

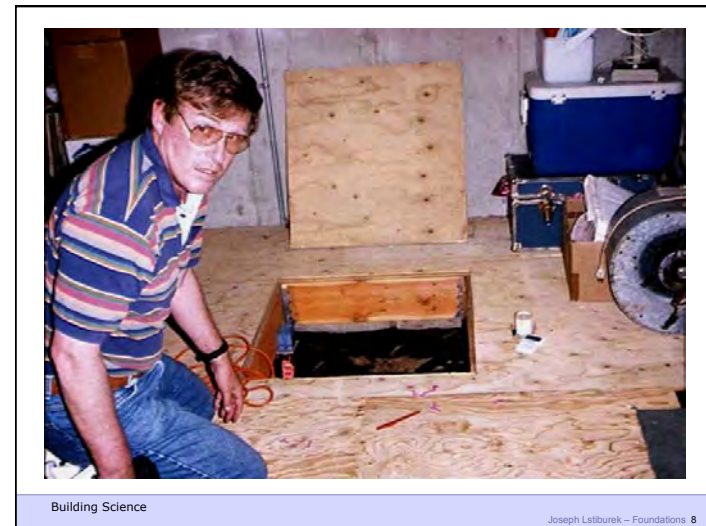
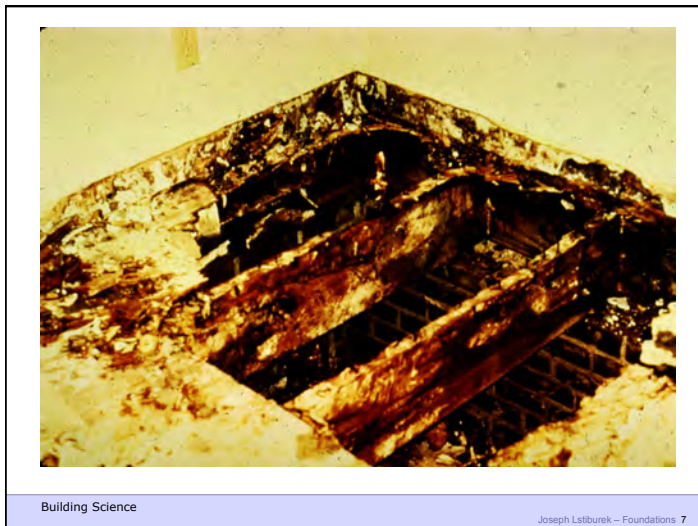
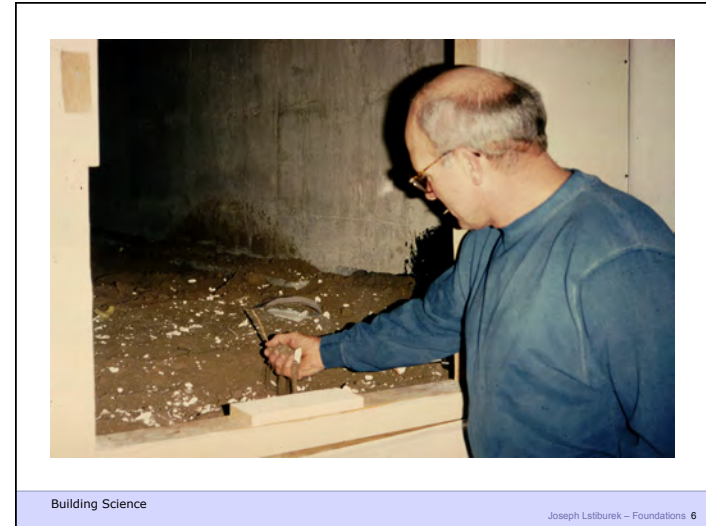
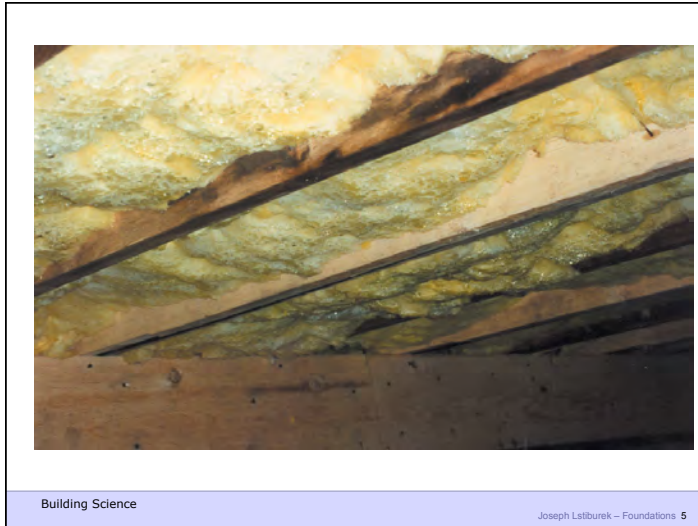
Joseph Lstiburek, Ph.D., P.Eng, ASHRAE Fellow

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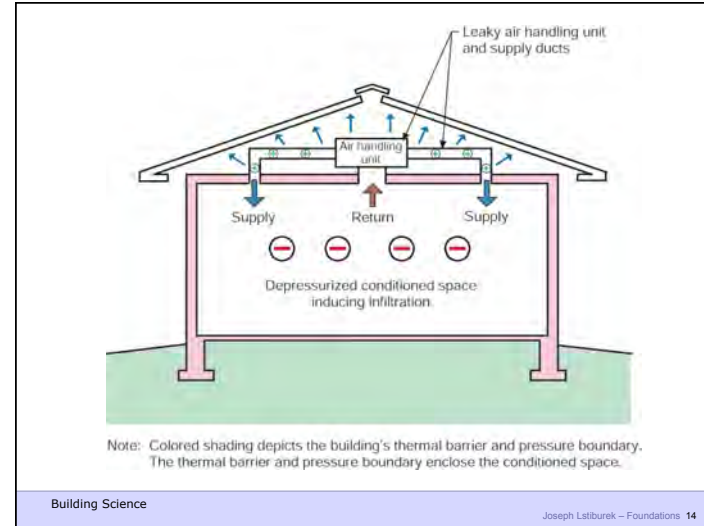






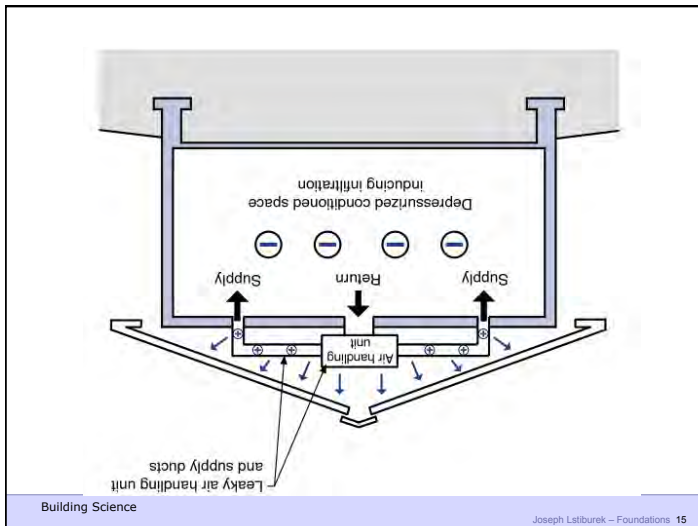
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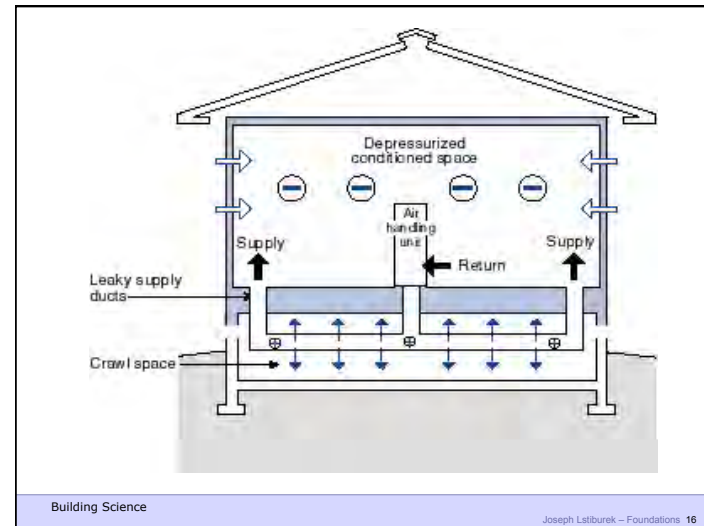
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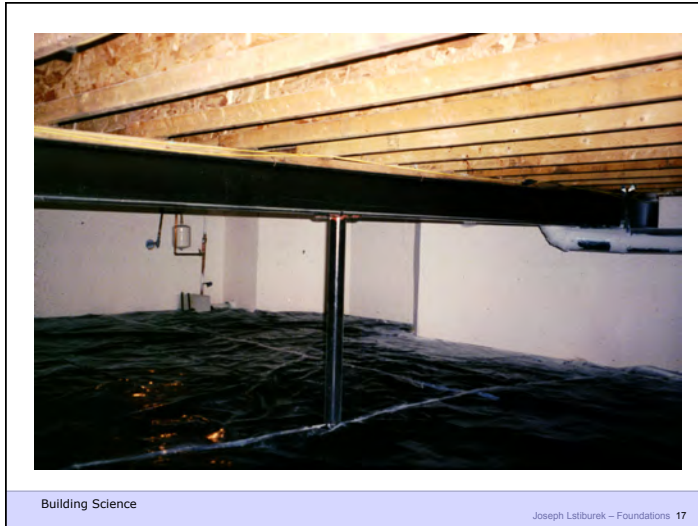
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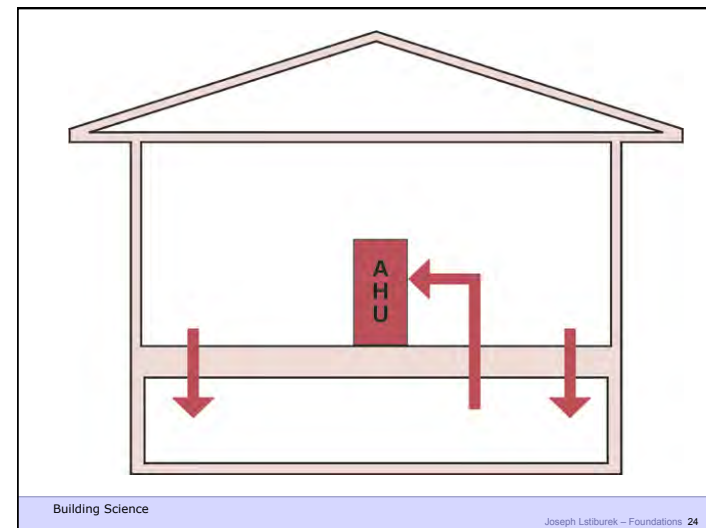
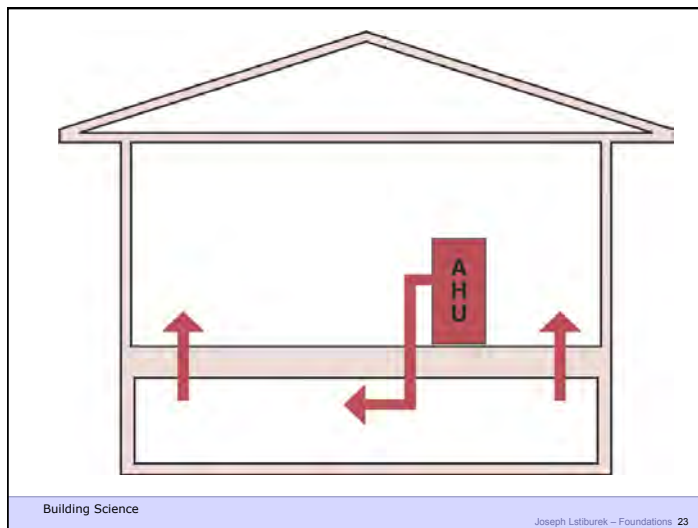
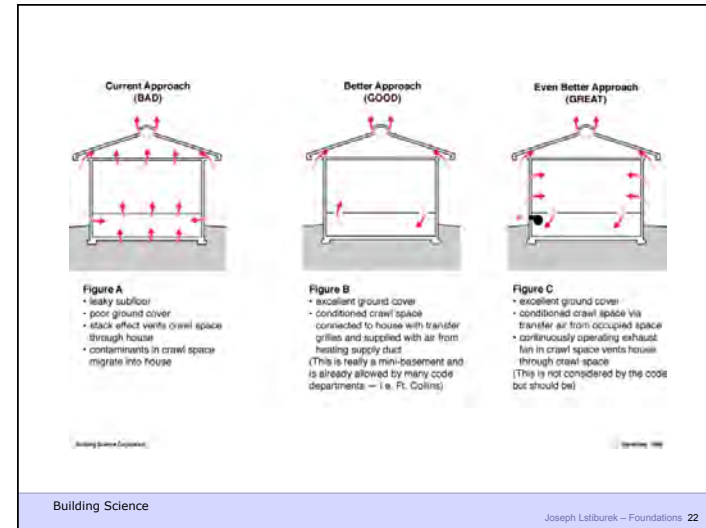
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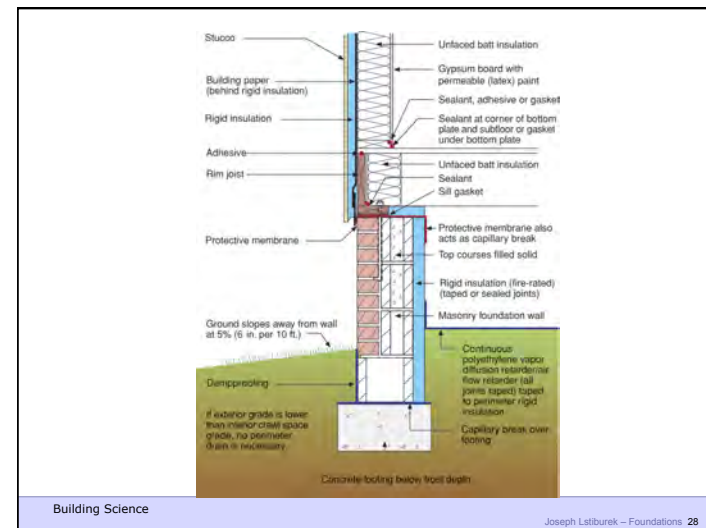
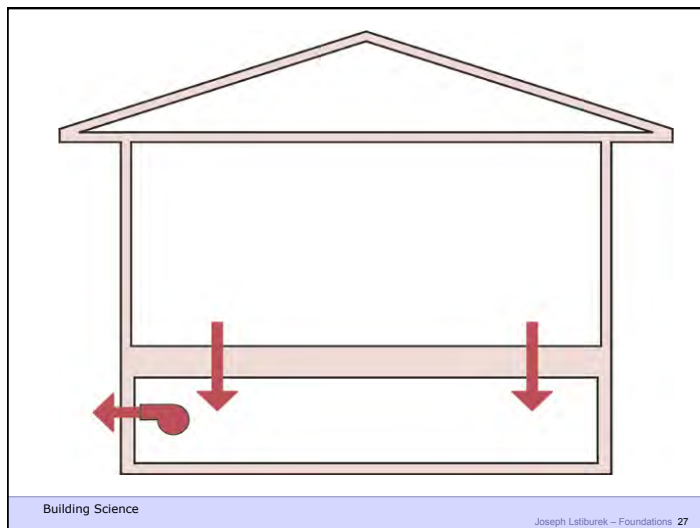
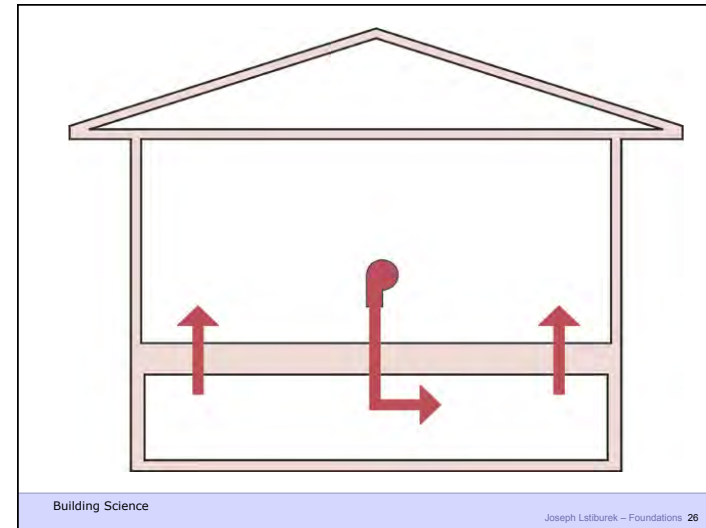
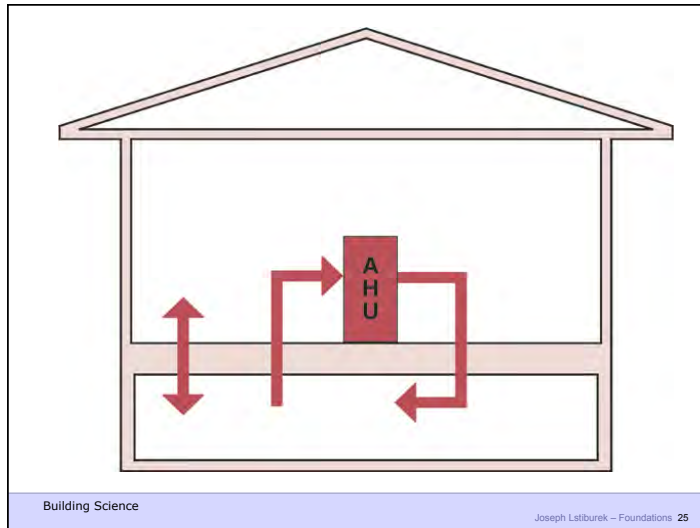


