Aerosols - Seek and Seal Envelope Leaks

Dave Bohac PE | Director of Research
Ben Schoenbauer | Senior Research Engineer
Jim Fitzgerald | Senior Building Analyst

Center for Energy and Environment

2017 Energy Design Conference

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- Engineering Services
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- Public Policy
- Innovation Exchange
  - Research
  - Education and Outreach

Multifamily Experience

- Facility assessments of over 2,000 buildings in Minnesota
- Completed over 20 research projects

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Current Multifamily Research Projects

PROJECT	ANTICIPATE FINDINGS
• Condensing boiler optimization	Available
• Multifamily ventilation optimization	Available
• Multifamily aerosol envelope air sealing	Available soon
• Indoor pool optimization	Mid 2017
• Demand controller recirculation loop	Mid 2017

Case studies of high efficiency through-wall furnaces
CenterPoint Energy (2017)

Multifamily Envelope Sealing Opportunity:

- **Existing.** Thousands of leaky units built before any tightness requirements.

- **New Construction**.
  - Lowrise - moderately tight with ventilation.
  - Highrise – limited tightness requirement.

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Benefits:

- Reduced air infiltration energy costs
- Reduced odor transfer & improved IAQ
- Improved comfort from reduced drafts
- Reduced noise transmission (neighbors and outside)
- Improved envelope durability
- Reduced stack effect

Envelope Sealing Challenges:

- **Existing buildings.** No/difficult/costly access to distributed air leaks. 10% to 25% reduction is challenging.

- **New Construction**. Single family approaches only recently starting to carry over to multifamily buildings. How can we do this more effectively for both exterior leakage and compartmentalization?

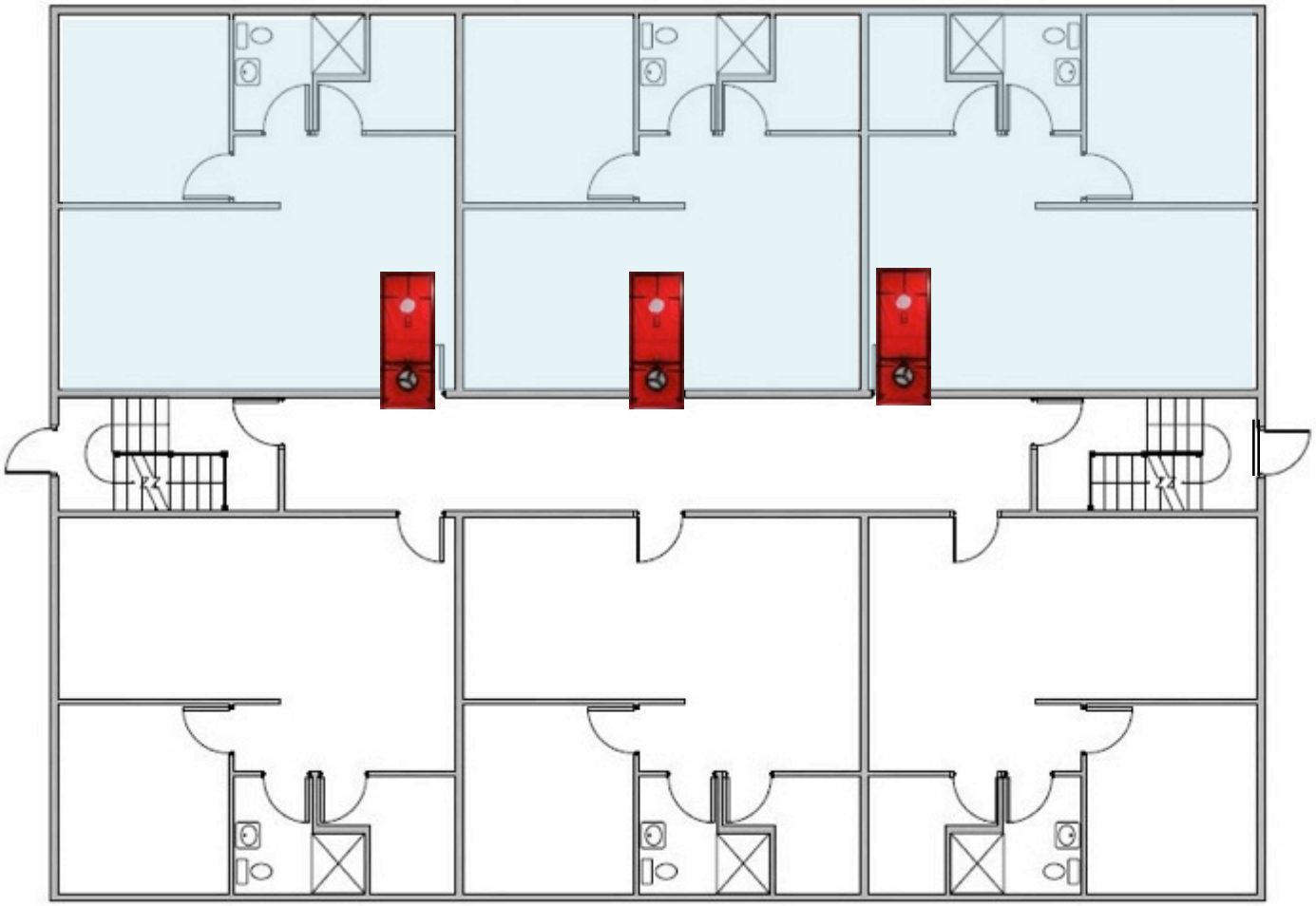
Building Tightness Specification:

