Effect of Airtight Building Enclosures in High-Rise Residential Buildings

BEST3 – Atlanta, GA

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Overview

- Ventilation Background
- Airflow in Tall Buildings
- How Air-Leaky are High-Rise Multi-Unit Residential Buildings?
- Effects of Poor Ventilation
- Case Studies
Contributing Research at RDH for these studies:

- Shawn McIsaac, BASc.
- Graham Finch, M.Eng.
- Warren Knowles, P.Eng.
- Brian Hubbs, P.Eng.
Energy costs and Building Codes are driving tighter building enclosures

Reduction of make-up air through enclosure

Older HVAC systems relied on enclosure air leakage for make-up air – not designed to accommodate airtight enclosures (retrofits)

Some new construction HVAC systems still rely on corridor pressurization for make-up air, but assumptions of enclosure air leakage rates have not kept pace with \textit{actual} airtightness

Leads to potential ventilation problems – condensation, mold, odors, poor indoor air quality (IAQ), etc.
Air Flows & Air Leakage in Multi-Unit Residential Buildings

- Building pressures vary over the course of the day - year
- Can measure shell airtightness, but ignores windows, HVAC ducts and occupant behavior
- Interior airflows & difficult to predict
- We have a good qualitative sense of airflow and leakage but not necessarily quantitative back-up
Ventilation Strategies & Air Leakage are inter-related
How Air-Leaky Can Building Enclosures Be?

2012 International Energy Conservation Code (IECC) introduces air barrier and air leakage requirements nationally

Air Barrier Compliance Options C402.4.1.2

- Materials 0.004 cfm/ft² @ 75Pa (C402.4.1.2.1)
- Assemblies 0.04 cfm/ft² @ 75Pa (C402.4.1.2.2)
  ASTM E 2357 “Standard Test Method for Determining Air Leakage of Air Barrier Assemblies”
- Whole Building 0.4 cfm/ft² @ 75Pa (C402.4.1.2.3)
  ASTM E779 Standard Test Method for Determining Air Leakage Rate by Fan Pressurization

Washington State Energy Code requires Whole Building air leakage testing for buildings over 5-stories, but building does not have to pass prescribed value (yet)
## Various Whole Building Airtightness Standard Targets

<table>
<thead>
<tr>
<th>Standard</th>
<th>Equivalent Normalized Leakage Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASHRAE – “Tight” enclosure</td>
<td>0.10 cfm/ft(^2) @ 75 Pa (0.027 cfm/ft(^2) @ 10 Pa)</td>
</tr>
<tr>
<td>R2000 Standard – enclosure</td>
<td>0.13 cfm/ft(^2) @ 75 Pa (0.035 cfm/ft(^2) @ 10 Pa)</td>
</tr>
<tr>
<td>US Army Corps – enclosure</td>
<td>0.25 cfm/ft(^2) @ 75 Pa (0.067 cfm/ft(^2) @ 10 Pa)</td>
</tr>
<tr>
<td>ASHRAE – “Average” enclosure</td>
<td>0.30 cfm/ft(^2) @ 75 Pa (0.081 cfm/ft(^2) @ 10 Pa)</td>
</tr>
<tr>
<td>ASTM E779 – Whole Building</td>
<td>0.40 cfm/ft(^2) @ 75 Pa (0.11 cfm/ft(^2) @ 10 Pa)</td>
</tr>
<tr>
<td>2012 International Energy Conservation Code (IECC) - Enclosure Leakage</td>
<td><strong>0.40 cfm/ft(^2) @ 75 Pa (0.11 cfm/ft(^2) @ 10 Pa)</strong></td>
</tr>
<tr>
<td>ASHRAE – “Leaky” enclosure</td>
<td>0.60 cfm/ft(^2) @ 75 Pa (0.16 cfm/ft(^2) @ 10 Pa)</td>
</tr>
</tbody>
</table>

\(\text{LEAKIER} \rightarrow \text{TIGHTER}\)

@10 Pa calculated assuming \(n=0.65\)
Typical Energy Consumption: 1980s-1990s MURB

