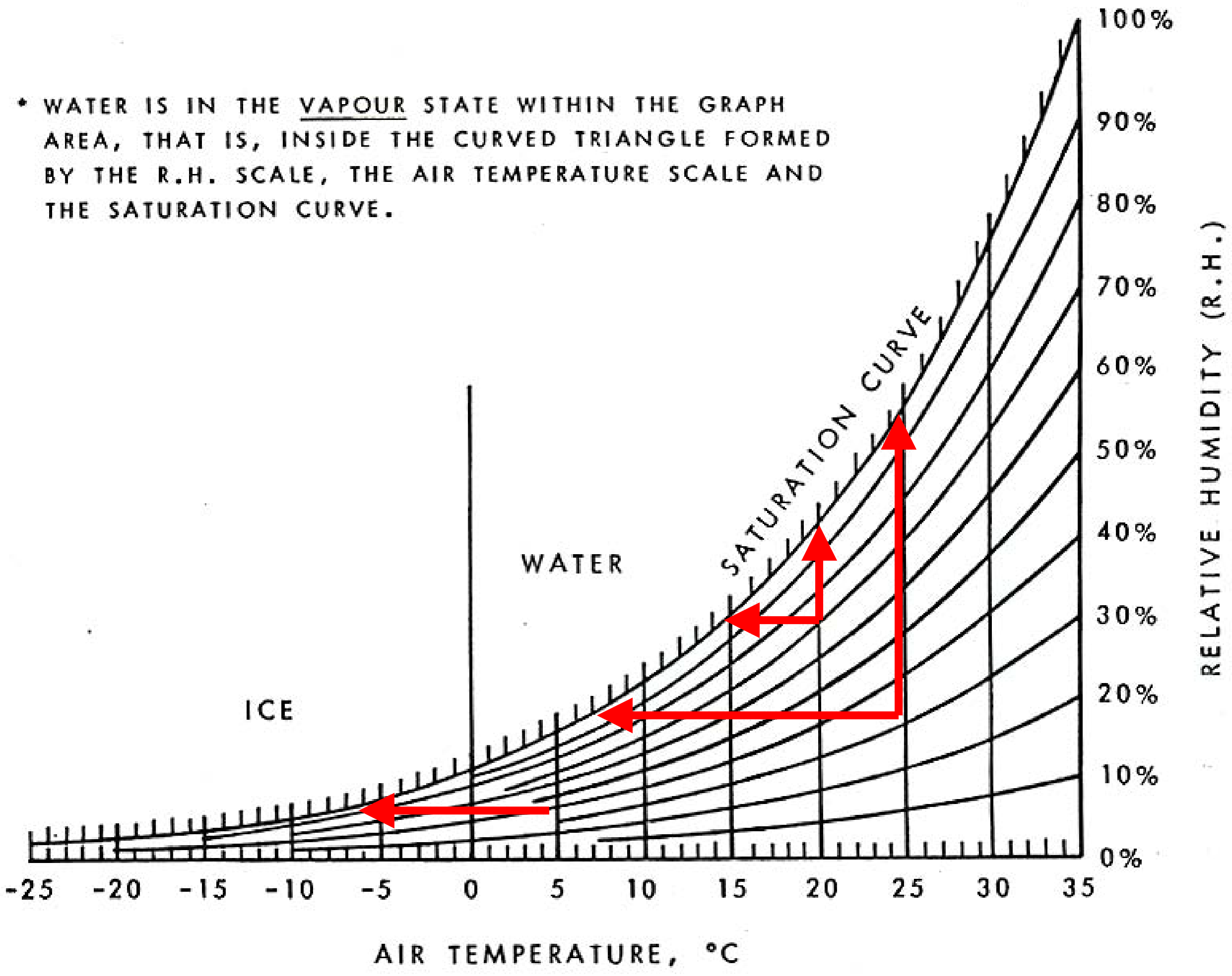
Blue region = Insulation

Bad insulators = gradient approaches horizontal, means R/R_T relatively small ratio

Good insulators = steep gradient means R/R_T approaches 1

Domains for Analysis

Temperature gradient calculations



Domains for Analysis

Temperature gradient calculations

TABLE

COMPONENT	#	R	R/R_T	SUMMER		WINTER	
				ΔT	T	ΔT	T
EXTERIOR T							
EXT. AIR FILM	1						
	2						
	3						
	4						
	5						
	6						
	7						
INT. AIR FILM	8						
INTERIOR T							
TOTAL							

GRAPH