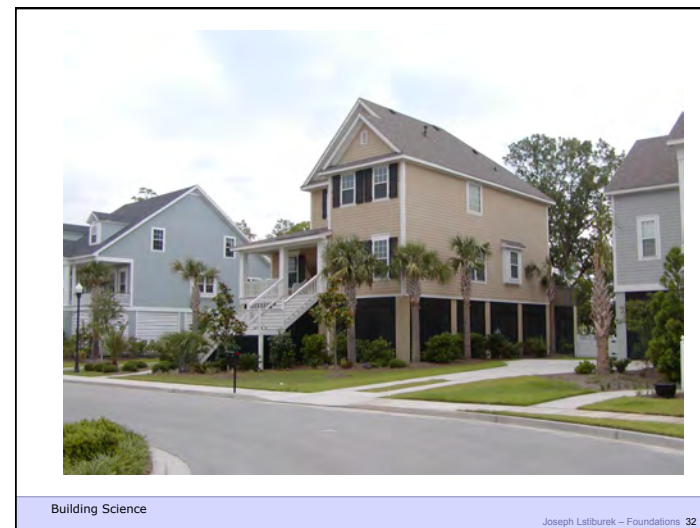
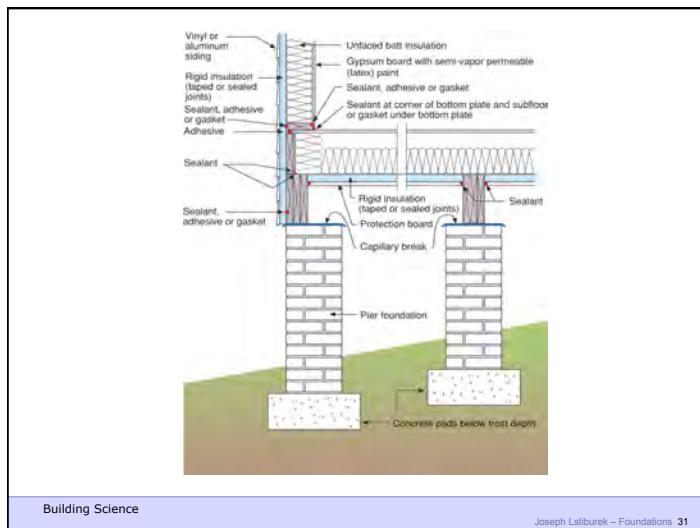
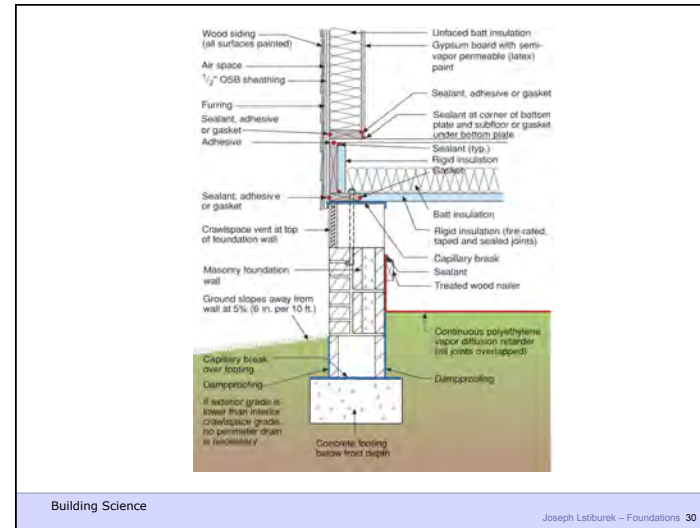
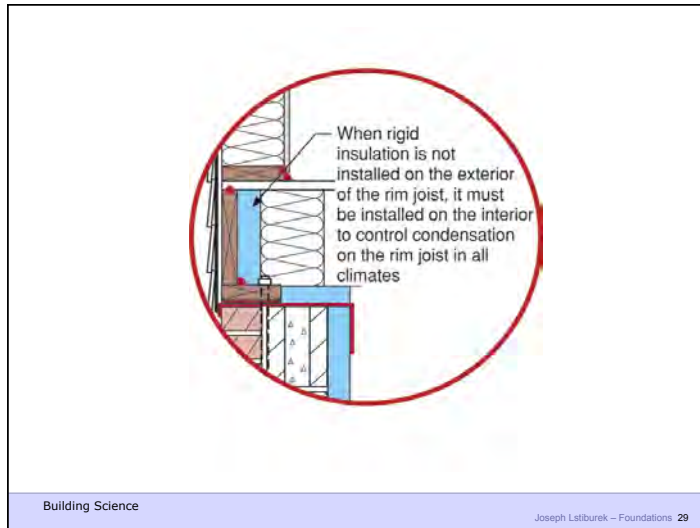
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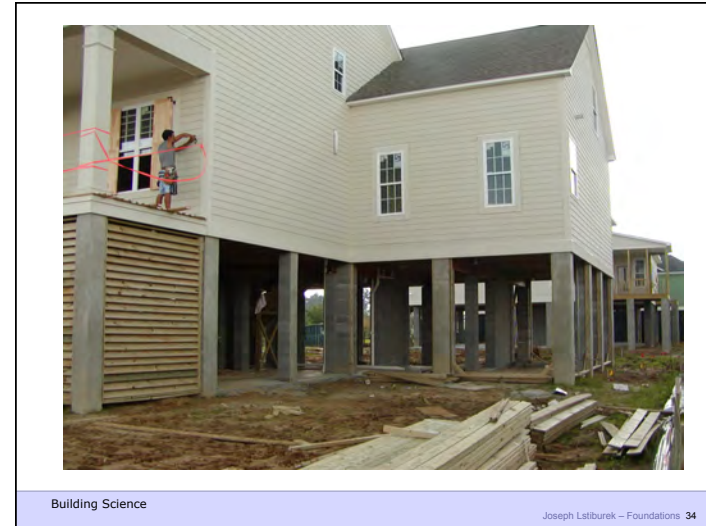
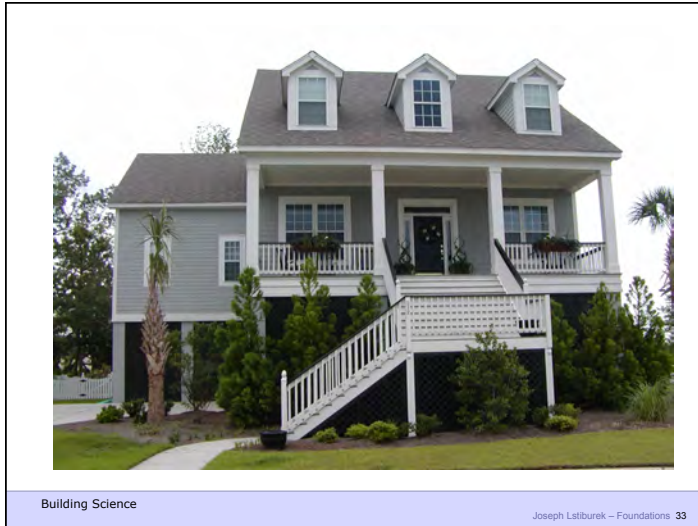
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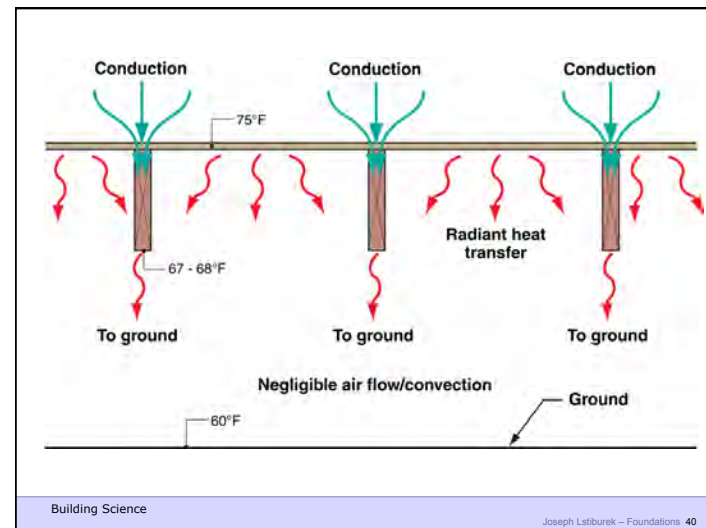
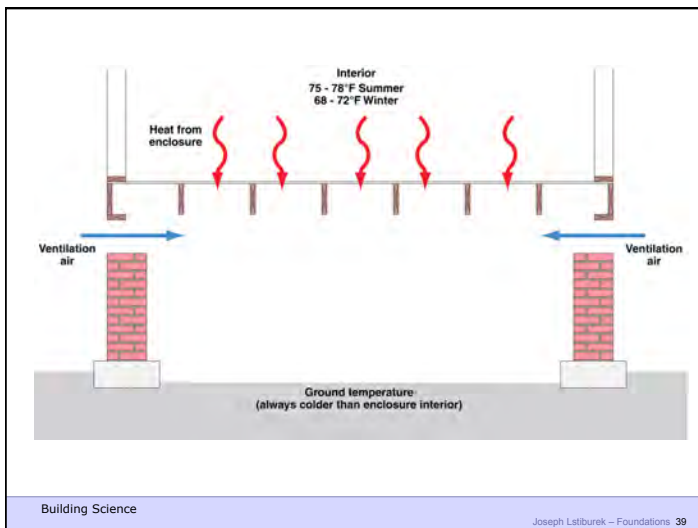
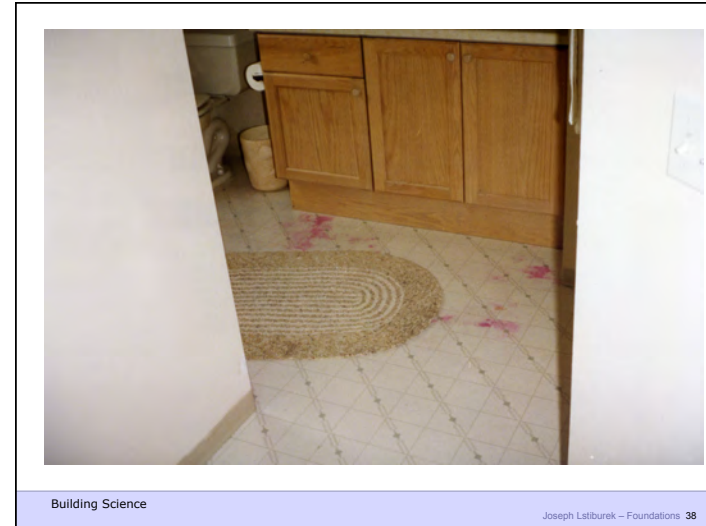


