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

Building Science

Adventures In Building Science

www.buildingscience.com

Handouts can be downloaded from:
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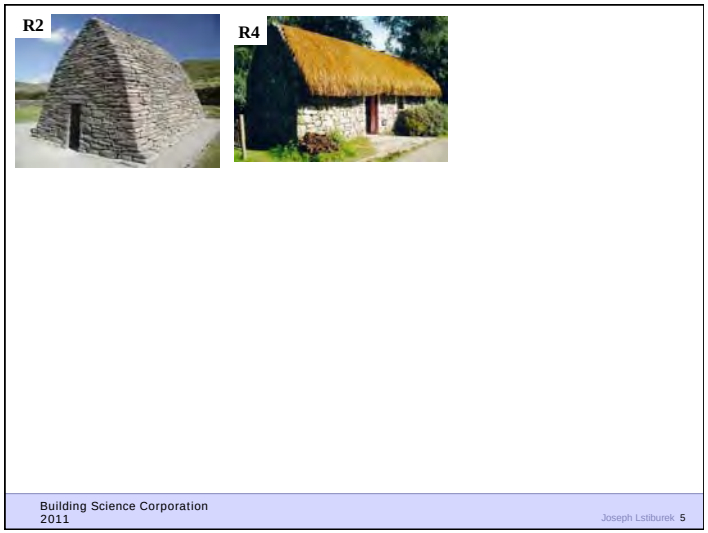
1. Environmental Separation

R2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R4
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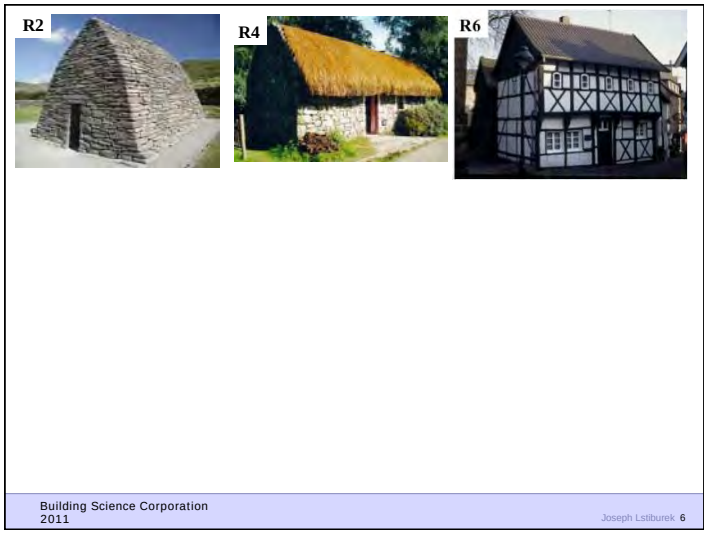
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R4
R6
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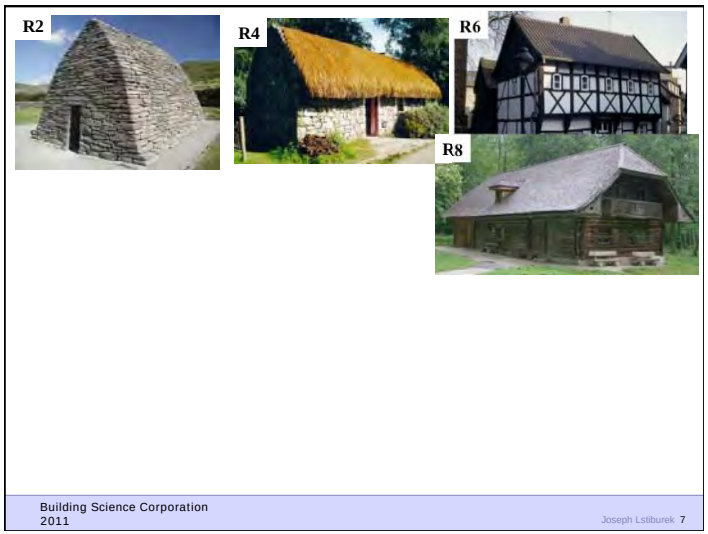
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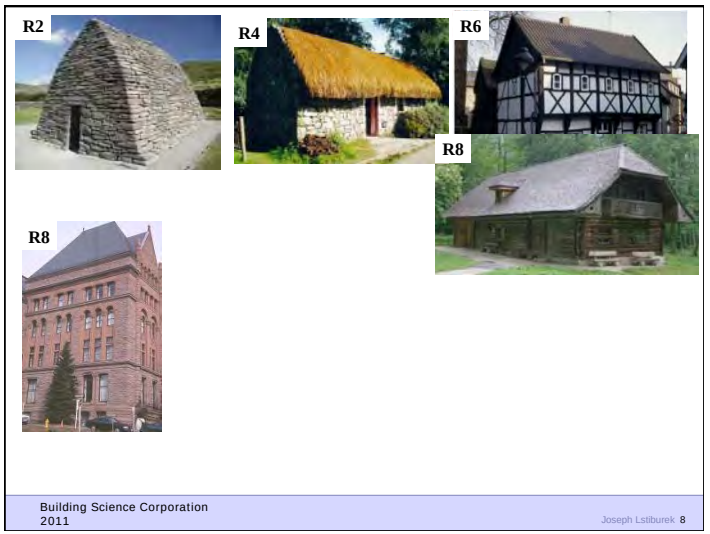
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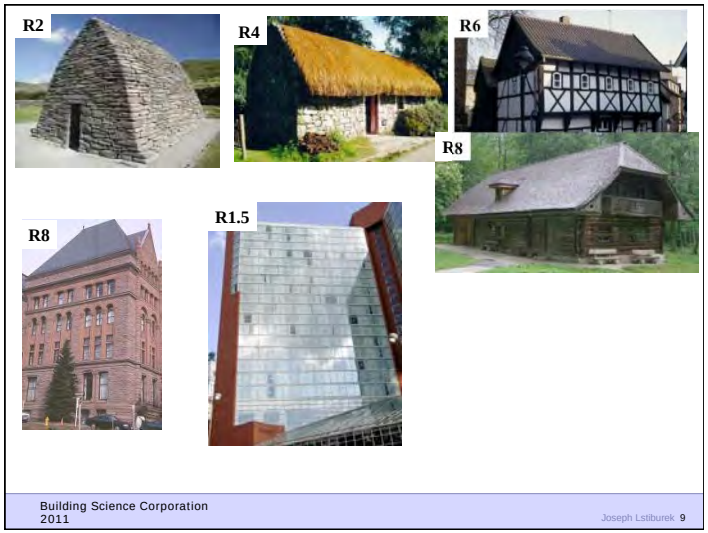
R2
R4
R6
R8
R8
R1.5
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R2
R4
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R8
R1.5
R2
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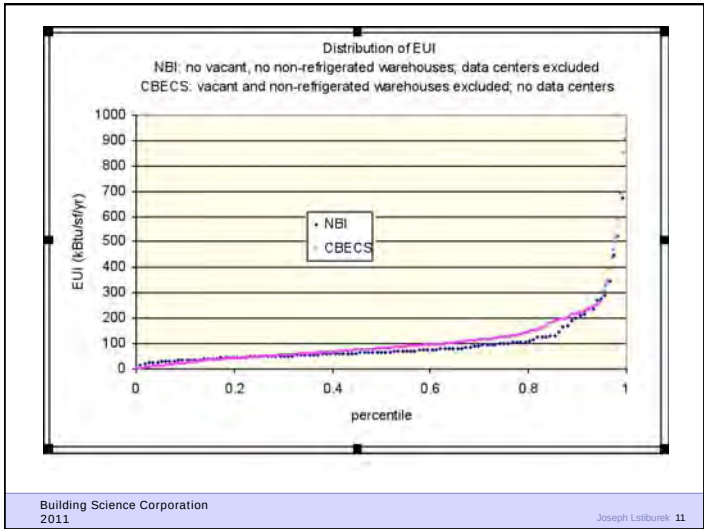
Distribution of EUI
NBI: no vacant, no non-refrigerated warehouses; data centers excluded
CBECS: vacant and non-refrigerated warehouses excluded; no data centers
EUI (kBtu/sf/yr)
1000
900
800
700
600
500
400
300
200
100
0
NBI
CBECS
0
0.2
0.4
0.6
0.8
1
percentile
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Life is Tough Enough As it Is…

Life is Tough Enough As it Is…
It's Harder When You Are Stupid

Don't Do Stupid Things

What is a Building?

