

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

Building Science

Adventures In Building Science

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Ventilation In Houses

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Build Tight - Ventilate Right

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Build Tight - Ventilate Right

How Tight?

What's Right?

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Air Barrier Metrics

Material 0.02 l/(s-m2) @ 75 Pa
 Assembly 0.20 l/(s-m2) @ 75 Pa
 Enclosure 2.00 l/(s-m2) @ 75 Pa
 0.25 cfm/ft2 @ 50 Pa

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Getting rid of big holes 3 ach@50
 Getting rid of smaller holes 1.5 ach@50
 Getting German 0.6 ach@50

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Best

As Tight as Possible - with -
 Balanced Ventilation
 Energy Recovery
 Distribution and Mixing
 Source Control - Spot exhaust ventilation
 Filtration
 Material selection

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Worst

Leaky - with – Nothing
 Spot Ventilation in Bathroom/Kitchen
 Exhaust Ventilation – with – No Distribution
 and No Mixing

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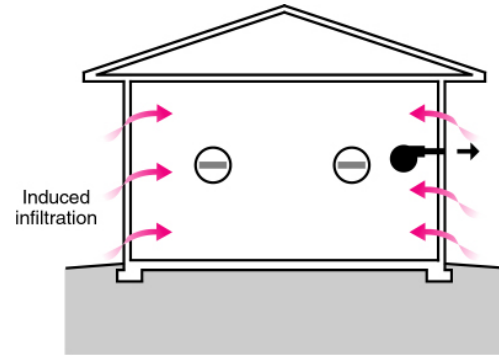
Three Types of Controlled Ventilation Systems

- Exhaust Ventilation
- Supply Ventilation
- Balanced Ventilation

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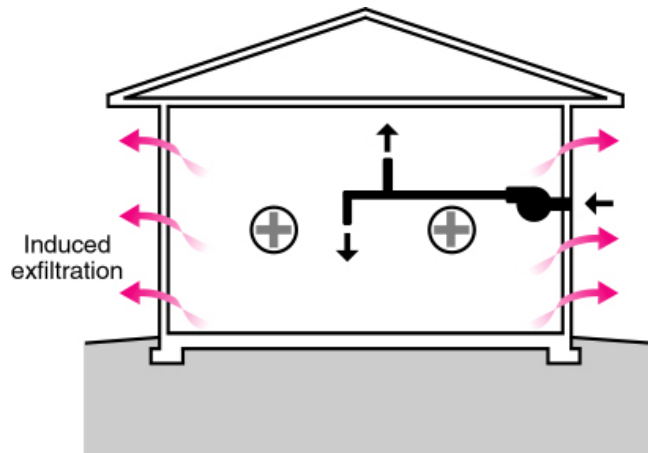
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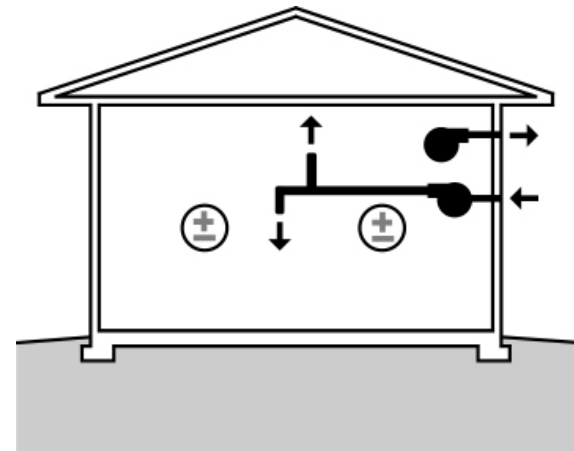
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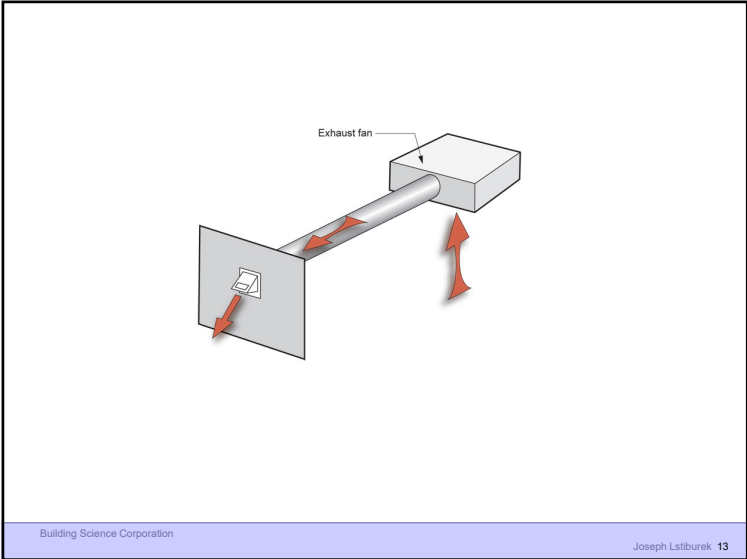
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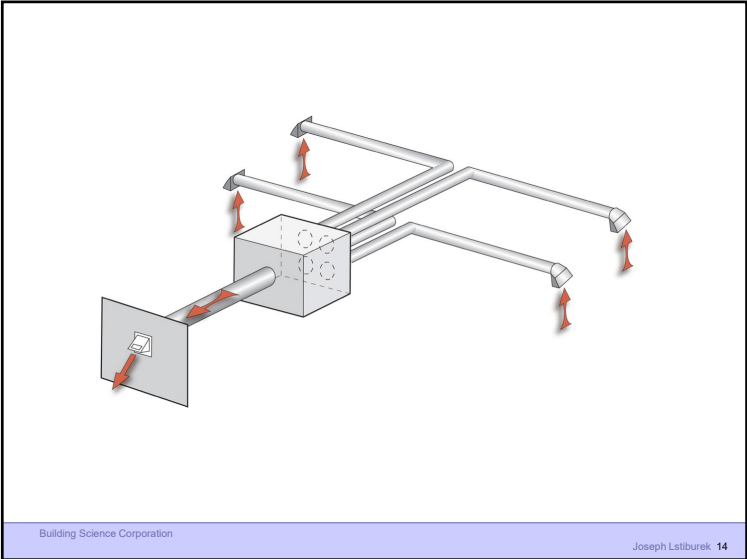
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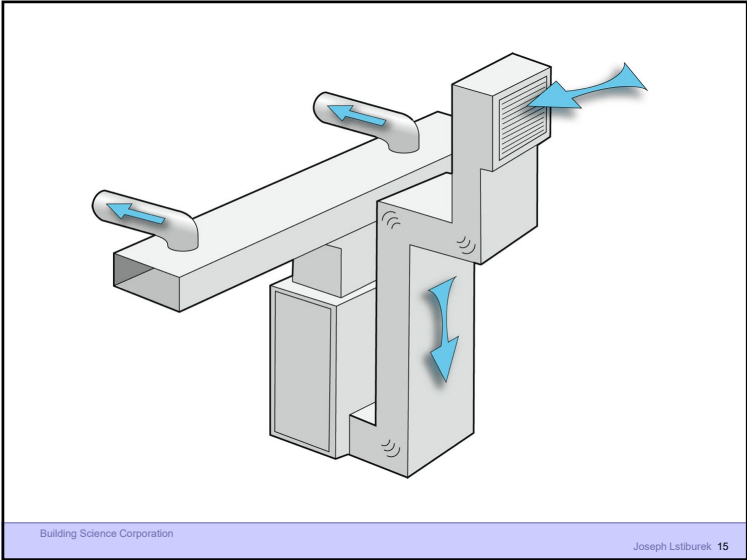
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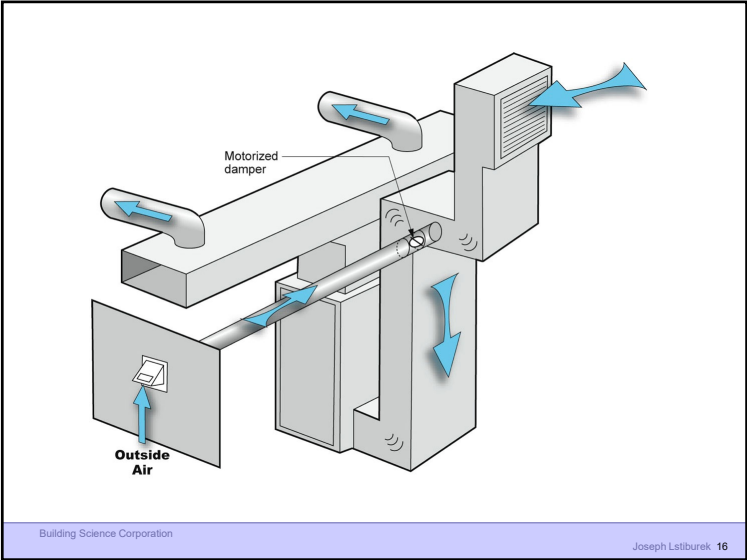
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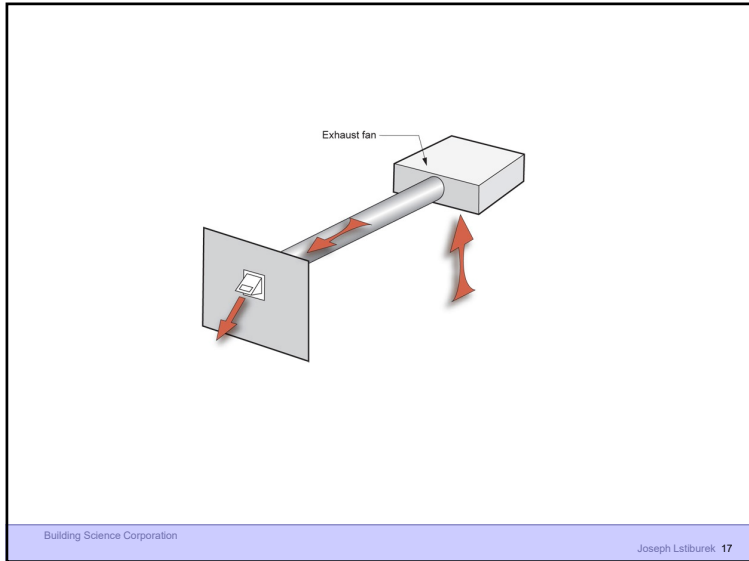
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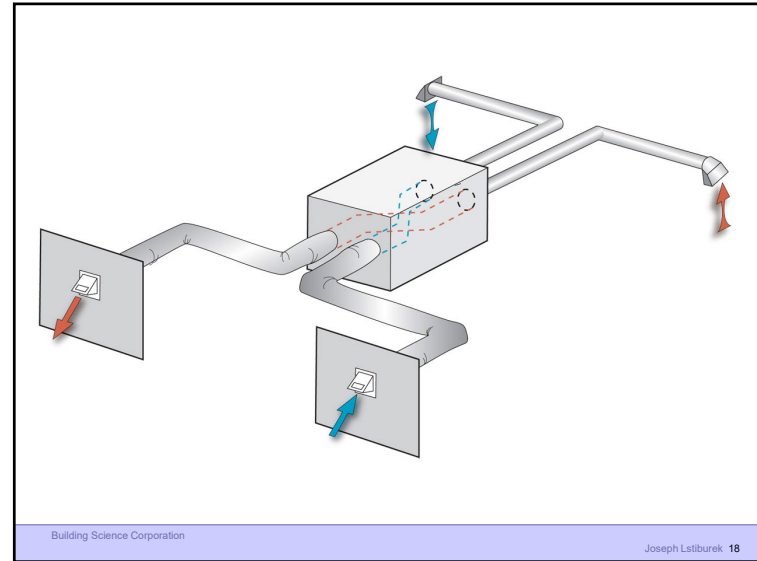
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Ventilation Rates Are Based on Odor Control

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Ventilation Rates Are Based on Odor Control
Health Science Basis for Ventilation Rates is Extremely Limited

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Ventilation Rates Are Based on Odor Control
 Health Science Basis for Ventilation Rates is
 Extremely Limited
 Almost Nothing Cited Applies to Housing

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Ventilation Rates Are Based on Odor Control
 Health Science Basis for Ventilation Rates is
 Extremely Limited
 Almost Nothing Cited Applies to Housing
 The Applicable Studies Focus on Dampness

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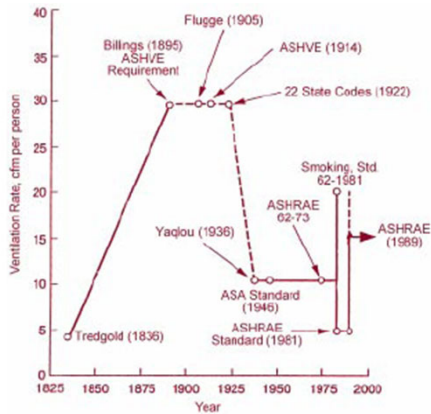


Figure 1: Minimum ventilating rate history.

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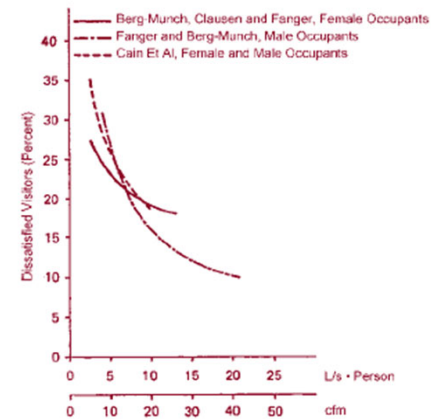


Figure 2: Odor acceptance.

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House
 2,000 ft²
 3 bedrooms
 8 ft. ceiling
 Volume: 16,000 ft³

.35 ach	93 cfm
.30 ach	80 cfm
.25 ach	67 cfm
.20 ach	53 cfm
.15 ach	40 cfm

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House
 2,000 ft²
 3 bedrooms
 8 ft. ceiling
 Volume: 16,000 ft³

.35 ach	93 cfm	62 - 73	5 cfm/person	20 cfm
.30 ach	80 cfm		10 cfm/person	40 cfm
.25 ach	67 cfm	62 - 89	15 cfm/person	60 cfm
.20 ach	53 cfm		.35 ach	90 cfm
.15 ach	40 cfm	62.2 - 2010	7.5 cfm/person	50 cfm
			+ 0.01	
		62.2 - 2013	7.5 cfm/person	90 cfm
			+ 0.03	

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Office
Occupant Density

15/1000 ft ² (67 ft ² /person)	62 - 89
15 cfm/person	
5/1000 ft ² (200 ft ² /person)	62.1 - 2007
17 cfm/person	

Correctional Facility Cell
Occupant Density

20/1000 ft ² (48 ft ² /person)	62.1 - 2007
10 cfm/person	

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C.P. Yaglou
 Harvard School of Public Health
 1936
 1955

150 ft ³	→	20 cfm/person
300 ft ³	→	12 cfm/person

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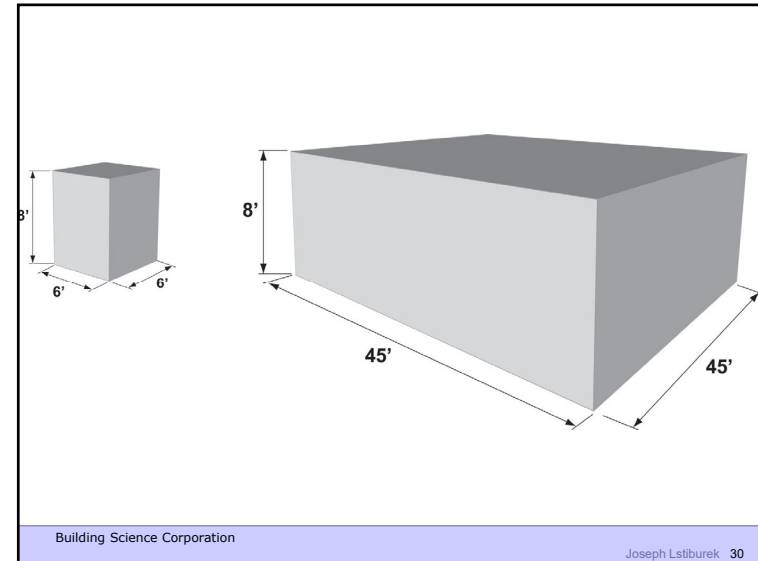
C.P. Yaglou
 Harvard School of Public Health
 1936
 1955

150 ft³ → 20 cfm/person 18.75 ft² 106 occupants
 300 ft³ → 12 cfm/person 37.5 ft² 53 occupants

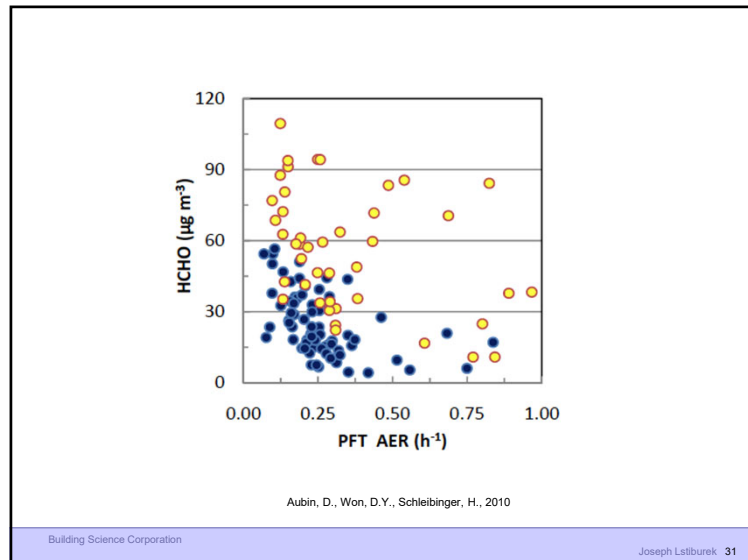
Experiment

470 ft³ → 59 ft²
 200 ft³ → 25 ft²
 100 ft³ → 12 ft²

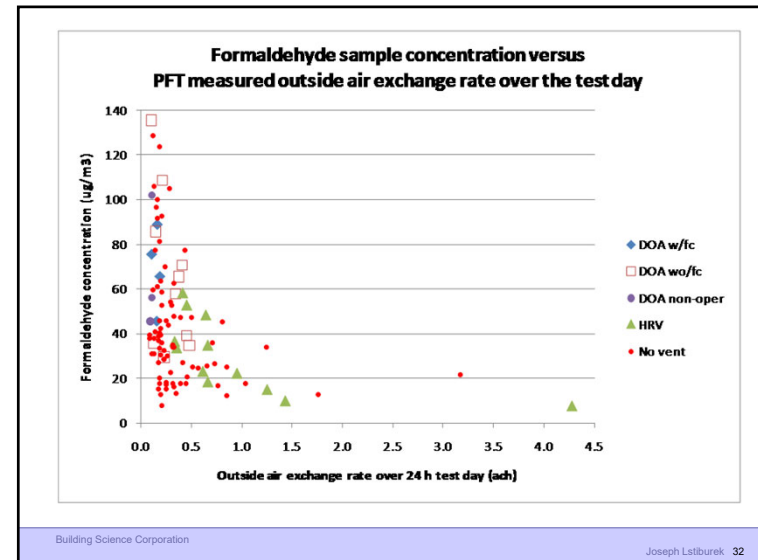
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ASHRAE Standard 62.2 calls for 7.5 cfm per person plus 0.03 cfm per square foot of conditioned area

Occupancy is deemed to be the number of bedrooms plus one

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ASHRAE Standard 62.2 calls for 7.5 cfm per person plus 0.03 cfm per square foot of conditioned area

Occupancy is deemed to be the number of bedrooms plus one

Outcome is often bad – part load humidity problems, dryness problems, energy problems

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IRC 2015 and 2018 calls for 7.5 cfm per person plus 0.01 cfm per square foot of conditioned area

Occupancy is deemed to be the number of bedrooms plus one

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3 Bedroom House – 2,500 ft²

30 cfm plus 75 cfm

105 cfm

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3 Bedroom House – 2,500 ft²
30 cfm plus 25 cfm
55 cfm

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3 Bedroom House – 2,500 ft²
30 cfm plus 25 cfm
55 cfm
With Balanced and Distributed 30 percent credit
38.5 cfm


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The Cult of The Blower Door

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Blower Door Can't Get You The True ACH
On A Short Term Basis – Hour, Day, Week

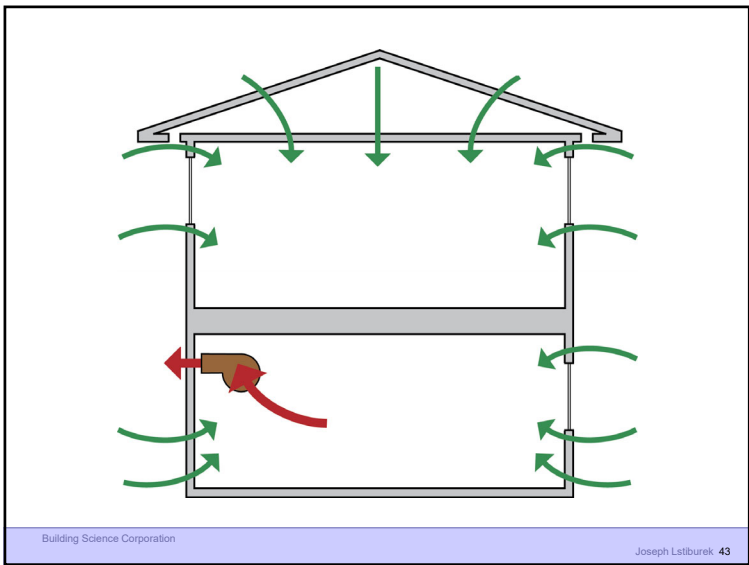
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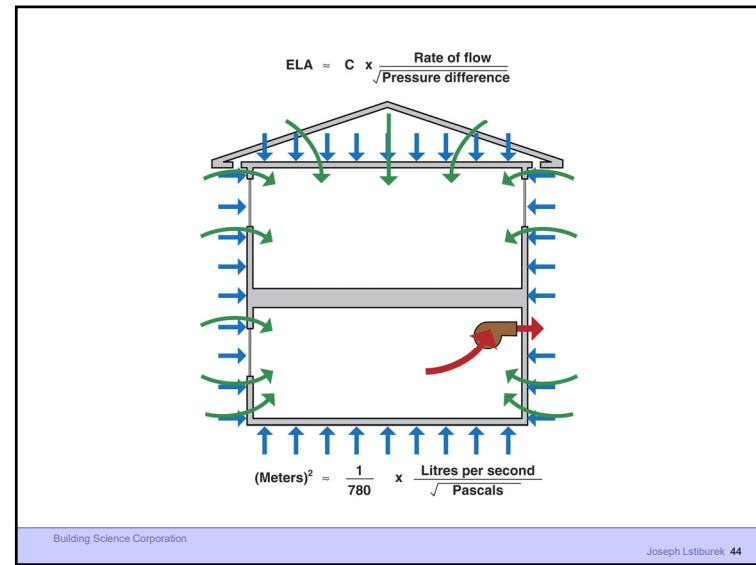
Don't Know Where The Holes Are
Don't Know The Type of Holes
Don't Know The Pressure Across The Holes