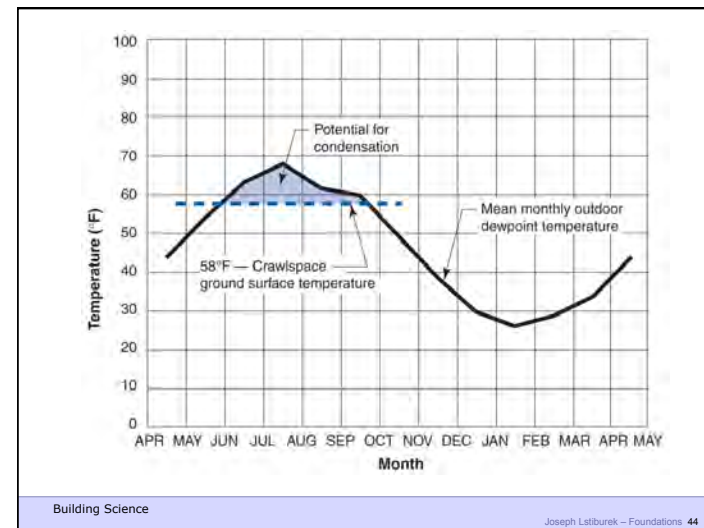
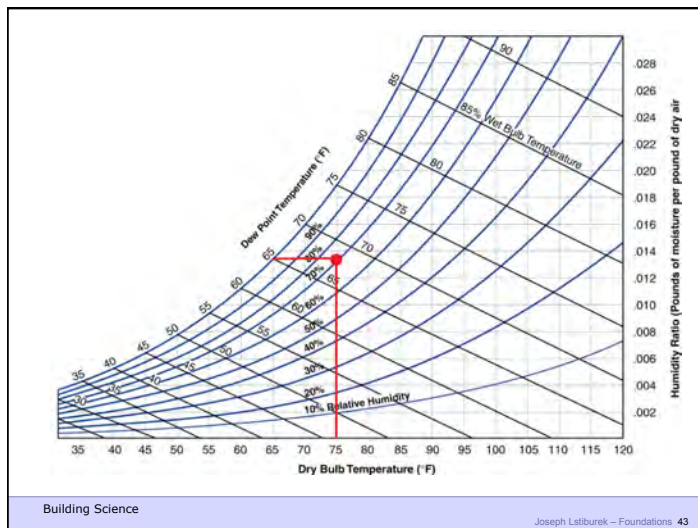
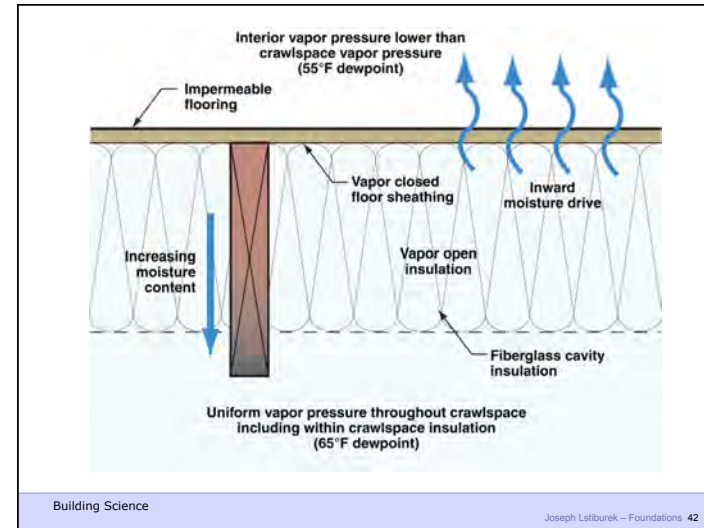
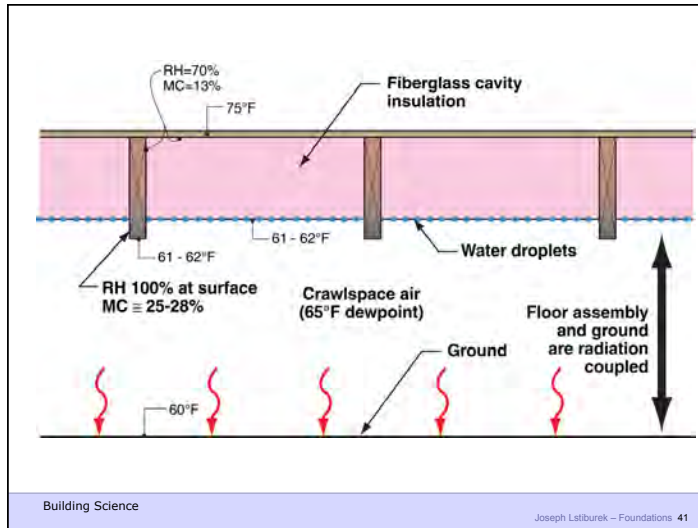


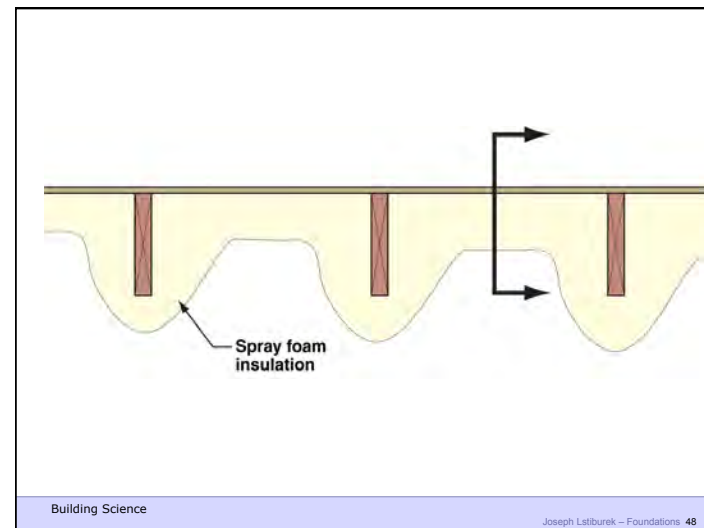
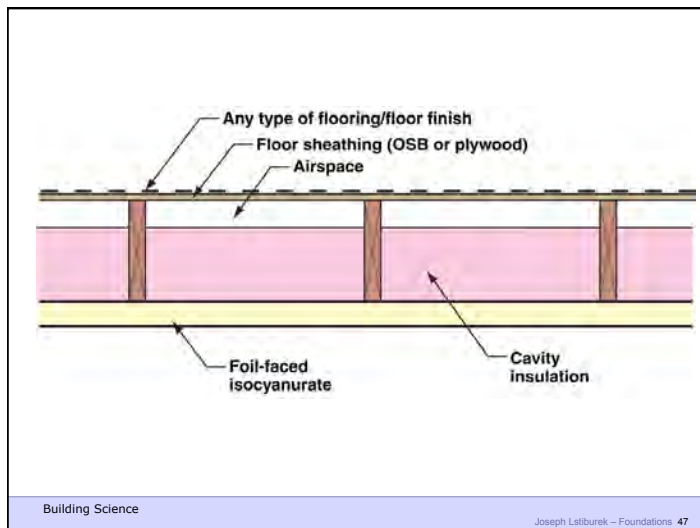
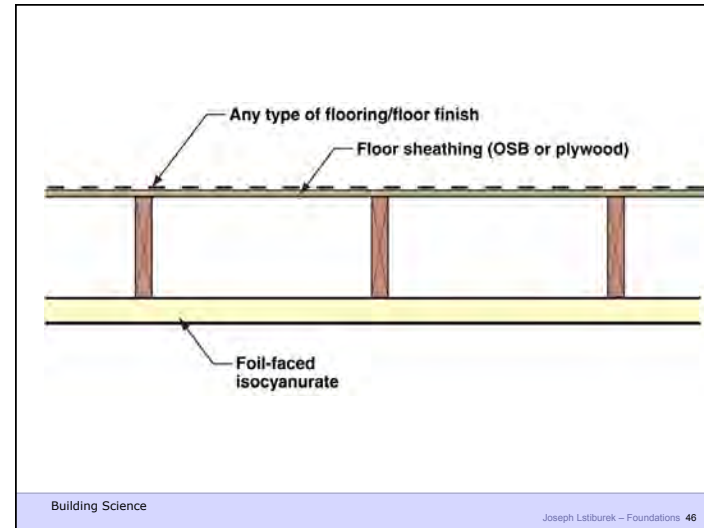
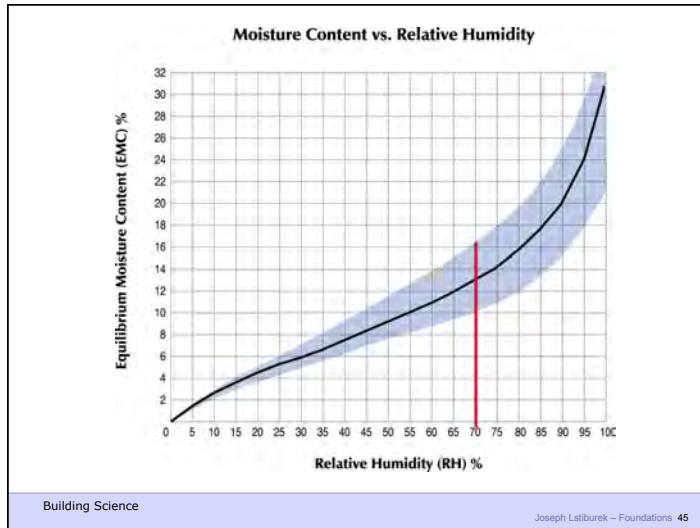


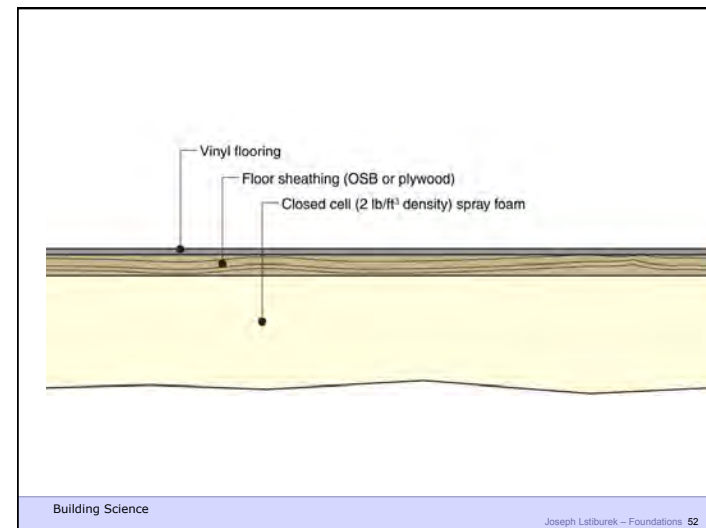
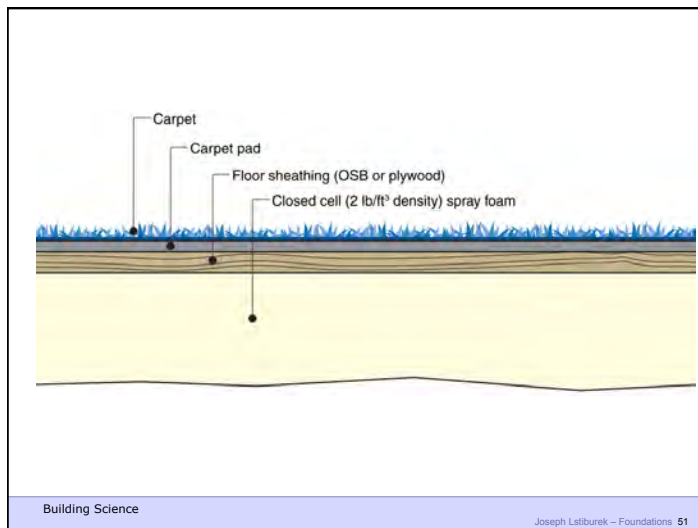
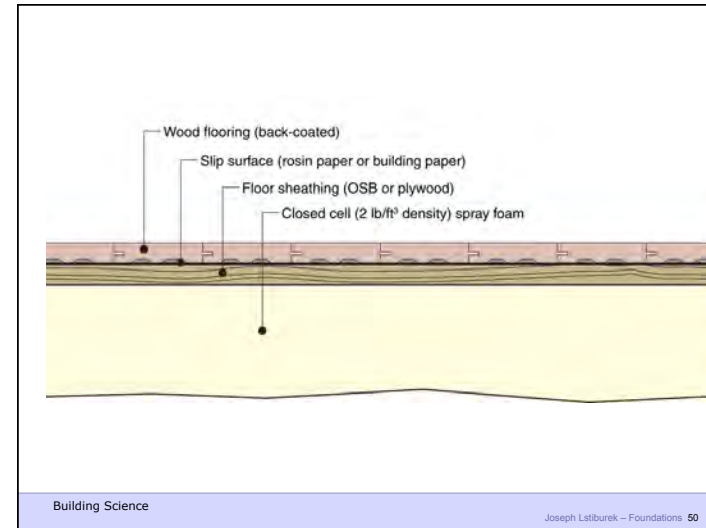
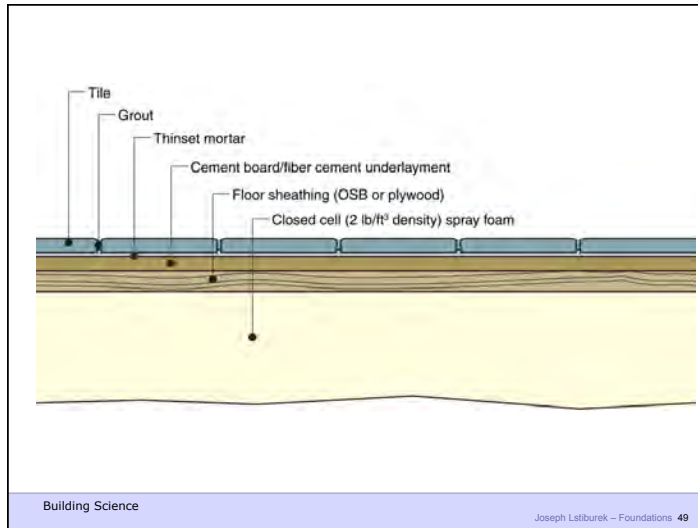


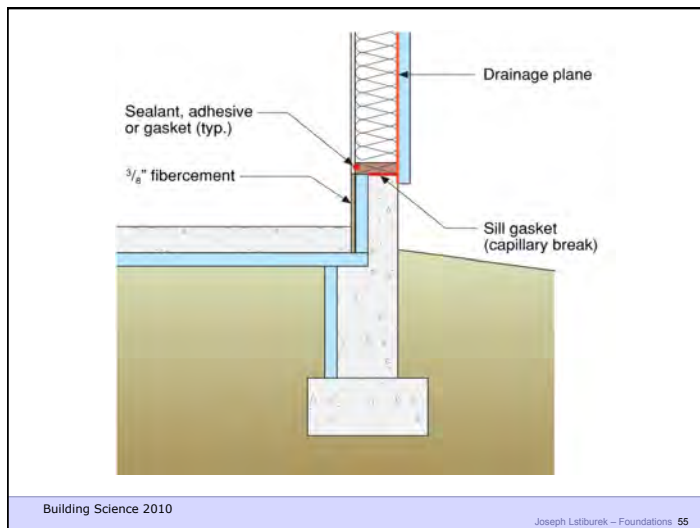
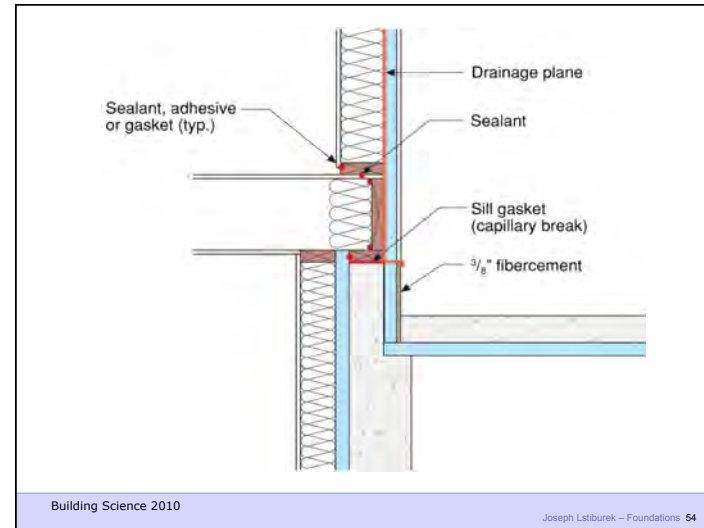
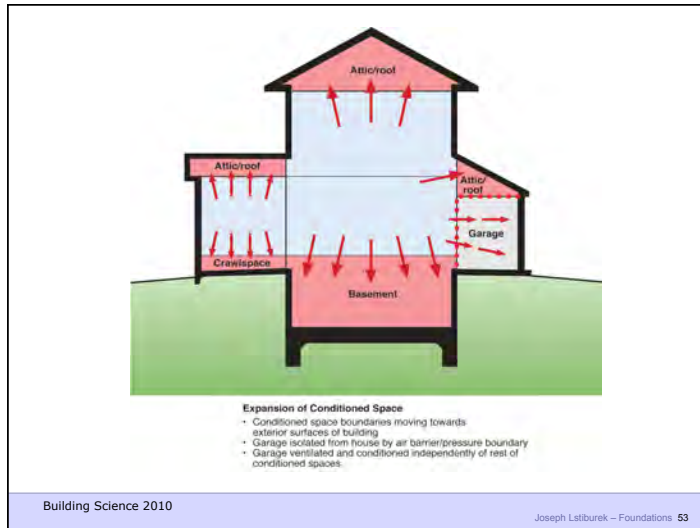