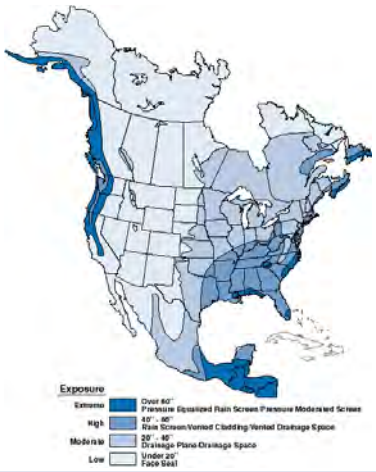
What is a Building?
It is an Environmental Separator

Control heat flow
Control airflow
Control water vapor flow
Control rain
Control ground water
Control light and solar radiation
Control noise and vibrations
Control contaminants, environmental hazards and odors
Control insects, rodents and vermin
Control fire
Provide strength and rigidity
Be durable
Be aesthetically pleasing
Be economical

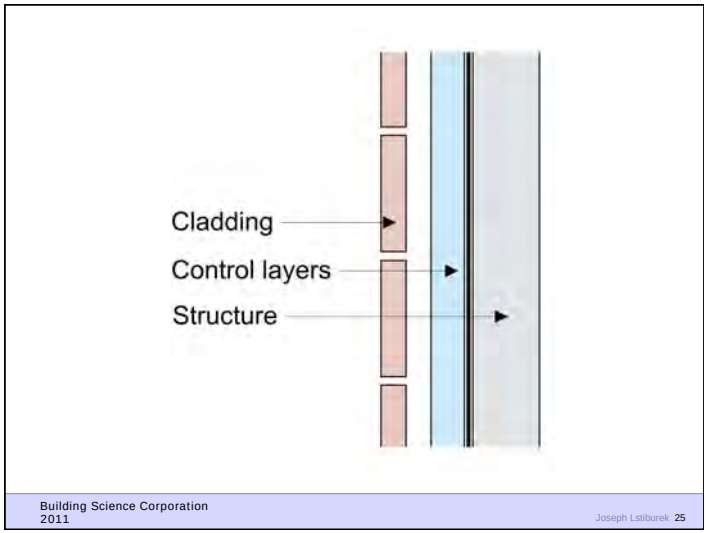
Not all performance objectives are equal.
Our focus is control of heat, air and moisture.

Damage Functions
Water, Heat and Ultra-Violet Radiation

Heat Flow Is From Warm To Cold
Moisture Flow Is From Warm To Cold
Moisture Flow Is From More To Less
Air Flow Is From A Higher Pressure to a Lower Pressure
Gravity Acts Down



Water Control Layer
Air Control Layer
Vapor Control Layer
Thermal Control Layer



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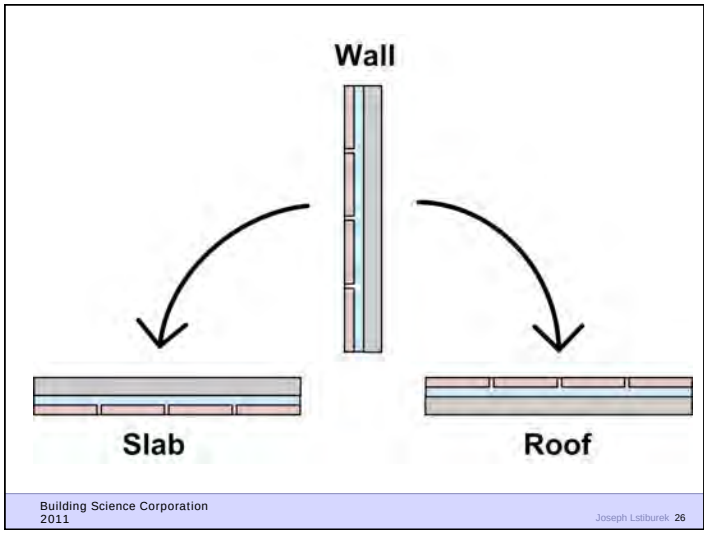

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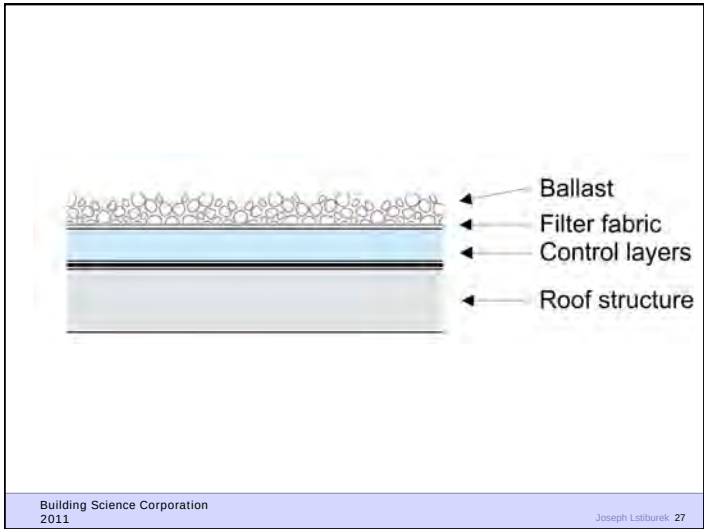

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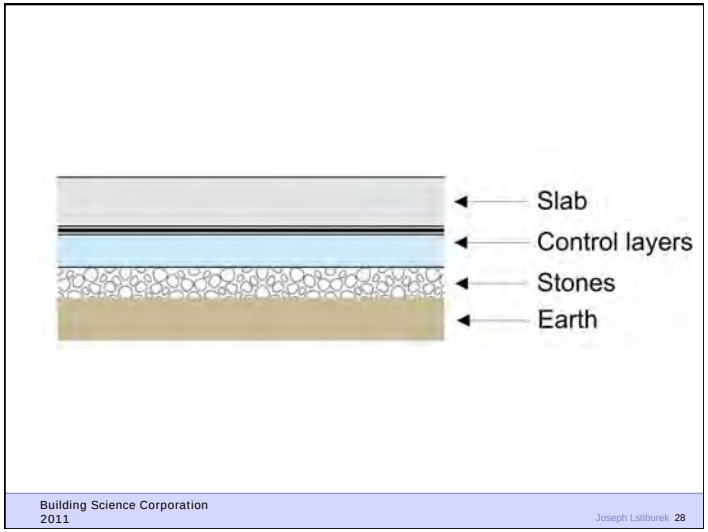

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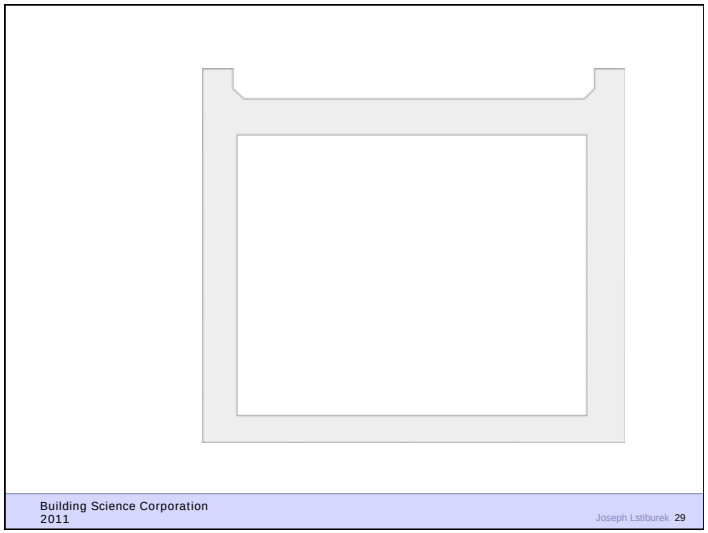

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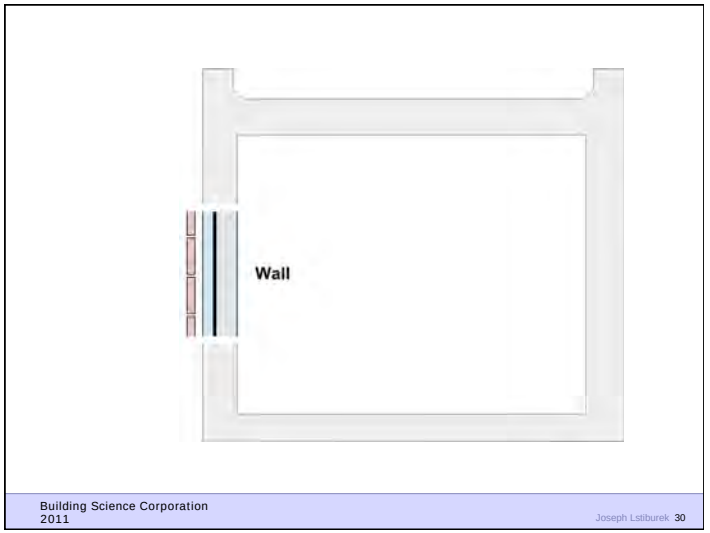

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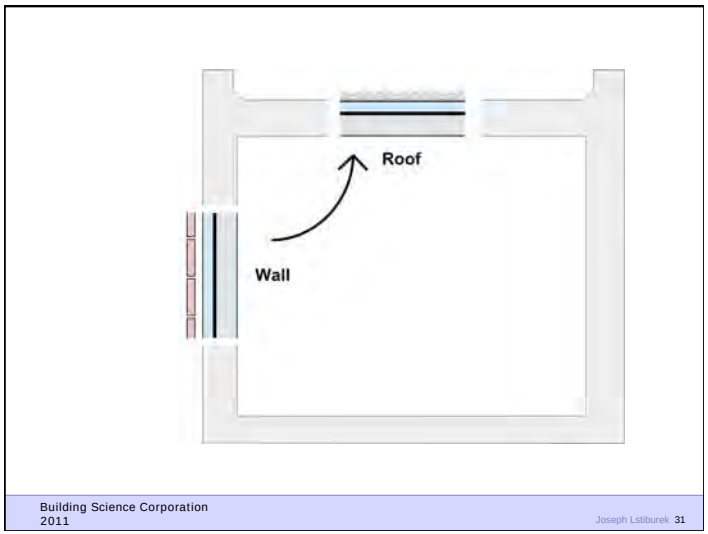