Average of 11 typical study buildings - Total 206 kWh/m²/yr

- Electric Baseboard Heating: 25, 12%
- Fireplaces: 38, 18%
- Ventilation Heating: 40, 19%
- Hot Water: 33, 16%
- Lights - Common: 4, 2%
- Lights - Suite: 16, 8%
- Plug and Appliances (Suites): 19, 9%
- Equipment and Amenity (Common): 28, 14%
- Elevators: 4, 2%

Units of kWh/m²/yr, % total
Energy Study – Vancouver and Victoria, B.C.
Typical Energy Consumption: Post 2000/Modern MURB

Average of several typical modern MURBs—Total >222 kWh/m²/yr

Units of kWh/m²/yr, % total

- Ventilation Heating, 87, 39%
- Fireplaces, 34, 16%
- DHW, 21, 9%
- Lights - Common, 4, 2%
- Lights - Suite, 16, 7%
- Plug and Appliances (Suites), 19, 9%
- Equipment and Amenity (Common), 20, 9%
- Elevators, 3, 1%
- Electric Baseboard Heating, 18, 8%

Energy Study – Vancouver and Victoria, B.C.

Typically up from <50 to up to 150 cfm/unit
Inefficiencies of pressurized corridor ventilation and poor thermally performing building enclosure masks true absolute importance of enclosure air leakage in MURBs.

For energy efficient buildings we need to de-couple ventilation from heating – move away from pressurized corridor approach to in-suite HRVs or central heat-recovery ducted to units (and health/IAQ).

Interior airtightness is critical to enclosure airtightness in terms of energy efficiency for MURBs – as it allows for compartmentalization – which allows for much more efficient ventilation strategies to be used.
Impact of Heat Recovery Ventilation & Efficient Enclosure

- Equipment and Amenity (Common), 28.3, 25%
- Elevators, 4.2, 4%
- Electric Baseboard Heating, 3.3, 3%
- Ventilation Heating, 6.4, 6%
- DHW, 32.9, 29%
- Lights - Suite, 15.9, 14%
- Lights - Common, 3.7, 3%
- Plug and Appliances (Suites), 18.8, 16%

More Efficient MURB ~114 kWh/m²
Energy Study – Vancouver and Victoria, B.C.
For in-suite ducted (rooftop or direct wall) ventilation work in high-rises, building pressures must be addressed:

- Significantly reduce Stack Effect by *compartmentalizing* units and corridors from shafts / elevators / stairwells.
- Construct airtight floors & walls.
- Balance mechanical pressures.
- In-suite ventilation systems require special maintenance – design consideration.

- Significant Energy Savings Potential for MURBs.
- Expensive to add in-suite ventilation to existing buildings.
Effects of Poor Ventilation

- Contamination Build-up
- Condensation
- Fungal Growth
- Health Problems
What symptoms are often linked to poor indoor air quality?

It is common for people to report one or more of the following symptoms:

- dryness and irritation of the eyes, nose, throat, and skin
- headache
- fatigue
- shortness of breath
- hypersensitivity and allergies
- sinus congestion
- coughing and sneezing
- dizziness
- nausea
How does mechanical ventilation alleviate problems with condensation and contaminants?

- Regular and predictable removal of moisture and contaminants through bathroom fans
- Dilution of contaminants and moisture with fresh heated outdoor air
Case Studies

→ Central Park Place, Burnaby, B.C. – Existing Building
→ The Strand, Portland, OR – New Construction
Central Park Place – Burnaby, BC

→ Three 22-story condominium towers – 1960s
→ Window replacement and building enclosure rehabilitation – 2011
→ Significantly increased airtightness of enclosure
→ Resulted in some poor Indoor Air Quality issues
→ HVAC system relies on corridor pressurization and opening windows
→ Improvements to Existing System Proposed
Existing Conditions

Condensation

- Related to lack of ventilation
- Build-up of moisture
- Typically collects on the coldest surfaces
Existing Conditions

→ Fungal Growth
  → Related to condensation
  → Moisture can support fungal growth

→ Other IAQ issues
Observations of Existing System

- Building Enclosure Pre-rehab
  - Air leakage through walls and interfaces
  - Some leakage through ducts
  - Natural uncontrolled air exchange through windows and doors
  - Uncontrolled leakage through adjacent walls
Building Enclosure Post-rehab