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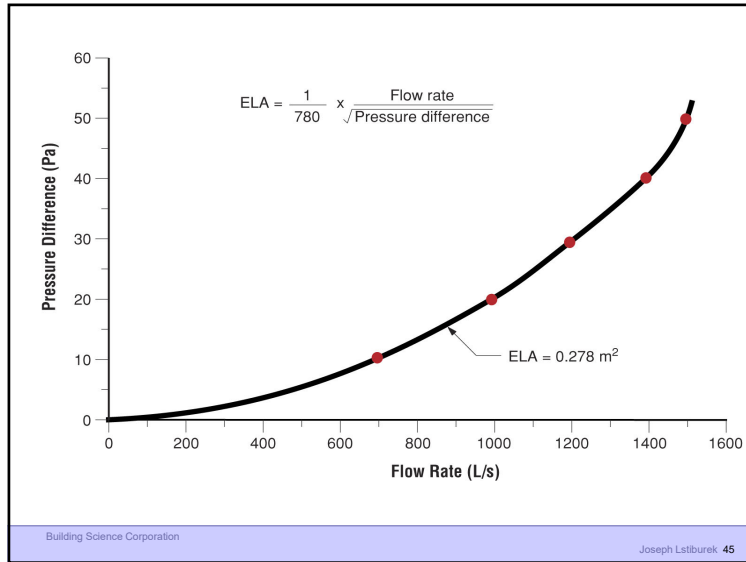
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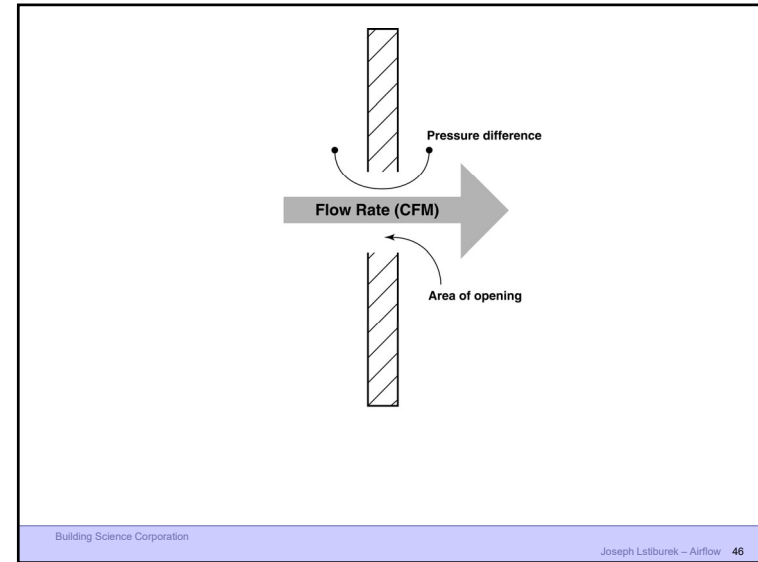
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Flow Through Orifices
 Turbulent Flow - "inertial effects"

Flow Through Porous Media
 Laminar Flow - "viscosity effects"

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Flow Through Orifices
 Turbulent Flow - "inertial effects"

Flow Through Porous Media
 Laminar Flow - "viscosity effects"

"true but not useful"

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$$Q = A \cdot C_D \left[\frac{2}{\rho} (\Delta P) \right]^{\frac{1}{2}} \quad \text{Bernoulli}$$

$$Q = C_K \frac{\rho}{\mu} (\Delta P) \quad \text{Darcy}$$

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$$Q = A \cdot C_D \left[\frac{2}{\rho} (\Delta P) \right]^{\frac{1}{2}} \quad \text{Bernoulli}$$

$$Q = C_K \frac{\rho}{\mu} (\Delta P) \quad \text{Darcy}$$

$$Q = A \cdot C (\Delta P)^{\frac{1}{2}}$$

$$Q = C (\Delta P)$$

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50

$$Q = A \cdot C_D \left[\frac{2}{\rho} (\Delta P) \right]^{\frac{1}{2}} \quad \text{Bernoulli}$$

$$Q = C_K \frac{\rho}{\mu} (\Delta P) \quad \text{Darcy}$$

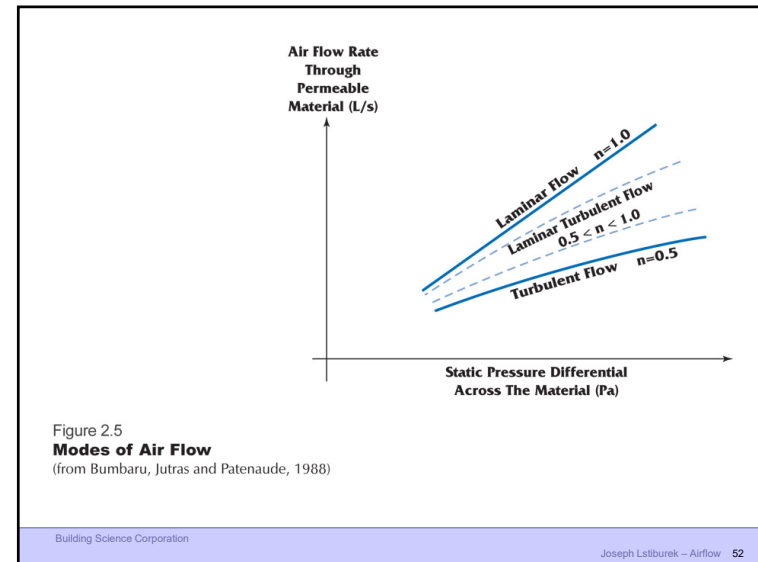
$$Q = A \cdot C (\Delta P)^{\frac{1}{2}}$$

$$Q = C (\Delta P)$$

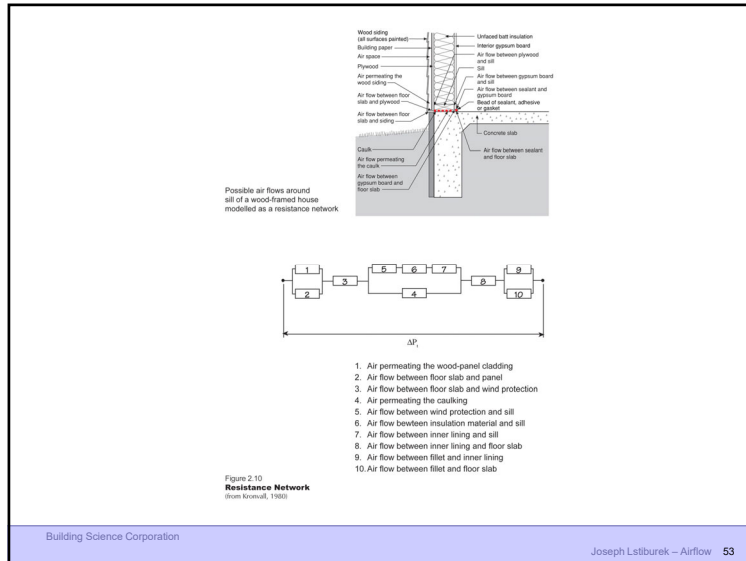
$$Q = A \cdot C (\Delta P)^n \quad \text{Kronval "an engineer"}$$

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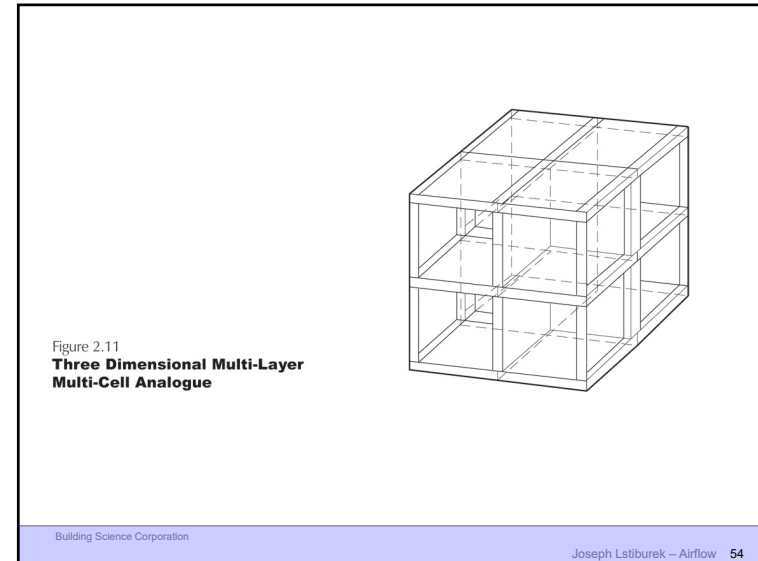
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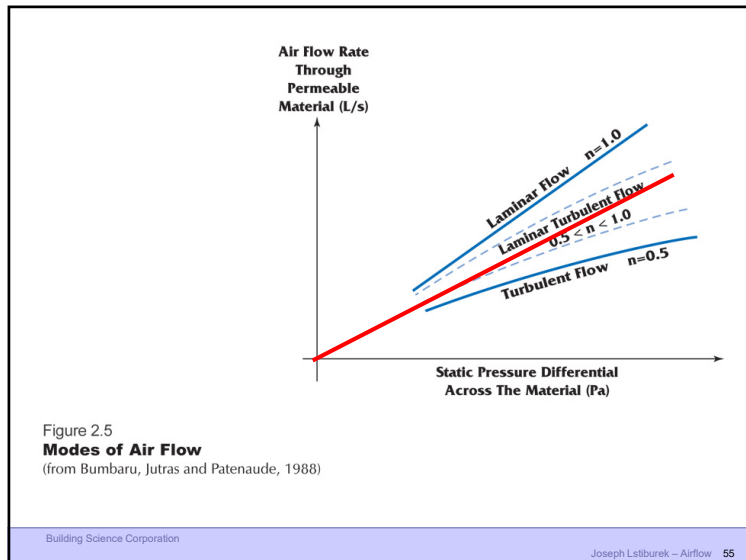
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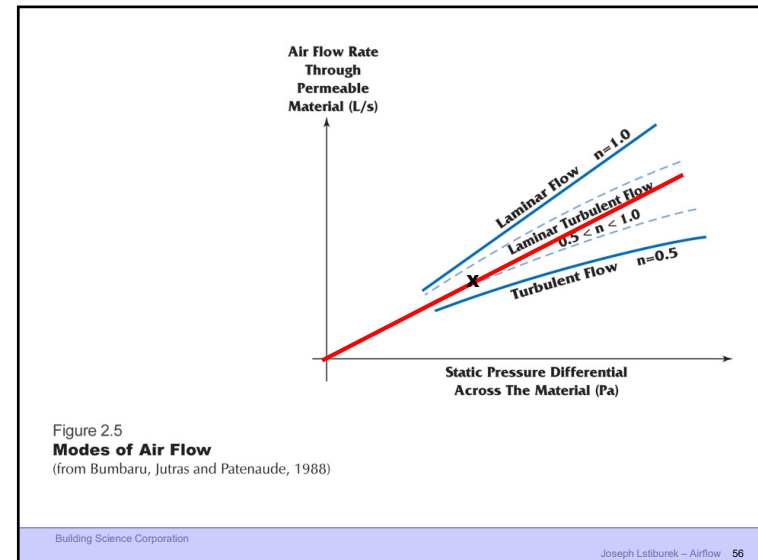
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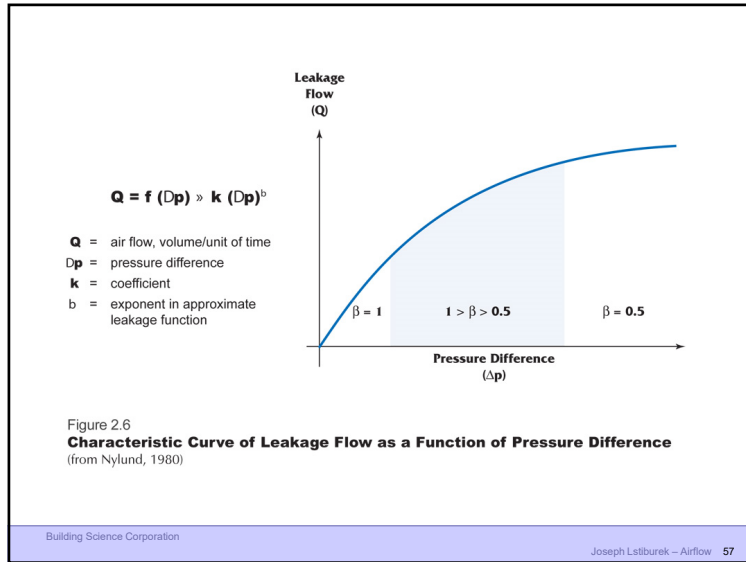
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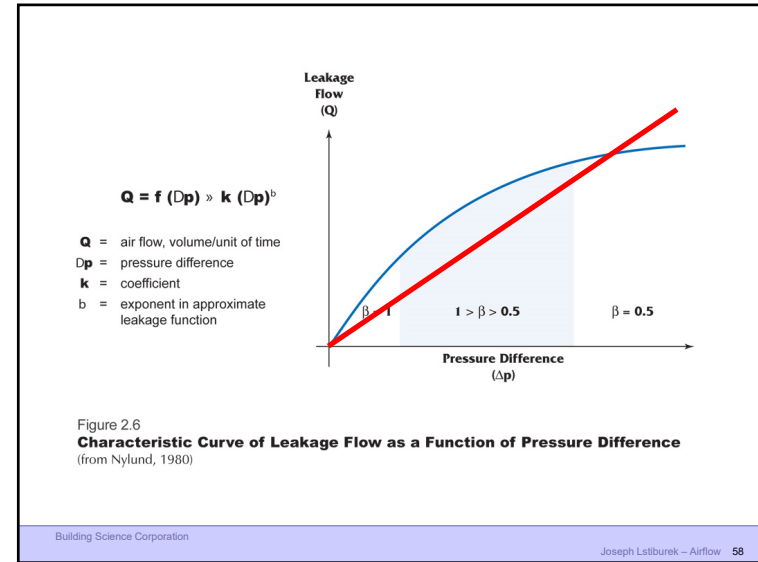
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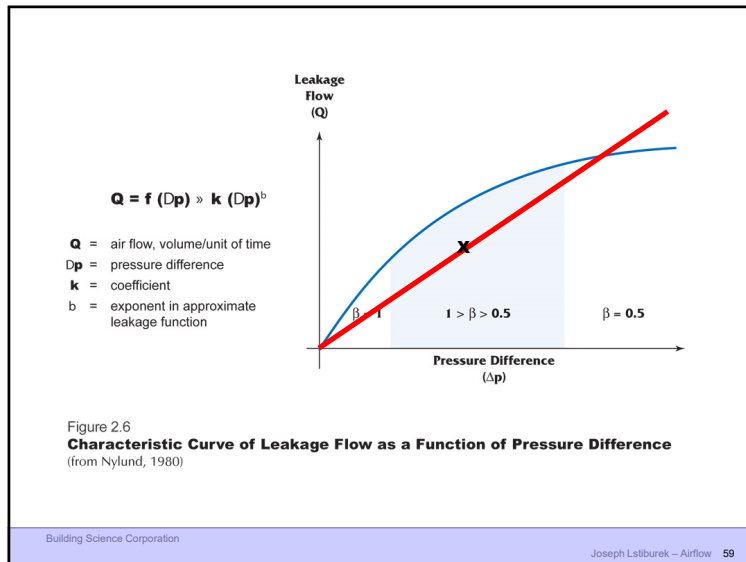
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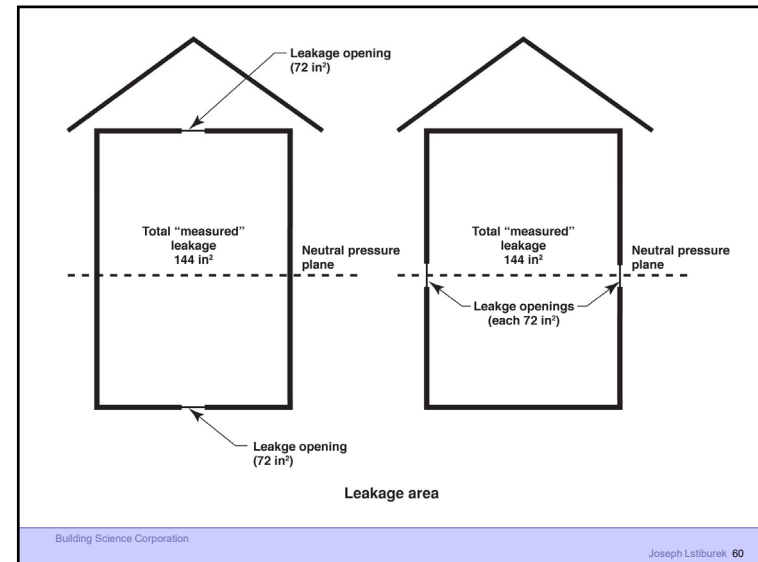
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Dilution Is Not The Solution To Indoor
Pollution
Source Control

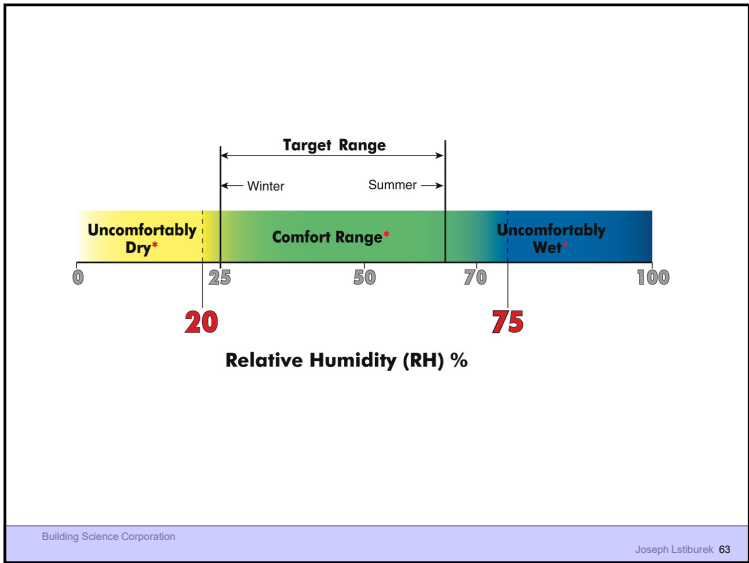
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Dilution For People
Source Control For The Building

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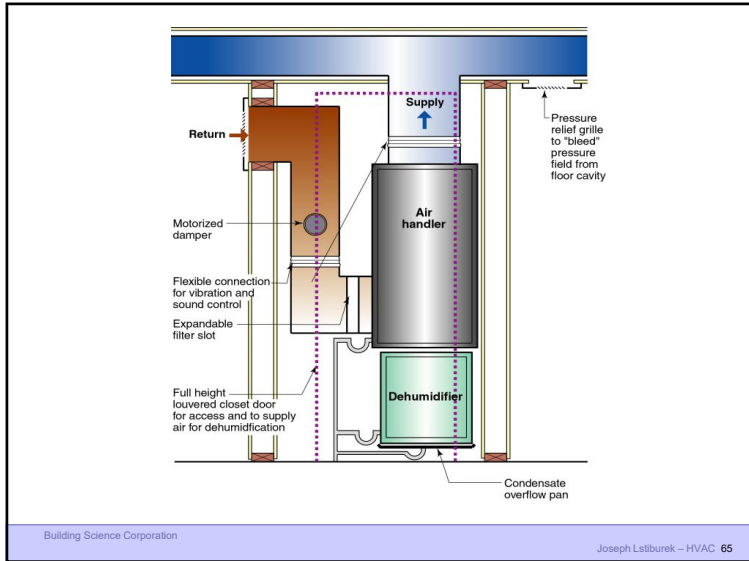


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Recommended Range of Relative Humidity
Above 25 percent during winter
Below 70 percent during summer