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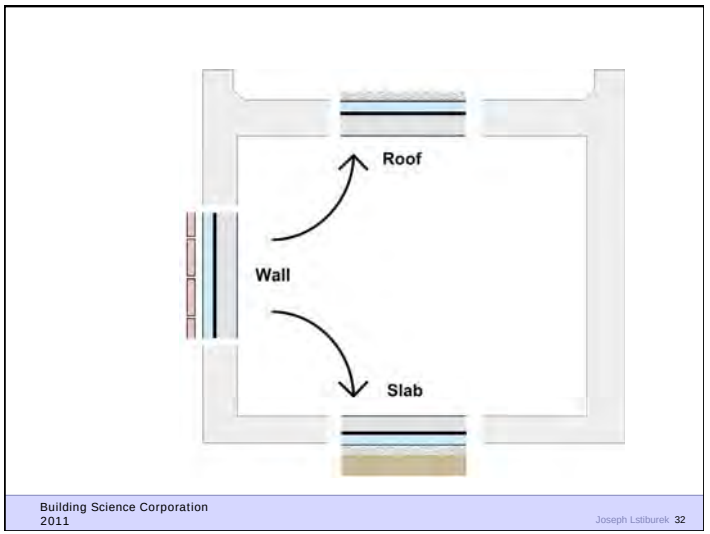

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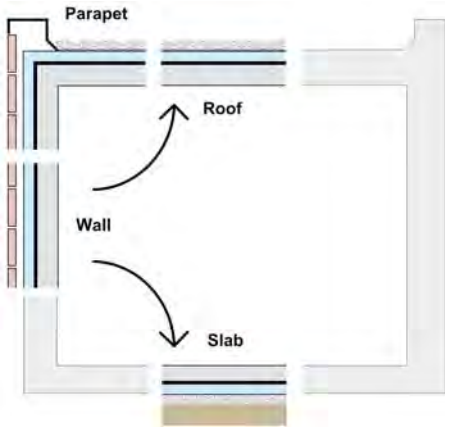

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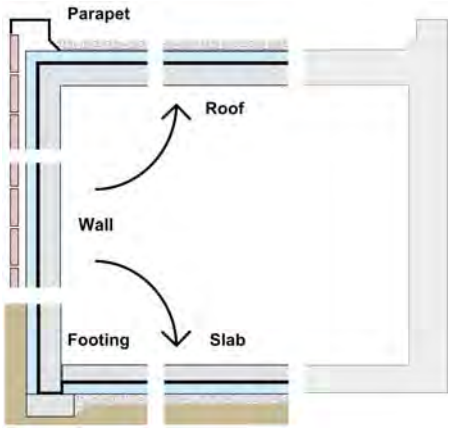

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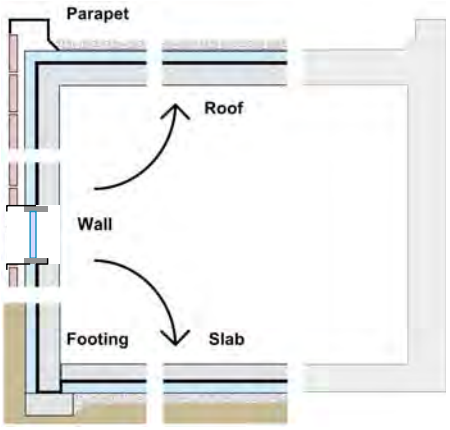

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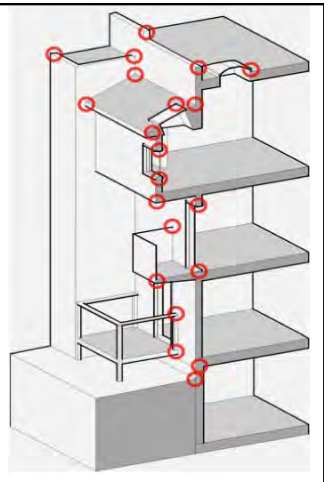
Enclosure Design: Details

- Details demand the same approach as the enclosure.
- Scaled drawings required at ○



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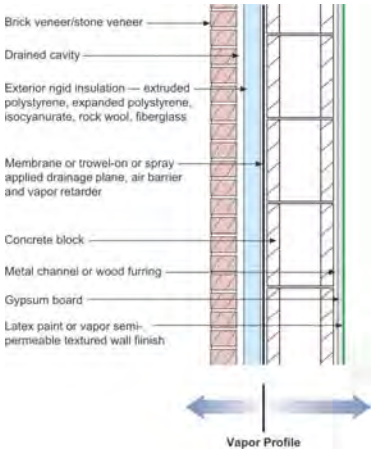

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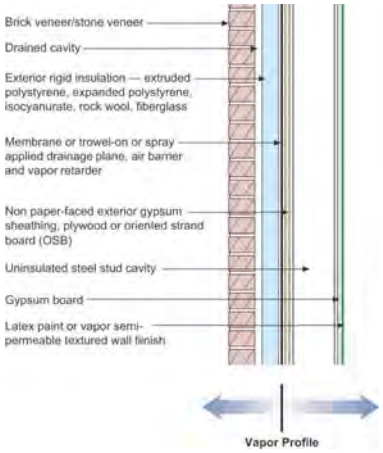

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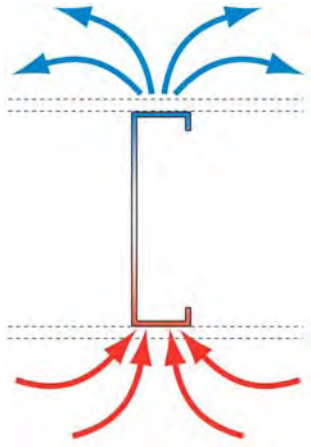

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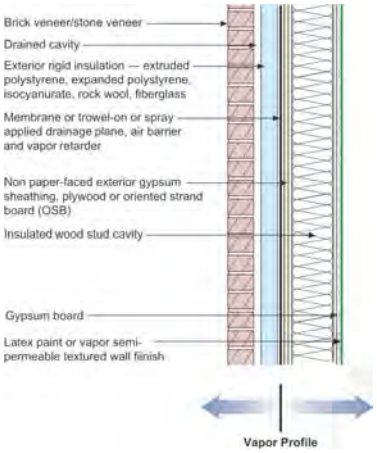

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Don’t Do Stupid Things

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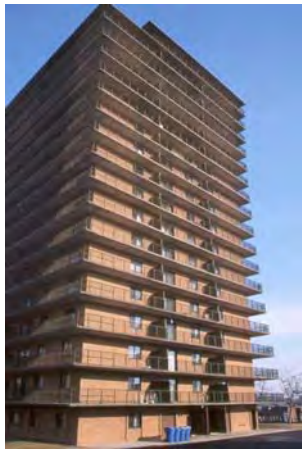

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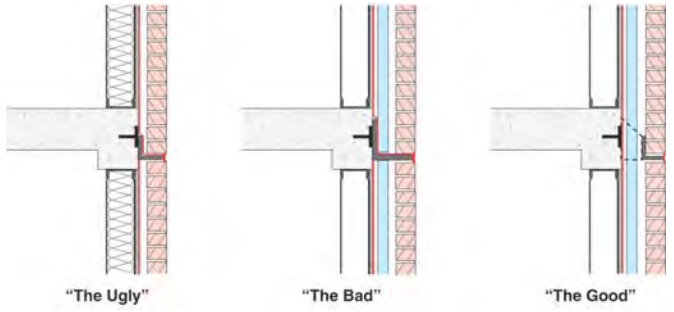

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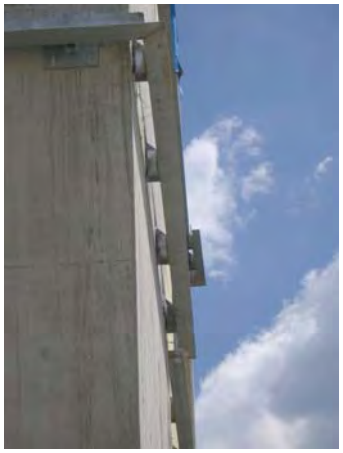

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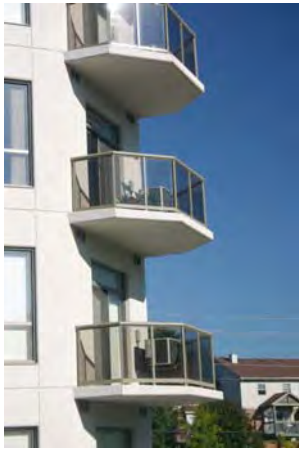

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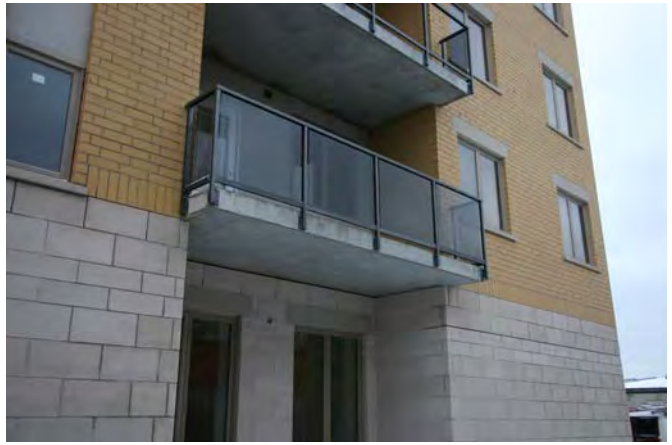