- Air leakage to the outside is close to zero through the upgraded walls, windows and doors
- Most of the air leakage in each unit is through the fan ducts
- Opening a window can increase natural ventilation if there is a pressure differential
- Still have uncontrolled leakage through adj. walls
Observations of Existing System

- **Bathroom Fans**
  - Installed in every unit
  - Some ability to exhaust unit
- 24 units were visited
  - 8 in East tower
  - 7 in North tower
  - 9 in West tower
- Flow rates varied from 12 cfm to 42 cfm (recommended 50-60cfm)
- Fans are loud making operation intrusive
- Fans were not operational in 2 units
Observations of Existing System

Approximate Fresh Air Supplied (East Tower)

- 2\textsuperscript{nd} floor – 110 cfm
- 4\textsuperscript{th} floor – 0 cfm
- 7\textsuperscript{th} floor – 250 cfm
- 12\textsuperscript{th} floor – 90 cfm
- 16\textsuperscript{th} floor – 250 cfm

ASHRAE 62.1 Design Supply = ~400 cfm per floor

- Design - ~9000 cfm whole building
- Current - 3000-6000 cfm whole building

1/3 to 2/3 of ASHRAE requirement
Pressure Differential Across Unit Doors

Review of 36 units on 5 different floors

- Floors 2, 4 and 7 – 16 units (44%) had airflow out to corridor
- Floors 12, 16 – 7 units (19%) had inward air flow beneath door; but much less than ASHRAE 62.1 standards
- Total of 13 units (36%) had no door undercut
Note on Original Mechanical Drawings:

“Each floor area is vented by means of openable windows or sliding doors”
Recommendations – Central Park Place
Incremental Approach

- Operation of Windows and Doors
- Adjust Door Undercuts
- Replace Bathroom Fans
- New Make-Up Air Unit (MAU)
Recommendations

Increase Natural Ventilation with Windows and Doors

- Limited effectiveness thus far
- Not practical in winter
- Heating outdoor air, warm air escaping
- Energy efficiency
Recommendations

Adjust Door Undercuts

Ensures air enters the units
Recommendations

→ Make-Up Air Unit
  → New energy efficient unit
  → New exhaust grilles on each floor
  → Delivers fresh, pre-heated air to each floor
  → Adequately pressurize hallways to ensure fresh air to units
  → Currently only supplying 3000cfm - 6000 cfm
    • ASHRAE 62.1 design 9000 cfm
Recommendations

→ New Bathroom Fans
  → Exhaust contaminants from units
  → **Quieter** than existing fans
  → Timer controlled operation as well as occupant controlled
  → Larger design capacity
Mechanical Upgrade Costs per Unit – Summary

- **In-Suite HRV**
- **New Fans + MAU**
- **New Fans only**

- **Project Costs**
- **HRV**
- **MAU**
- **Fan Cost**
12-story condominium building completed in 2006

Some units experienced condensation issues shortly after occupancy

Condensation occurred on thermally broken aluminum window-wall system

RDH performed monitoring study of interior conditions in 6 units (2 control units)

Make-up air relies on corridor pressurization
Data logging equipment installed in various locations.
Average Window Temperatures During a Condensation Occurrence

Control Unit Comparison - Average Window Temperatures During a Condensation Occurrence
(N601/N301 - Mar 10 0:00-8:00, W602/E902/W302 - Feb 14 0:00-8:00)

Legend:
- Glass Temperature
- Corner Post Temperature
- Frame Temperature
- Operable Vent Temperature
- Condensation Occurring More Than 1 Hour
- Condensation only occurred within 2F tolerance value
The average window temperatures in the condensation unit are equal to or higher than the corresponding control unit. This indicates window construction is not the causal factor.
Effect of HVAC Use on Window Temperatures

Control Unit

Condensation Unit
Effect of HVAC Use on Window Temperatures

- Thermostat set at 70° F results in steady window temperatures of +/- 65° F
- Window temperature steadily declines when the furnace is turned off (night)
  Window temperatures drop between 58-61° F
- Condensation occurs
Effect of Fan Use/ Increased Makeup Air on Unit Dew Point

Figure B9-W302 - W302 - Fan Usage vs Dew Points at Moisture Sources

- Dryer (On)
- Master Bath Fan (On)
- Guest Bath Fan (On)
- Kitchen Fan (On)
- Laundry Dew Point (F)
- Master Bath Dew Point (F)
- Guest Bath Dew Point (F)
- Kitchen Dew Point (F)
- Zone 1 Condensation
- Zone 2 Condensation
- Zone 3 Condensation
Shower occurs without bathroom fan, kitchen fan is run for 3 hrs, overall dew point throughout the unit decreases.