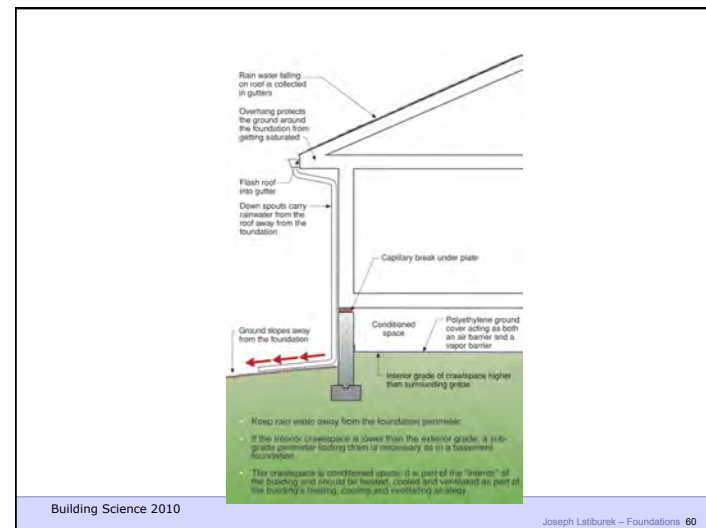
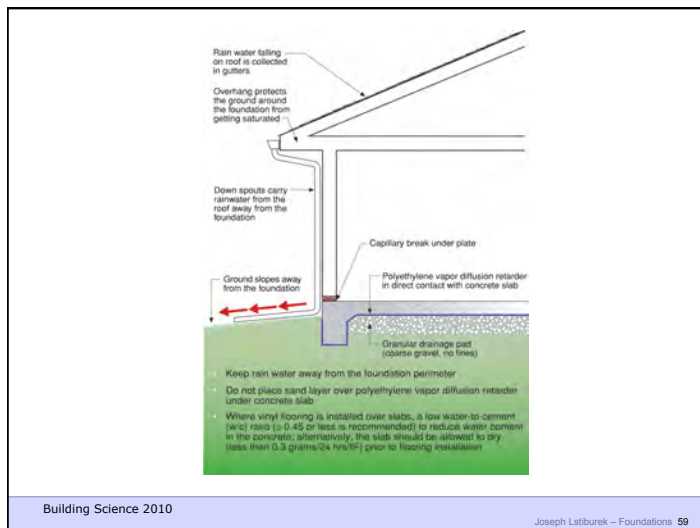
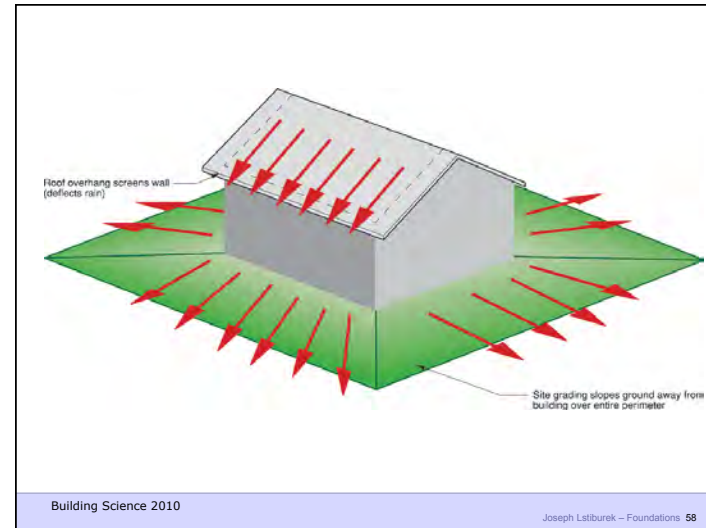
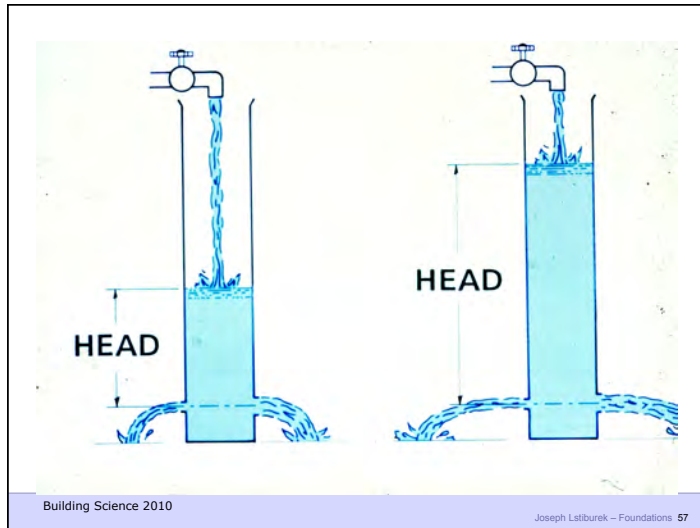
Mechanisms of Flow

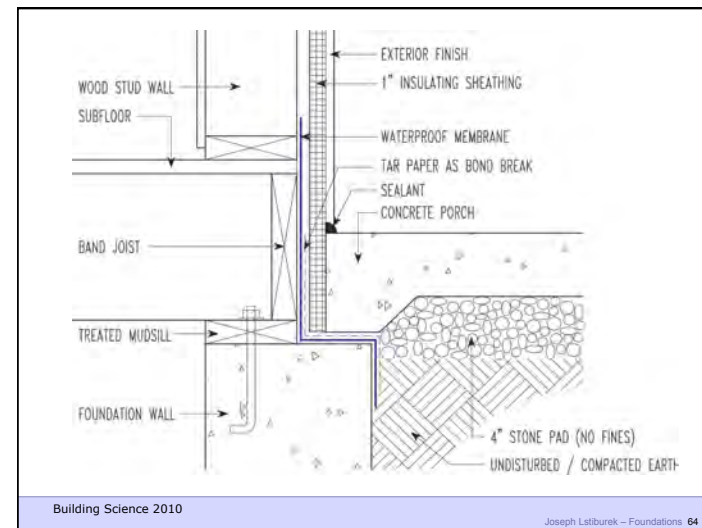
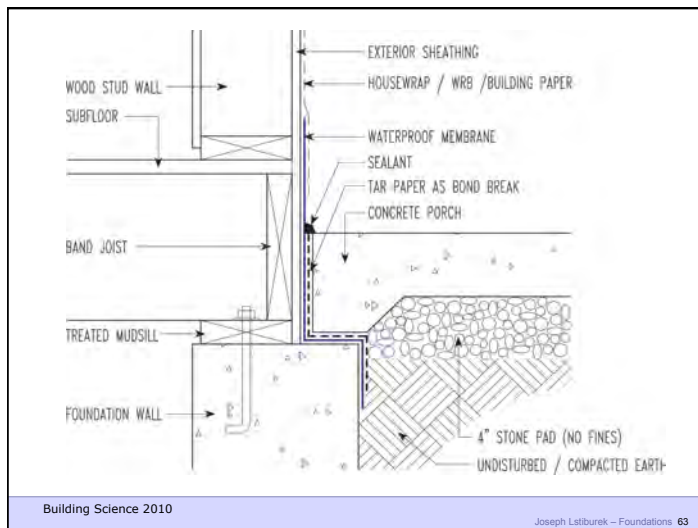
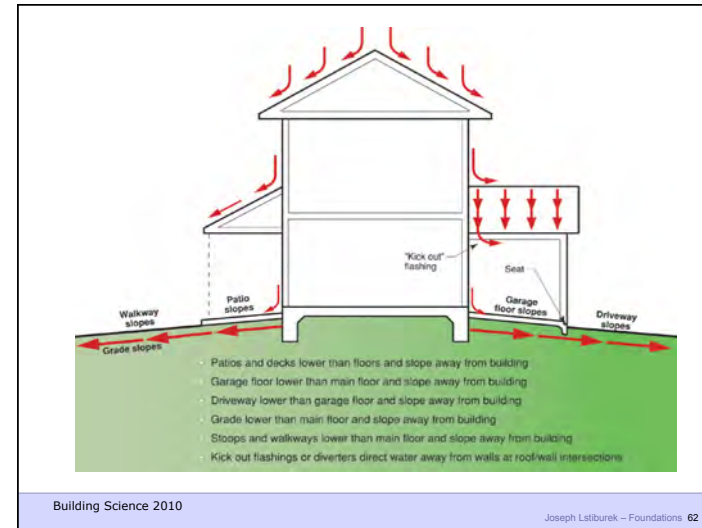
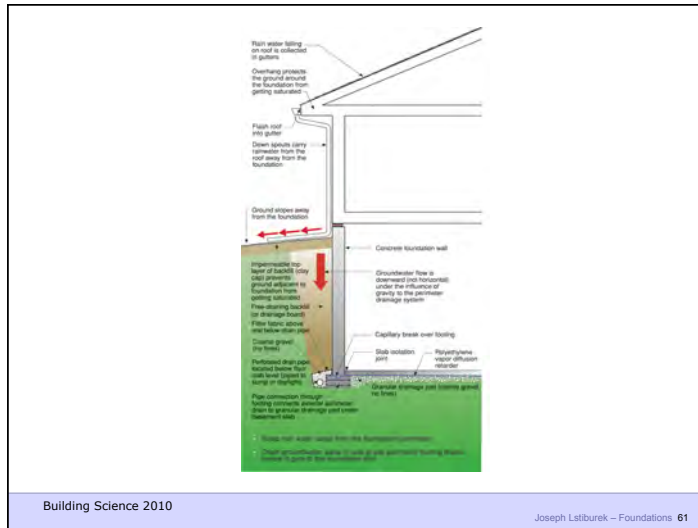
- Liquid

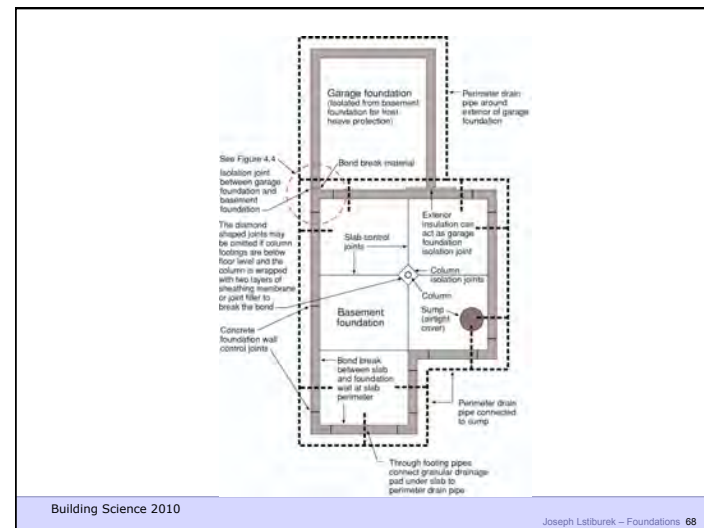
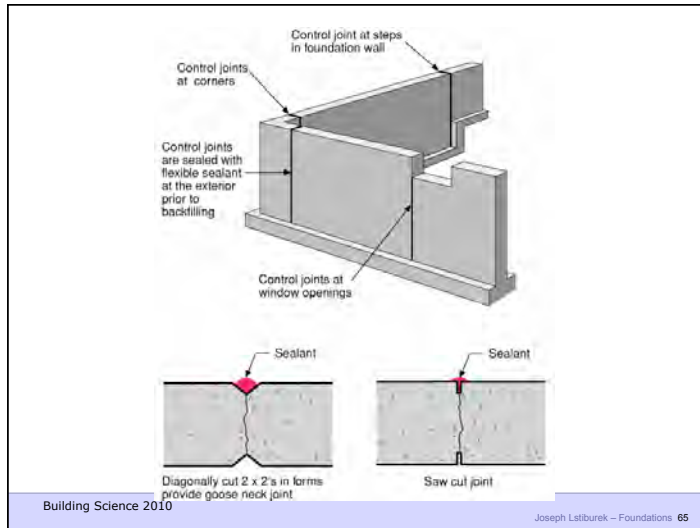
Bulk	Hydrostatic Pressure
Capillary	Concentration Gradient
Osmosis	Concentration Gradient
- Vapor

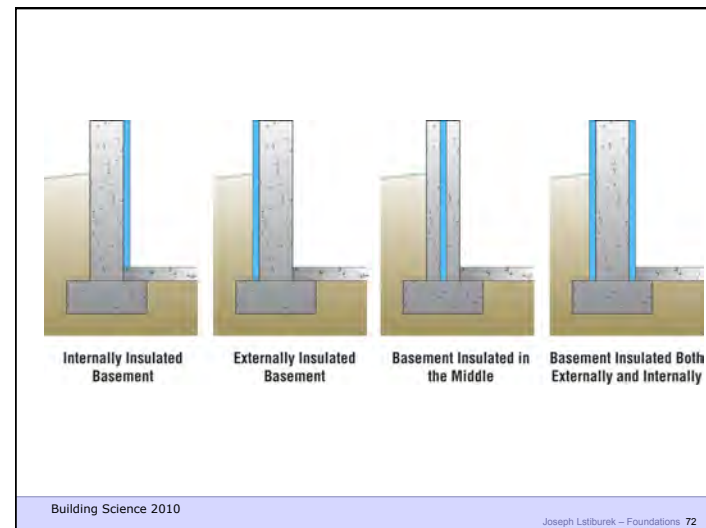
Diffusion	Vapor Pressure
Air Transport	Air Pressure

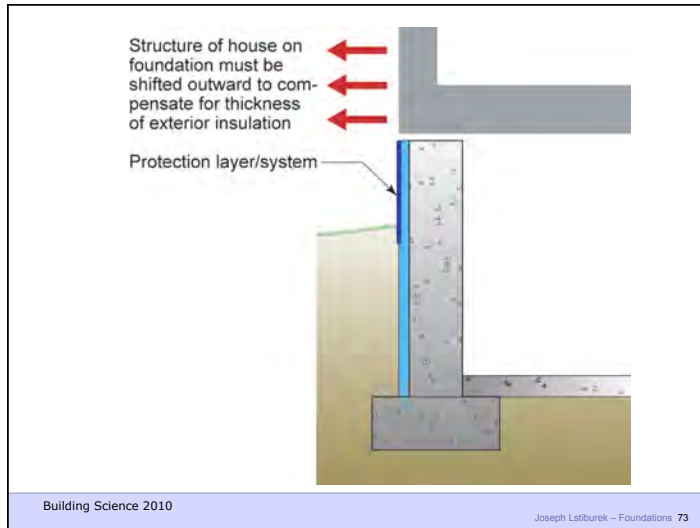
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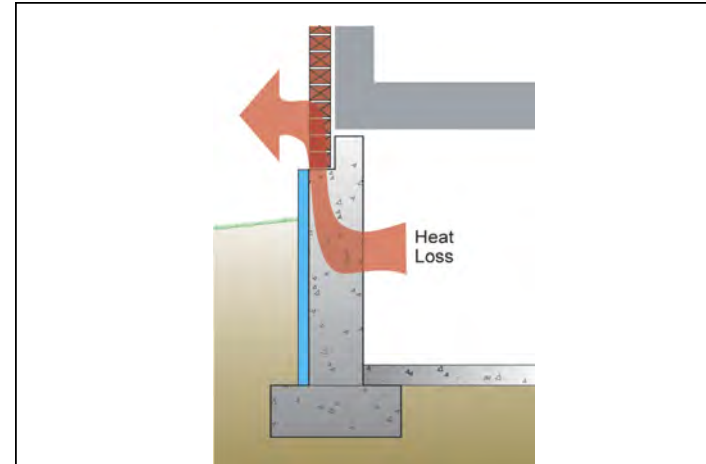