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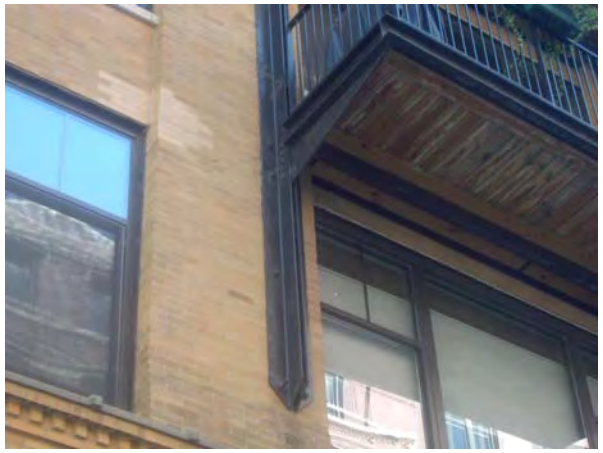

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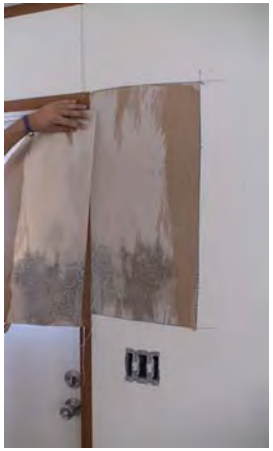

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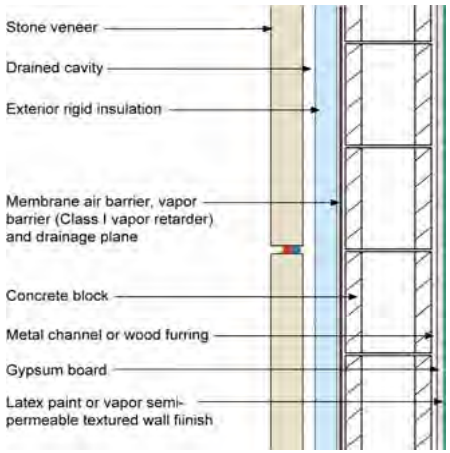
Air Barrier Metrics

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



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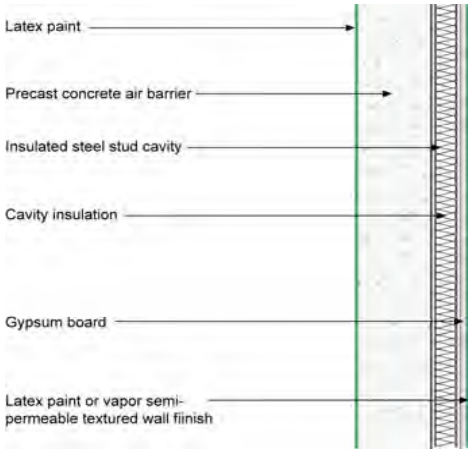

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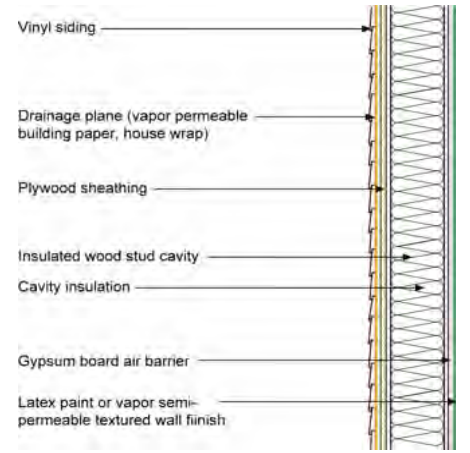

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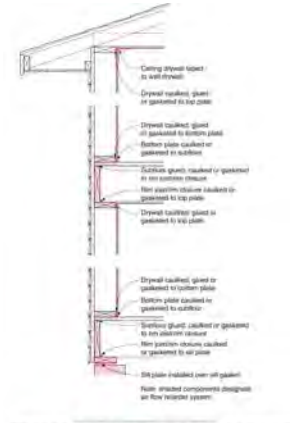
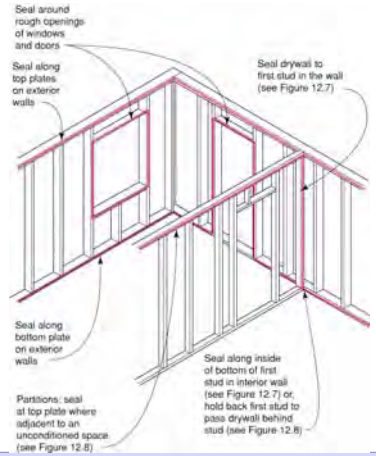
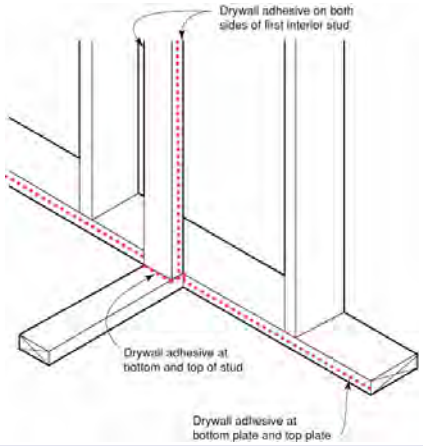
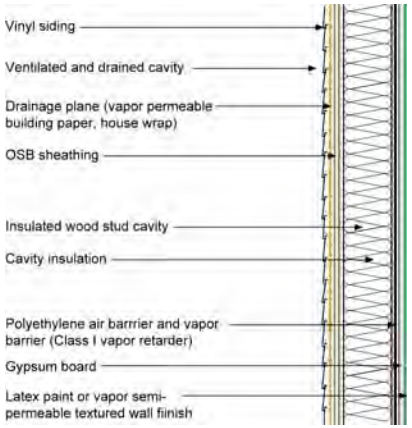


Interior Air Flow Retarder Using Drywall and Framing







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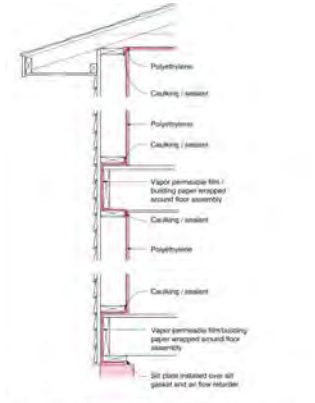

Interior Air Flow Retarder Using Polyethylene

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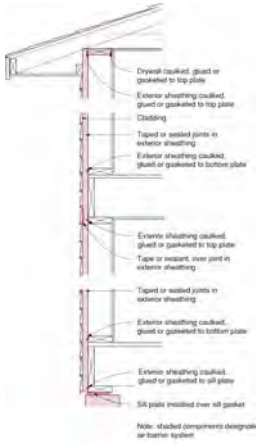

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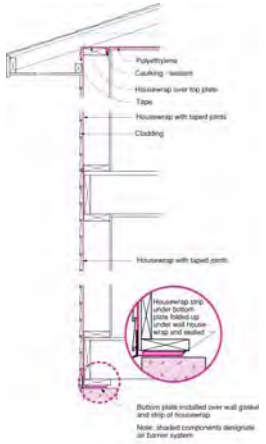

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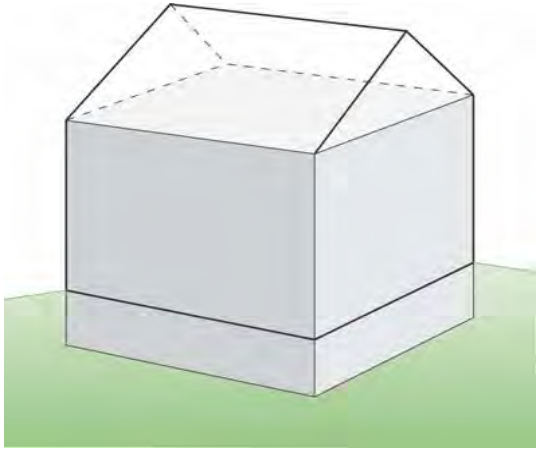

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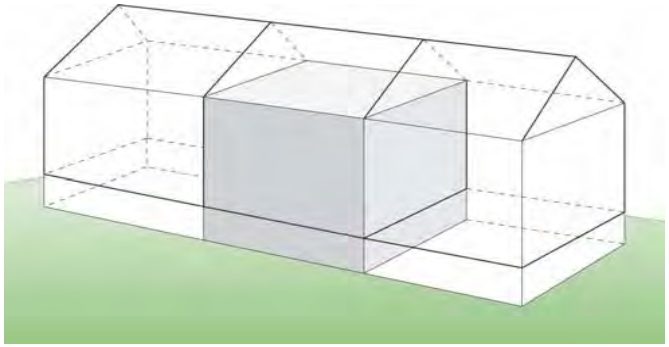

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Joseph Lstiburek 111

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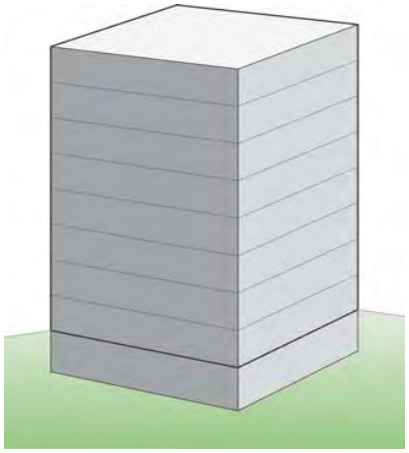
Joseph Lstiburek 112