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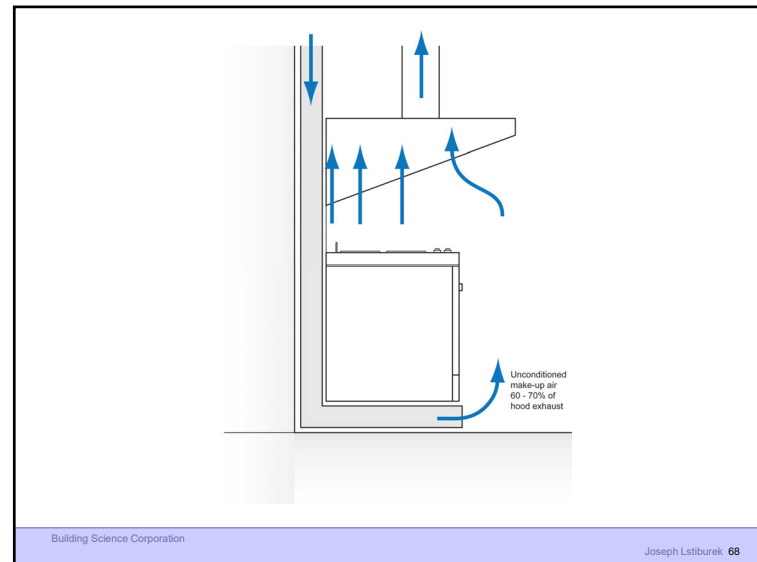
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Kitchen Exhaust Hoods

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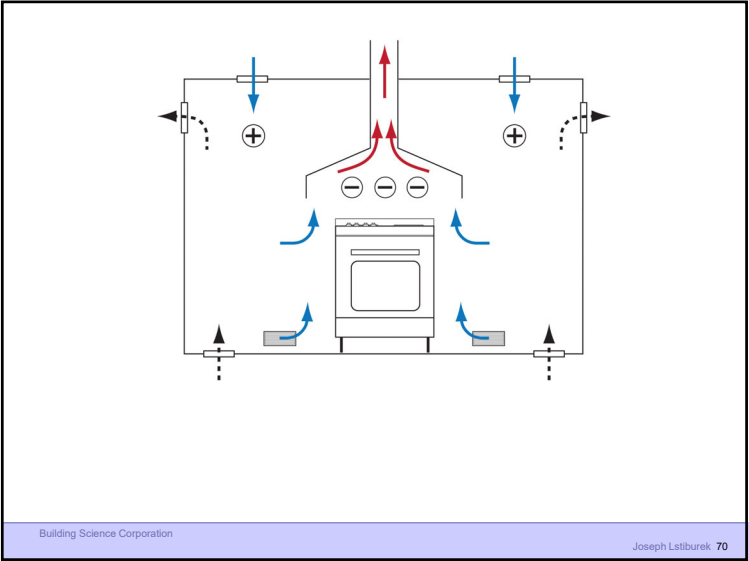
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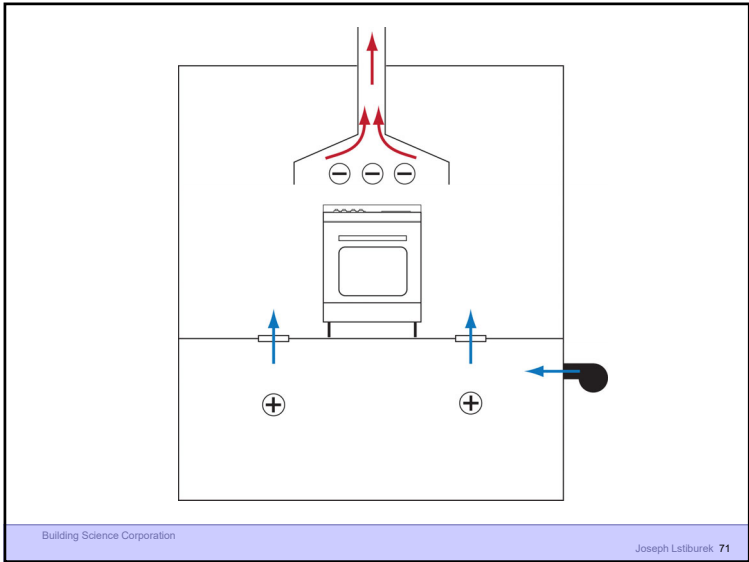
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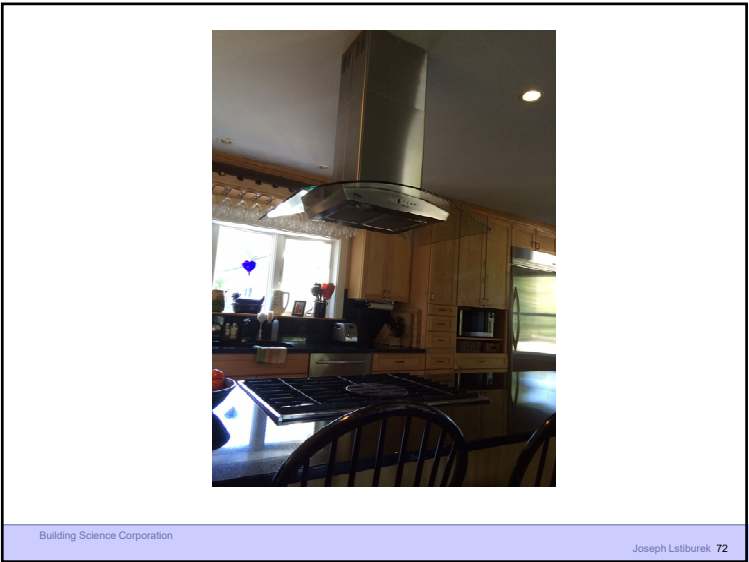
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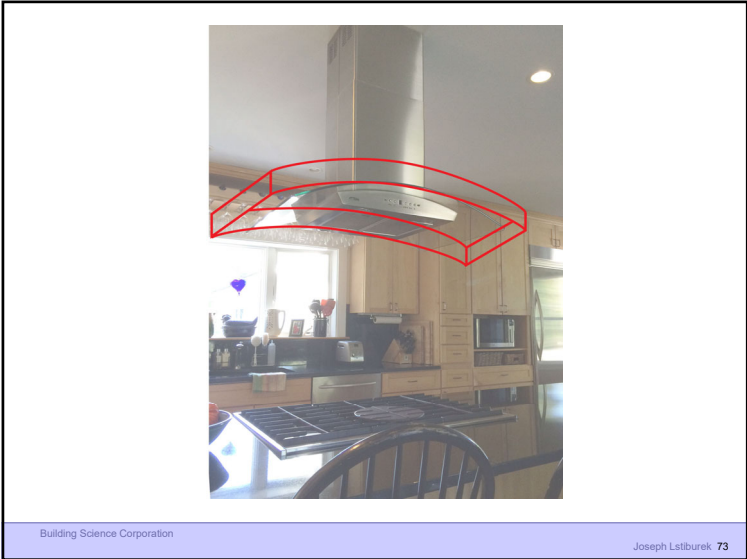
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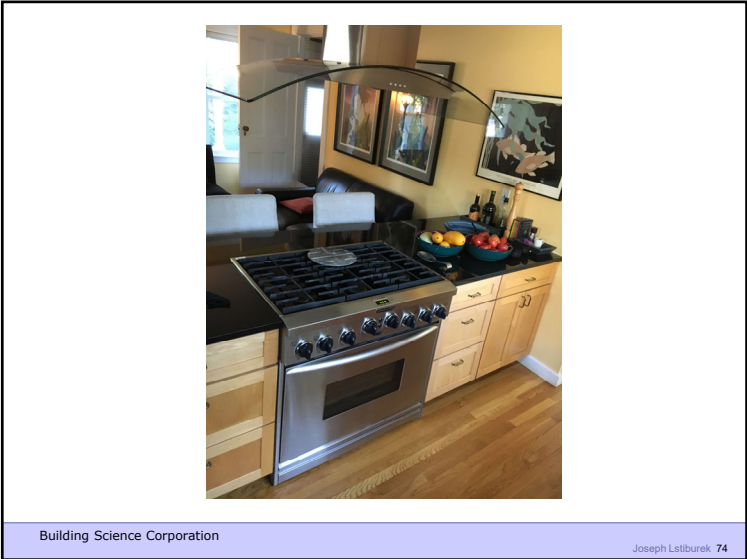
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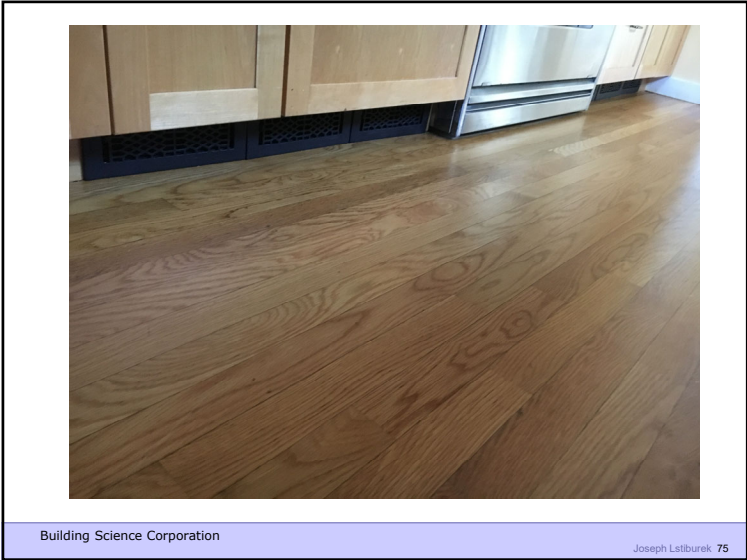
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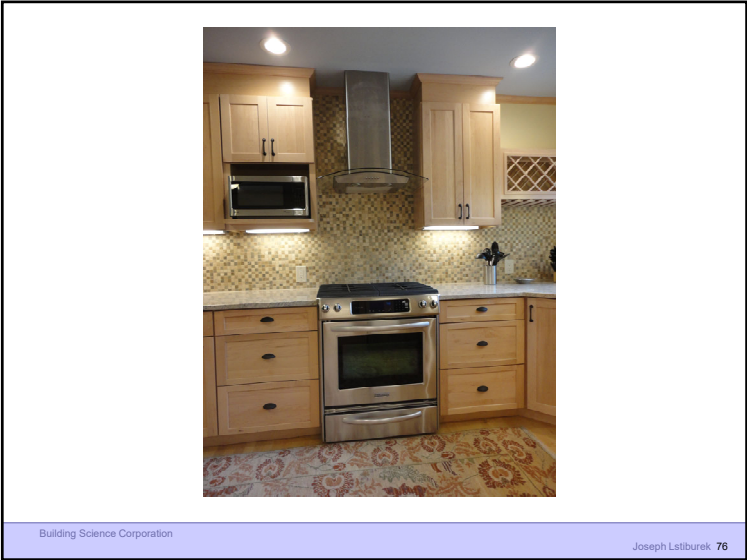
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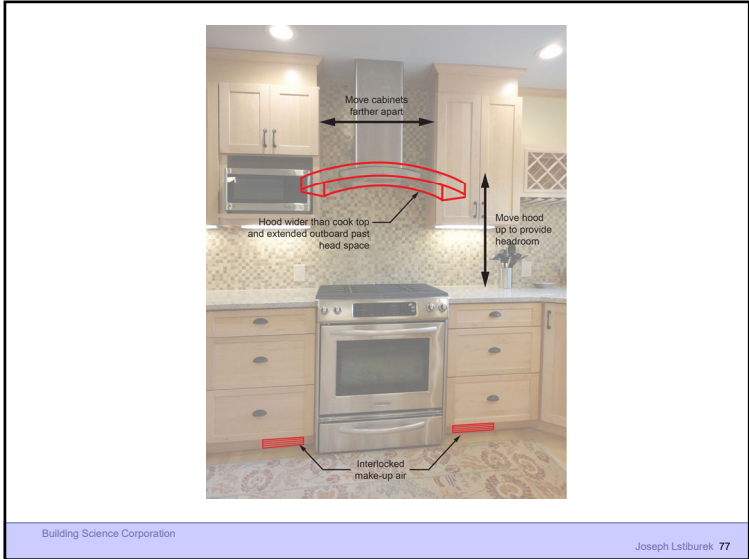
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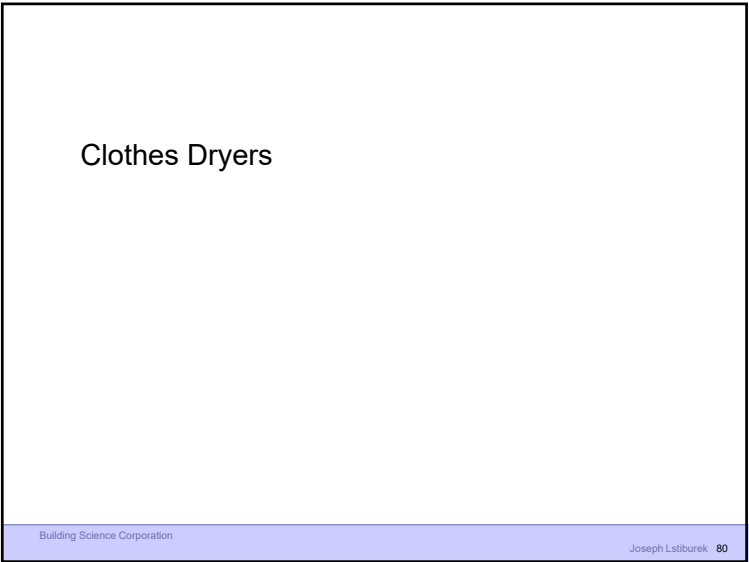
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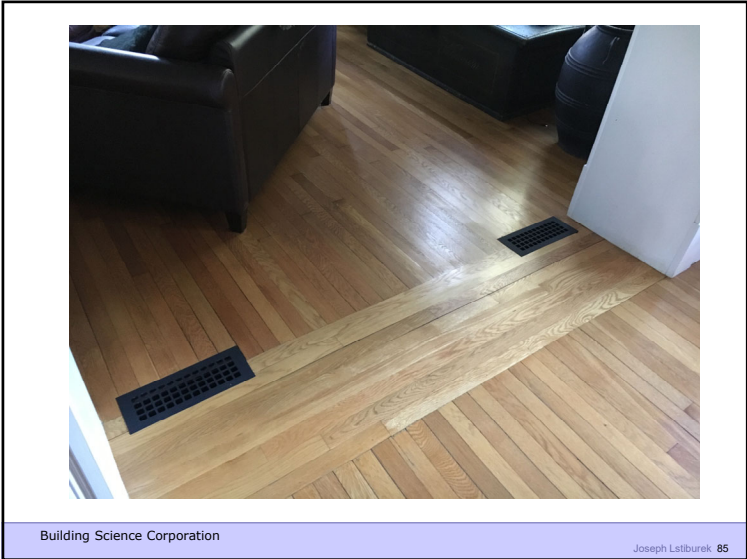
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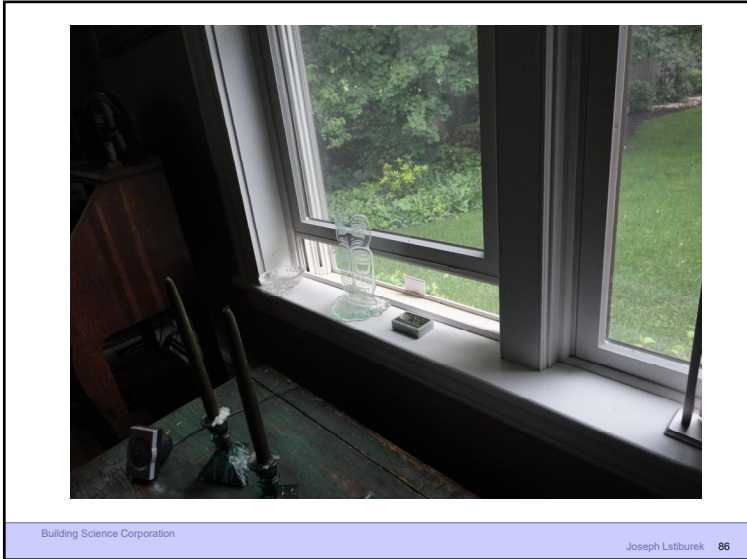
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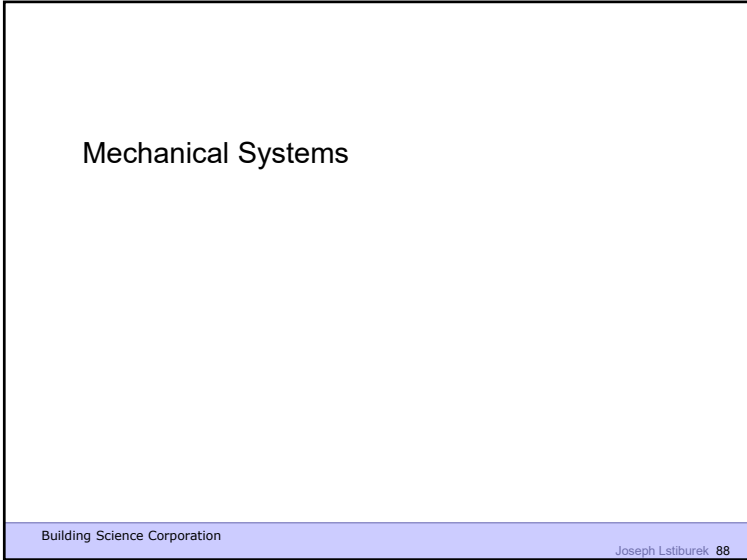
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Mechanical Systems
Cooling System To Make It Cold

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Mechanical Systems
Cooling System To Make It Cold
Dehumidification System To Make It Dry

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Mechanical Systems
Cooling System To Make It Cold
Dehumidification System To Make It Dry
Heating System To Make It Warm

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Mechanical Systems
Cooling System To Make It Cold
Dehumidification System To Make It Dry
Heating System To Make It Warm
Energy Recovery System To Keep It Cold
and Dry and Warm and Comfortable

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Mechanical Systems
Cooling System To Make It Cold
Dehumidification System To Make It Dry
Heating System To Make It Warm
Energy Recovery System To Keep It Cold
and Dry and Warm and Comfortable
Distribution System To Make It Uniform

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Mechanical Systems
Cooling System To Make It Cold
Dehumidification System To Make It Dry
Heating System To Make It Warm
Energy Recovery System To Keep It Cold
and Dry and Warm and Comfortable
Distribution System To Make It Uniform
Range Hoods Are A Special Kind of Hell

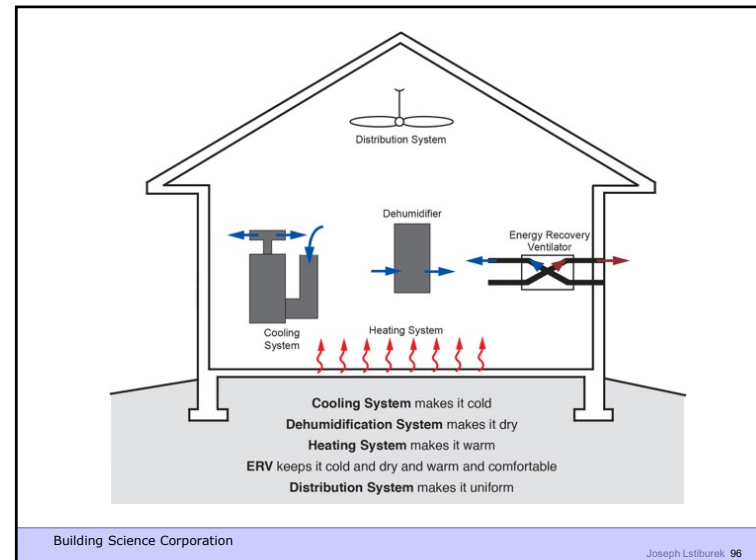
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The Best Approach is Not to Combine
Them.....