- **Leakage: cfm50 or cfm75**. Measure the air flow rate needed to pressurize and/or depressurize the building by 50Pa (0.2 in. wc.) or 75Pa (0.3 in. wc)

- **Normalized leakage.** Divide leakage by building volume or envelope area
  - **ACH50.** 60*cfm50/volume
  - **cfm50/sf or cfm75/sf**.
    building envelope area = exterior walls + roof + floor (6 sides)

Apartment Building Test Options:

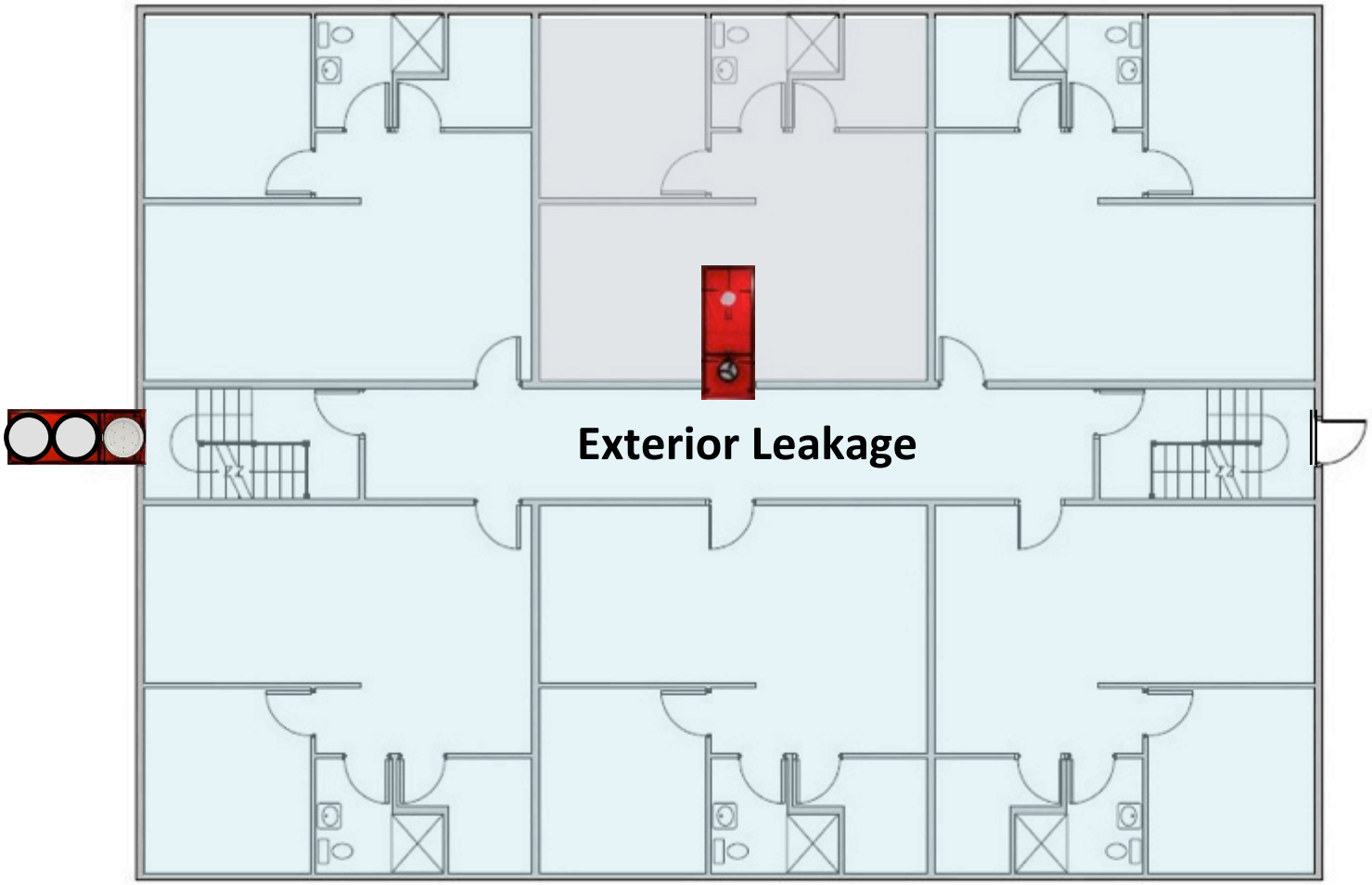
Guarded Test: Interior Leakage



Source: Paul Morin, TEC

Apartment Building Test Options:

Whole Building: Exterior Leakage



Source: Paul Morin, TEC

Envelope Tightness Requirements:

- **Minnesota Energy Code (2015).**
  - SF and 1 to 3 story MF: 3.0 ACH50
  - 4+ story MF: 0.4 cfm75/sf

    typically met by either **Materials** (0.004 cfm75/sf) or **Assemblies** (0.04 cfm75/sf) prescriptive options

- **Green Communities (MHFA)**. EPA ENERGY STAR for multifamily high rise = 0.3 cfm50/sf (4 – 8 ACH50).

LEED v4 Envelope Tightness: Energy

	Homes & Lowrise (1 – 3 Story)	Midrise (4 – 8 Story)	Highrise (9+ Stories)
Prerequisite	3.0 ACH50	0.3 cfm50/sf* or Air Sealing Checklist	Continuous air barrier
EA Credit	Air Infiltration	Annual Energy Use	Optimize Energy Performance
