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

Stuff That Is Very Useful but Ignored by the Research Community
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”
“this is a lie”
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”
\[ Q = A \cdot C_D \left[ \frac{2}{\rho} (\Delta P) \right]^{\frac{1}{2}} \] Bernoulli

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

Bernoulli

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

Darcy

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

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

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

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

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

\[ Q = A \cdot C \left( \Delta P \right)^n \] Kronval “an engineer”
Figure 2.5
**Modes of Air Flow**
(from Bumbaru, Jutras and Patenaude, 1988)
Figure 2.5

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\[ Q = f(\Delta p) \approx k(\Delta p)^b \]

- \( Q \) = air flow, volume/unit of time
- \( \Delta p \) = 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)
\[ Q = f(Dp) \sim k(Dp)^b \]

- **Q** = air flow, volume/unit of time
- **Dp** = pressure difference
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**Figure 2.6**
**Characteristic Curve of Leakage Flow as a Function of Pressure Difference**
(from Nylund, 1980)
\[ Q = f(Dp) \times k(Dp)^b \]

- **Q** = air flow, volume/unit of time
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- **k** = coefficient
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**Figure 2.6**

**Characteristic Curve of Leakage Flow as a Function of Pressure Difference**
(from Nylund, 1980)
Figure 2.7

Two Dimensional Multi-Cell Analogue
Figure 2.8

Three Dimensional Multi-Cell Analogue
Figure 2.9

Two Dimensional Multi-Layer Multi-Cell Analogue
Possible air flows around sill of a wood-framed house modeled as a resistance network.

Figure 2.10
Resistance Network
(from Kronwall, 1980)

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 2.11

Three Dimensional Multi-Layer Multi-Cell Analogue
Figure 2.12
Three Dimensional Multi-Layer
Multi-Cell Non-Contiguous
Analogue
Figure 3.1
**Exterior Air Pressure Field**
(from Hutcheon & Handegord, 1983)

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

Figure 3.2
**Exterior Air Pressure Field Extending Below Grade**
Pressure coefficients on walls and roof of rectangular buildings without parapets.
Figure 3.3
*Interior Air Pressure Field*
Figure 3.4

**Interstitial Air Pressure Field**

- **Brick veneer**
- **Air space**
- **Rigid insulation**
- **Concrete masonry wall**
- **Gypsum board**
- **Cavity spaces within the demising wall are at a negative pressure relative to the exterior and relative to the interior occupied space.**
- **Metal studs are perforated permitting air to be drawn through the wall cavities.**
- **Interior spaces are at a positive pressure relative to the exterior.**
- **Air is drawn through the furring space behind the gypsum board (furring strips are not continuous).**
Figure 3.5
Air Conveyance System Air Pressure Field
(from Sauer & Howell, 1990)
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 barrier system not present to prevent air from being extracted from roof assembly

Corrugated metal roof deck

Membrane roof

Rigid insulation

1. Return plenum operates under negative pressure relative to occupied space and exterior

2. Suspended ceiling

3. Top chord bearing roof truss

4. Interior gypsum

Building paper

Interior gypsum should extend to underside of roof deck and be sealed

Exterior sheathing

Metal stud wall

Cavity insulation

Brick veneer
Brick veneer

Building paper

Interior gypsum should extend to underside of floor deck and be sealed

Exterior sheathing

Metal stud wall

Cavity insulation

Top chord bearing truss

Return plenum operates under negative pressure relative to occupied space and exterior

Suspended ceiling

Interior gypsum
Figure 6.1

Compartmentalizing Dropped Ceiling
Figure 3.8

Hotel HVAC System

- Air exhausted from bathrooms via central rooftop exhaust fans
- Air supplied from corridors via undercut doors
Building Science

Brick veneer

Air space

Building paper

Gypsum sheathing

Fiberglass cavity insulation

Interior gypsum board

Metal studs are perforated permitting air to be drawn through wall cavity

Interconnected hollow wall cavity constructed from metal studs with punched openings acting as an air duct

Interior spaces are at a positive pressure relative to the exterior
Pressure Field Due to Fan-Coil Unit

Plan View
- Room is at positive air pressure relative to exterior-driven air from corridor and air supplied to room from fan-coil unit pulling air from exterior through the demising wall.
- Fan-coil unit depressurizes dropped ceiling assembly due to return plenum design.
- Demising wall cavity pulled negative due to connection to dropped ceiling return plenum.