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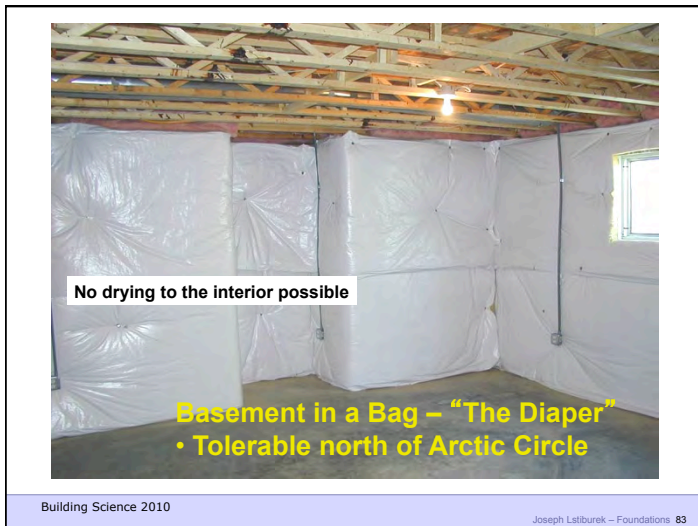
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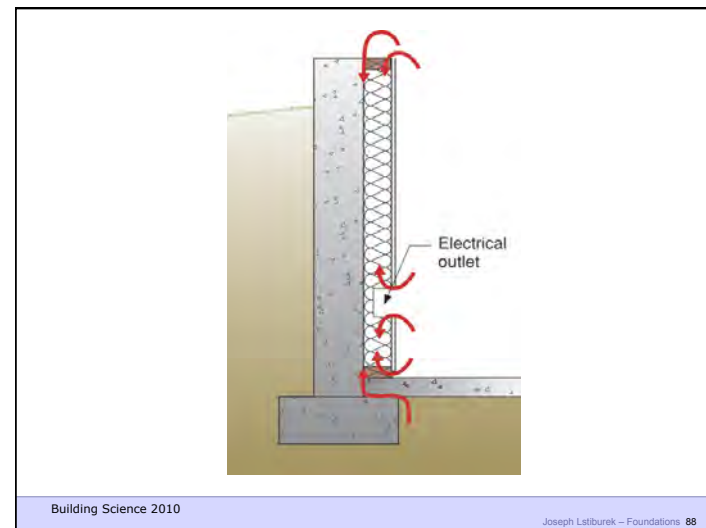
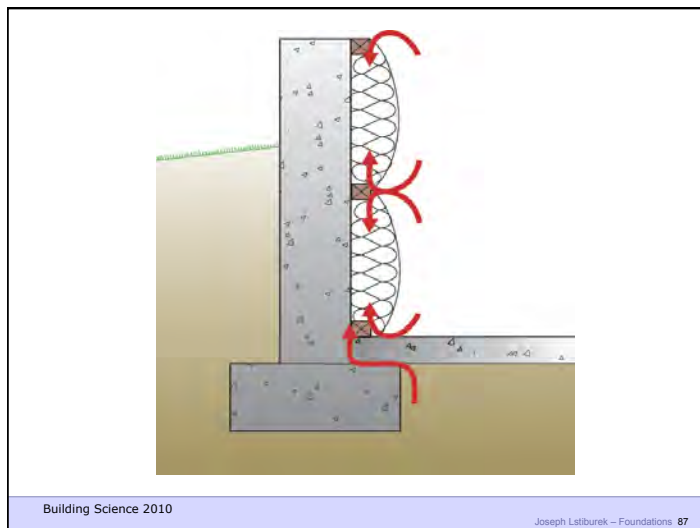
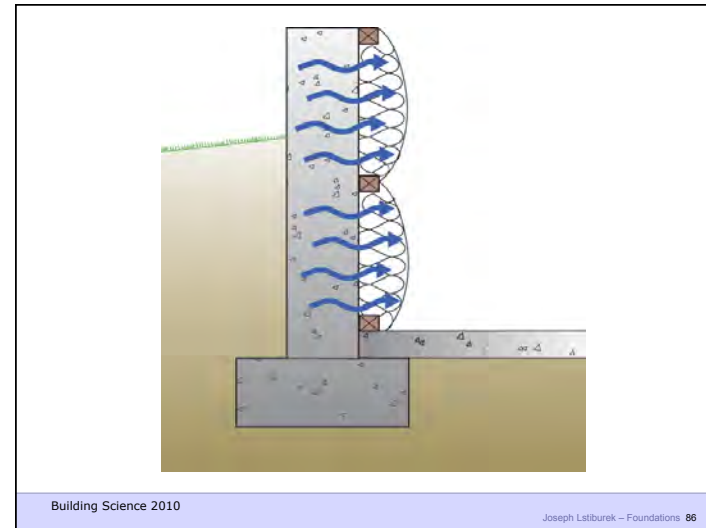
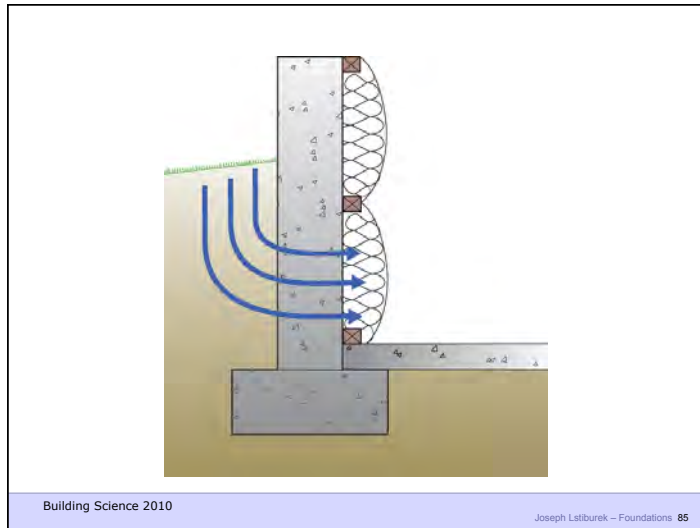
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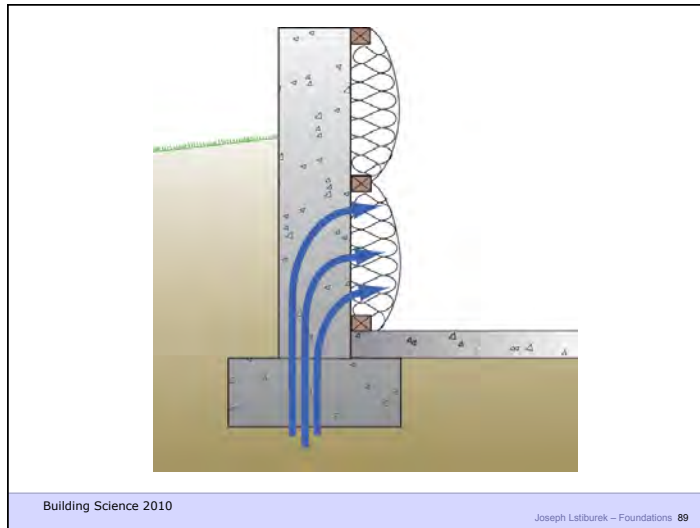


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Surface Tension: Wettable

Water attracted to surface more than self

$\theta < 90^\circ$

normal material:
"wetable"

Water attracted to self more than surface

$\theta > 90^\circ$

hydrophobically treated:
"non-wetable"

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Capillary Pressures

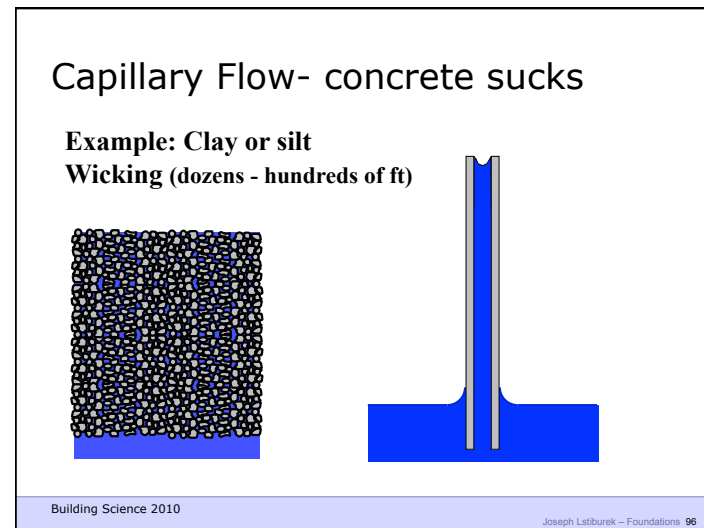
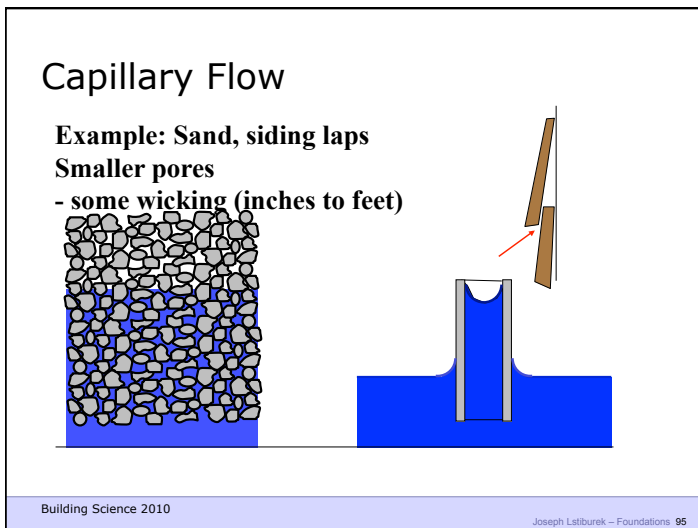
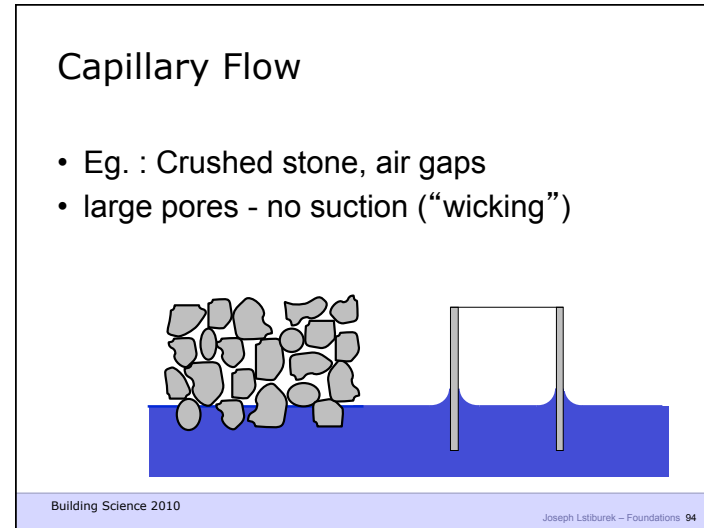
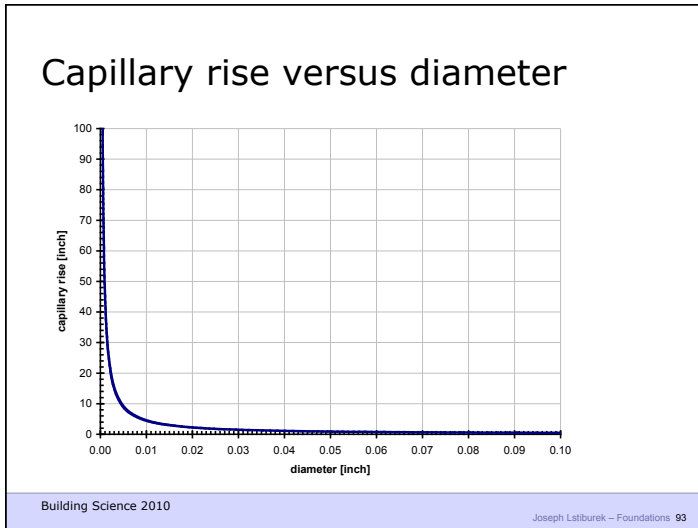
- Result of surface tension = attraction to surfaces
 - pressure varies with pore size
 - e.g., height rise in a glass tube

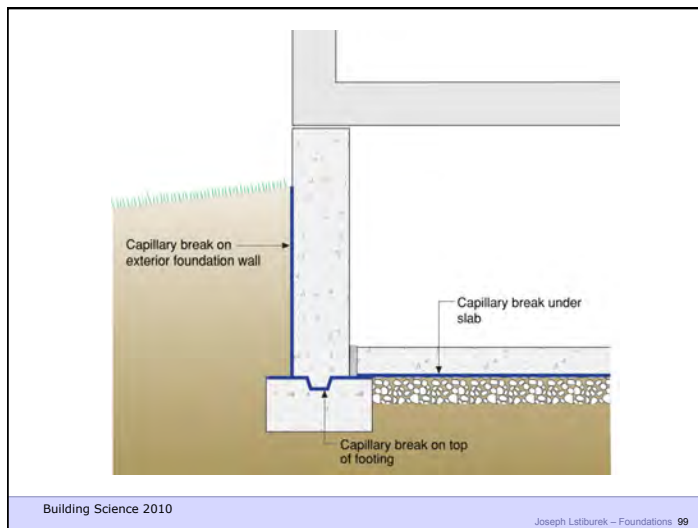
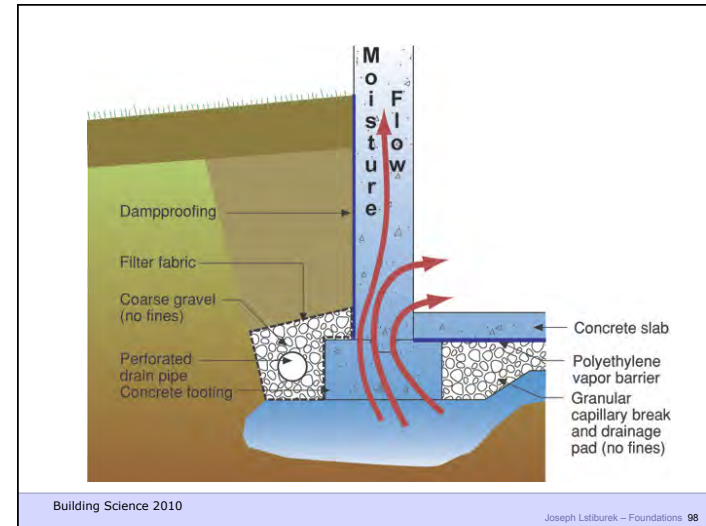
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Calculating capillary rise

$$h = \frac{2 \sigma \cos \theta}{g \rho r}$$

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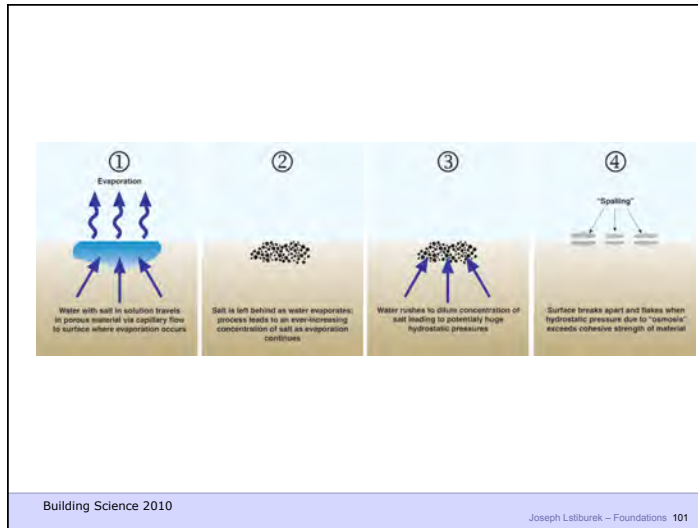