Points	**1:** 2.75 ACH50 or 0.125 cfm50/sf **2:** 2.50 ACH50 or 0.0925 cfm50/sf	1 pt/% reduction Base= 0.40 cfm75/sf Requires leakage testing	1 pt/2% reduction Base= 0.40 cfm75/sf Requires leakage testing

* - Commissioning: Energy Star High Rise Testing & Verification, total leakage

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To minimize waste of energy caused by uncontrolled air leakage into and from conditioned spaces.

LEED v4 Envelope Tightness: Environmental Tobacco Smoke

- **MF Midrise and Highrise.** None.

- **Highrise (9+ Stories).**
  - Prerequisite: 3.0 ACH50
  - EA Credit: Air Infiltration (exterior leakage, zone 5-7)
    - 1 pt: 2.75 ACH50 or 0.125 cfm50/sf
    - 2 pt: 2.0 ACH50 or 0.0925 cfm50/sf

To prevent or minimize exposure of building occupants, indoor surfaces, and ventilation air distribution systems to environmental tobacco smoke.

Envelope Aerosol Sealing

- Pressurize apartment
- Spray air sealing fog
- Sealant particles build up on gaps as they flow through the leaks

Similar to process used for aerosol duct sealing

How does it do that?

No, really?

(animation video here)

Sealant is a synthetic acrylic – typically rolled or sprayed on for monolithic exterior air barrier. Diluted for aerosol application.

Sealant is low VOC: GREEN Guard Gold Certified for use in California school and health care facilities.