Pressure Field Due to Central Exhaust

Plan View
- Leakage of central exhaust duct pulls air out of service shaft depressurizing shaft and demising walls.
Figure 5.5

HVAC System for Hotel

- 25 L/s is extracted from each suite
- 15 suites per floor plus 100 L/s extracted from each corridor
- 475 L/s extracted per floor
- 2,850 L/s extracted from 6 floors with suites
- Each suite’s PTHP supplies 30 L/s when it is operating. One additional PTHP serves each corridor supplying 100 L/s of outside air. A total of 550 L/s is supplied per floor when all the PTHP’s on a floor are operating.
- However, the typical duty cycle of a PTHP is approximately 20%, i.e. 80% of the units are off at any one time.
- When 3 suite PTHP’s and the corridor PTHP are operating only 190 L/s supplied to a floor. If 475 L/s is extracted per floor, a deficit of 285 L/s exists per floor or 1,710 L/s for all the suite floors combined.
Figure 3.23
AHU Depressurizing Exterior Wall Assembly
Plan View
Figure 6.3
“Bleeding” Pressure Fields
Figure 5.7
New Air Pressure Relationships
- Hotel suite floors supplied with 4,200 L/s of preconditioned air
- Hotel suite floors are exhausted to a total of 2,850 L/s.
- Surplus of 1350 L/s pressurizes suite floors
- Stairwell held open with magnetic latches
Figure 5.6
Air Leakage Test Zones
Smoke Extraction System

- If hotel is pressurized 25 Pa and smoke floor/floors are depressurized 25 Pa, net minimum smoke control pressure difference is greater than the design specified 25 Pa.
- Approximately 1,000 L/s per floor is required to pressurize each floor 25 Pa relative to the exterior or approximately 6,000 L/s to pressurize the 6 hotel floors with suites when the roof top exhaust systems are not operating.
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
Figure 5.1

**Problem Pressure Relationship**

- The classrooms in this school operate at a negative pressure with respect to the crawl space.

Rooftop exhaust depressurizes dropped ceiling and classrooms.

Classrooms are at a negative pressure relative to the crawl space and the exterior.

Vented crawl space is at the same pressure as the exterior and at a positive pressure relative to the classrooms.
Figure 5.2

**Moisture Movement**
- This wall section illustrates moisture movement from the crawl space into the wall cavities and dropped ceiling.

Air pulled into dropped ceiling due to negative pressure from roof top exhaust and AHU’s within dropped ceiling (see also Figure 3.21)

Moist air flows between openings in masonry wall and into air spaces beneath plaster

Air from crawl space flows between open joints in precast concrete planks

Soil moisture evaporates into the crawl space

Vented crawl space

Concrete foundation wall

Exposed soil

Concrete footing

Wood furring strips create air space

Concrete masonry wall

Baseboard

Precast concrete floor plank

Plaster
Figure 5.3

Ground Cover Installation

- This wall section illustrates proper installation of the polyethylene ground cover.
Figure 5.4
New Air Pressure Relationship
- Closing the crawl space vents and using an exhaust fan in the crawl space depressurizes the crawl space relative to the classrooms

Classrooms are at a positive pressure relative to the crawl space even with the rooftop exhaust operating.

Exhaust fan creates negative pressure in the crawl space relative to the classrooms.

Continuous ground cover reduces evaporation.

Vents are closed.
Figure 5.10
HVAC System as Designed
Figure 5.11

Unintended Pressurization of Interstitial Cavity
Figure 5.12

Modified Pressure Relationship
\( P_o \) = outside air pressure  
\( P_i \) = inside air pressure  
\( P_c \) = cavity air pressure  
\( A_E \) = leakage area across exterior of wall assembly  
\( A_I \) = leakage area across interior of wall assembly

\[ \Delta P_E = P_o - P_c \]
\[ \Delta P_I = P_c - P_I \]