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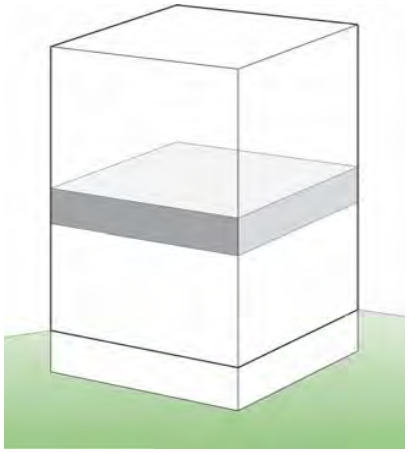

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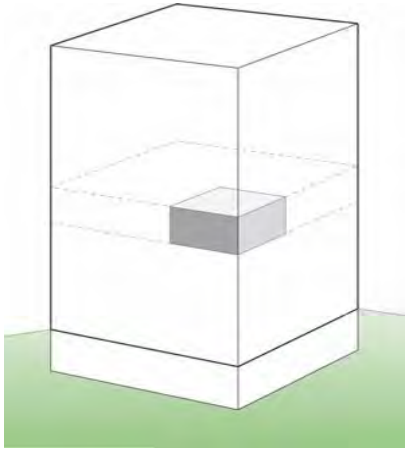

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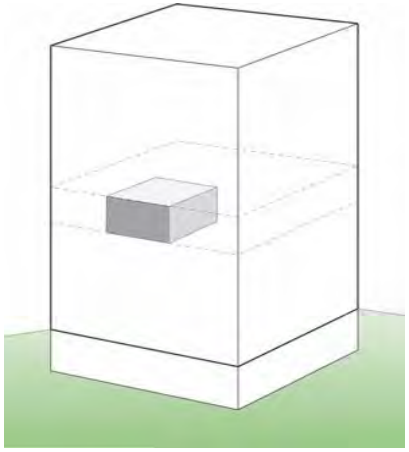

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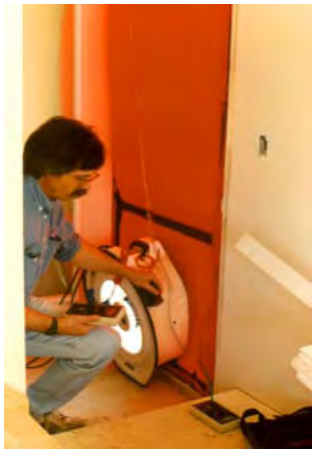

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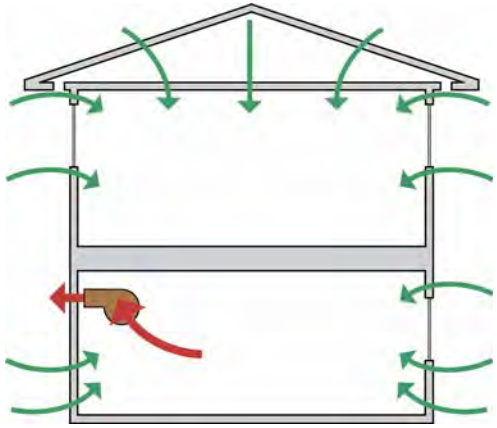

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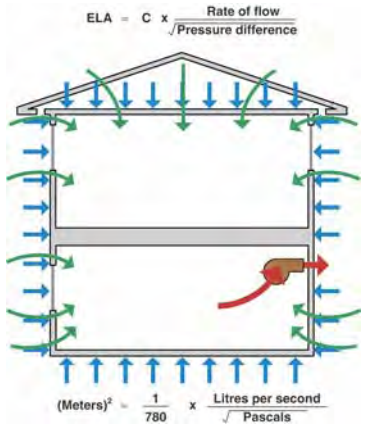

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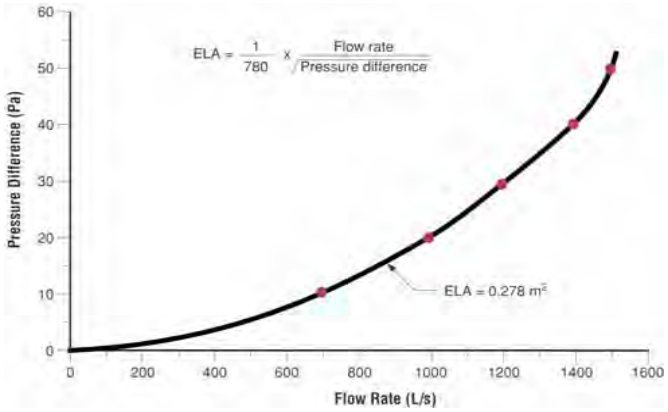

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Stuff That Is Not Particularly Useful But Studied and Researched to Death

Stuff That Is Very Useful but Ignored by the Research Community

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Stuff That Is Not Particularly Useful But Studied and Researched to Death

"this is called Physics"

Stuff That Is Very Useful but Ignored by the Research Community

"this is called Engineering"

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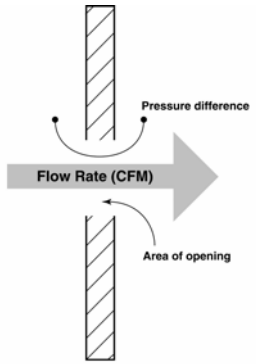

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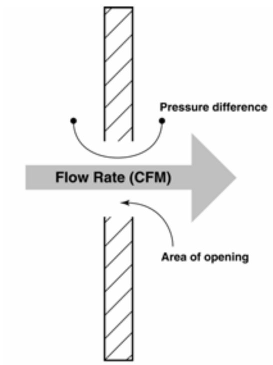

"this is a lie"

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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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$$Q = A \lozenge C_D \frac{2}{\ } (P)^{\frac{1}{2}}$$ Bernoulli

$$Q = C_K \frac{\ }{\ } (P)$$ Darcy

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$Q = A \sqrt{C_D} \frac{2}{} (P)^{\frac{1}{2}}$ Bernoulli

$Q = C_K (P)$ Darcy

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

$Q = C (P)$

$Q = A \sqrt{C_D} \frac{2}{} (P)^{\frac{1}{2}}$ Bernoulli

$Q = C_K (P)$ Darcy

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

$Q = C (P)$

$Q = A \sqrt{C} (P)^{n}$ Kronval "an engineer"

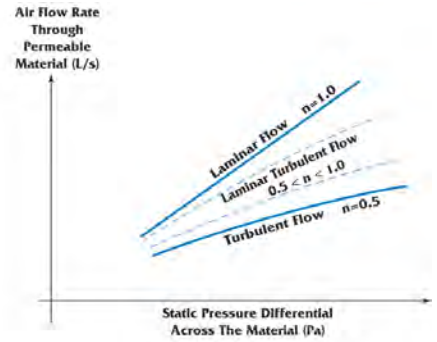

Figure 2.5
Modes of Air Flow
(from Bumbaru, Jutras and Patenaude, 1988)

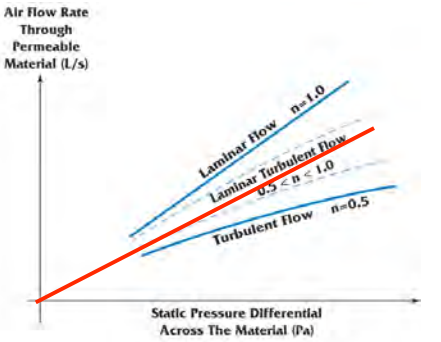

Figure 2.5
Modes of Air Flow
(from Bumbaru, Jutras and Patenaude, 1988)

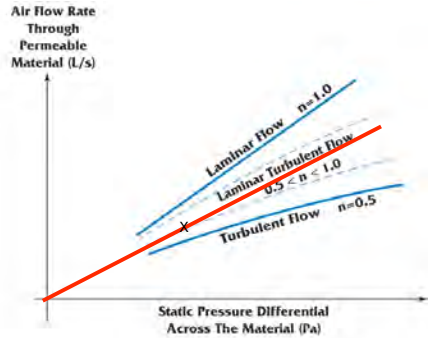

Figure 2.5
Modes of Air Flow
(from Bumbaru, Jutras and Patenaude, 1988)

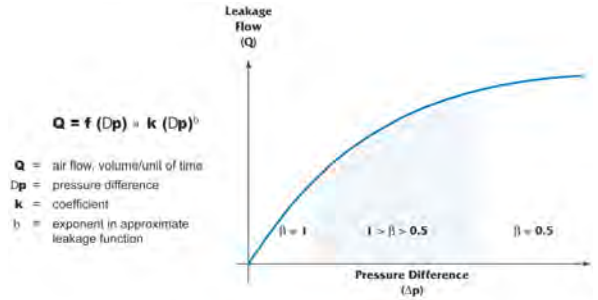

Figure 2.6
Characteristic Curve of Leakage Flow as a Function of Pressure Difference
(from Nylund, 1980)

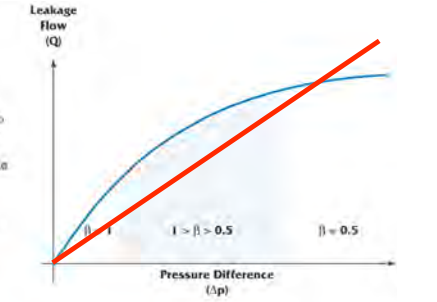

Figure 2.6
Characteristic Curve of Leakage Flow as a Function of Pressure Difference
(from Nylund, 1980)