Benefits:

- Automatically finds and seals leaks
- Very effective at sealing small, diffuse leaks
- Reliably meet air tightness requirements
- Simultaneous air leakage testing documents results
- Potential savings for avoided conventional air sealing (?)

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Study Objectives:

Demonstrate sealing capability and evaluate commercialization

- Refine sealing technique – measure leakage and noise transmission reduction & identify sealing locations
- How to incorporate into sealing strategy – preseal “large” leaks and protect horizontal surfaces as necessary
- Time estimates
- Model energy savings and effect on ventilation

1. Sealed 18 units in 3 new construction buildings
2. Sealed 9 units in 3 existing buildings

Project Team

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- Ben Schoenbauer
- Jim Fitzgerald
- Kirk Kolehma
- Megan Hoye

UC Davis Western Cooling Efficiency Center

- Curtis Harrington
- Mark Modera

Aerosol Sealing Process:

All In One Visit

1. Walk thru to identify pre-sealing & protection requirements (prior to sealing visit?)
2. Pre-seal large gaps & temporary sealing as necessary
3. Site work prep – cover horizontal surfaces
4. Set up sealing equipment
5. Perform sealing
6. Remove coverings
7. Clean surfaces (if necessary)
8. Post-sealing air leakage test
9. Air leakage test when unit finished?

Site Work Prep: pre-seal wide gaps

Sprinkler head

Plumbing penetration

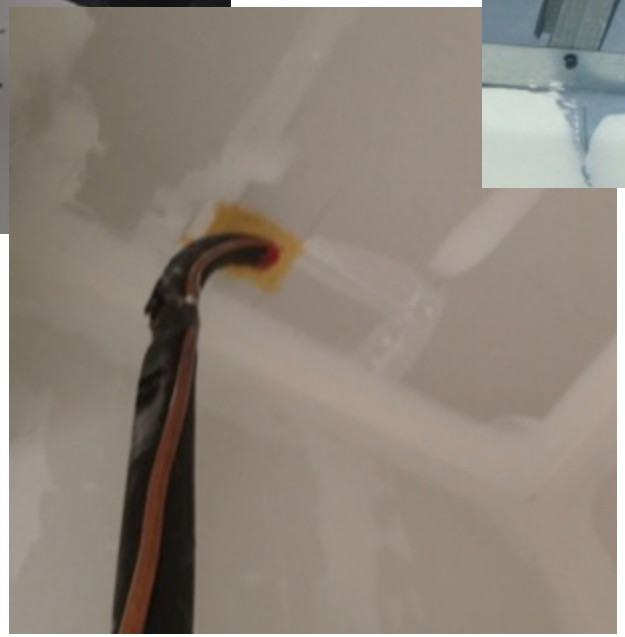
Site Work Prep: pre-seal wide gaps

Range electric line

Low-voltage wiring

Site Work Prep: pre-seal wide gaps

AC Line set



Duct – narrow enough to leave?

Site Work Prep: pre-seal wide gaps

Construction	Plumbing	Electrical	Mechanical
Floor wall connection	Showerhead penetration	Range plug	Line sets for HVAC
Sprinkler penetration	Sink penetrations	Electric baseboards	Vent duct penetrations
	Waste line penetrations	Low voltage wiring	Fresh air duct penetration
	Clothes washer connections	Additional wiring penetrations	Combustion and exhaust air penetrations
	Toilet water connection		PTAC wall penetration
	Kitchen water connection		Gas line penetrations (range, HVAC, laundry)