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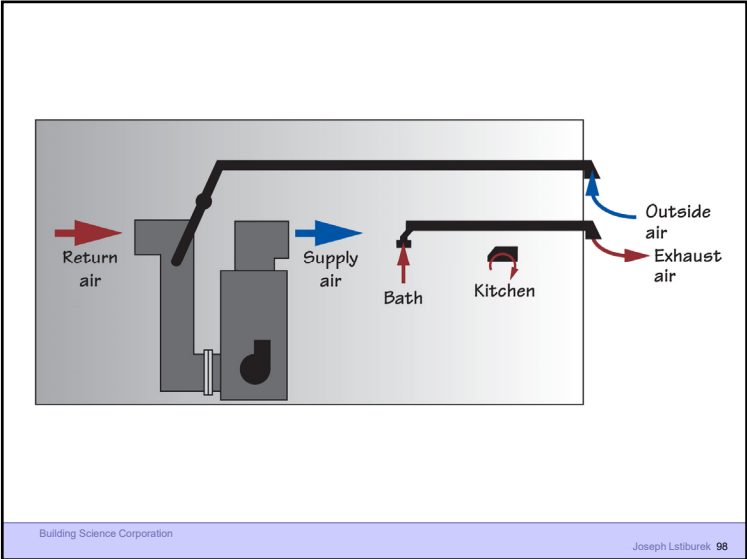


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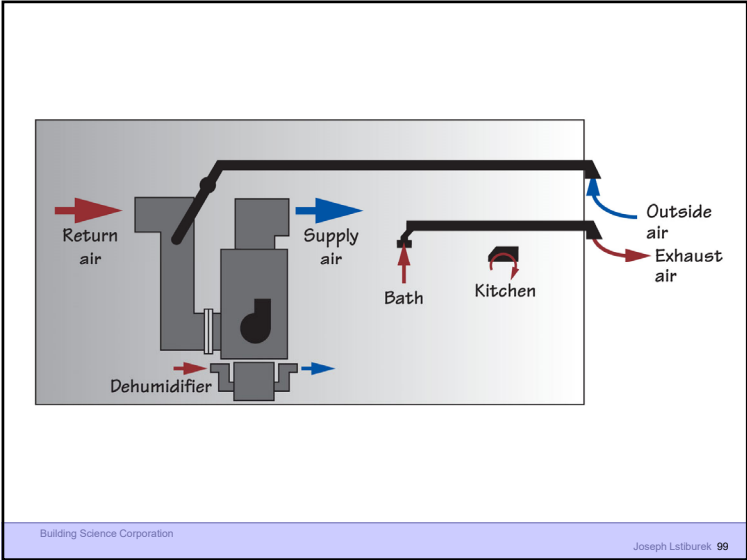
Approaches

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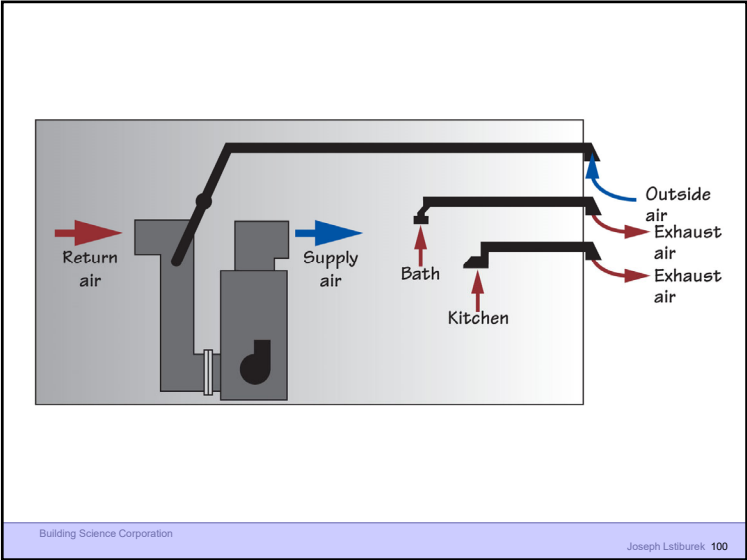
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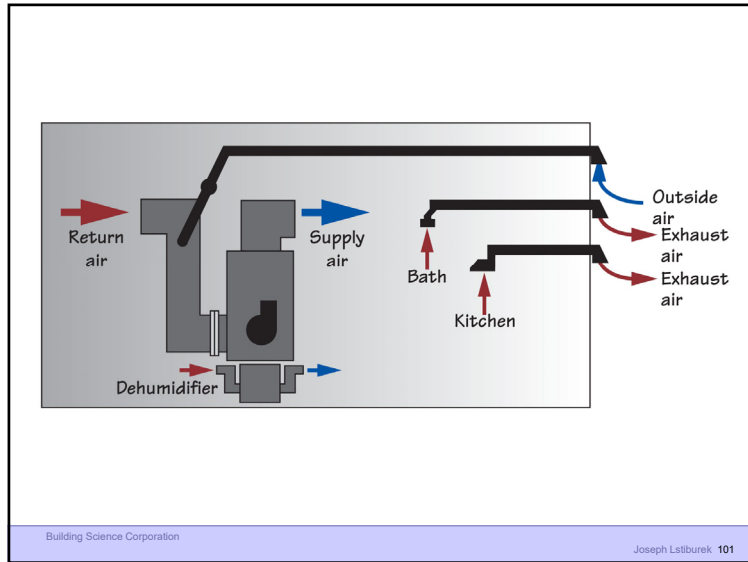
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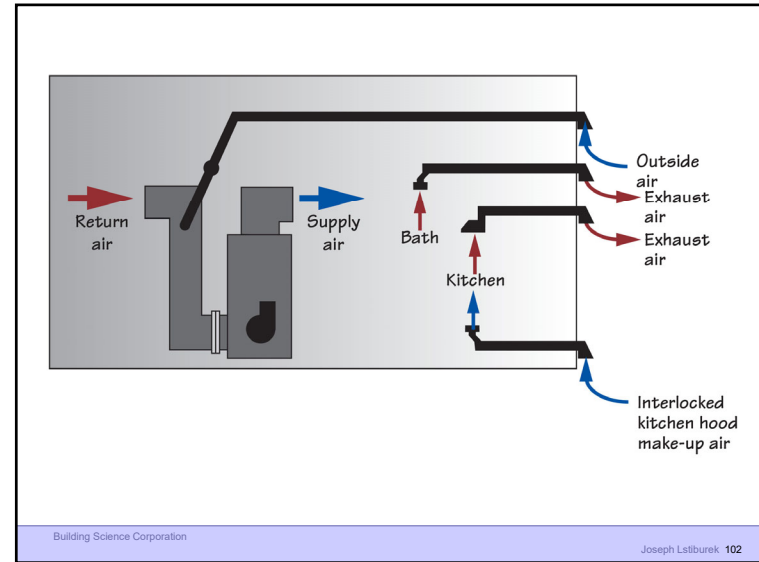
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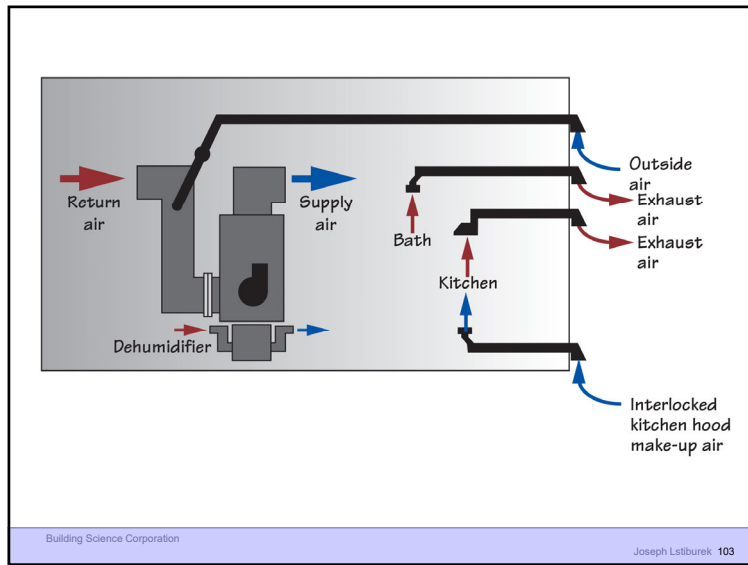
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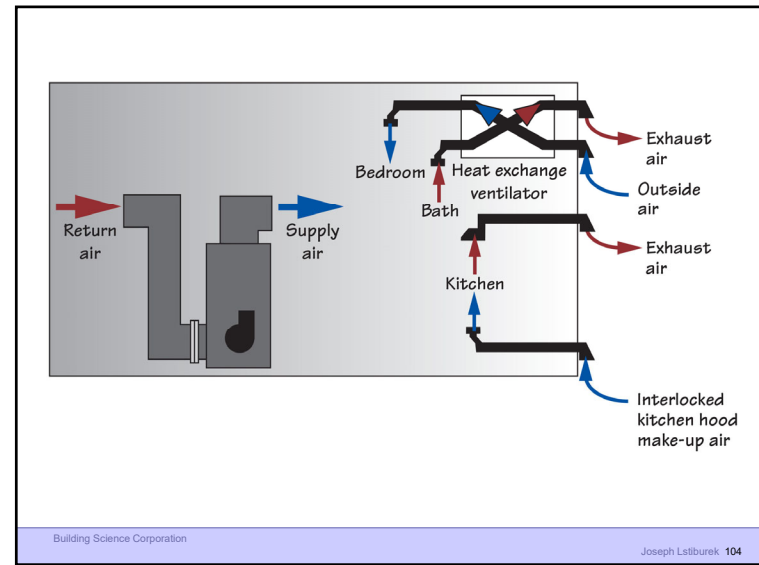
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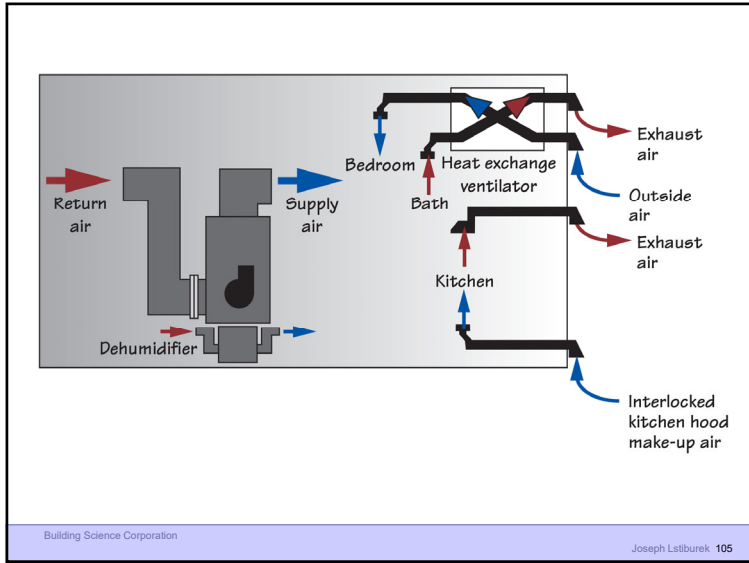
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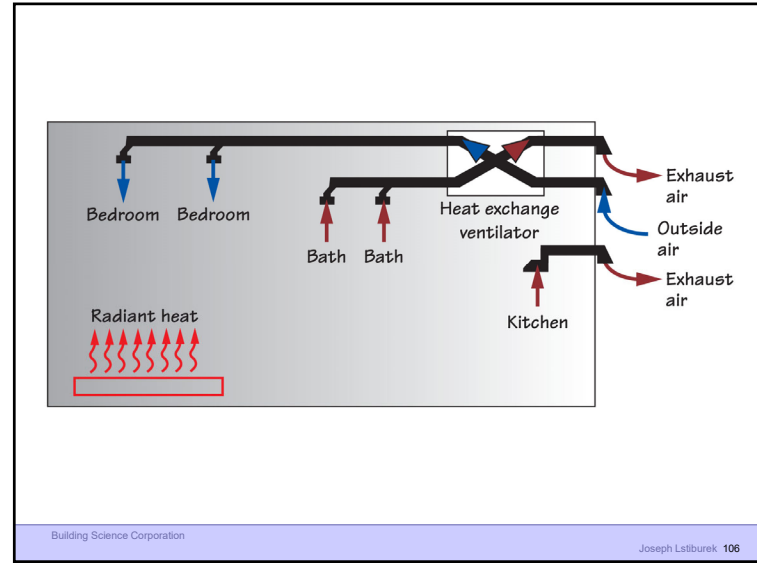
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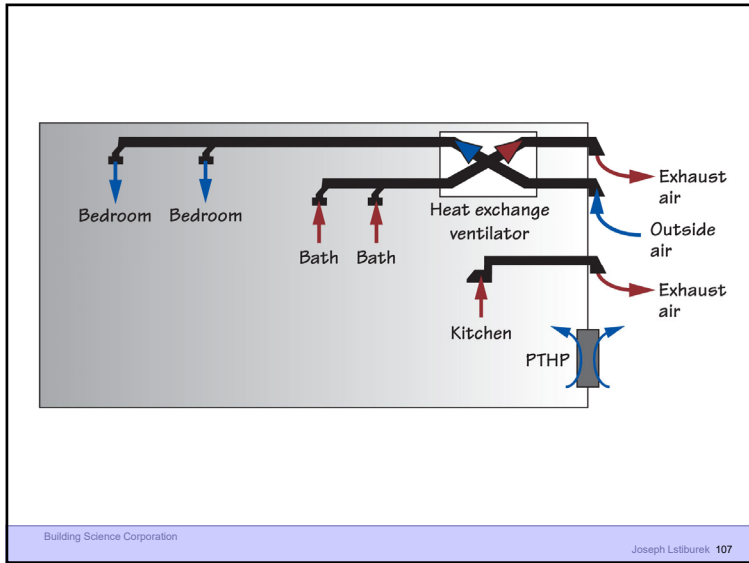
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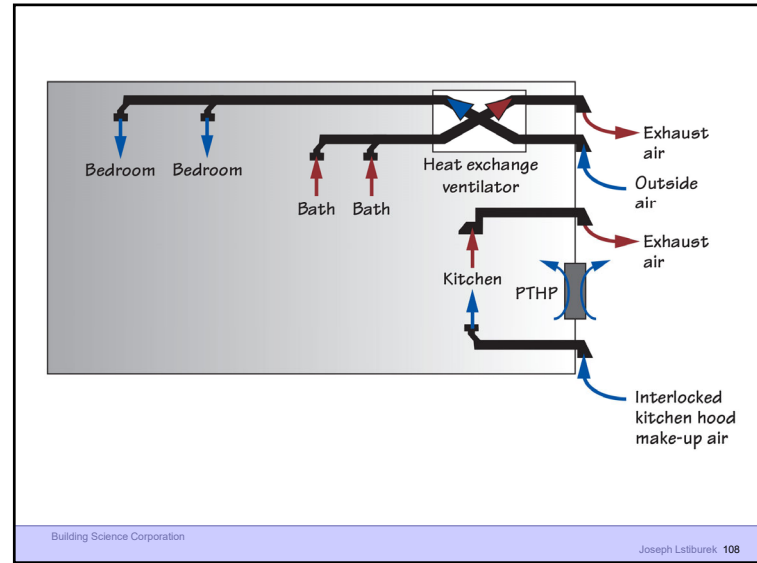
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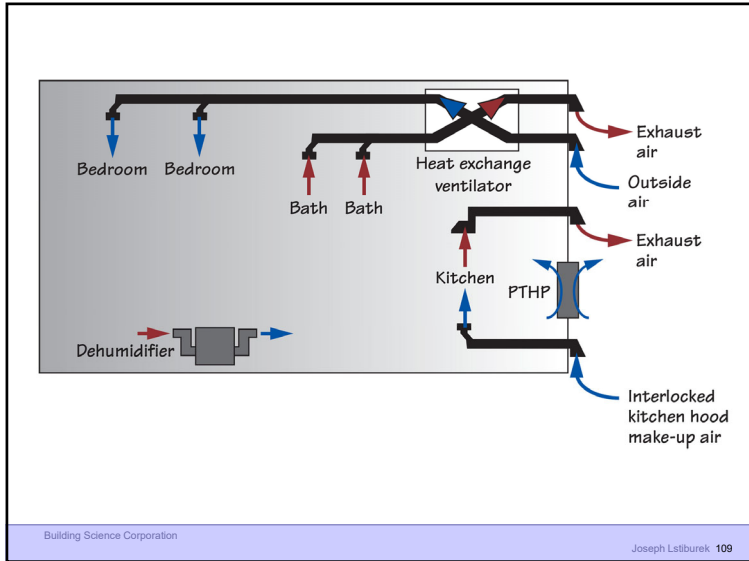
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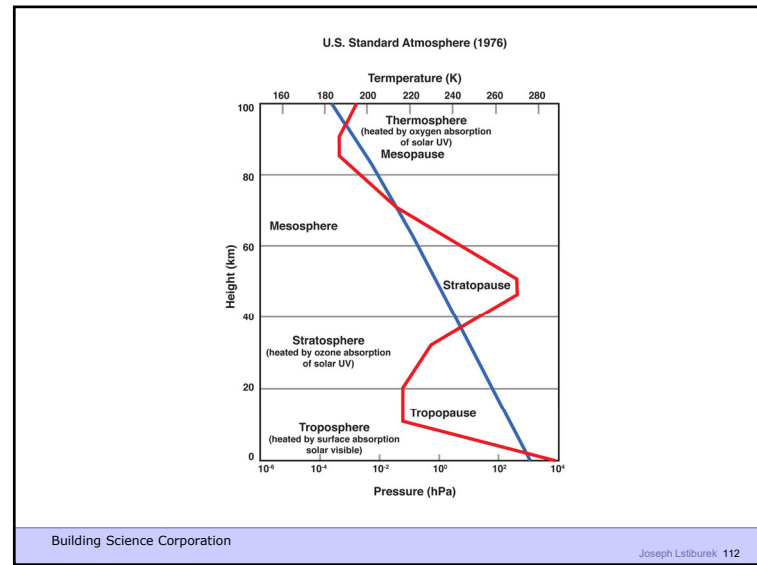


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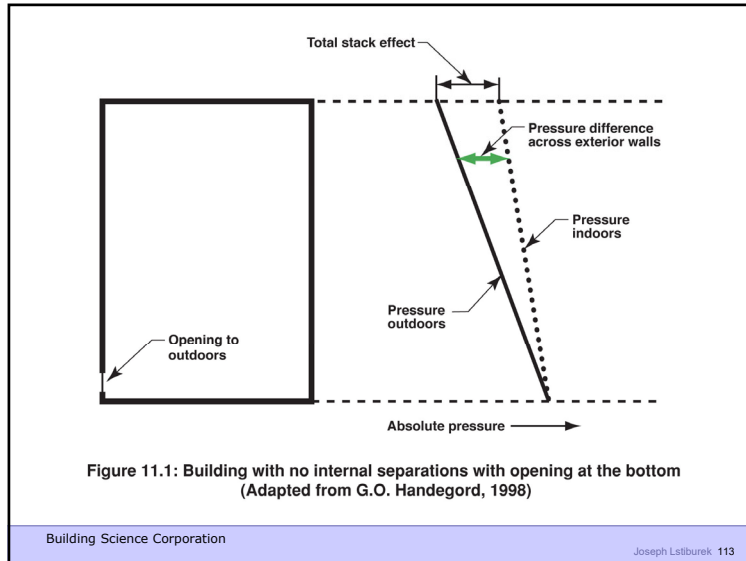
Lapse Rate

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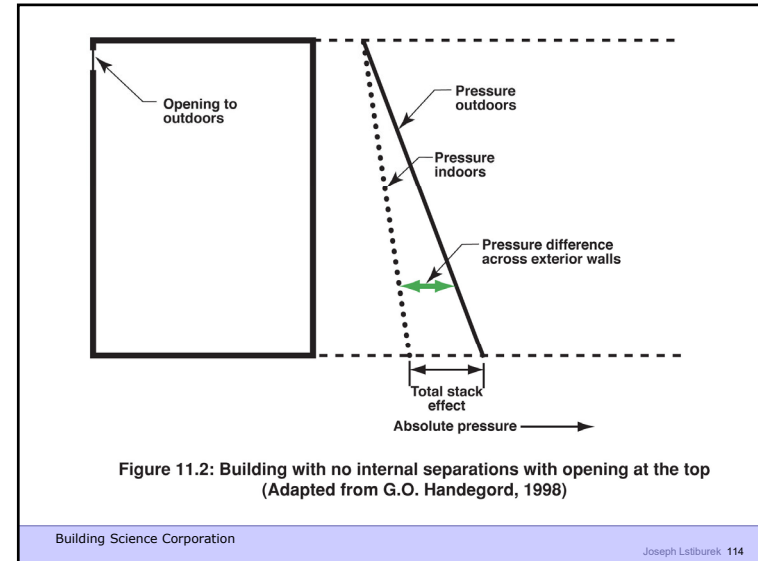
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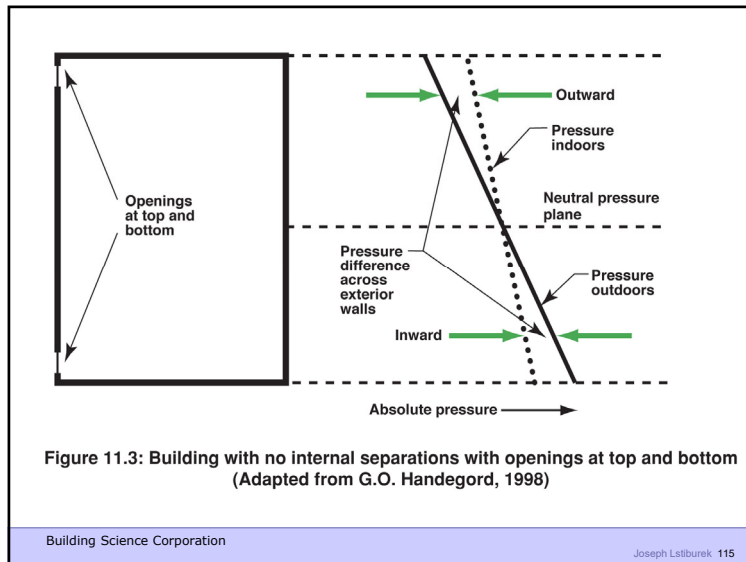
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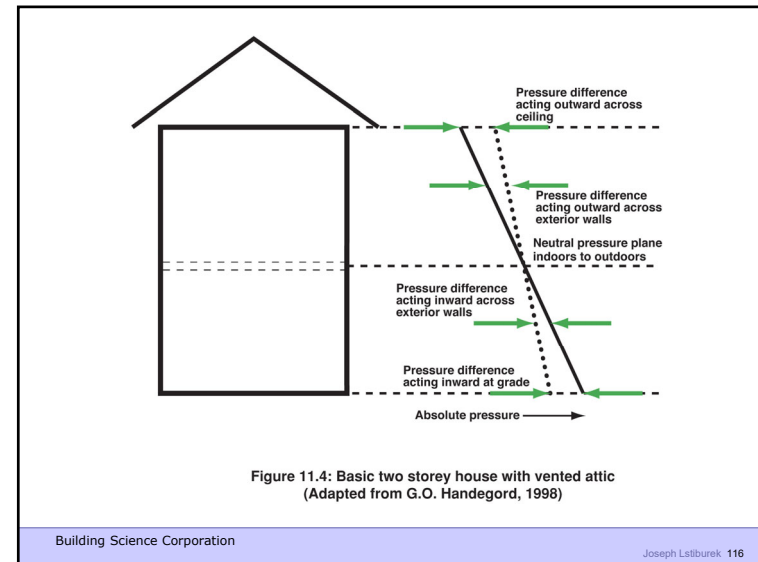
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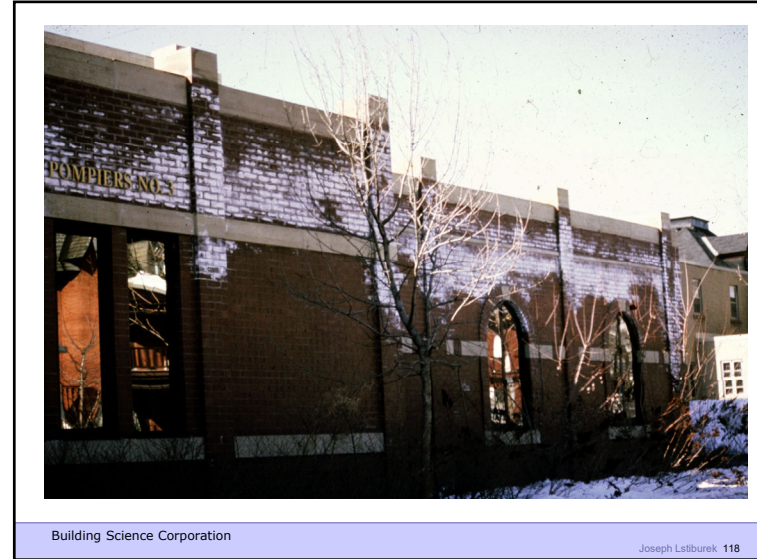
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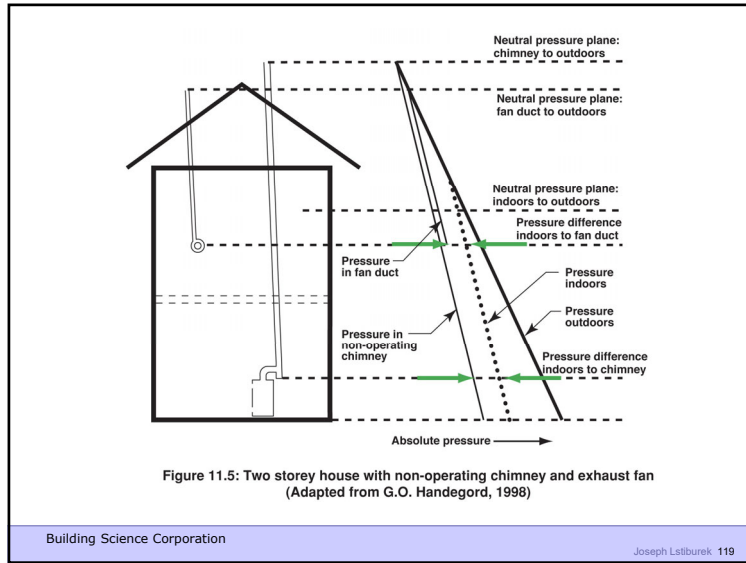