Shower #2 occurs again no bath-room fan **AND** no kitchen fan, overall unit dew point does not equalize for 10-12hrs.

The bathroom dew point does not recover.
CO₂ Levels Indicate Volume of Fresh Air Exchange

Figure B5

Control Unit Comparison - CO₂ Levels
Control units W602 and E902 both have low average CO₂ levels indicating higher air exchange rates.

No coinciding condensation in either unit.

Unit W302 has an average CO₂ 50% higher than the other units indicating a significantly lower air exchange rate.

There is coinciding condensation in unit.
Most Significant Factors in Condensation

- Lack of ventilation make up air under door (+ high RH)
- Poor air distribution to windows from heating vents
- Lack of HVAC and exhaust fan use by occupants

Figure B1

### Condensation Causal Factor Summary

<table>
<thead>
<tr>
<th>Causal Factor</th>
<th>HVAC / Ventilation</th>
<th>Window Construction</th>
<th>Occupant Use</th>
<th>Overall Moisture Level (average dew point levels)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HVAC / Ventilation</strong></td>
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<td></td>
<td></td>
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<tr>
<td>Heat Distribution</td>
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<tr>
<td>@ Vent</td>
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<tr>
<td>@ Window (low air flow)</td>
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<tr>
<td>Low Flow</td>
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<td>Condensation Resistance</td>
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<td><strong>Occupant Use</strong></td>
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<td>HVAC Unit (lack of use)</td>
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<td>Room Temp (low temp)</td>
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<td>Exhaust Fans (lack of use)</td>
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<td>Curtains (closed and insulating)</td>
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<td>CO2 Levels</td>
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<tr>
<td>Moisture Generation</td>
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<tr>
<td>Overall Moisture Level (average dew point levels)</td>
<td>6</td>
<td></td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

1 - 5 Scale: 1-2 – Not a significant factor in causing condensation, 4-5 – Key factor causing condensation

Control Unit
Recommendations – The Strand

- Increase Ventilation Air
- Increase Exhaust Air
- Address Occupant Load
Direct all heating supply vent grills at the window sills. Particular attention should be focused on exterior corners where temperatures are lowest.

Program in-suite HVAC unit to continuously circulate air for at least 30 minutes after each heating cycle.

Balance corridor pressurization to remain positive to unit.
Recommendations – Increase Exhaust Air

- Install continuous exhaust fan in master bathroom, or run dryer booster fan to continuously exhaust air from the unit.

- Equip bathroom fans with humidistat-controlled switch, or occupant sensor and timer to ensure the fans are exhausting during entire elevated moisture periods.

(Humidistat or timer should not be user adjustable)
→ Maintain an interior temperature at 70°F during cold winter months

→ Minimize or open window coverings during periods of cold exterior temperatures

→ Crack open windows during cold weather (about ¼ ”)

→ Open interior doors to allow air circulation

→ Run kitchen fans when cooking

→ Run bathroom fans when showering and bathing until moisture build-up is fully evacuated

→ Ensure clean dryer vents and lint traps
Summary of Findings
Summary of Findings

Existing Buildings

→ Be aware of effects of tightening enclosure during retrofits
→ Consider adding continuous operation exhaust fans
→ Balance corridor ventilation (add MAU if necessary)
→ Check and improve undercut at entry doors
→ Add in-suite ventilation (HRVs) where feasible
→ **Provide operating information to occupants**

New Construction

→ Compartmentalize units
→ De-couple ventilation from heating/cooling (HRVs)
→ Locate heating source near windows to “wash” with warm air
→ Provide continuous exhaust
→ **Provide operating information to occupants**
Questions