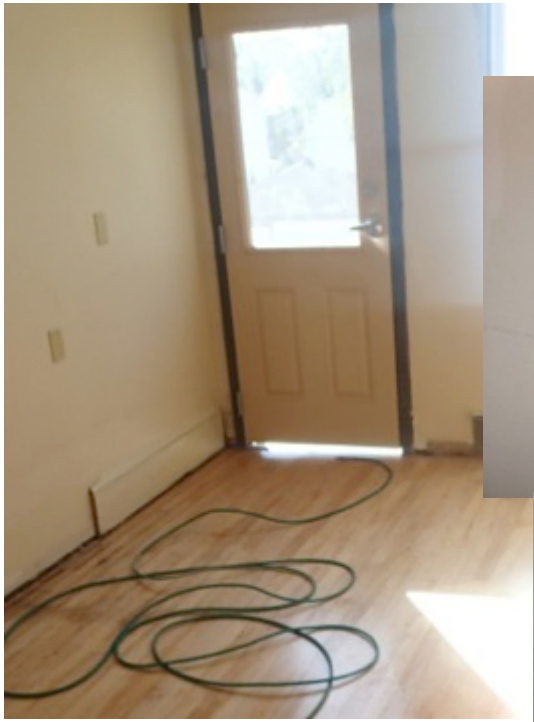
1 to 2 hours/unit

Site Work Prep: baseboards

Seal before quarter round, caulk after?

What about leaky wood floors?

Site Work Prep: temporary sealing



Exterior doors

Exhaust fan ducts

Plumbing penetrations

Combustion vents

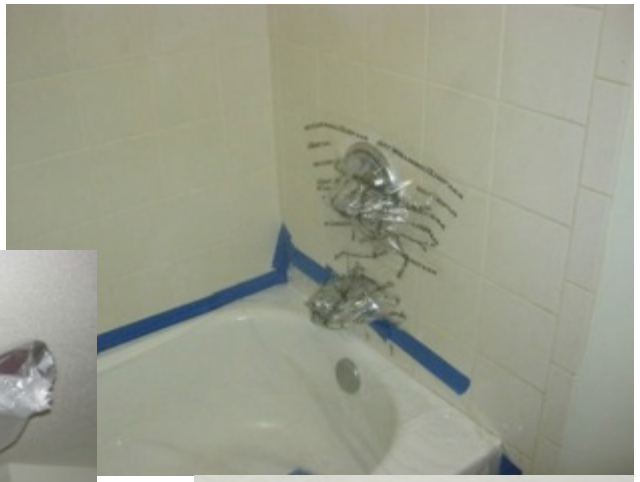
Shower handles

Fill traps or cover waste line openings

Site Work Prep: temporary sealing

Construction	Plumbing	Electrical	Mechanical
Door frames	Bathroom handles	Intercom	Bath fan
Floors (i.e. finished hardwood)	Drains	Low voltage outlets	Kitchen fan
Exterior doors (not used for fan frame)	Waste lines	Smoke detectors	Additional ventilation
Large holes/openings in the envelope		Alarms	Combustion and exhaust air
Windows (leaky)		Sprinkler heads	PTAC openings
			Outdoor air intakes
			Forced air registers
			Forced air returns

Site Work Prep: cover horizontal surfaces



Site Work Prep: cover horizontal surfaces

Ideal: drywall mud/tape no other finishes (bare floor better)

Not ideal: ready for occupancy

Site Work Prep: cover horizontal surfaces

Construction	Plumbing	Electrical	Mechanical
Floors	Tub or shower surrounds and floors	Ceiling Fans	Top surface of baseboard heating
Window sills	Toilets, sinks, other bathroom pieces	Light switches	
Window meeting rail and muntins	Plumbing fixtures	Light fixtures	
Door tops and hardware	Sprinkler heads		
Top surface of baseboards, trims, and molding			
Horizontal surfaces of cabinets and built-ins			

Temporary seals & covers: 3 to 7 hours/unit

Site Work:

Set-up, Seal & Breakdown

- Blower door and nozzles
- 100Pa pressurization
- ~ 90% RH maintained
- Open windows & purge