Figure 4.5
Measurement of Series Differential Pressure
\[ Q = C_E A_E \Delta P_E^n = C_I A_I \Delta P_I^n \]

\[
\frac{C_E A_E}{C_I A_I} = \frac{\Delta P_I^n}{\Delta P_E^n}
\]

\[
\Rightarrow \frac{A_E}{A_I} = \left( \frac{\Delta P_I}{\Delta P_E} \right)^n
\]

\[
\Rightarrow \left( \frac{A_E}{A_I} \right)^{\frac{1}{n}} = \frac{\Delta P_I}{\Delta P_E}
\]

from Hutcheon & Handegord, 1983
Figure 4.3

**Multi-Channel Pressure Measurements**

- Six channel micromanometer connected to laptop computer used to map pressure in the hotel room described in Figure 3.6
- All pressures measured relative to exterior air pressure
- Pressure response determined by opening and closing doors, cycling fan-coil, rooftop exhaust and corridor make-up air systems
Figure 3.25

**Electrical Analogue of Hotel Room**

- \( R_1 \) = Leakage area between ambient and exterior wall cavity
- \( R_2 \) = Leakage area between exterior wall cavity and demising (partition) wall cavity
- \( R_3 \) = Leakage area between exterior wall cavity and hotel room
- \( R_4 \) = Leakage area between exterior wall cavity and demising (partition) wall cavity
- \( R_5 \) = Leakage area between demising (partition) wall cavity and hotel room
- \( R_6 \) = Leakage area between demising (partition) wall cavity and corridor demising wall cavity
- \( R_7 \) = Leakage area between hotel room and corridor demising wall cavity
- \( R_8 \) = Leakage area between demising (partition) wall cavity and corridor demising wall cavity
- \( R_{90} \) = Leakage area between corridor demising wall cavity and corridor
- \( V_{wl} \) = Pressure in exterior wall
- \( V_a \) = Pressure in hotel room
- \( V_c \) = Pressure in corridor
- \( V_{dcp} \) = Pressure in demising (partition) wall cavity
- \( V_{scp} \) = Pressure in corridor demising wall cavity
Figure 4.6
Series of Rooms Connected to Corridor
**Figure 4.7**

**Initial Pressure Measurements**

- Door to corridor in Room A closed
- Doors to corridor for Rooms B and C are open
- Windows in all rooms closed
Figure 4.8
Subsequent Pressure Measurements

- An opening of known size, $A_k$, is added to $A_E$ (i.e. window in Room A is opened)
Figure 4.9

**Determining Leakage Area** $A_{ACor}$

- Windows in Rooms B and C are opened
- Windows in Room A are closed
- Doors to corridor for all rooms are initially closed; door in Room A subsequently opened
Tracer Gas Data (HVAC System on intermittently)

- **SF6 (mg/m^3)**
  - 50
  - 45
  - 40
  - 35
  - 30
  - 25
  - 20
  - 15
  - 10
  - 5
  - 0
- **Time (12:00 - 20:00)**
  - 12:00
  - 12:58
  - 13:46
  - 14:34
  - 15:22
  - 16:10
  - 16:58
  - 17:46
  - 18:34
  - 19:22

Legend:
- **Basement**
- **First floor**
- **NW**
- **NE**
- **SW**
- **SE**
Standard Contam96 Analytical Model (HVAC System on)

**SF6 (mg/m^3)**

- **Basement**
- **First floor**
- **NW**
- **NE**
- **SW**
- **SE**

**Time**

- 12:00 to 19:30

**Graph Description**

The graph illustrates the concentration of SF6 (sulfur hexafluoride) in different areas over time. The concentrations are measured in milligrams per cubic meter (mg/m^3). The graph shows the trend of SF6 levels for the Basement, First floor, NW, NE, SW, and SE areas, with time ranging from 12:00 to 19:30.
• Tracer gas test of a production Building America house in Sacramento
• 2-story, 4 bedrooms, ~2500 square feet
• Ventilation systems tested: supply and exhaust ventilation, with and without mixing via central air handler
Floor Plan - 2 Story House
Zones – 2 Story House

- Tracer gas decay tests—establish uniform concentration of tracer gas and then activate ventilation system to remove it
- Reciprocal age-of-air can be calculated from decay curves (if weather conditions are sufficiently constant)
Example Results of Tracer Gas Testing

Laundry Exhaust, 100% of 62.2 Rate, Doors Closed, Transfer Grills Open, No Mixing

