Mechanical Systems
Mechanical Systems
Cooling System To Make It Cold
Mechanical Systems
Cooling System To Make It Cold
Dehumidification System To Make It Dry
Mechanical Systems
Cooling System To Make It Cold
Dehumidification System To Make It Dry
Heating System To Make It Warm
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
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
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
Don’t Try to Combine Them......
Cooling System makes it cold
Dehumidification System makes it dry
Heating System makes it warm
ERV keeps it cold and dry and warm and comfortable
Distribution System makes it uniform
Build Tight - Ventilate Right
Build Tight - Ventilate Right
How Tight?
What’s Right?
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
<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Getting rid of big holes</td>
<td>3 ach@50</td>
</tr>
<tr>
<td>Getting rid of smaller holes</td>
<td>1.5 ach@50</td>
</tr>
<tr>
<td>Getting German</td>
<td>0.6 ach@50</td>
</tr>
</tbody>
</table>
Best

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

Leaky - with – Nothing
Spot Ventilation in Bathroom/Kitchen
Exhaust Ventilation – with – No Distribution
and No Mixing
Three Types of Controlled Ventilation Systems

Exhaust Ventilation
Supply Ventilation
Balanced Ventilation
Induced infiltration
Induced exfiltration
Motorized damper

Outside Air
Ventilation Rates Are Based on Odor Control
Ventilation Rates Are Based on Odor Control
Health Science Basis for Ventilation Rates is Extremely Limited
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Almost Nothing Cited Applies to Housing
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
Figure 1: Minimum ventilating rate history.
Figure 2: Odor acceptance.
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
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 |

Ventilation Rates

| .35 ach | 90 cfm |
| -.35 ach | 90 cfm |
| 62 - 73 | 5 cfm/person | 20 cfm |
| 10 cfm/person | 40 cfm |
| 62 - 89 | 15 cfm/person | 60 cfm |
| .35 ach | 90 cfm |
| 62.2 - 2010 | 7.5 cfm/person | 50 cfm |
| + 0.01 |
| 62.2 - 2013 | 7.5 cfm/person | 90 cfm |
| + 0.03 |
Office

Occupant Density

15/1000 ft$^2$ (67 ft$^2$/person)  
15 cfm/person  

5/1000 ft$^2$ (200 ft$^2$/person)  
17 cfm/person

Correctional Facility Cell

Occupant Density

20/1000 ft$^2$ (48 ft$^2$/person)  
10 cfm/person
C.P. Yaglou
Harvard School of Public Health
1936
1955

150 ft³  →  20 cfm/person
300 ft³  →  12 cfm/person
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
Aubin, D., Won, D.Y., Schleibinger, H., 2010
Formaldehyde sample concentration versus PFT measured outside air exchange rate over the test day.
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.
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
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
3 Bedroom House – 2,500 ft²
30 cfm plus 75 cfm
105 cfm
3 Bedroom House – 2,500 ft²
30 cfm plus 25 cfm
55 cfm
The Cult of The Blower Door
Blower Door Can’t Get You The True ACH On A Short Term Basis – Hour, Day, Week
Don’t Know Where The Holes Are
Don’t Know The Type of Holes
Don’t Know The Pressure Across The Holes
ELA = C \times \frac{\text{Rate of flow}}{\sqrt{\text{Pressure difference}}}

(Meters)^2 \approx \frac{1}{780} \times \frac{\text{Litres per second}}{\sqrt{\text{Pascals}}}

Building Science Corporation

Joseph Lstiburek 51
\[ ELA = \frac{1}{780} \times \frac{\text{Flow rate}}{\sqrt{\text{Pressure difference}}} \]

Pressure Difference (Pa)

Flow Rate (L/s)

ELA = 0.278 m²
Pressure difference

Flow Rate (CFM)

Area of opening
Flow Through Orifices
  Turbulent Flow - “inertial effects”

Flow Through Porous Media
  Laminar Flow - “viscosity effects”
Flow Through Orifices

Turbulent Flow - “inertial effects”

Flow Through Porous Media

Laminar Flow - “viscosity effects”

“true but not useful”
\[ Q = A \cdot C_D \left[ \frac{2}{\rho} (\Delta P) \right]^{\frac{1}{2}} \quad \text{Bernoulli} \]

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

\[ Q = C_K \frac{\rho}{\mu} (\Delta P) \] \text{ Darcy}

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

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

Bernoulli

\[ Q = C_K \frac{\rho}{\mu} (\Delta P) \]  

Darcy

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

\[ Q = C(\Delta P) \]

\[ Q = A \cdot C(\Delta P)^n \]  

Kronval “an engineer”
Figure 2.5

**Modes of Air Flow**
(from Bumbaru, Jutras and Patenaude, 1988)
Possible air flows around sill of a wood-framed house modelled as a resistance network.