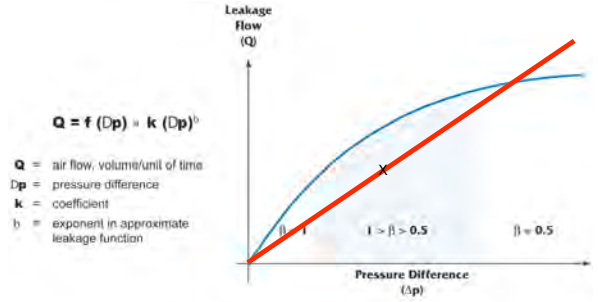

Figure 2.6
Characteristic Curve of Leakage Flow as a Function of Pressure Difference
(from Nylund, 1980)

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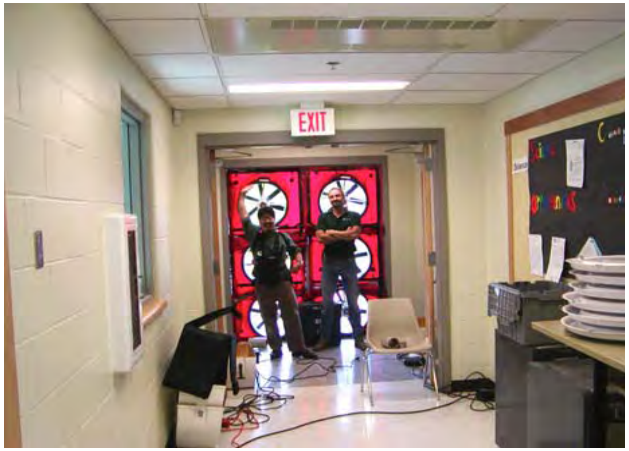

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Building Science Corporation
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Joseph Lstiburek 140

Building Science Corporation
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Joseph Lstiburek 141

Building Science Corporation
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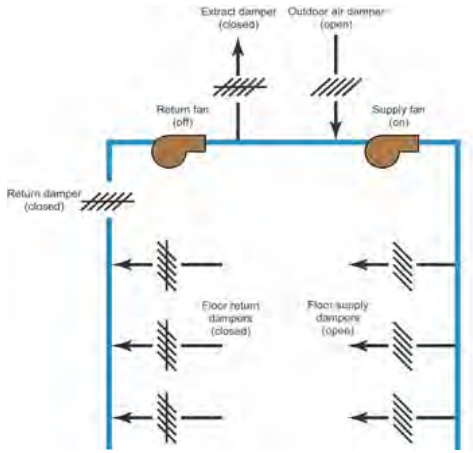
Joseph Lstiburek 142

Building Science Corporation
2011
Joseph Lstiburek 143



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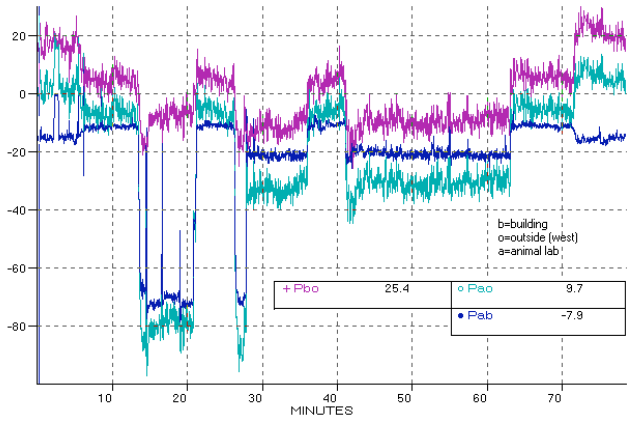
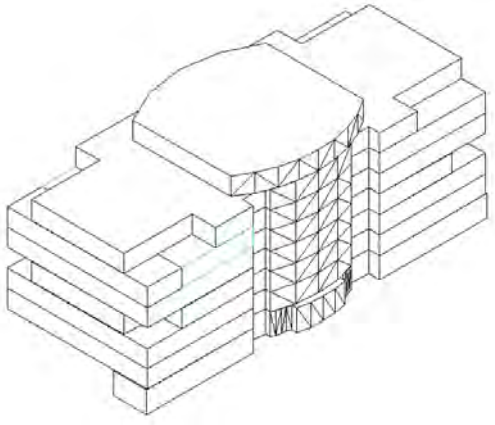
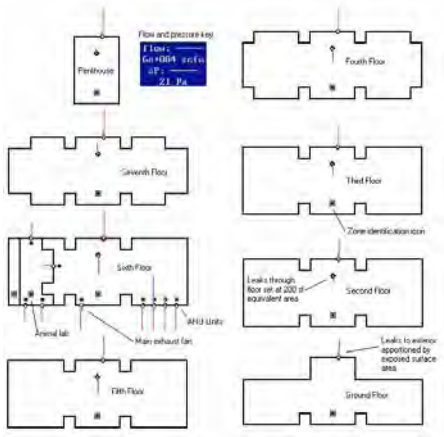
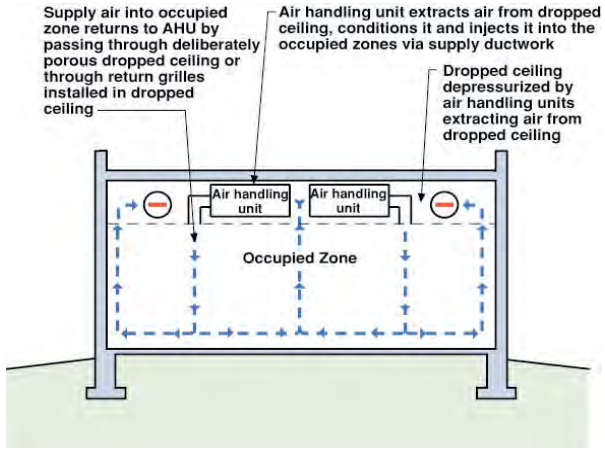
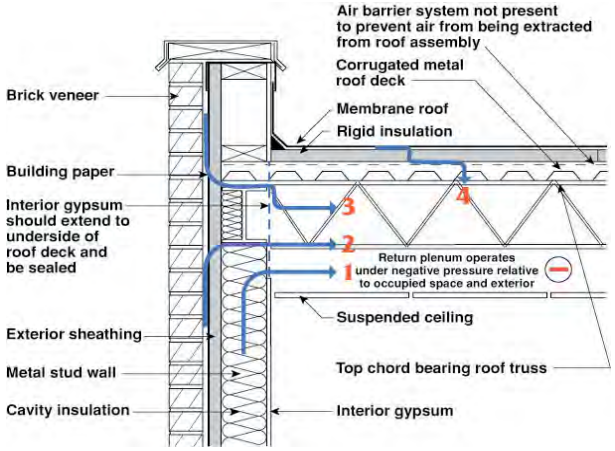

20
0
-20
-40
-60
-80
10
20
30
40
50
60
70
MINUTES
b=building
o=outside (west)
a=animal lab
+ Pbo 25.4
○ Pao 9.7
• Pab -7.9




Penthouse
Seventh Floor
Sixth Floor
Animal lab
AHU Units
Main exhaust fan
Fifth Floor
Fourth Floor
Third Floor
Zone identification icon
Second Floor
Ground Floor


Supply air into occupied zone returns to AHU by passing through deliberately porous dropped ceiling or through return grilles installed in dropped ceiling
Air handling unit extracts air from dropped ceiling, conditions it and injects it into the occupied zones via supply ductwork
Dropped ceiling depressurized by air handling units extracting air from dropped ceiling
Air handling unit
Air handling unit
Occupied Zone



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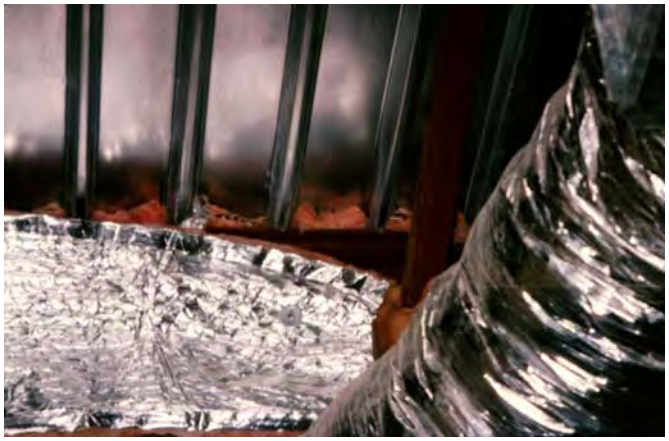
Building Science Corporation 2011 Joseph Lstiburek 150



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Building Science Corporation 2011 Joseph Lstiburek 152

Building Science Corporation
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Joseph Lstiburek 153

Building Science Corporation
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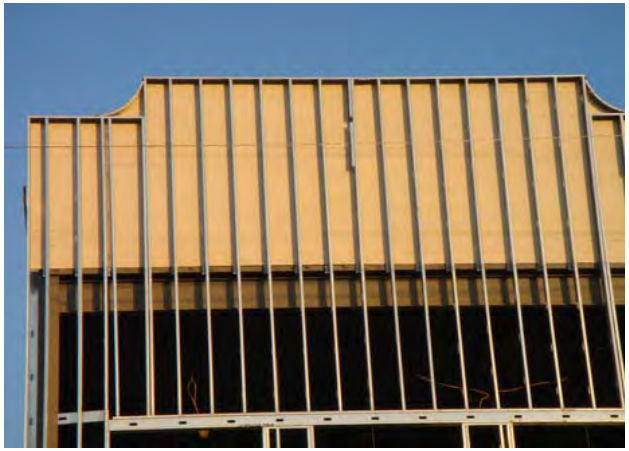
Joseph Lstiburek 154