<table>
<thead>
<tr>
<th>Zone</th>
<th>Measured Reciprocal Age of Air (1/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BR1</td>
<td>0.18</td>
</tr>
<tr>
<td>Living</td>
<td>0.16</td>
</tr>
<tr>
<td>Kitchen</td>
<td>0.16</td>
</tr>
<tr>
<td>BR2</td>
<td>0.11</td>
</tr>
<tr>
<td>BR3</td>
<td>0.13</td>
</tr>
<tr>
<td>MBR</td>
<td>0.14</td>
</tr>
</tbody>
</table>
Example Results of Tuned CONTAM Model

Laundry Exhaust, 100% of 62.2 Rate, Doors Closed, Transfer Grills Open, No Mixing

<table>
<thead>
<tr>
<th>Zone</th>
<th>Reciprocal Age of Air (1/hr)</th>
<th>Measured</th>
<th>Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>BR1</td>
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<td>MBR</td>
<td>0.14</td>
<td>0.13</td>
<td></td>
</tr>
</tbody>
</table>
Total Pollutant Concentration by Room

Pollutant Concentration (ppm)

- BR3
- MBR
- BR2
- Kitchen
- Living
- BR1
Figure 5.13

**Well-Defined Pressure Boundary**
- Pressure boundary defines effective building envelope environmental separator
Figure 5.14

**Poorly-Defined Pressure Boundary**

- Pressure boundary poorly defined — ineffective at ceiling
- Pressure boundary not continuous at ceiling
Figure 5.15

**Tight Rim Closure**

- Floor assembly “inside” well-defined pressure boundary
- Pressure boundary continuous at rim closure
Figure 5.16

**Leaky Rim Closure**
- Floor assembly “outside” pressure boundary
- Pressure boundary not continuous at rim closure
Figure 5.17

**Pressure Boundary at Interior Floor**
- Pressure boundary not contiguous with building envelope thermal boundary

Floor cavity is effectively outside of the building due to poor rim closure.
Figure 5.18

**Wind Tunnel Effect**

“Wind tunnel” effect through open webbed floor trusses as a result of poor rim closure.
Figure 5.19
Supply Duct Leakage
- Leakage of supply ducts into floor space pressurizes floor space leading to exfiltration at rim closure
Figure 5.20
**Return Duct Leakage**
- Leakage of return ducts into floor space depressurizes floor space leading to infiltration at rim closure
Figure 5.21

**Combined Floor Paths and Pressure Drivers**

- Vertical and horizontal communication of open webbed floor trusses through fireplace and utility chaseways
- Pressure drivers are wind, the stack effect and the operation of the HVAC system
Figure 1: Ventilation of Exterior Walls

- Outside air supplied into supply manifold
- Exhaust manifold vented through roof
Figure 2: Plan View — Ventilation

- Outside air introduced into supply manifold at bottom of walls through vents penetrating exterior wall and stone
- Vents minimum 14 inches x 14 inches
Figure 3: Supply Manifold

- Existing stone cladding
- Existing plywood interior sheathing
- Cavity insulation removed
- New plywood sheathing
- Two layers of foil-faced rigid insulation (Thermax) with joints staggered, offset and taped
- Fibercement interior finish
- Wood frame manifold; 12 inches wide by 18 inches high
- 6 inch diameter hole in each stud bay
- Sealant, adhesive or caulking
Second layer of 2-inch foil-faced isocyanurate held in place with cap screws; all seams and screw openings taped with aluminum tape.

Interior cladding
1x4 borate-treated furring screwed to studs

First layer of 2-inch foil-faced isocyanurate held in place with cap screws; all seams and screw openings taped with aluminum tape.

Sealant
New concrete slab (w/c ratio less than 0.45)
Epoxy coating on slab

Waterproof membrane taped to first layer of foil-faced isocyanurate.

Ground slopes away from wall at 5% (6 in. per 10 ft.)

Two 2-inch diameter holes per stud bay block

One 4-inch diameter hole per stud bay

Screened vent hood
Solid blocking (no vent here)

Two 2-inch diameter holes per stud bay

1x4 borate-treated furring screwed to bottom chord of trusses

Second layer of 2-inch foil-faced isocyanurate held in place with cap screws; all seams and screw openings taped with aluminum tape

First layer of 2-inch foil-faced isocyanurate held in place with cap screws; all seams and screw openings taped with aluminum tape

1x4 borate-treated furring screwed to studs

Interior cladding