1. Air permeating the wood-panel cladding
2. Air flow between floor slab and panel
3. Air flow between floor slab and wind protection
4. Air permeating the caulking
5. Air flow between wind protection and sill
6. Air flow between insulation material and sill
7. Air flow between inner lining and sill
8. Air flow between inner lining and floor slab
9. Air flow between fillet and inner lining
10. Air flow between fillet and floor slab

Figure 2.10
**Resistance Network**
(from Kronvall, 1980)
Figure 2.11
Three Dimensional Multi-Layer Multi-Cell Analogue
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)
\[ Q = f(Dp) \approx k(Dp)^b \]

- **Q** = air flow, volume/unit of time
- **Dp** = pressure difference
- **k** = coefficient
- **b** = exponent in approximate leakage function

**Figure 2.6**
**Characteristic Curve of Leakage Flow as a Function of Pressure Difference**
(from Nylund, 1980)
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Figure 2.6
**Characteristic Curve of Leakage Flow as a Function of Pressure Difference**  
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\[ Q = f(Dp) = k(Dp)^b \]

- **Q** = air flow, volume/unit of time
- **Dp** = pressure difference
- **k** = coefficient
- **b** = exponent in approximate leakage function

**Figure 2.6**

**Characteristic Curve of Leakage Flow as a Function of Pressure Difference**
(from Nylund, 1980)
Leakage opening (72 in^2)

Total "measured" leakage 144 in^2

Neutral pressure plane

Leakage opening (72 in^2)

Leakage openings (each 72 in^2)

Neutral pressure plane

Leakage area
Dilution Is Not The Solution To Indoor Pollution
Source Control
Dilution For People
Source Control For The Building
Recommended Range of Relative Humidity

Above 25 percent during winter
Below 70 percent during summer
Pressure relief grille to "bleed" pressure field from floor cavity

Motorized damper

Flexible connection for vibration and sound control

Expandable filter slot

Full height louvered closet door for access and to supply air for dehumidification

Air handler

Dehumidifier

Condensate overflow pan
Kitchen Exhaust Hoods
Unconditioned make-up air 60 - 70% of hood exhaust
Clothes Dryers
Fireplaces
Approaches
Return air

Supply air

Bath

Kitchen

Outside air

Exhaust air

Exhaust air

Interlocked kitchen hood make-up air
Lapse Rate
Figure 11.1: Building with no internal separations with opening at the bottom (Adapted from G.O. Handegord, 1998)
Figure 11.2: Building with no internal separations with opening at the top
(Adapted from G.O. Handegord, 1998)
Figure 11.3: Building with no internal separations with openings at top and bottom (Adapted from G.O. Handegord, 1998)
Figure 11.4: Basic two storey house with vented attic
(Adapted from G.O. Handegord, 1998)
Figure 11.5: Two storey house with non-operating chimney and exhaust fan
(Adapted from G.O. Handegord, 1998)
Figure 11.6: Two storey house with operating chimney
(Adapted from G.O. Handegord, 1998)
Stack effect
Stack effect and wind
Chimney effect
Stack Effect Flow Out (Exfiltration)

$P_{\text{inside}}$ drops with height slower than $P_{\text{outside}}$

$P_{\text{outside}}$ drops with height faster than $P_{\text{inside}}$

Neutral Pressure Plane

Stack Effect Flow In (Infiltration)
Figure 11.8: Stack effect pressures in high rise office building
(Adapted from G.O. Handegord, 1998)
Figure 11.9: Multi-storey building with floor spaces isolated from vertical shafts (Adapted from G.O. Handegord, 1998)
Figure 11.12: Apartment building with tighter apartment entry doors
(Adapted from G.O. Handegord, 1998)
Reduced Individual Unit Stack Effect
Motorized damper — typically closed (connected to fire control system)

Smoke and hot gas vent
($3\frac{1}{2}\%$ of shaft or 3 ft$^2$ per elevator car)

Constant airflow regulator

Exhaust from elevator shaft
Figure 3.12
**Ductwork and Air Handlers in Basements**
- No air pressure differences result in a house with an air handler and ductwork located in a basement if there are no leaks in the supply ducts, the return ducts or the air handler and if the amount of air delivered to each room equals the amount removed.
Figure 3.13
**Ductwork and Air Handlers in Vented Attics**

- No air pressure differences result in a house with an air handler and ductwork located in a vented attic if there are no leaks in the supply ducts, the return ducts or the air handler and if the amount of air delivered to each room equals the amount removed.
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.
Duct Leakage Should Be Less Than 5% of Rated Flow As Tested By Pressurization To 25 Pascals
Note: Colored shading depicts the building’s thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.
Figure 3.16

**Leaky Supply Ductwork in Vented Crawl Space**

- Air pressurization pattern with mechanical system ducts in the crawl space
Figure 3.14

**Leaky Ductwork and Air Handlers in Basements**

- Air pressurization patterns in a house with leaky ductwork in the basement
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.
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
Draft hood

Chimney (highly variable flow)

Dilution air (variable flow)

Combustion air (constant flow)