Building Science Corporation
2011
Joseph Lstiburek 155



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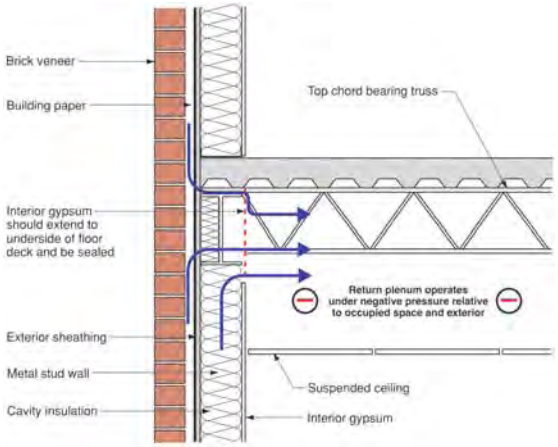

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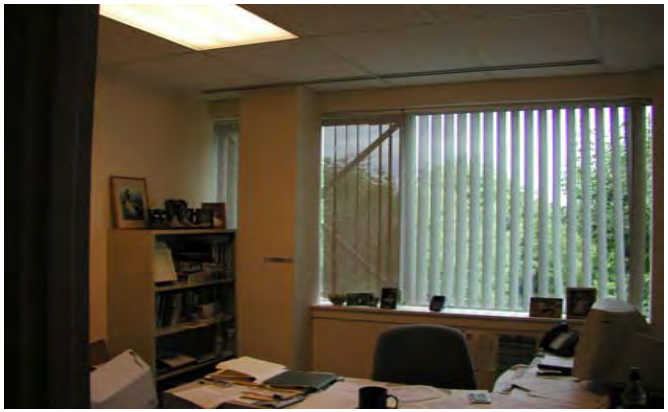
Building Science Corporation
2011
Joseph Lstiburek 158



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Building Science Corporation
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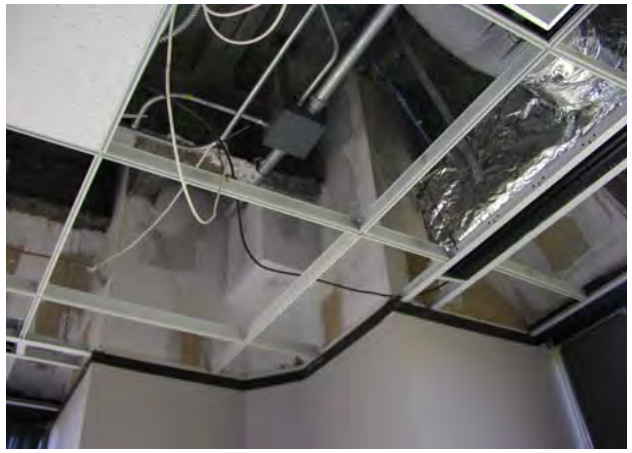
Joseph Lstiburek 160



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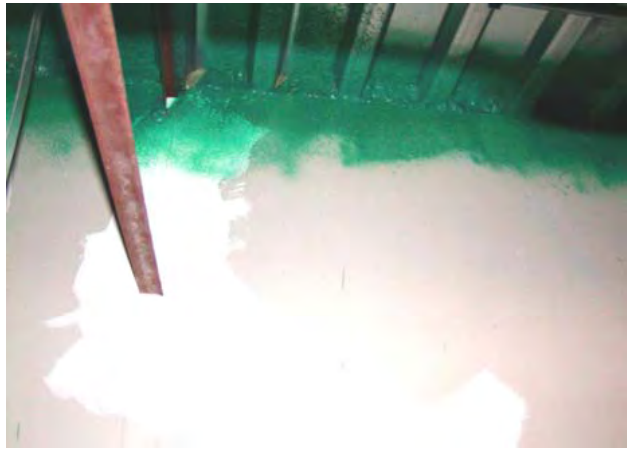

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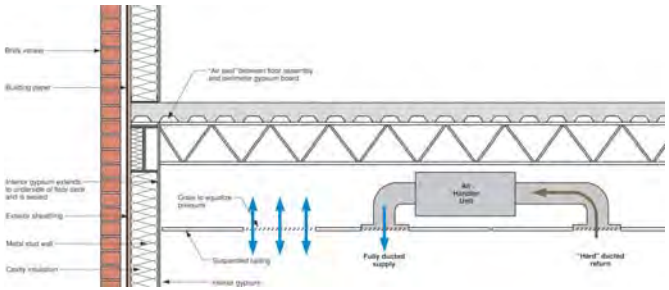
Building Science Corporation
2011
Joseph Lstiburek 164



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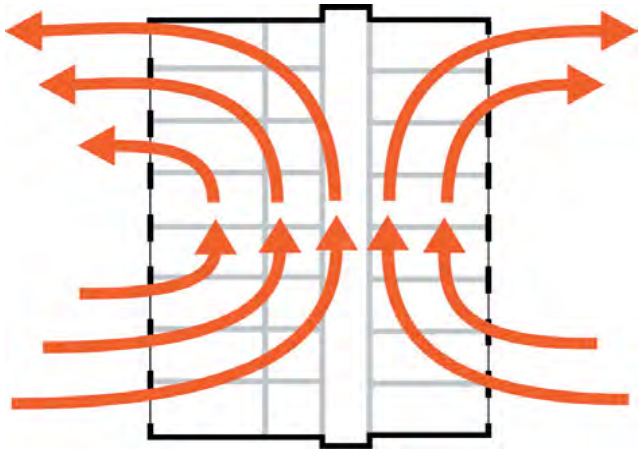

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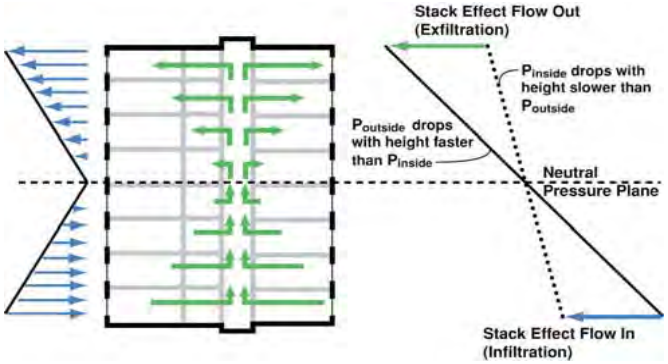

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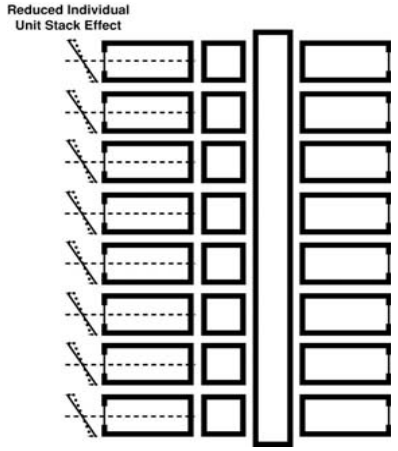

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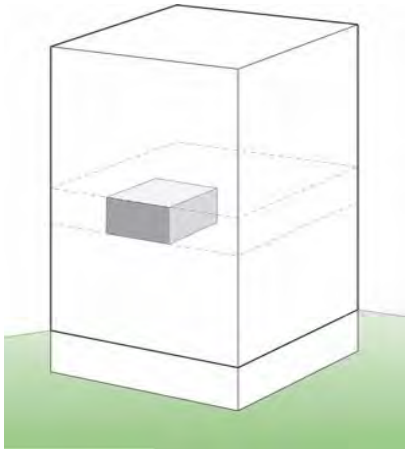

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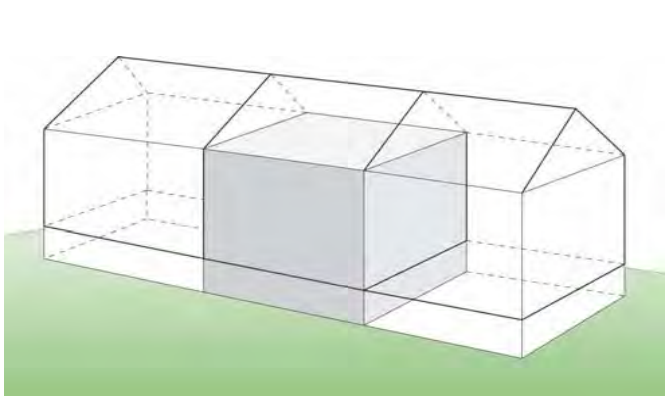

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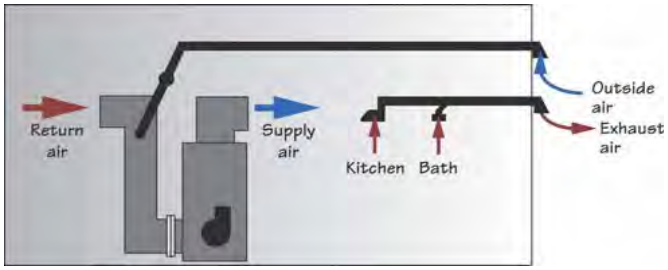