Figure 11.5: Two storey house with non-operating chimney and exhaust fan (Adapted from G.O. Handegord, 1998)

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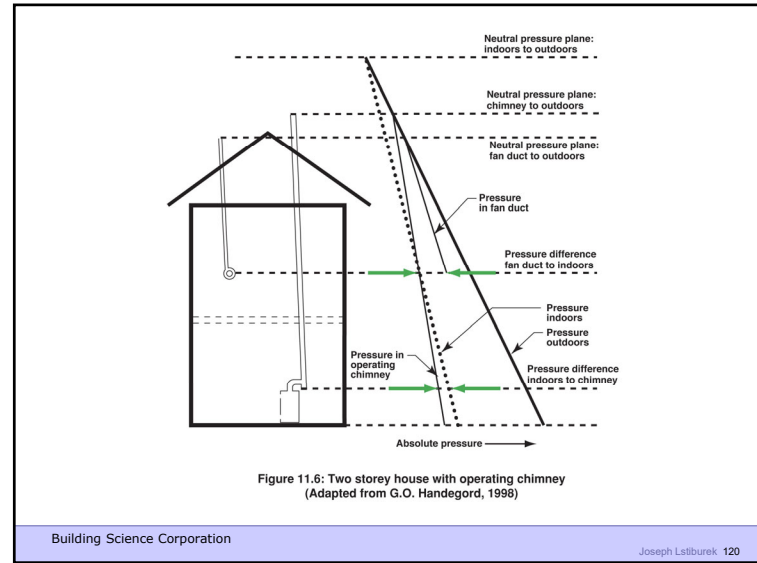
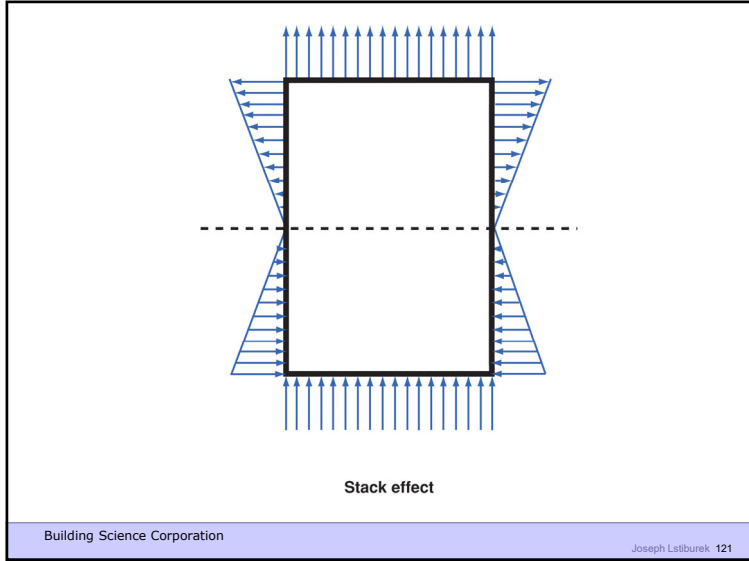


Figure 11.6: Two storey house with operating chimney (Adapted from G.O. Handegord, 1998)