6 to 7 hours/unit

Remove Covers & Pack-up

- Care to not disturb seals
- Minimal clean-up

1.5 to 3.5 hours

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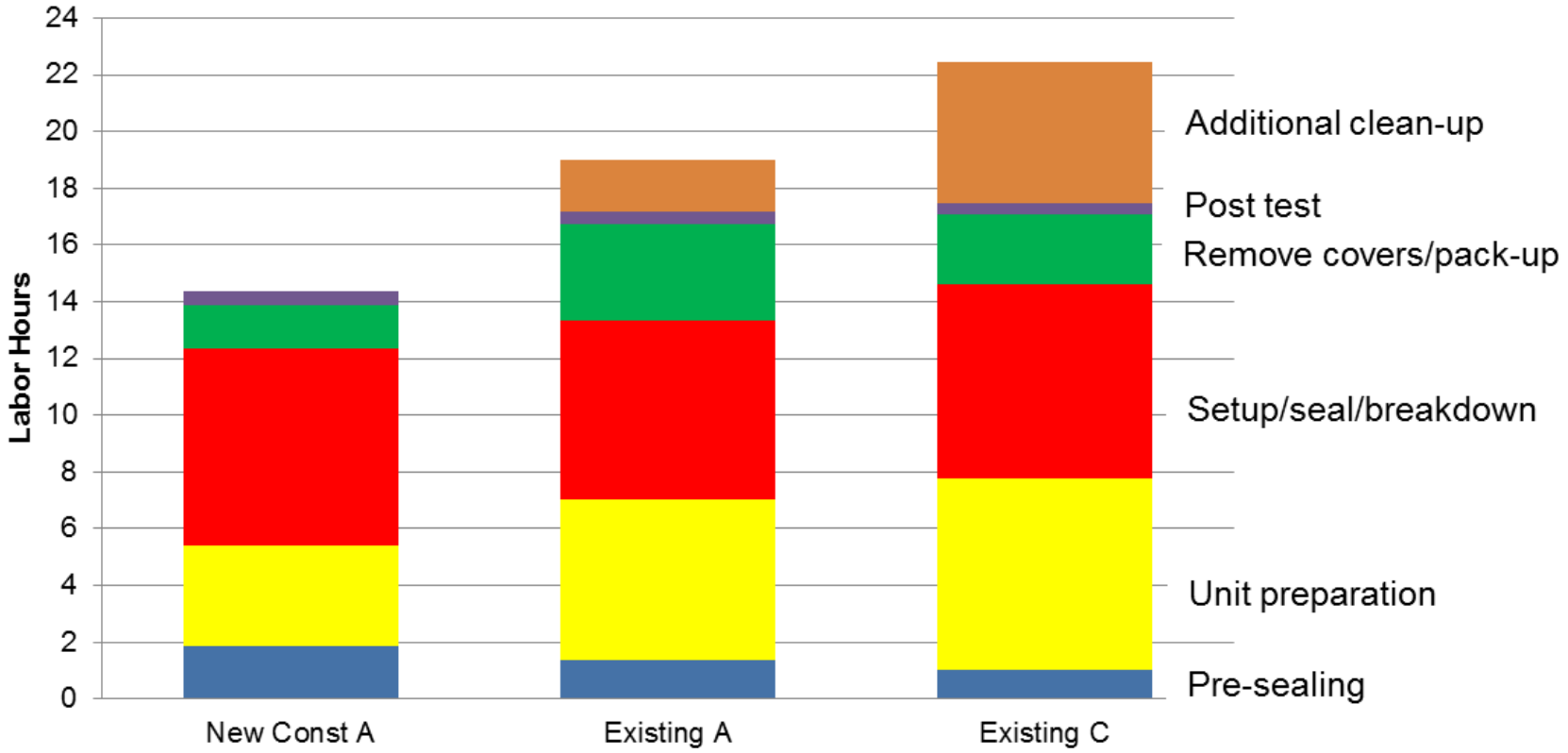
Site Work Prep: how long does it take?