Capillarity + Salt = Osmosis

- Mineral salts carried in solution by capillary water
- When water evaporates from a surface the salts left behind form crystals in process called efflorescence
- When water evaporated beneath a surface the salts crystallize within the pore structure of the material in called sub-efflorescence
- The salt crystallization causes expansive forces that can exceed the cohesive strength of the material leading to spalling

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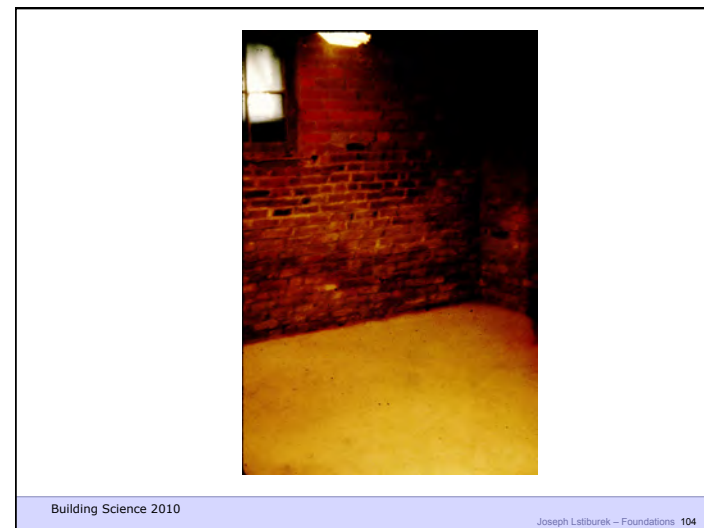
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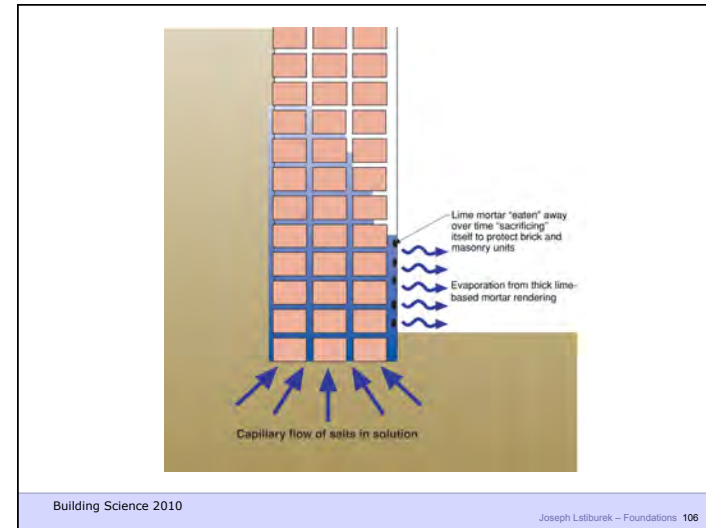
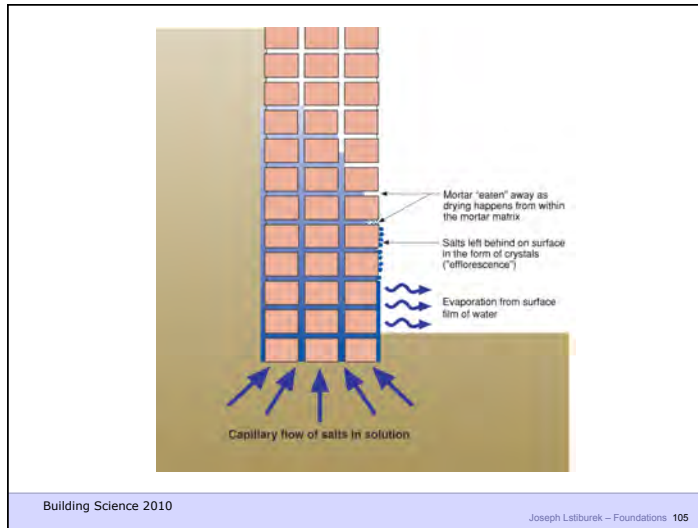


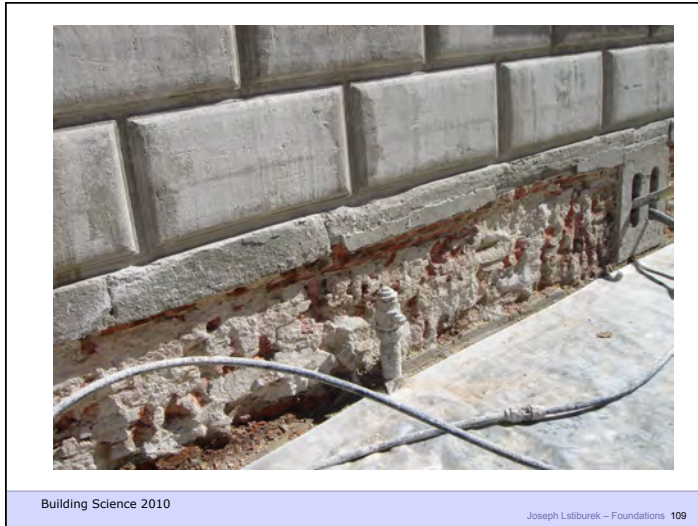
Diffusion + Capillarity + Osmosis = Problem

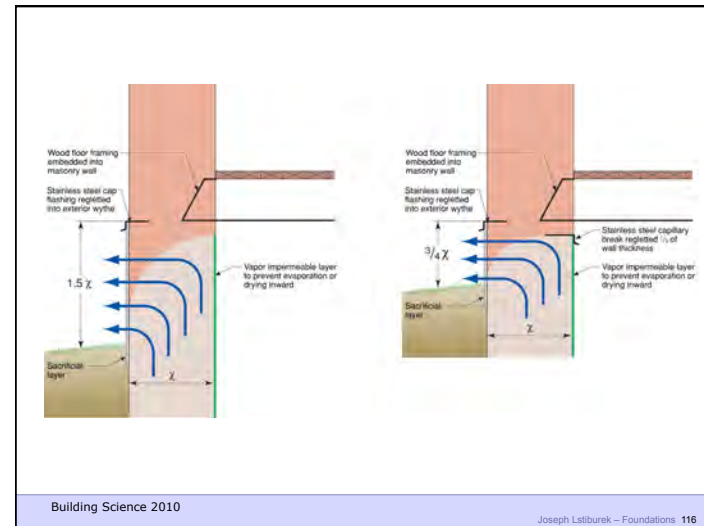
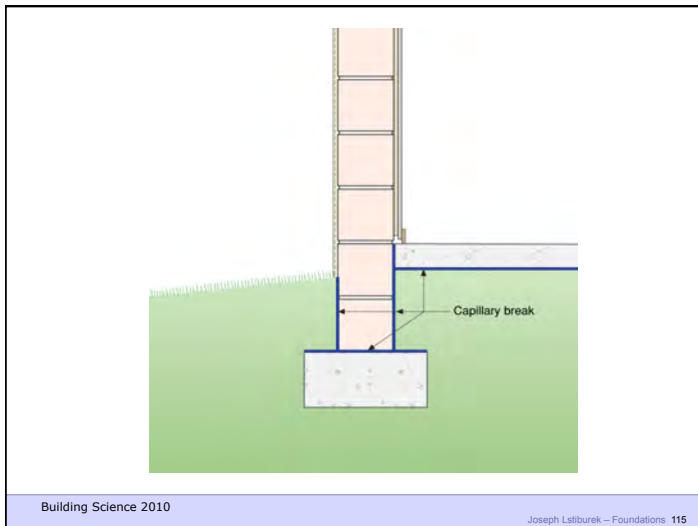
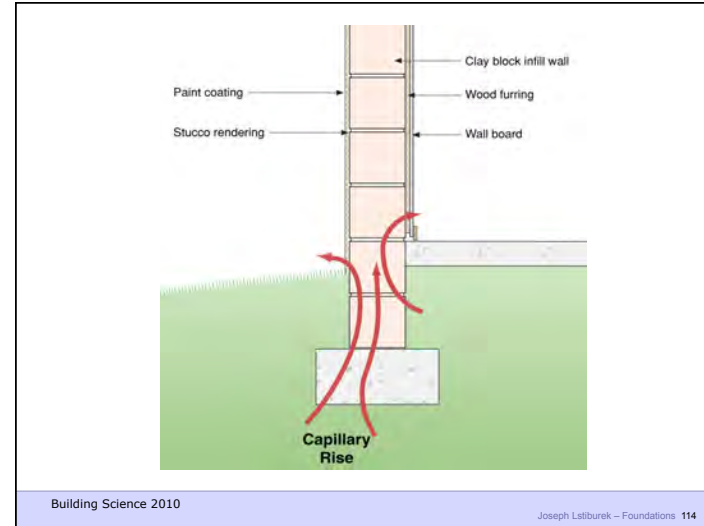
- Diffusion Vapor Pressure 3 to 5 psi
- Capillary Pressure 300 to 500 psi
- Osmosis Pressure 3,000 to 5,000 psi

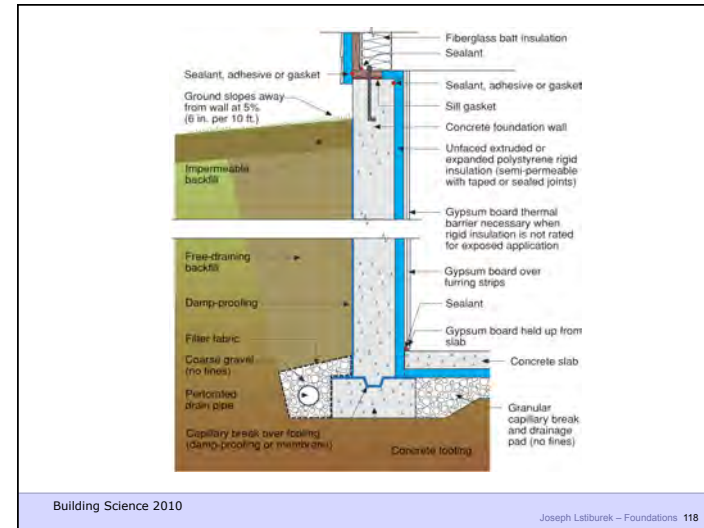
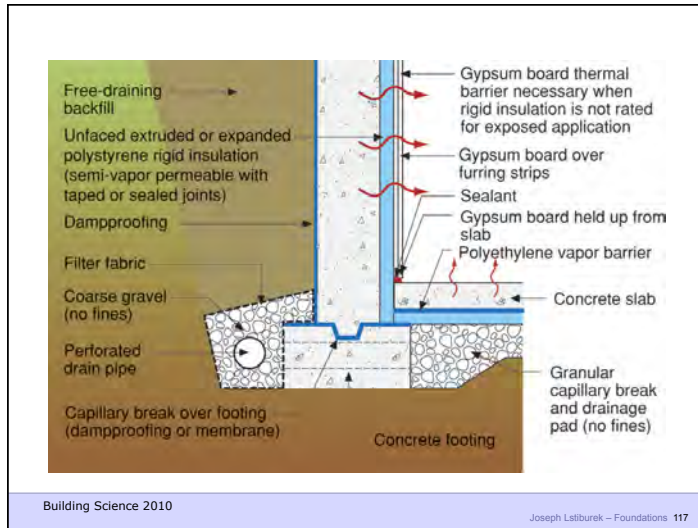
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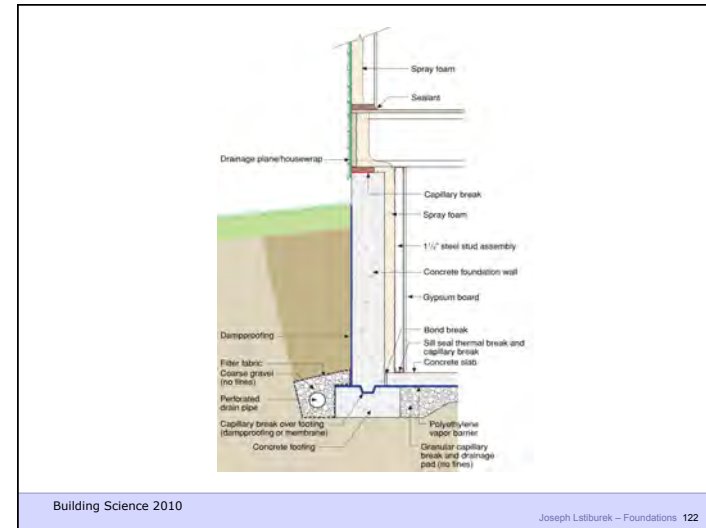
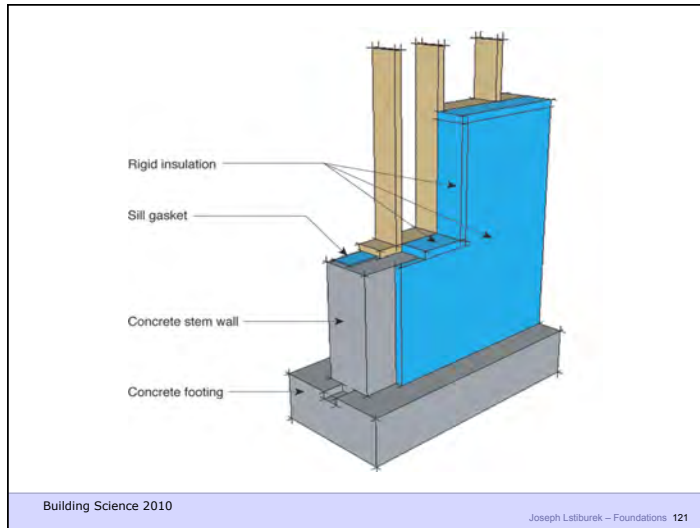