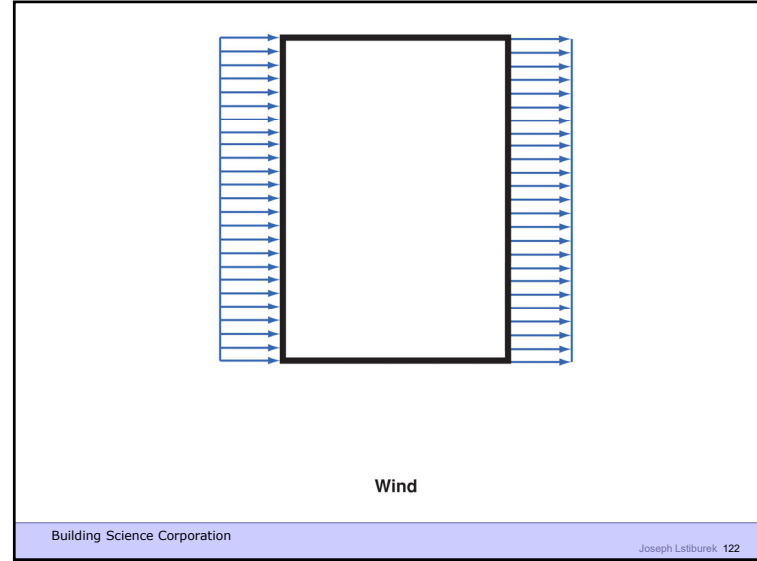
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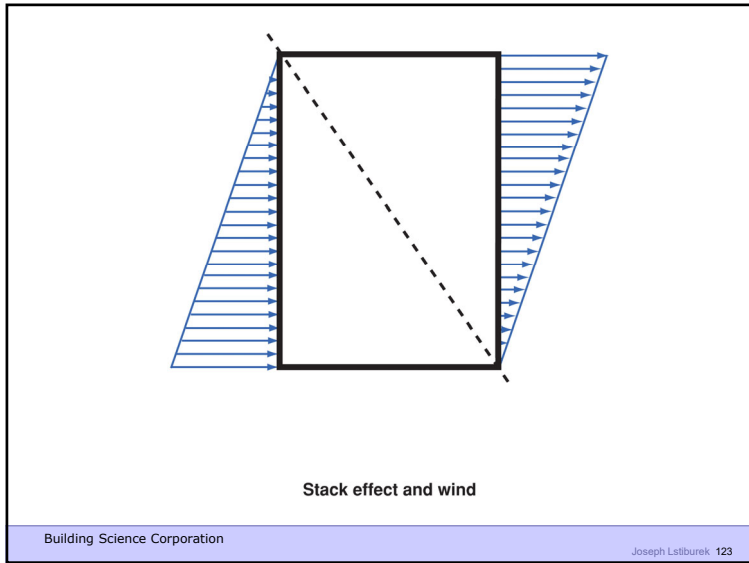
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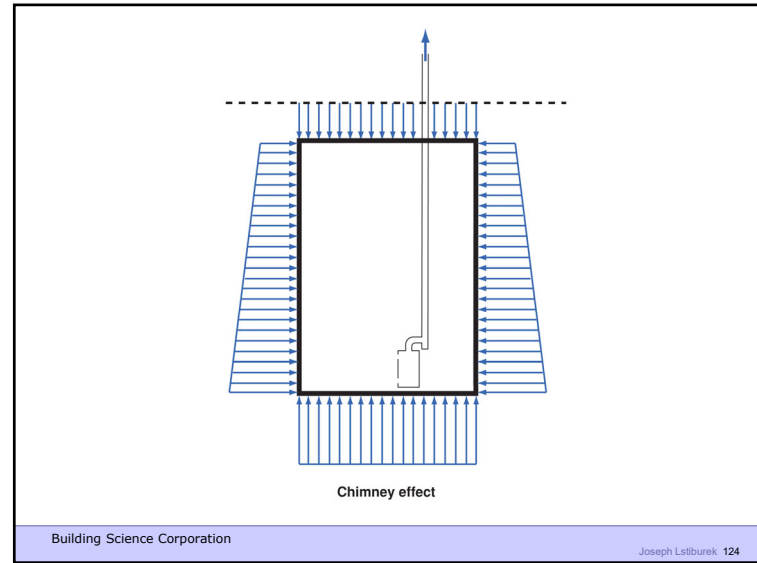
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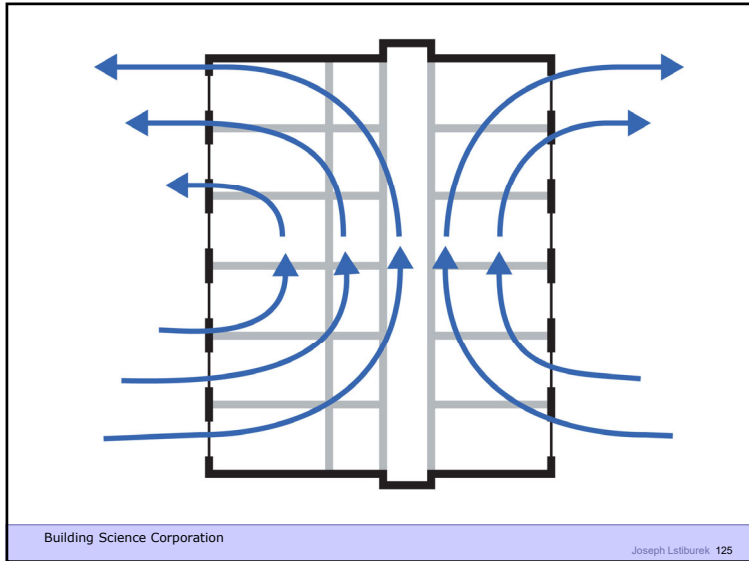
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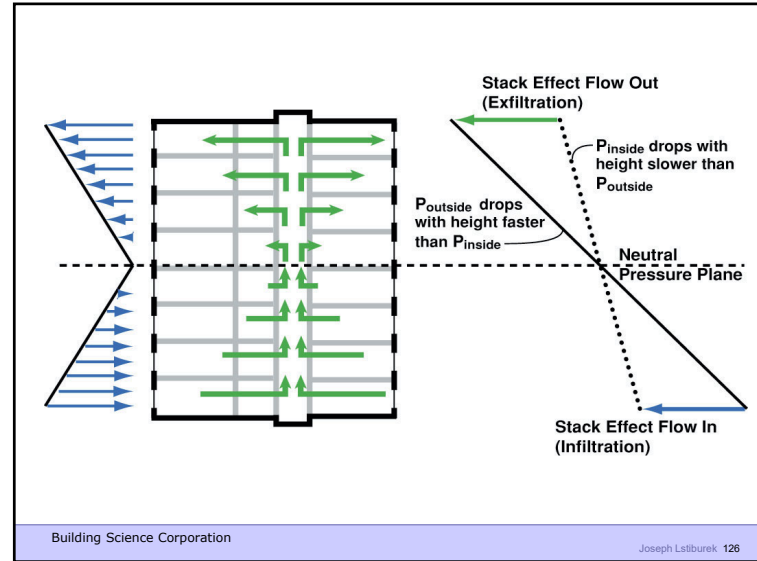
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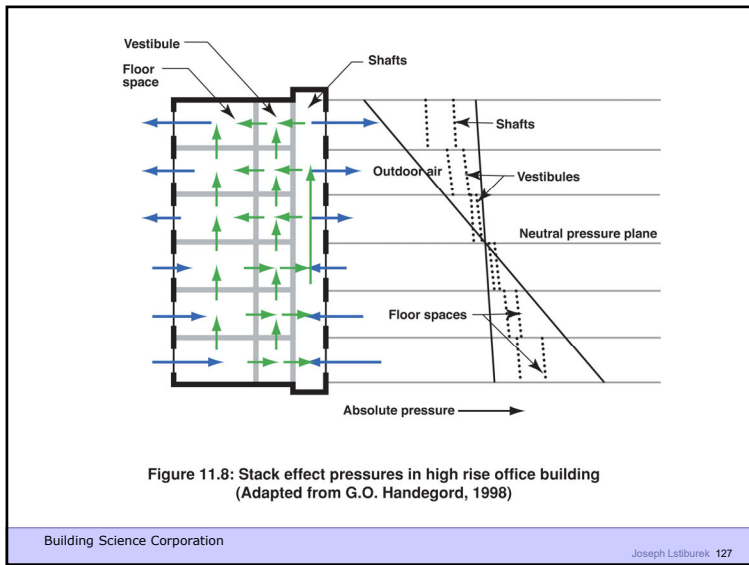
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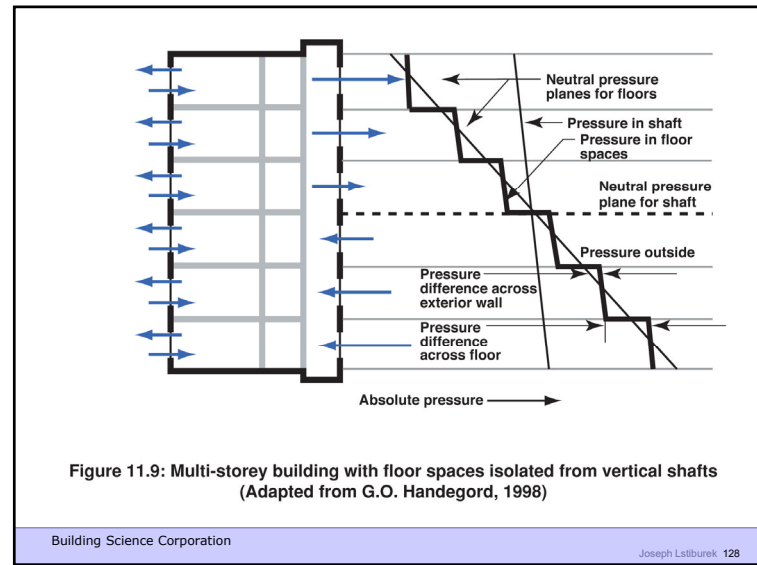
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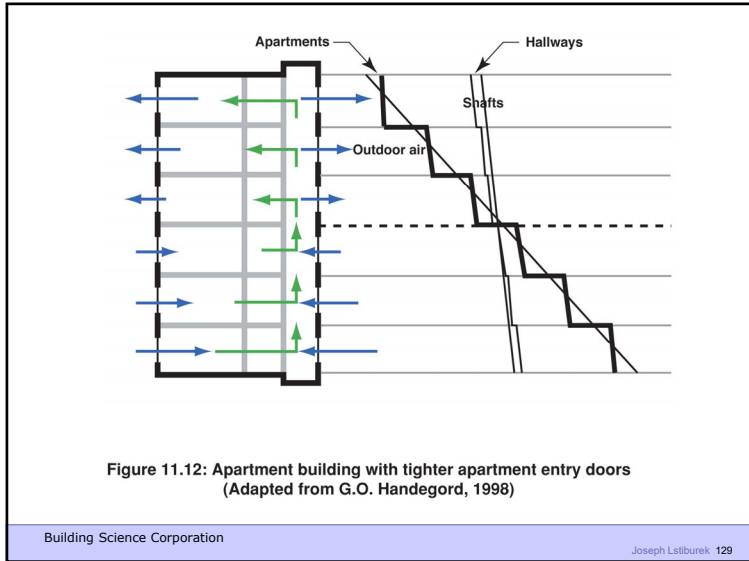
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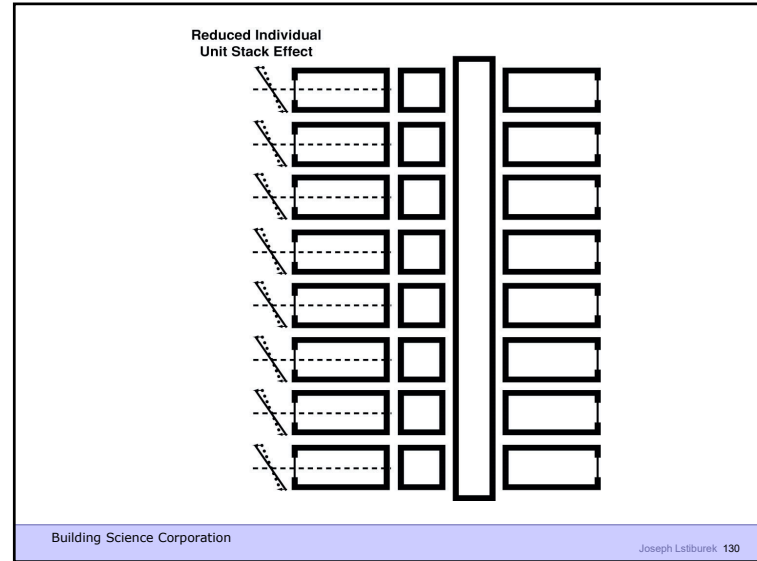
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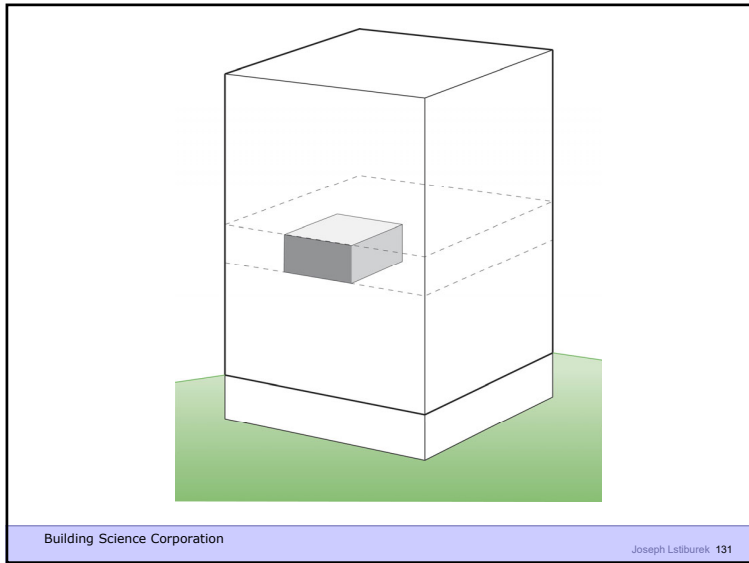
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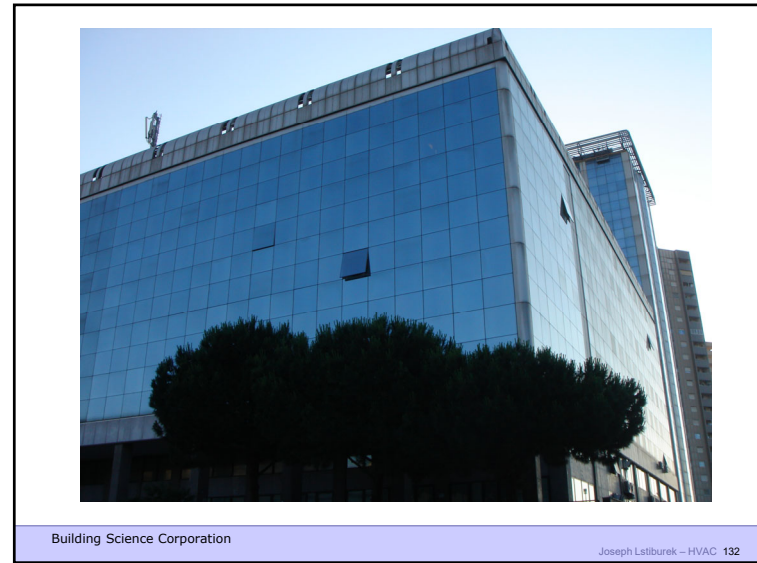
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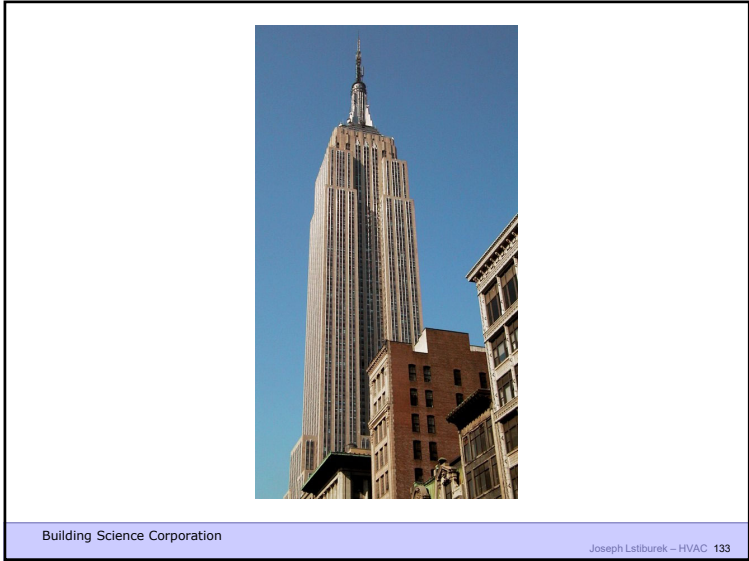
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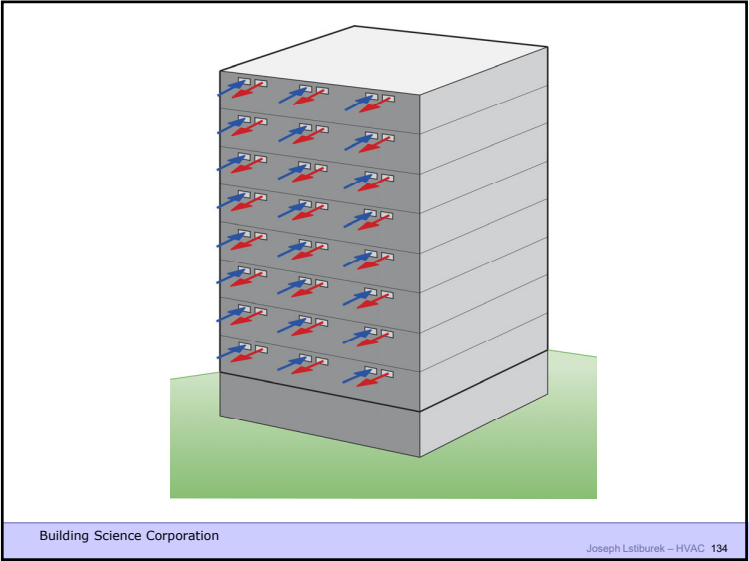
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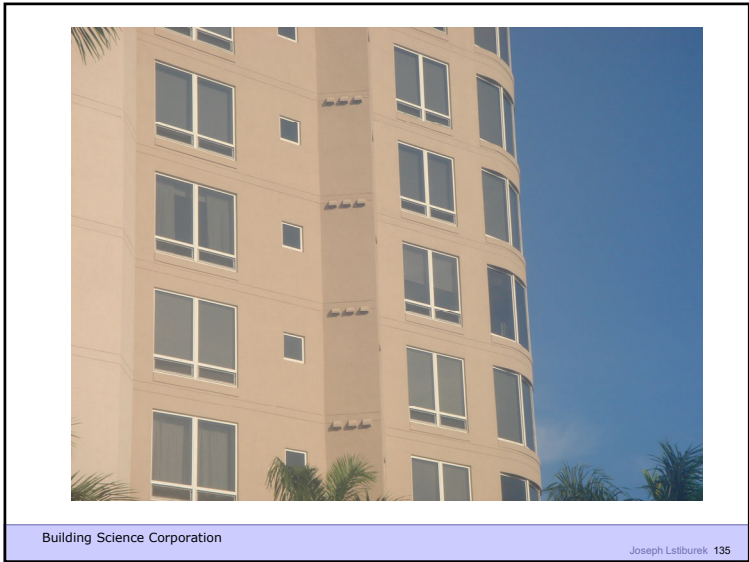
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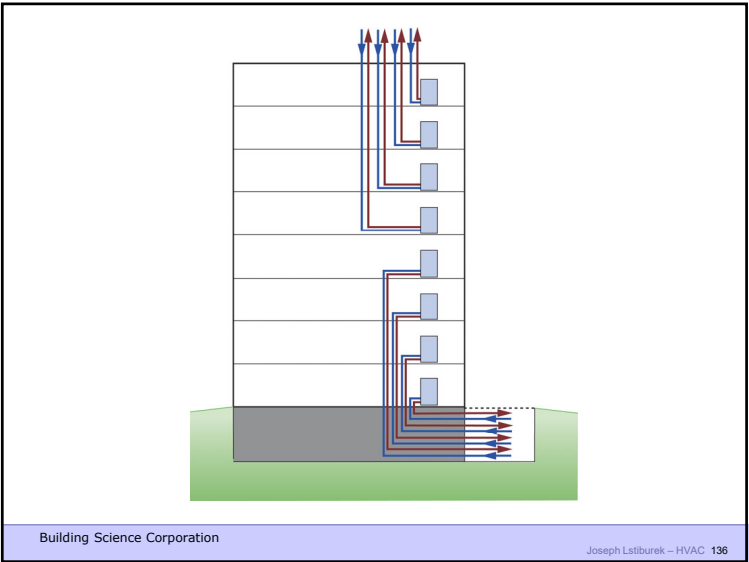
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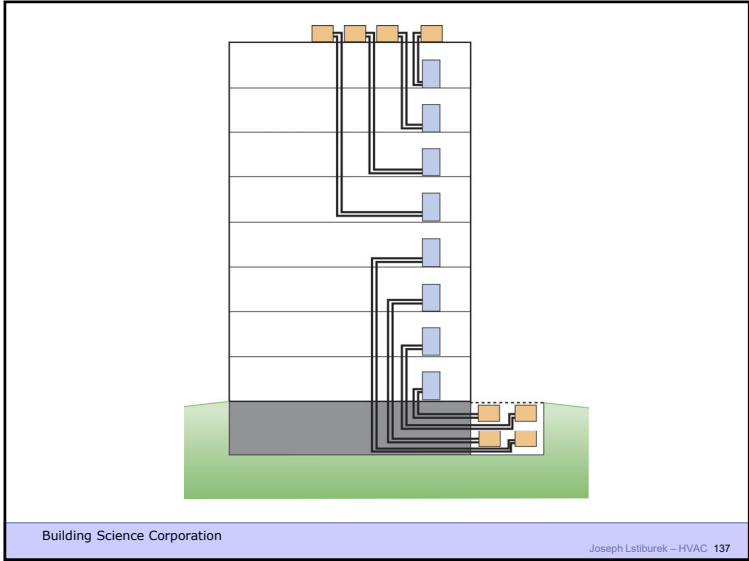
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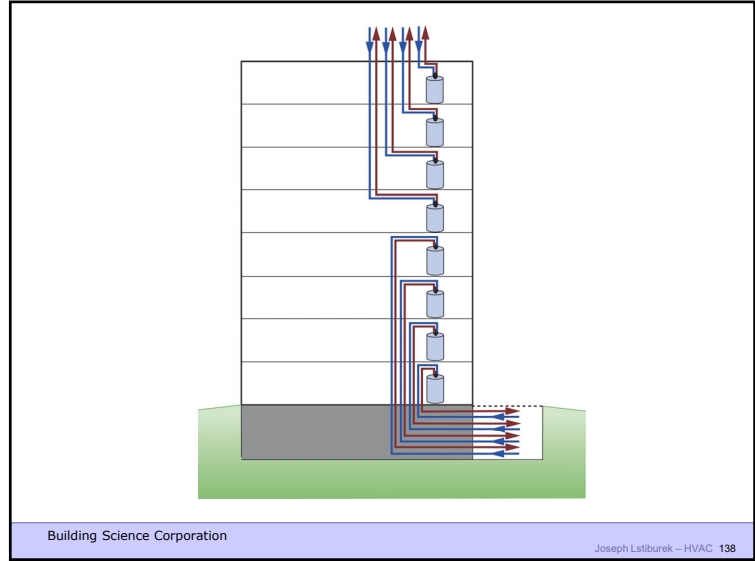
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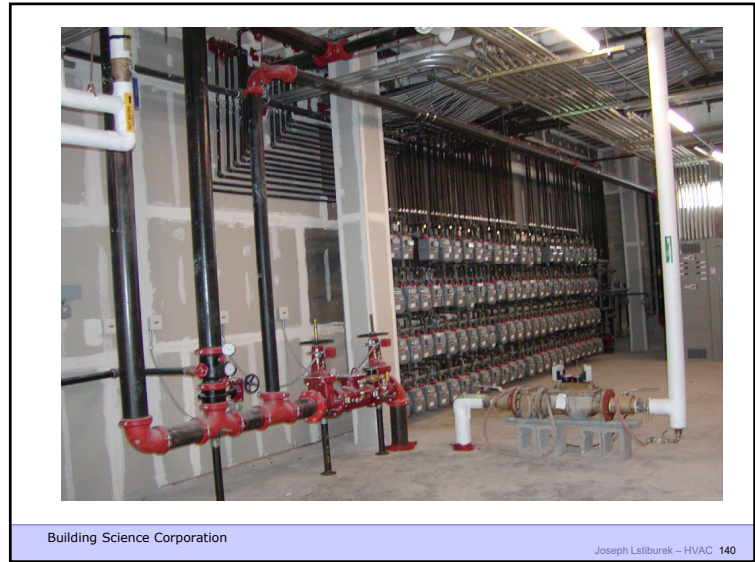
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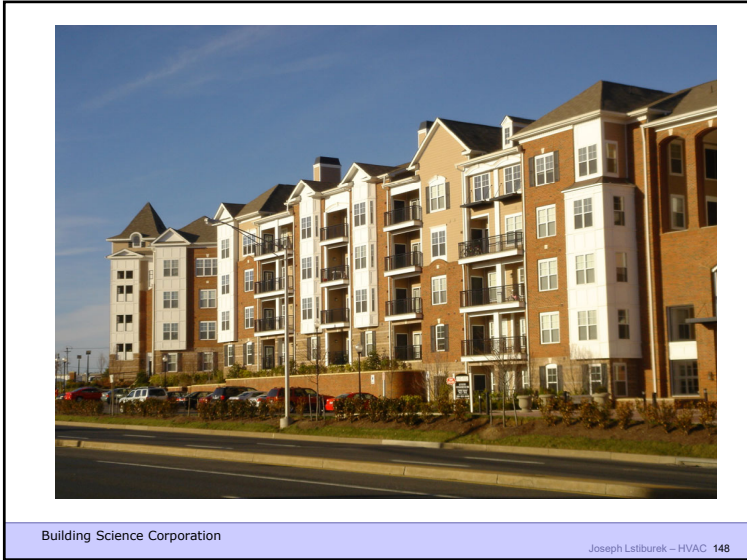
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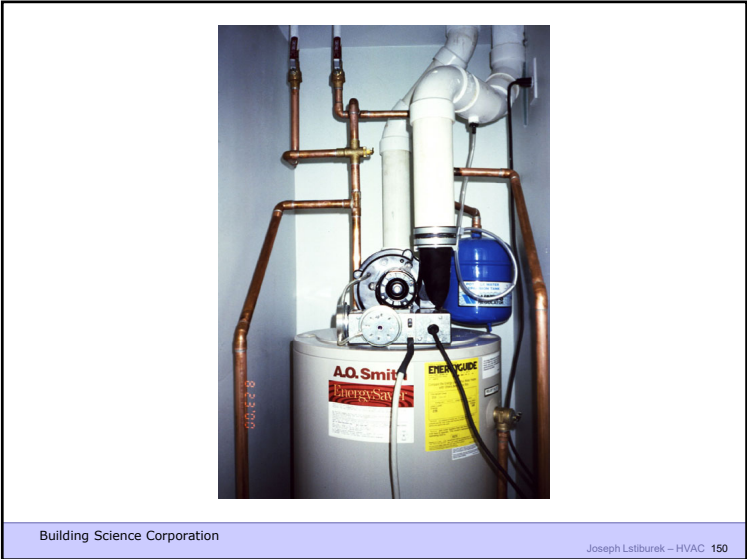
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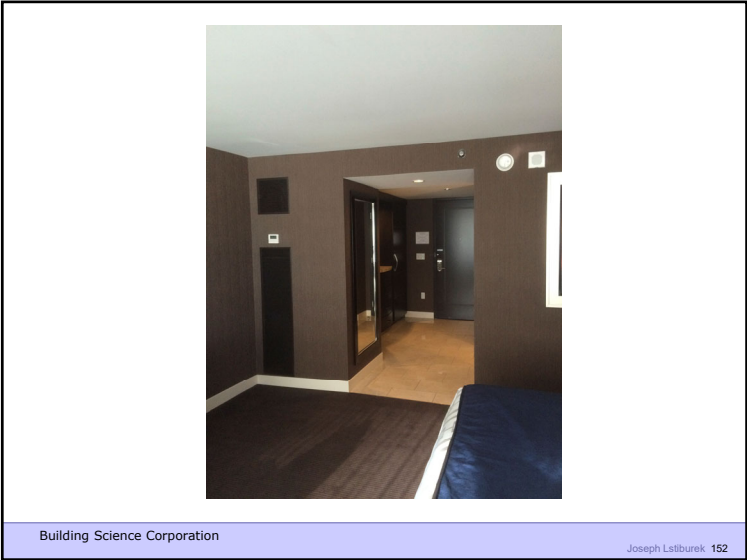
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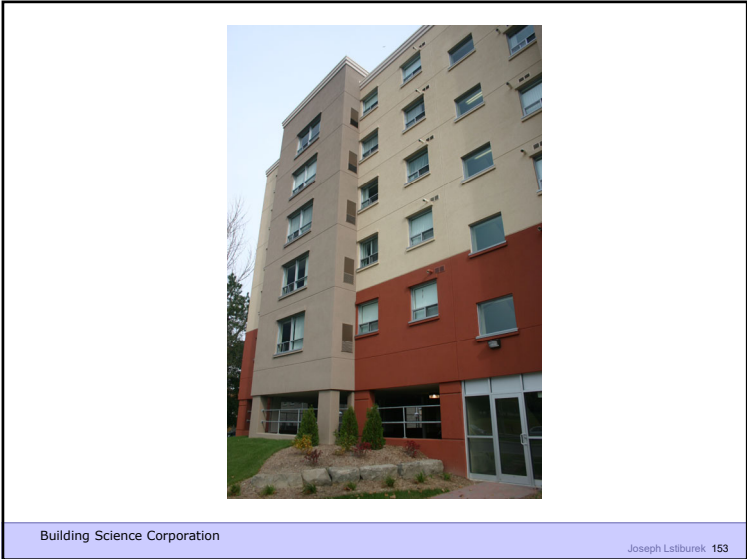
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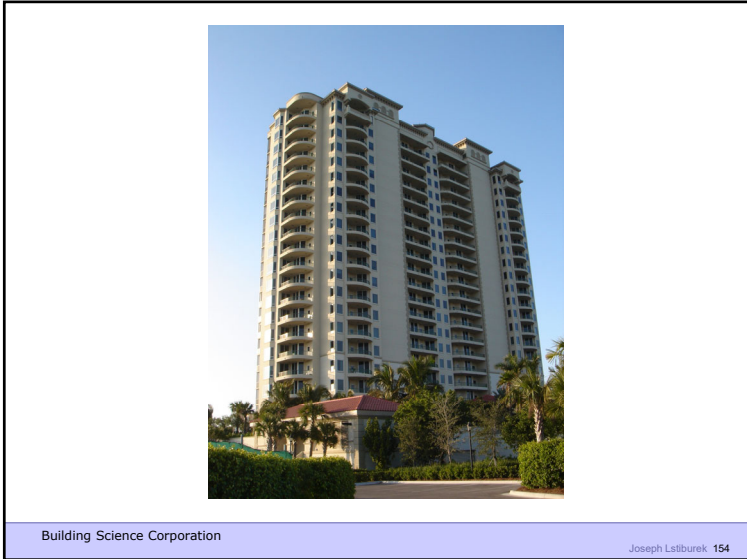
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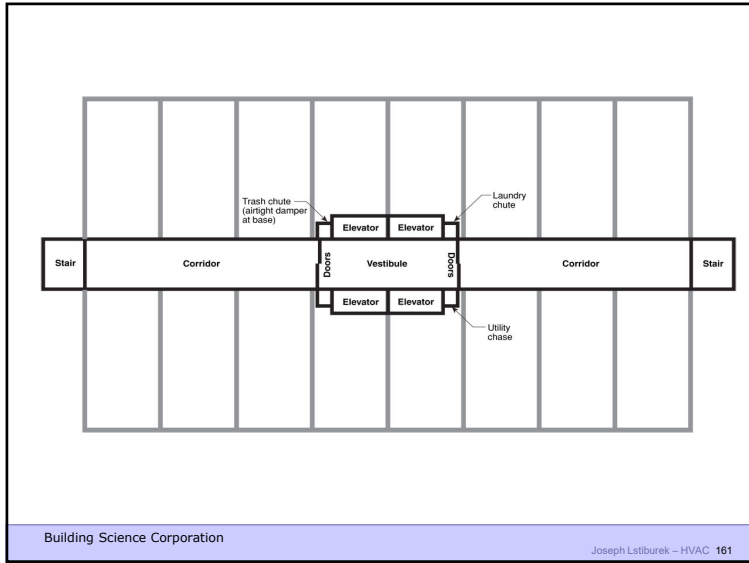
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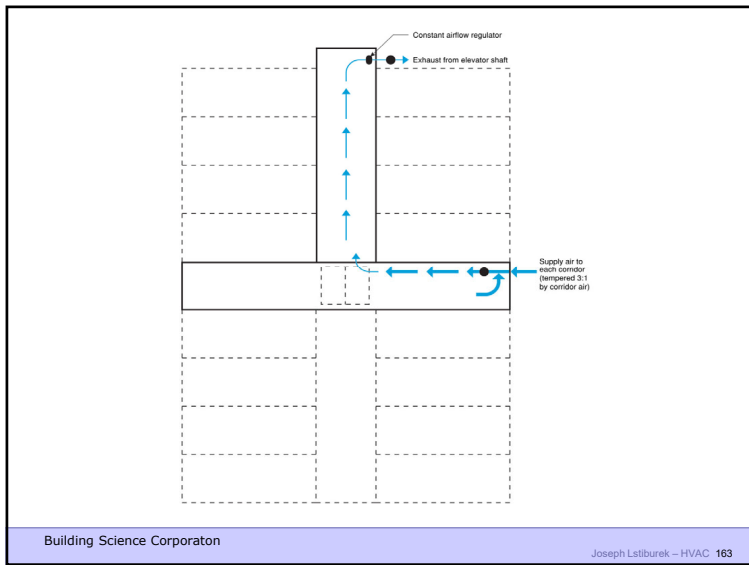
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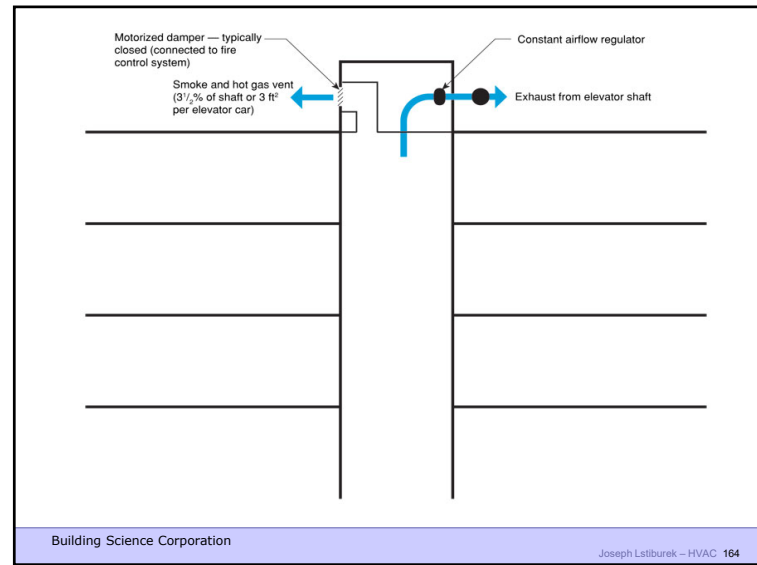
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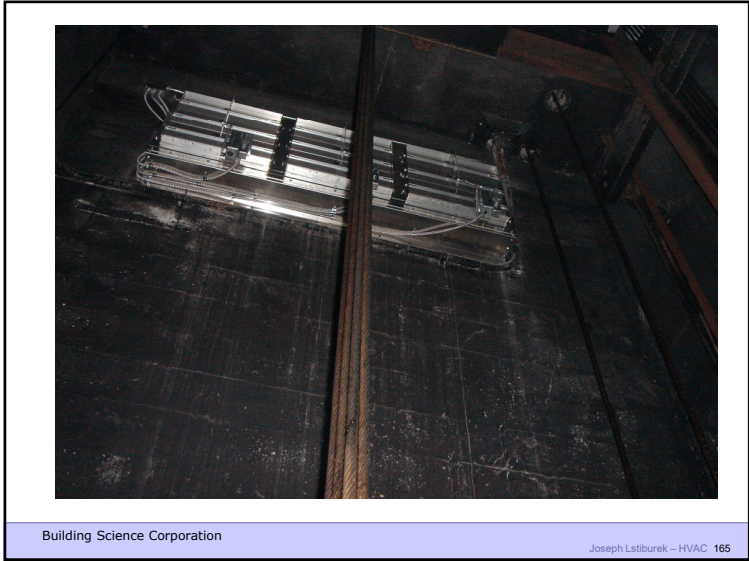
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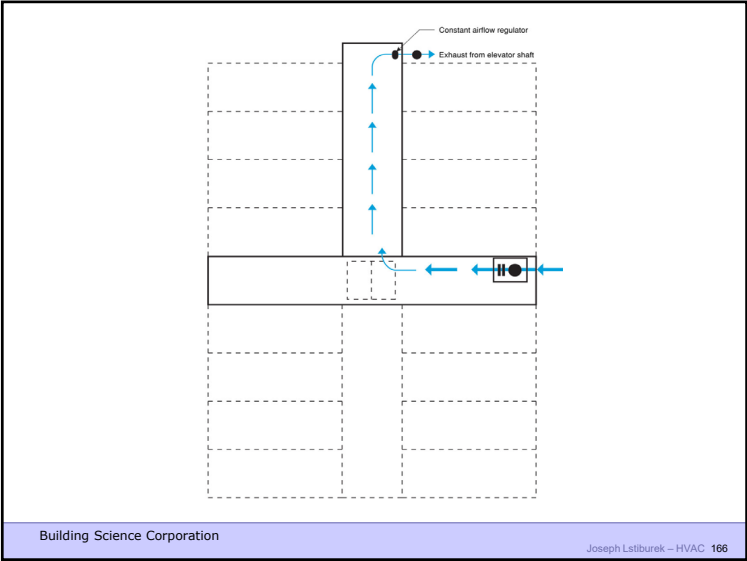
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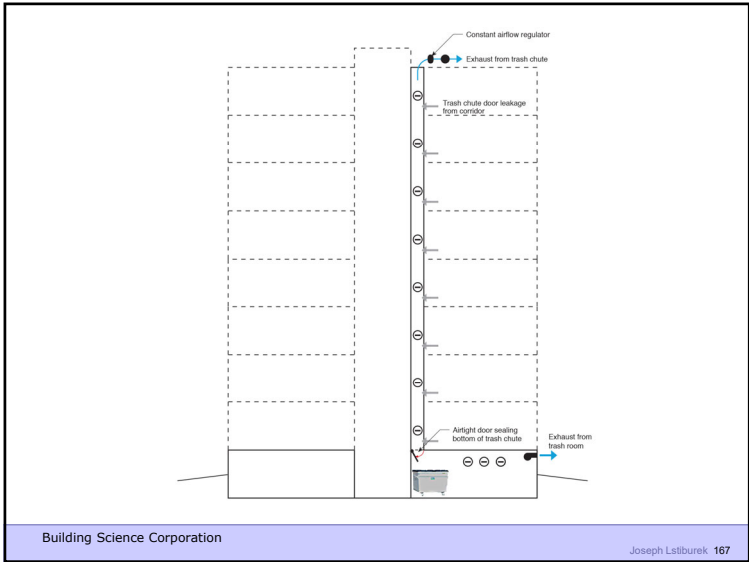
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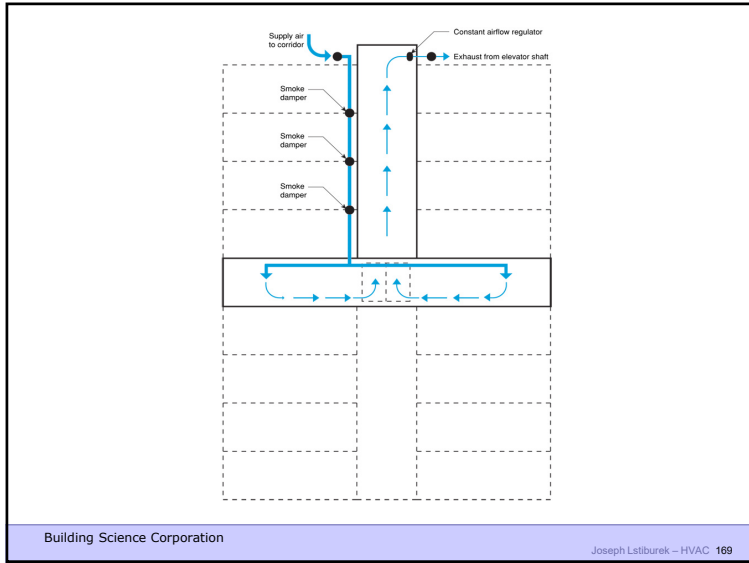
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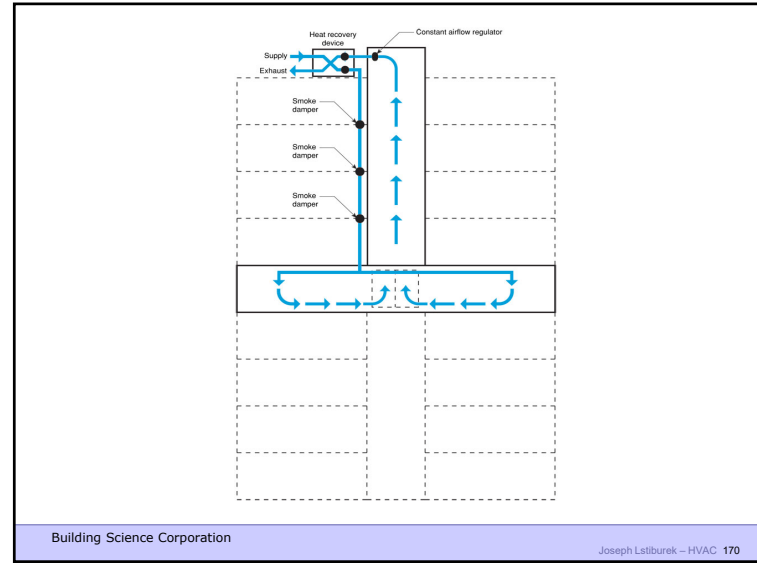
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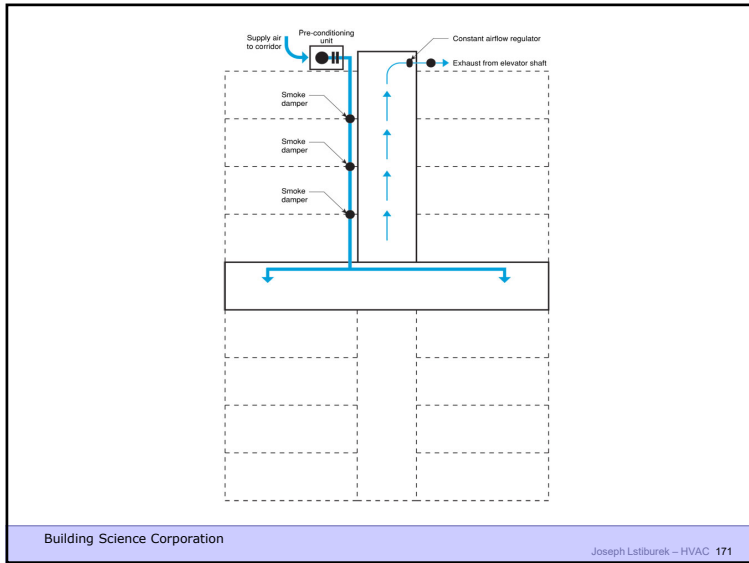
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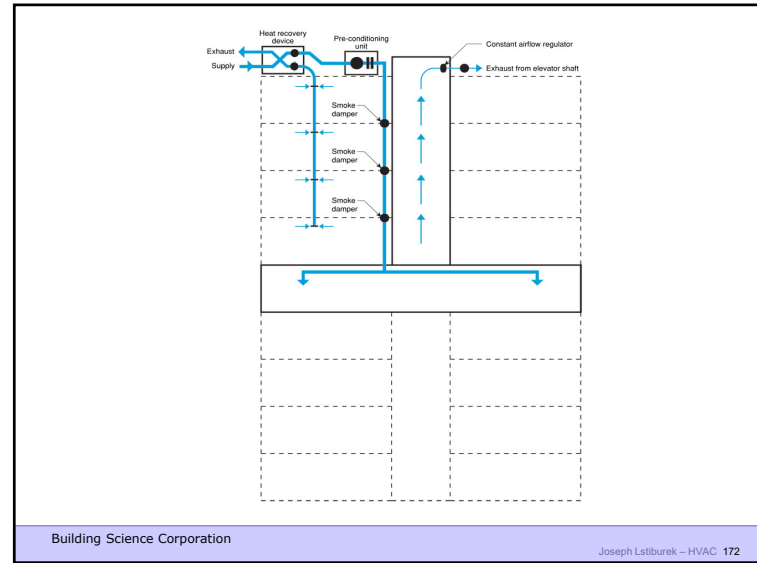
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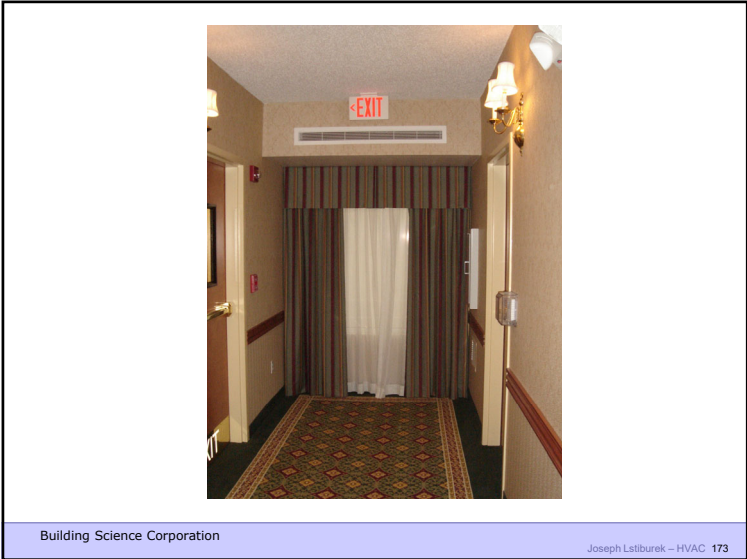
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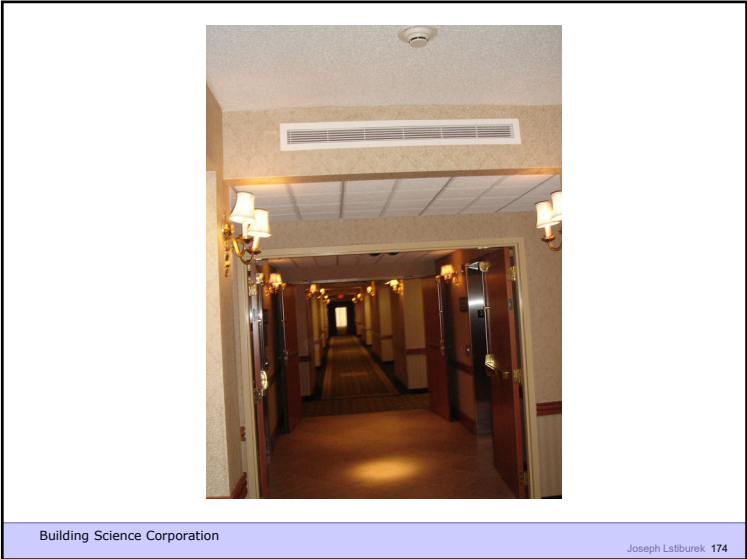
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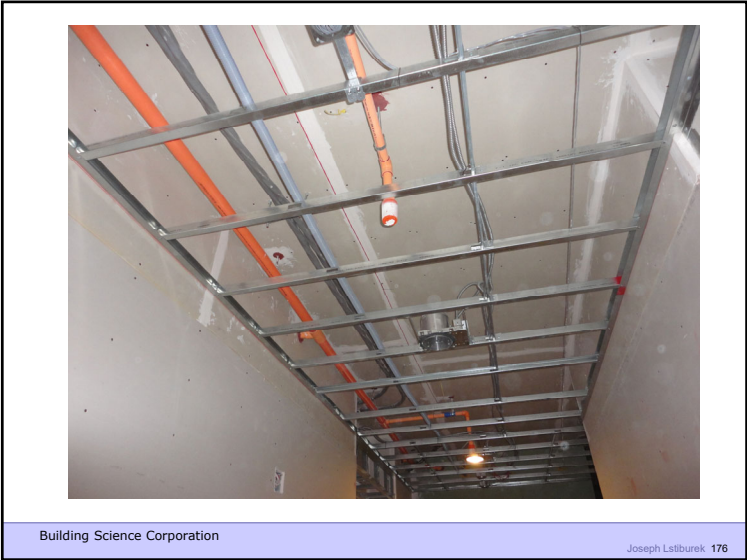
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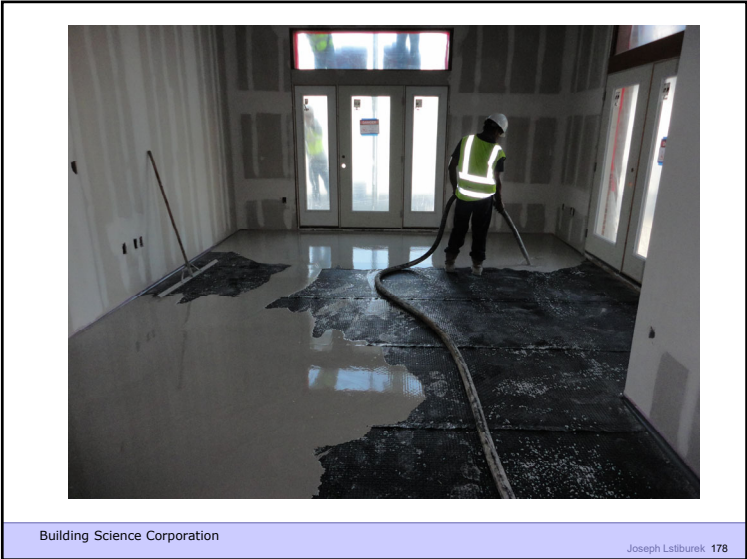
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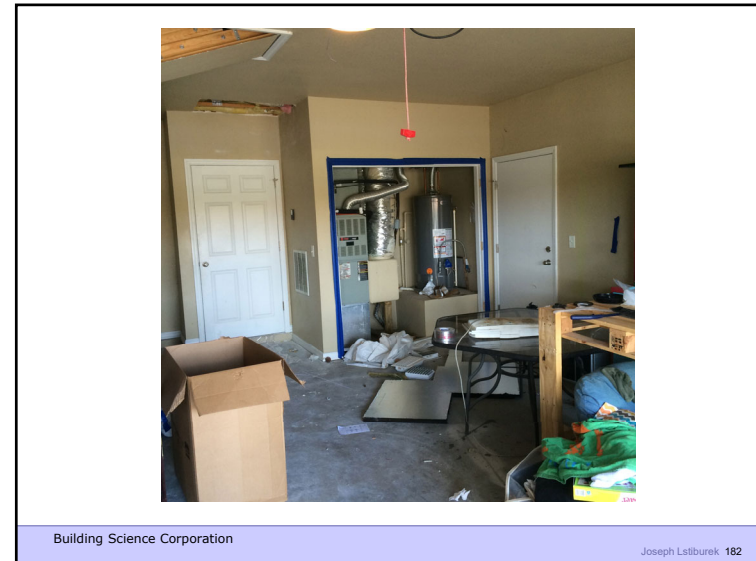
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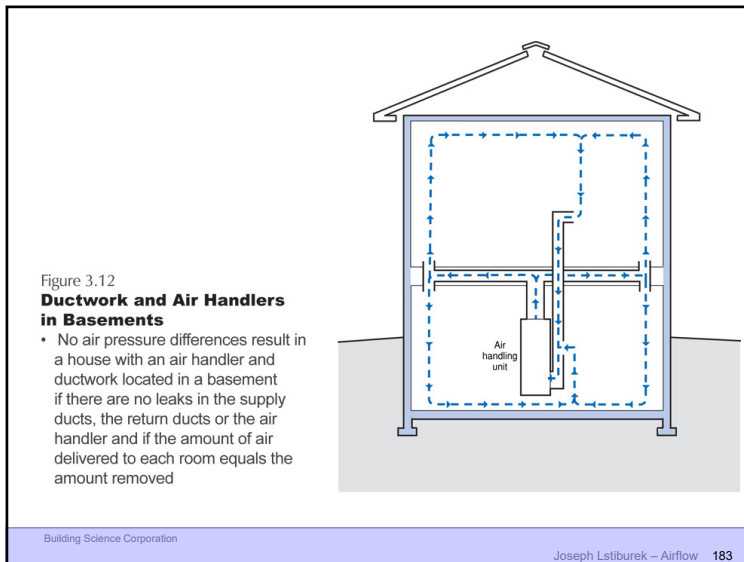
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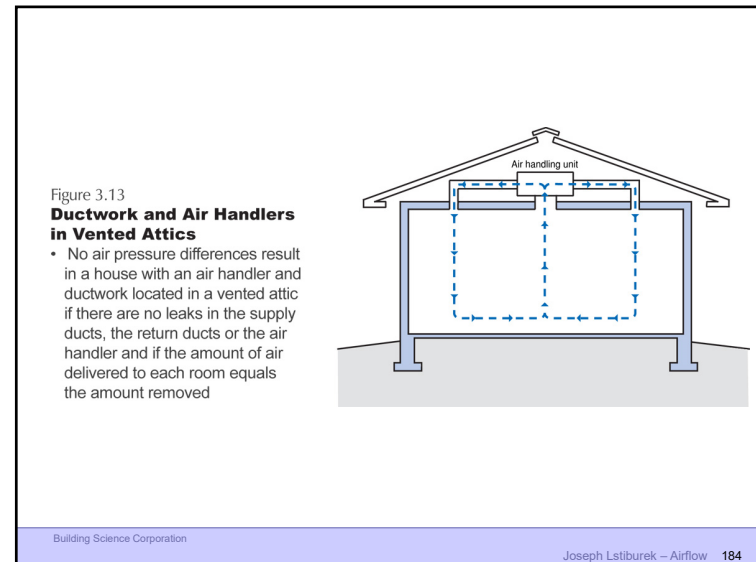
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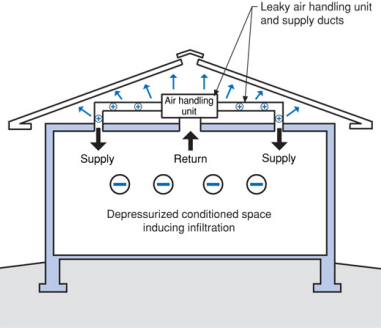