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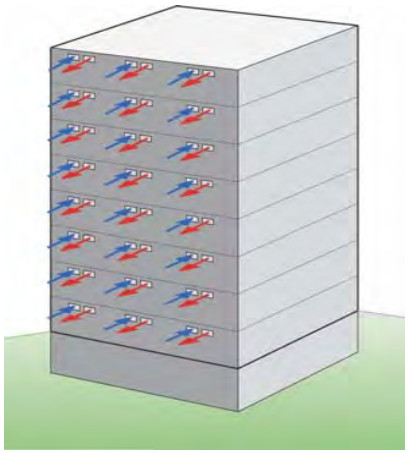

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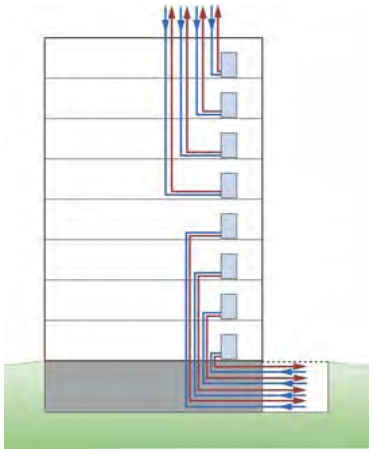

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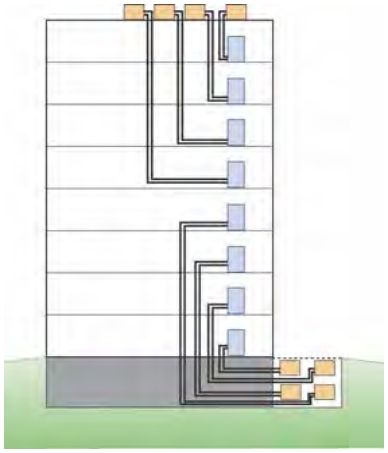

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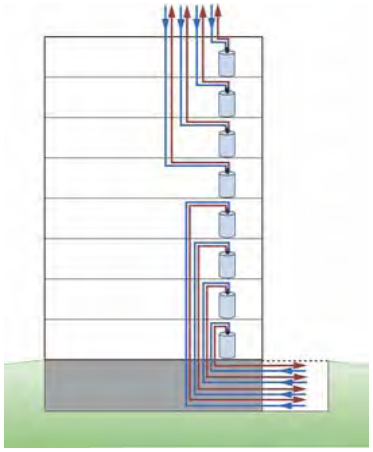

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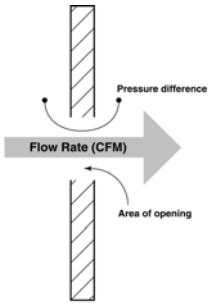
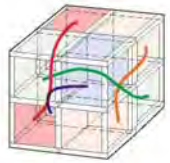


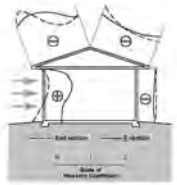
Air Flow

- Air flow depends on size of hole
- Air flow depends on pressure difference
  Flow = Area x $\sqrt{\Delta P}$ x Coefficient
- Air flows from higher pressure to lower pressure

Three Dimensional Multi-Layer Multi-Cell Analogue

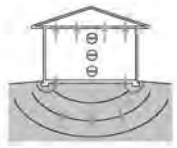


Three Dimensional Multi-Layer Multi-Cell Non-Contiguous Analogue

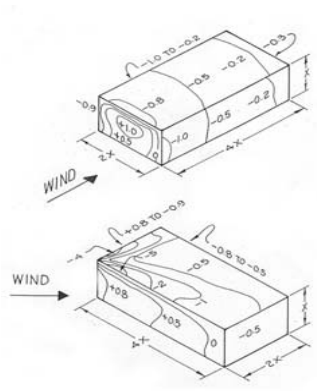


Exterior Air Pressure Field

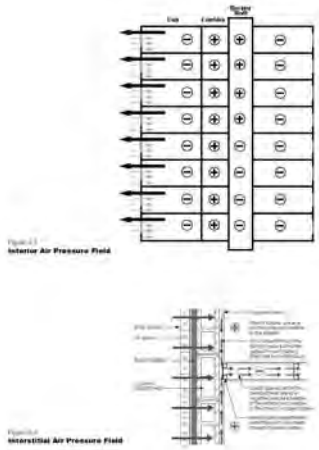
Distribution of pressures (+) and suctions (−) on a house with a low-sloped roof with wind perpendicular to eave



Exterior Air Pressure Field Extending Below Grade



Pressure coefficients on walls and roof of rectangular buildings without parapets.



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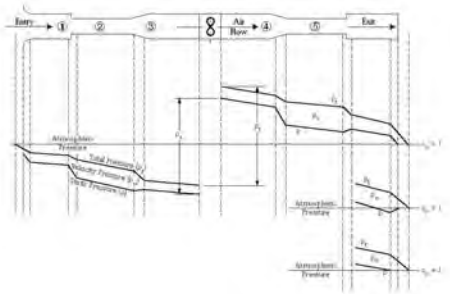

Figure 3.5
Air Conveyance System Air Pressure Field
(from Sauer & Howell, 1990)

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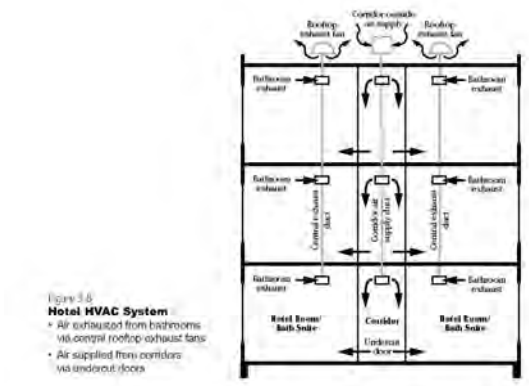
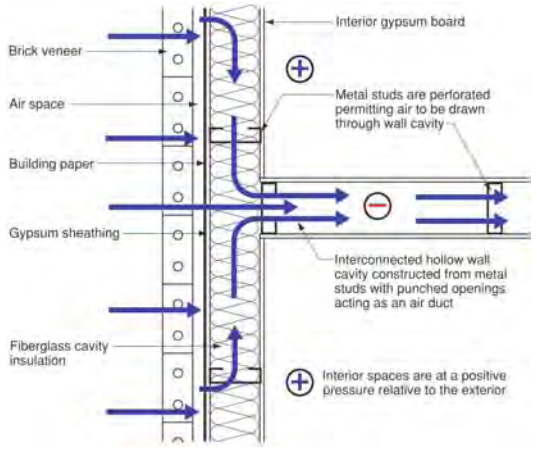
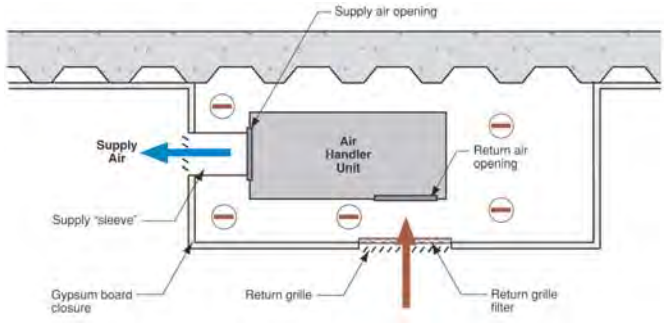


Figure 3.8
Hotel HVAC System
- Air exhausted from bathrooms via central rooftop exhaust fans
- Air supplied from corridors via undercut doors





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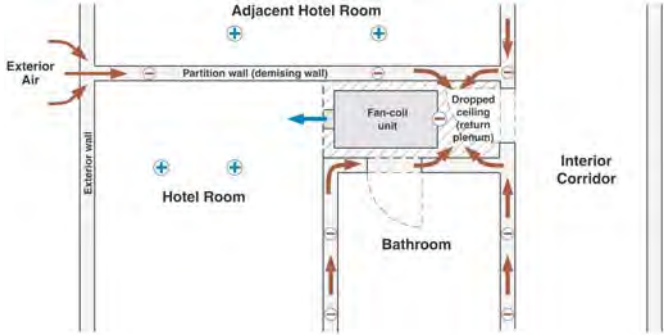

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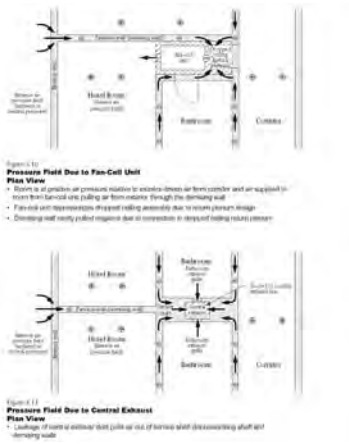

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Building Science Corporation 2011 Joseph Lstiburek 196

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Building Science Corporation
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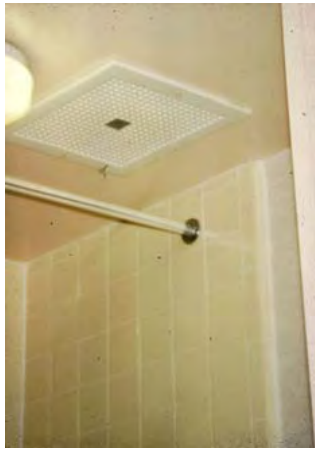

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Joseph Lstiburek 200

Building Science Corporation
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Joseph Lstiburek 201

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Building Science Corporation
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Joseph Lstiburek 203

Building Science Corporation
2011
Joseph Lstiburek 204

Building Science Corporation
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Joseph Lstiburek 205