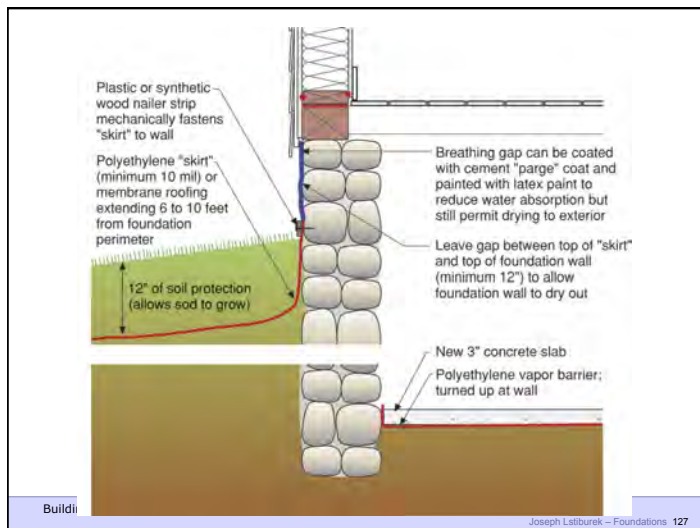


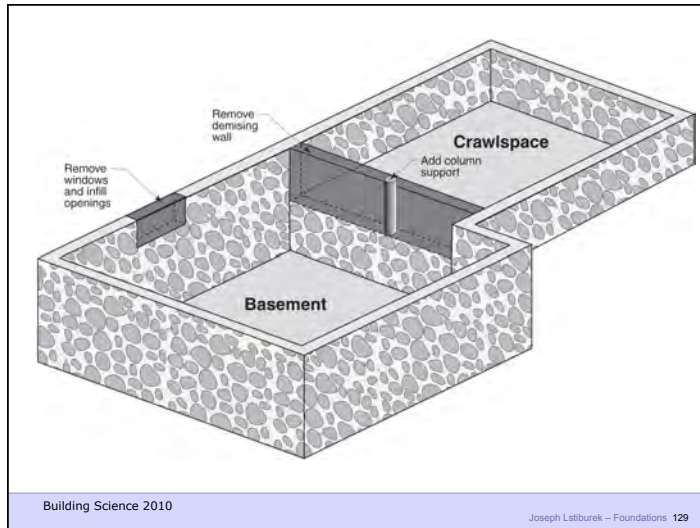


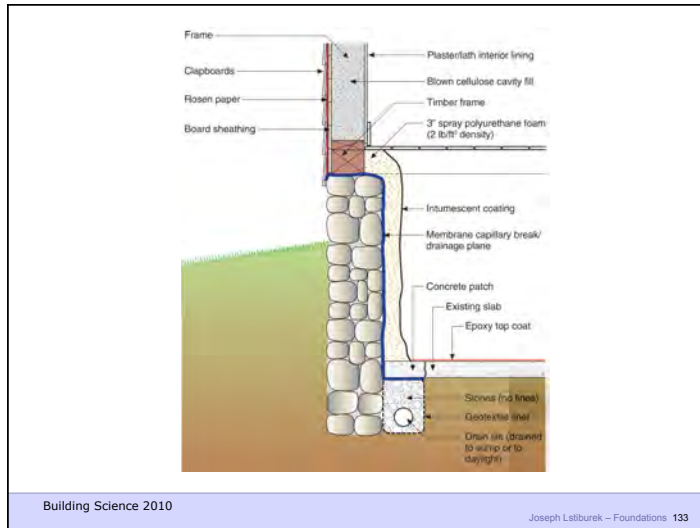


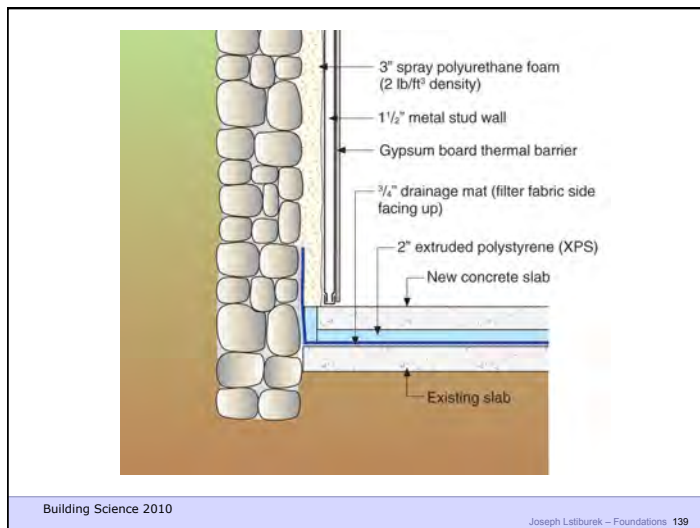






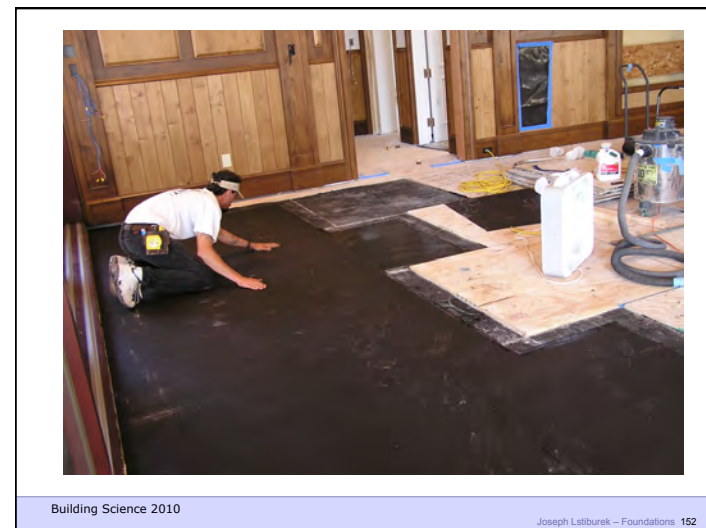
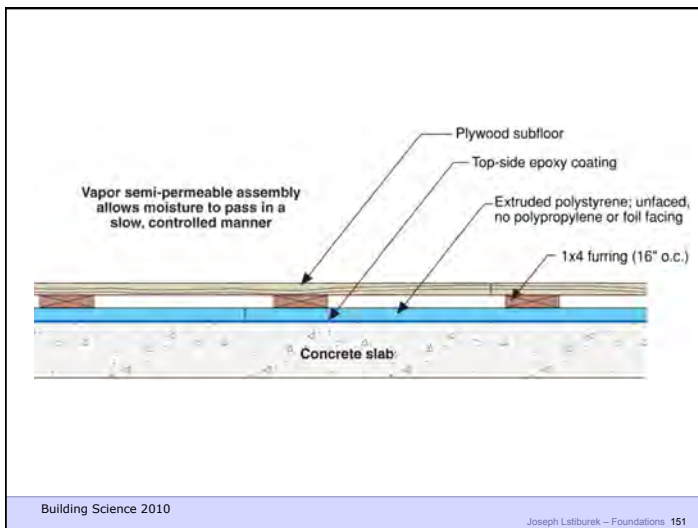


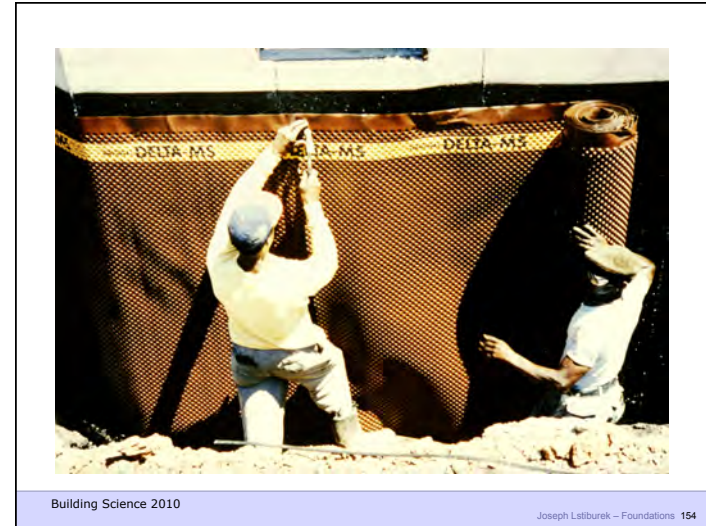
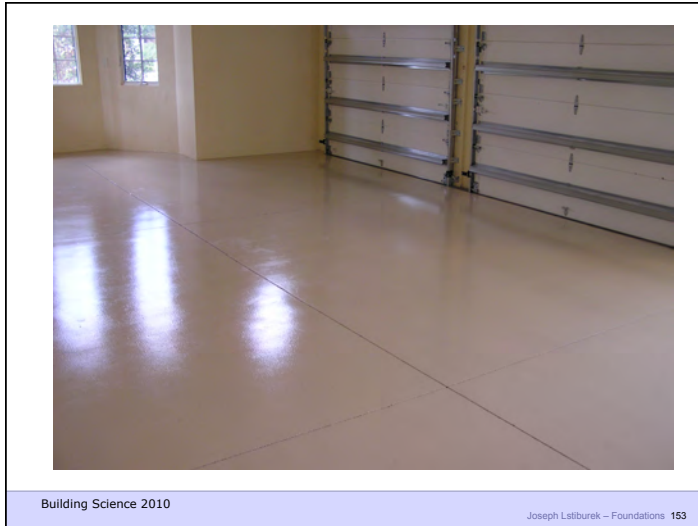


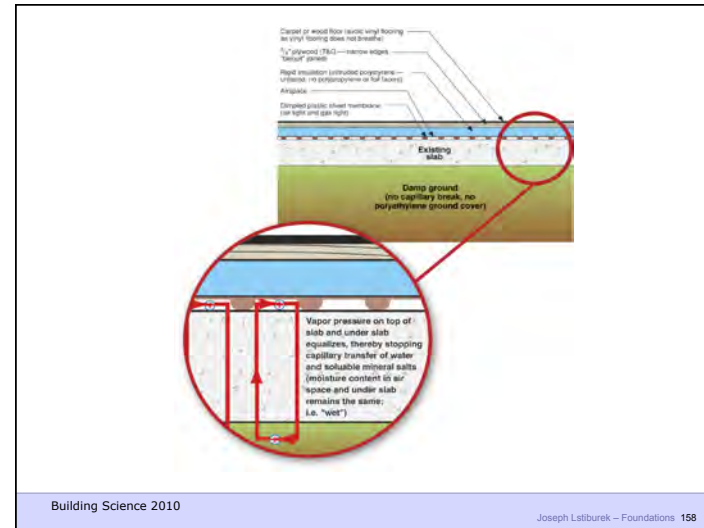


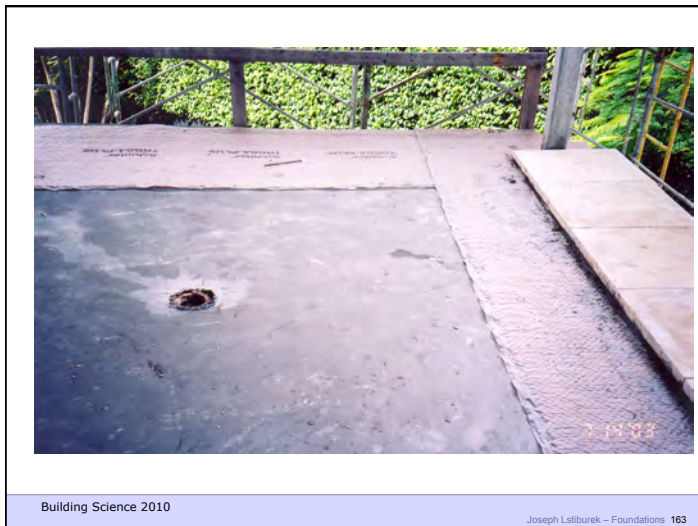
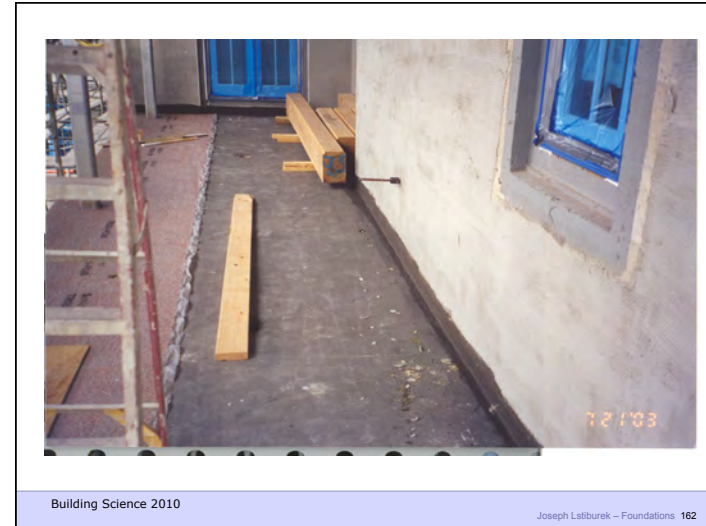