Figure 3.15
Leaky Ductwork and Air Handlers in Vented Attics

- Supply ductwork and air handler leakage is typically 20% or more of the flow through the system

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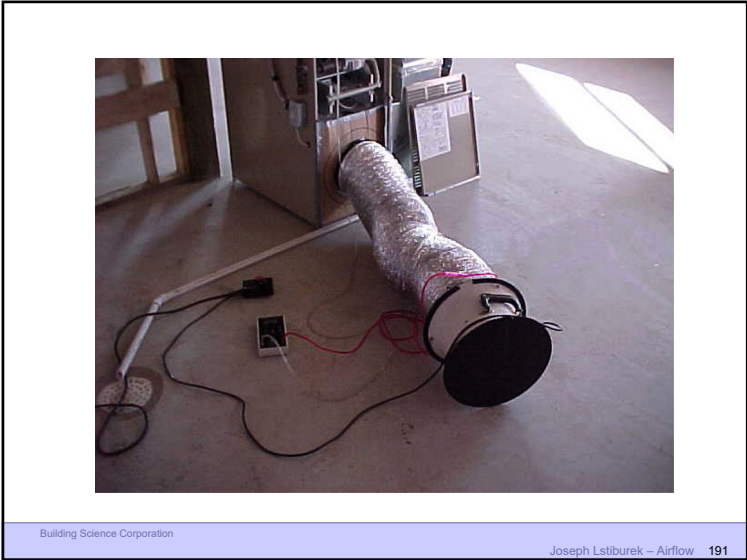
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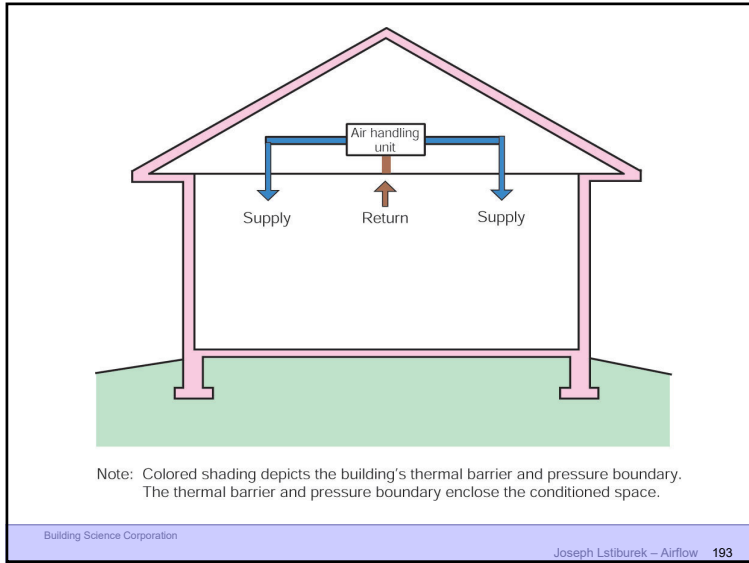
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Duct Leakage Should Be Less Than 5% of Rated Flow As Tested By Pressurization To 25 Pascals

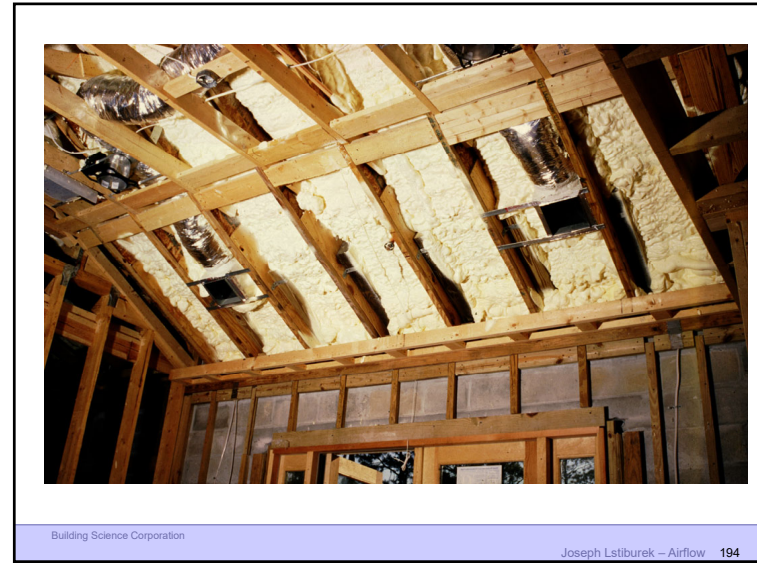
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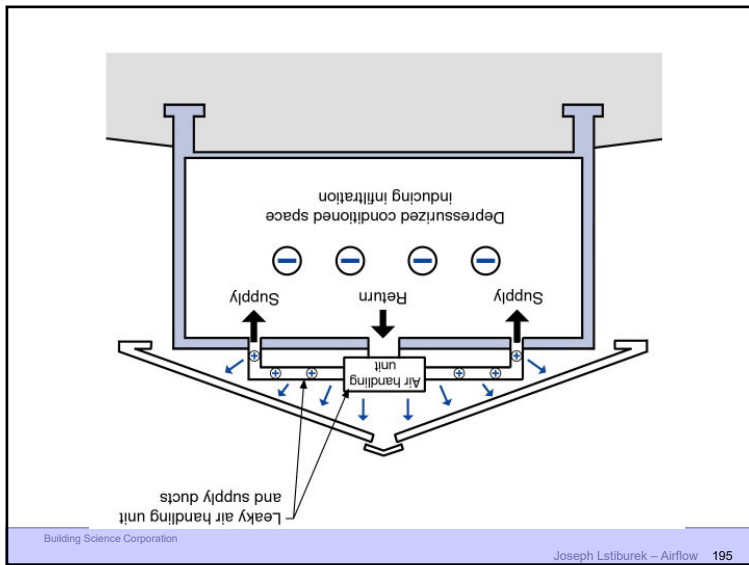
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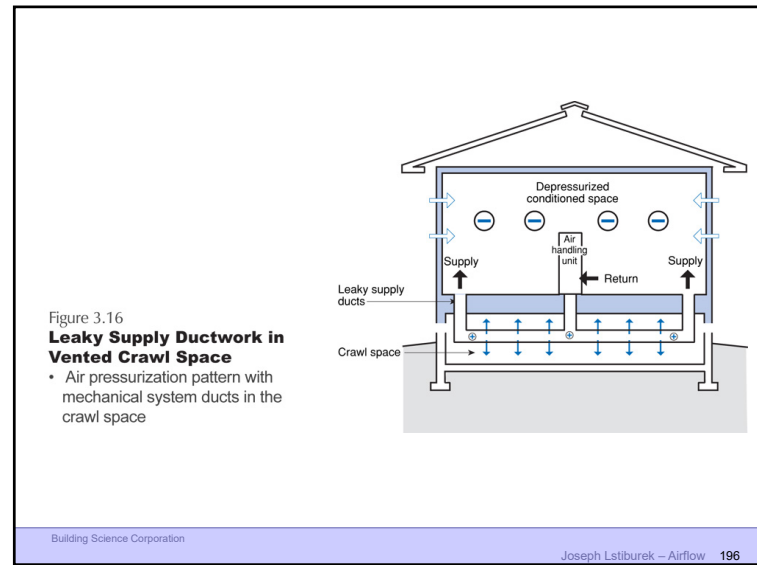
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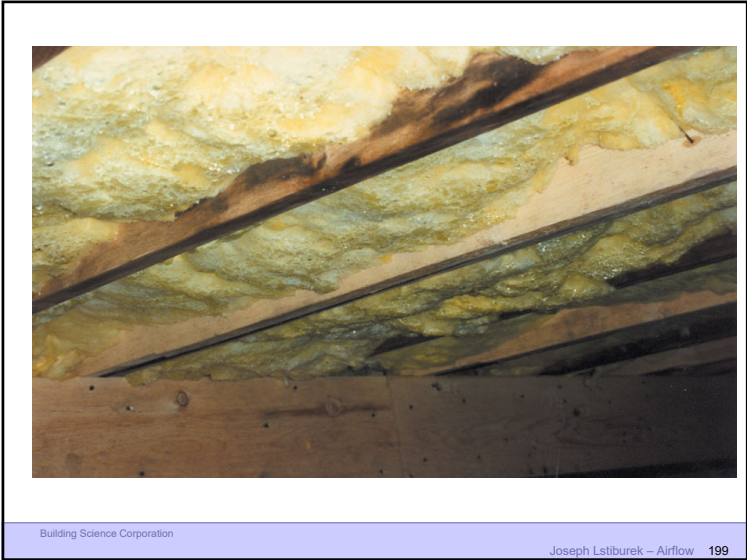
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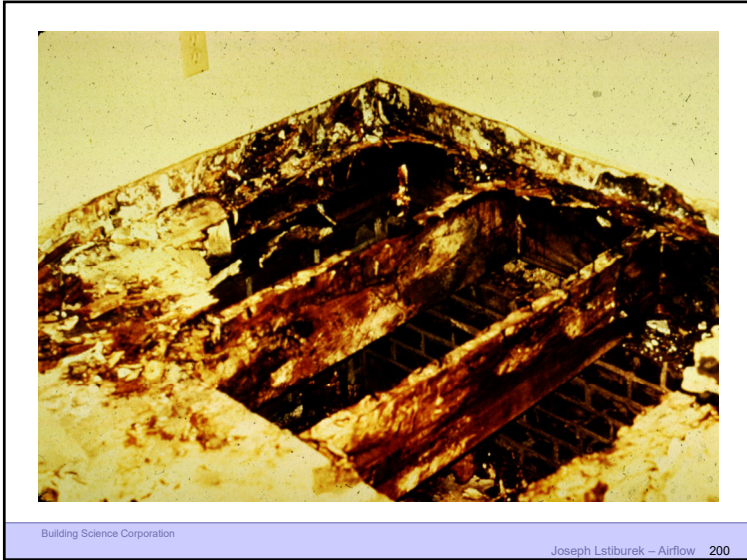
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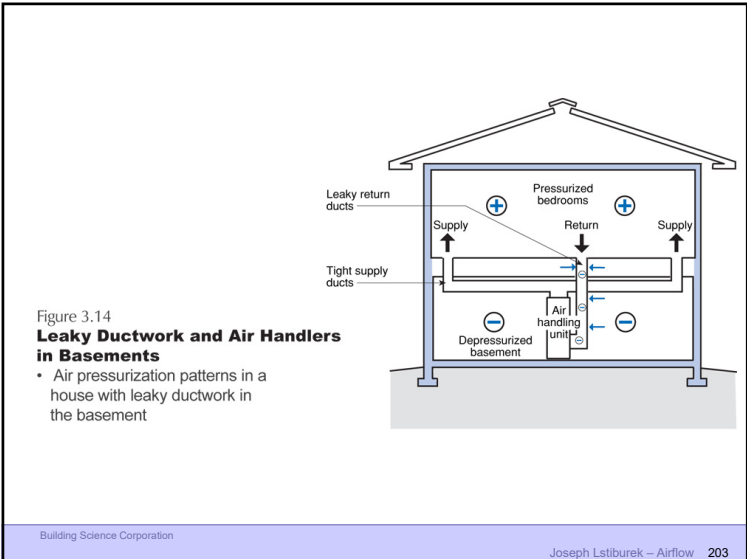
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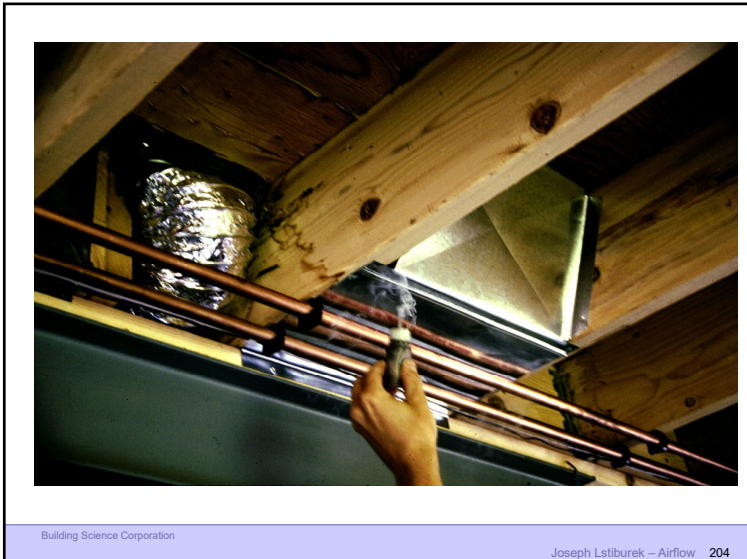
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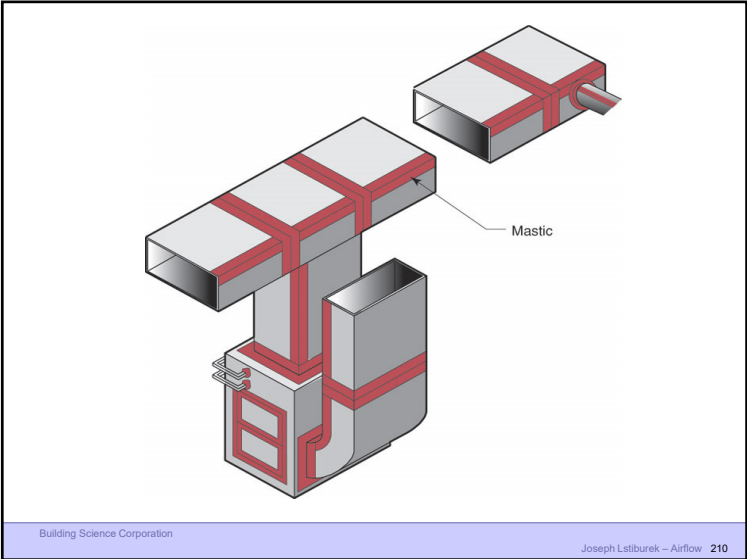
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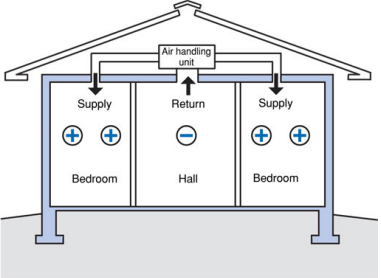
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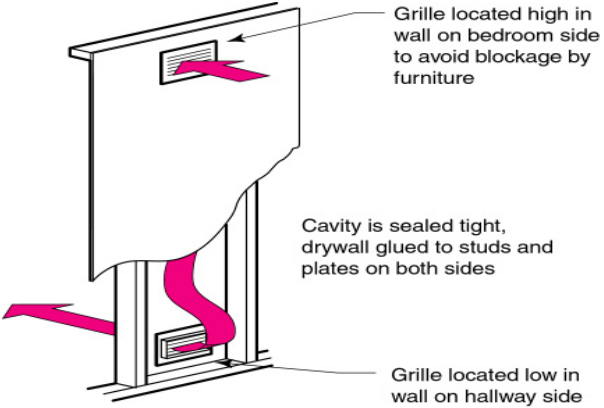
Figure 3.18
Insufficient Return Air Paths

- Pressurization of bedrooms often occurs if insufficient return pathways are provided; undercutting bedroom doors is usually insufficient; transfer grilles, jump ducts or fully ducted returns may be necessary to prevent pressurization of bedrooms
- Master bedroom suites are often the most pressurized as they typically receive the most supply air
- When bedrooms pressurized, common areas depressurize; this can have serious consequences when fireplaces are located in common areas and subsequently backdraft



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Grille located high in wall on bedroom side to avoid blockage by furniture

Cavity is sealed tight, drywall glued to studs and plates on both sides

Grille located low in wall on hallway side

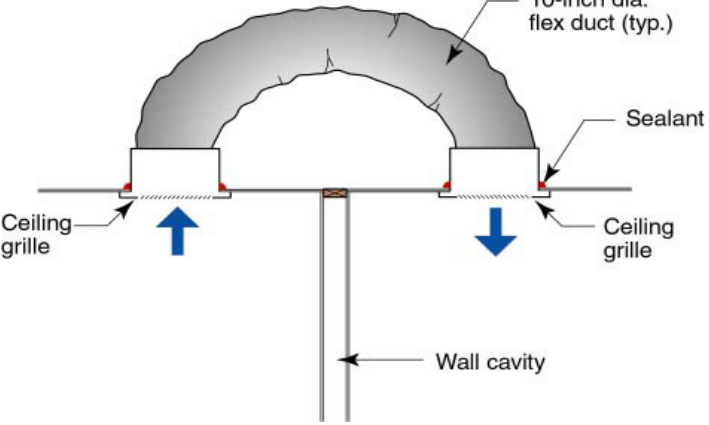
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10-inch dia. flex duct (typ.)

Sealant

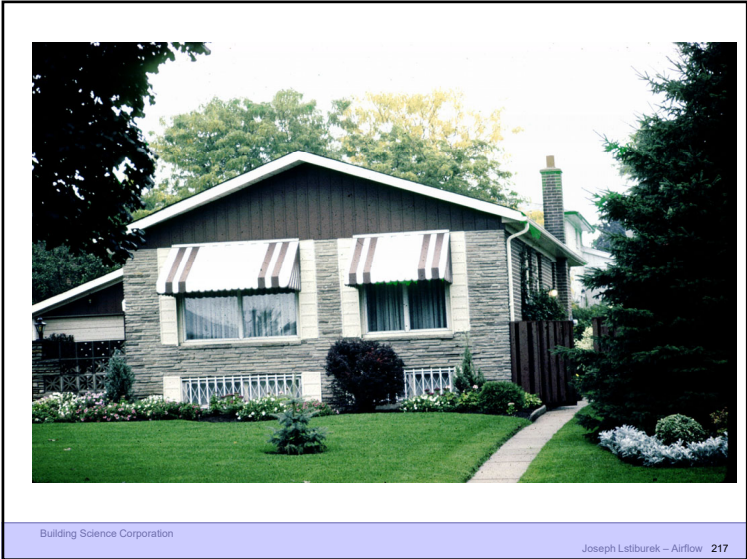
Ceiling grille

Wall cavity

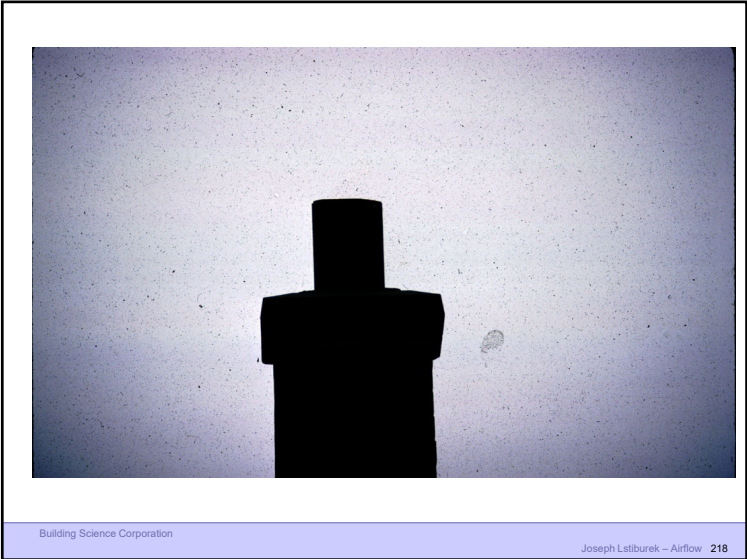
Ceiling grille

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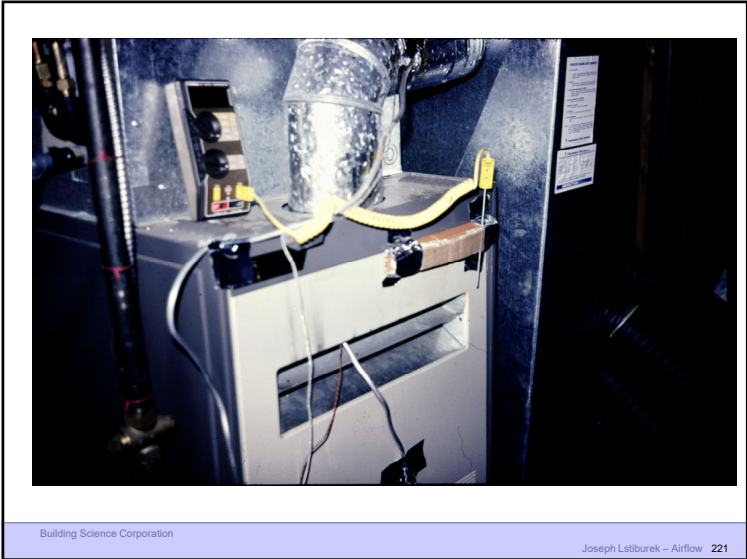
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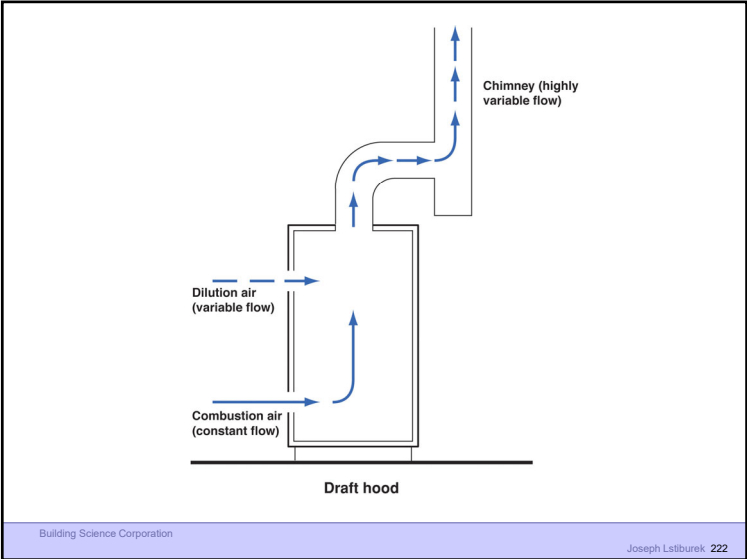
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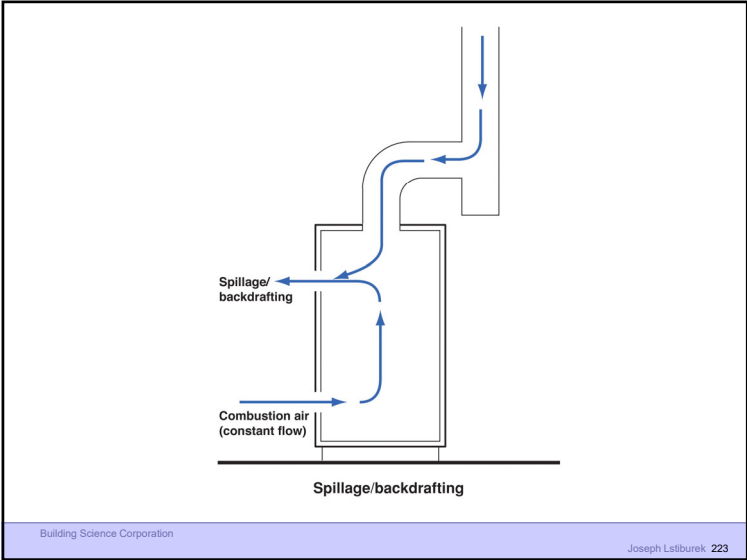
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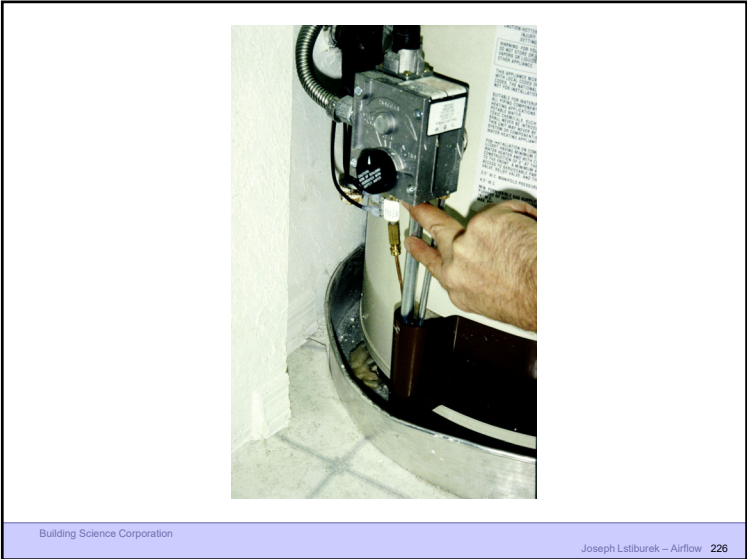
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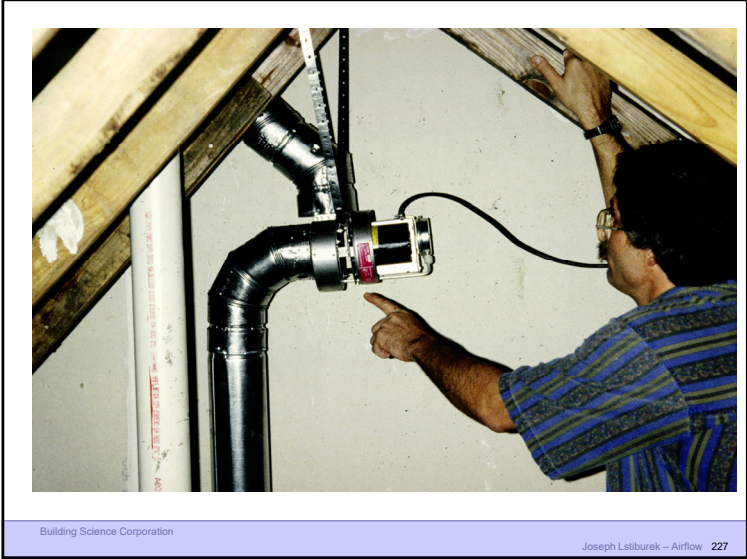
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