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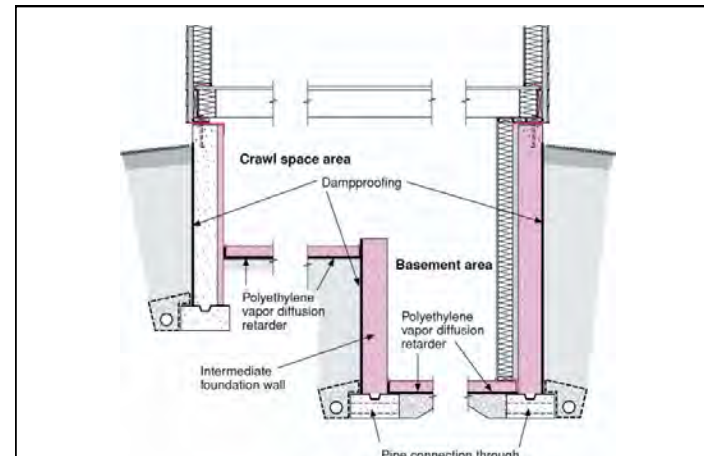
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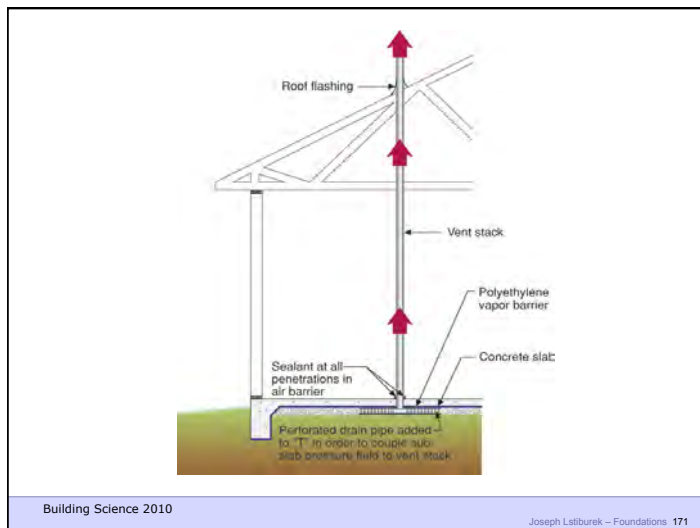
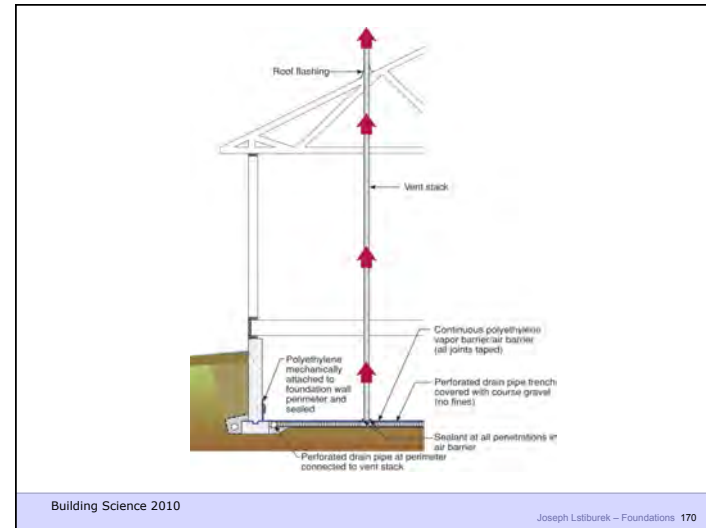
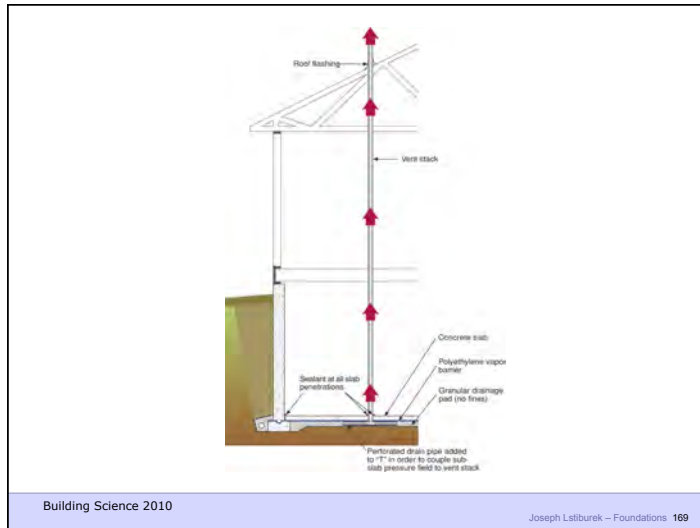
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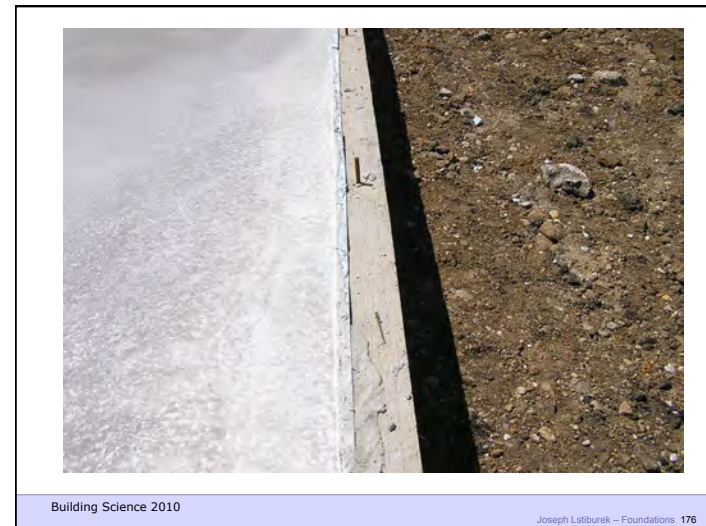
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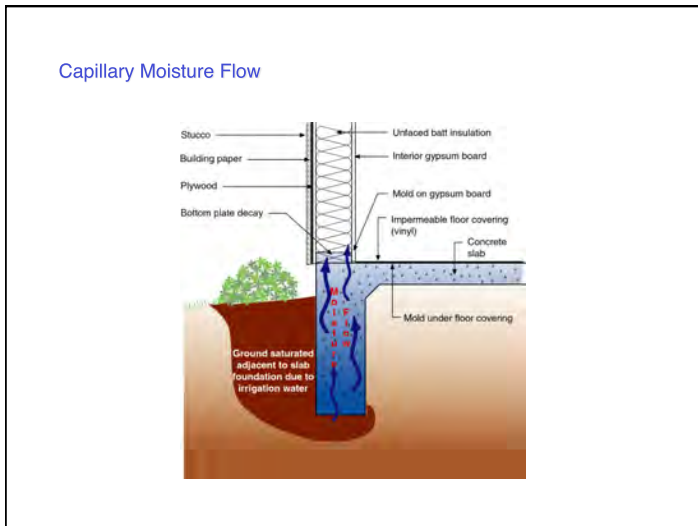
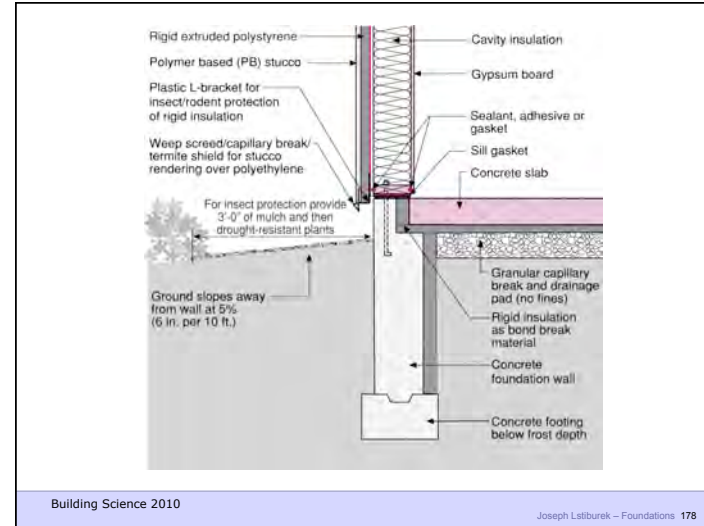


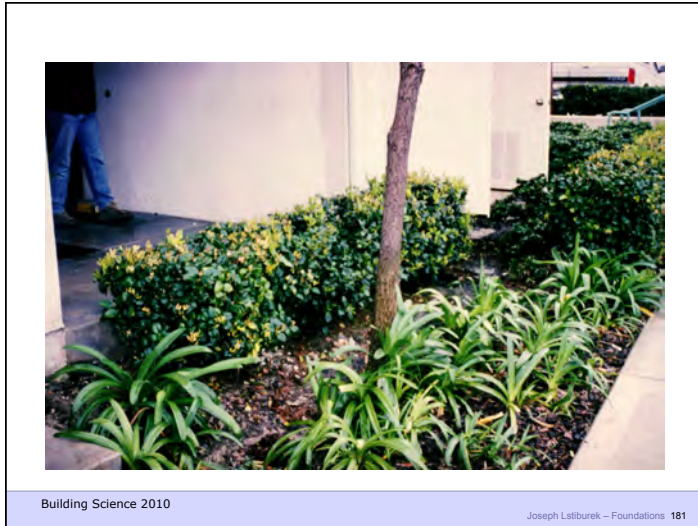
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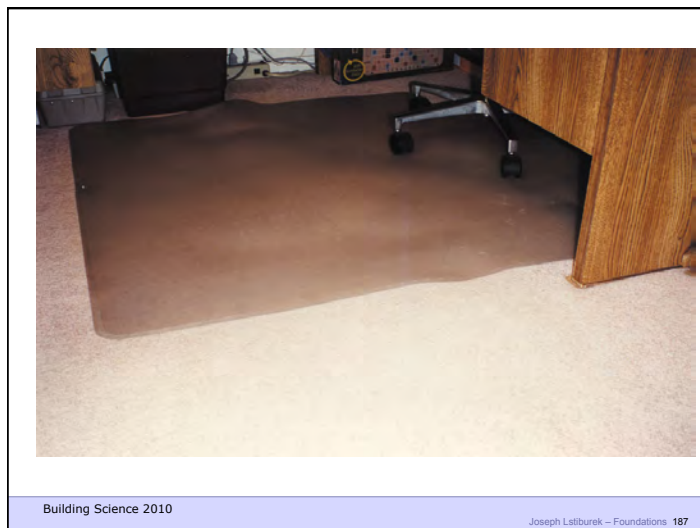
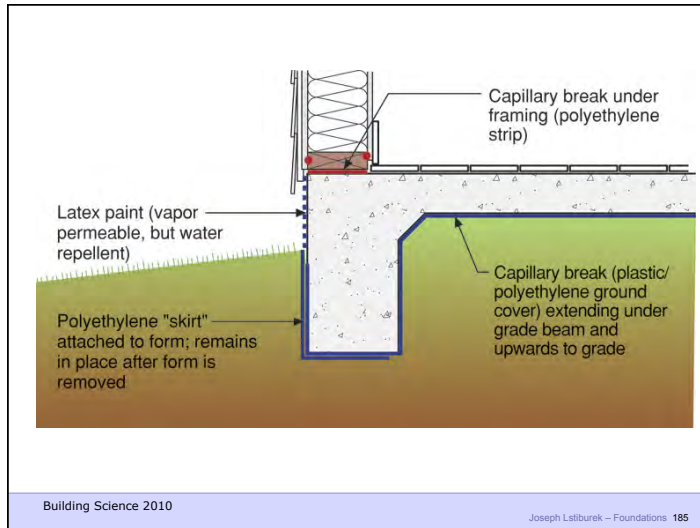
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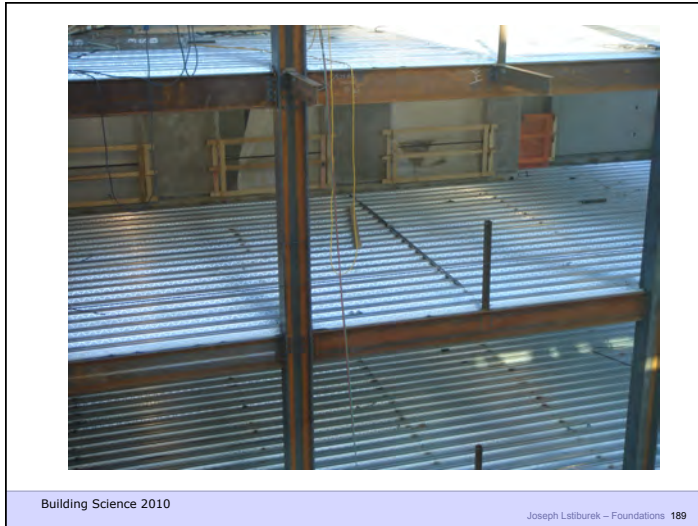






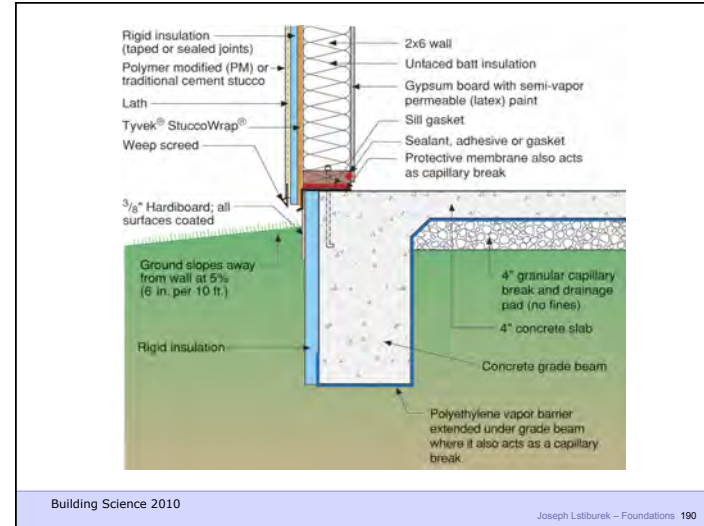






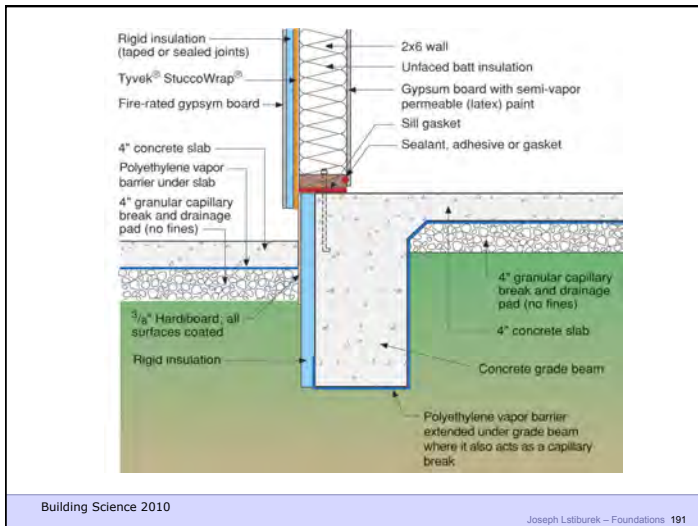
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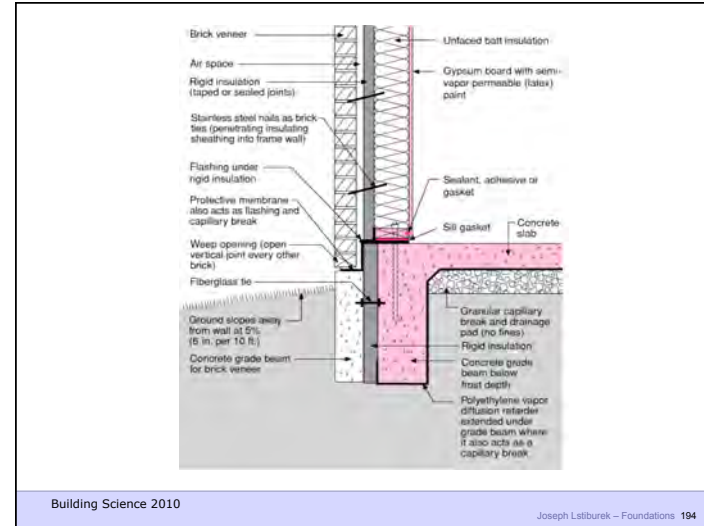
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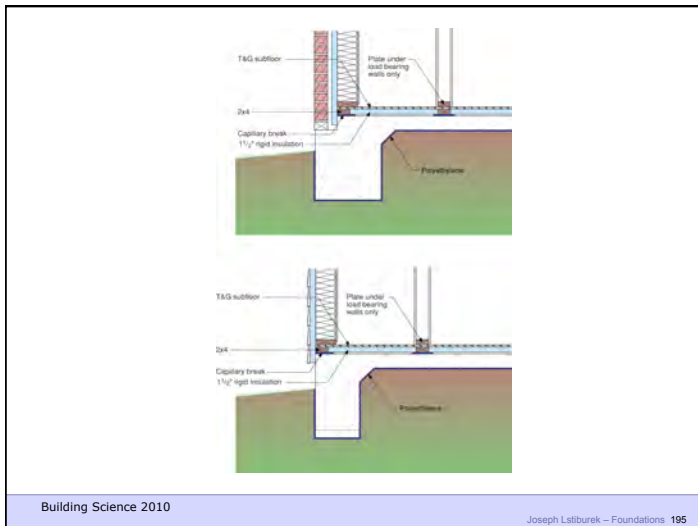
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