14 – 22 hours: still learning

Site Work Prep: reduce time

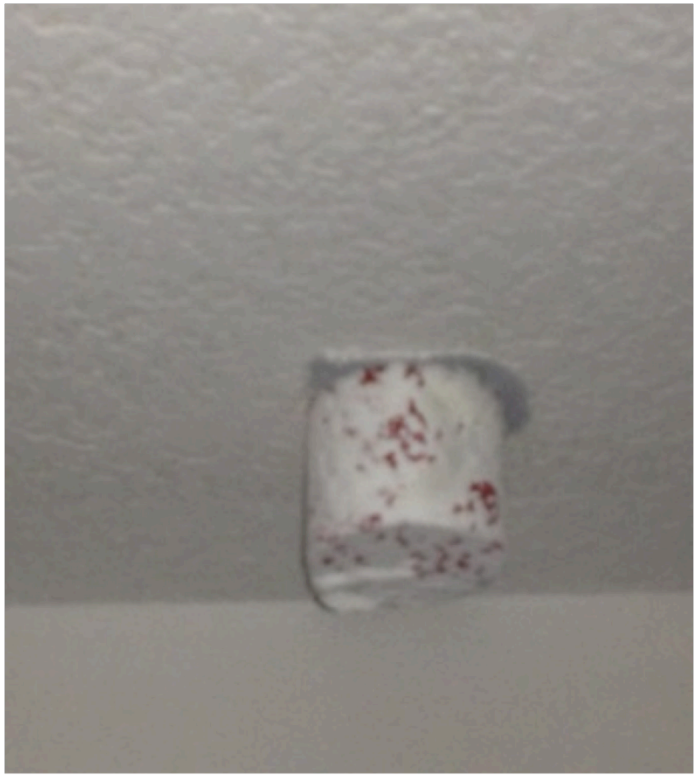
Opportunities to reduce labor time

- Pre-sealing: new construction – GC or sub completes
- Unit preparation: select time during construction when
  - Minimum horizontal surfaces to protect
  - Leaks are accessible
  - Seals will be durable
- Sealing time: new generation of more portable equipment is being developed & stop when no longer cost effective
- Breakdown/clean-up: minimize surfaces to cover and better positioning of spray nozzles

Sealed Penetrations

Plumbing Penetrations

Sealed Penetrations



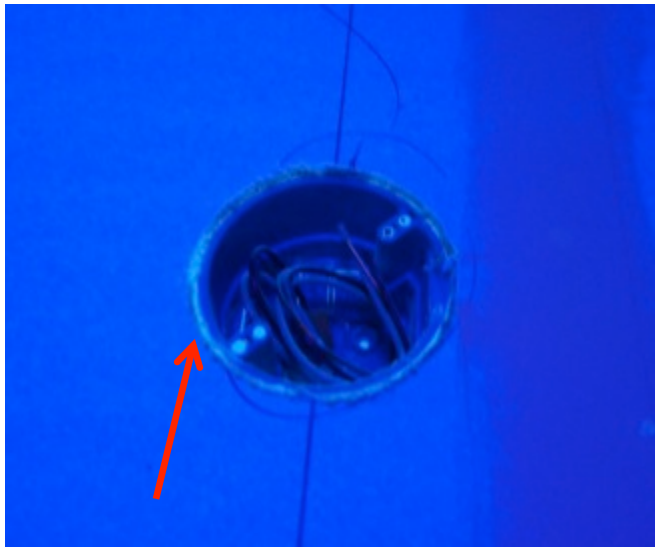
Sprinkler Head

Kitchen exhaust fan

Sealed Penetrations

Electrical Boxes

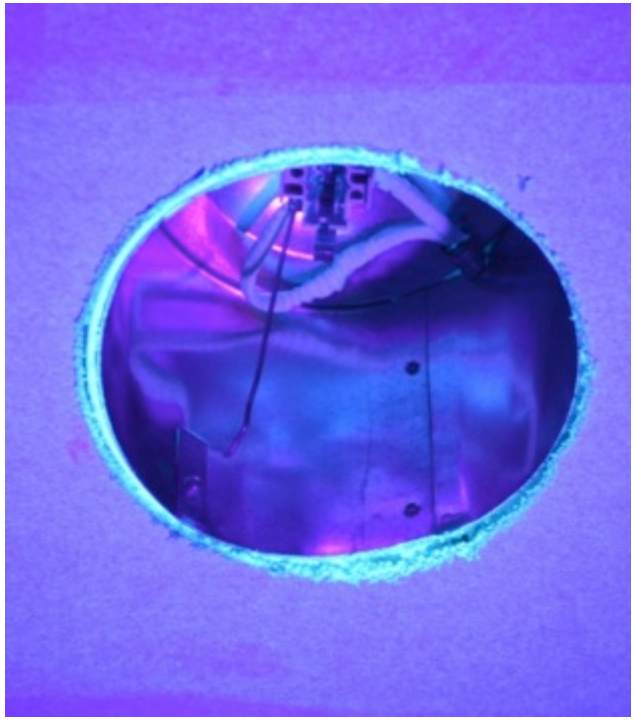
Site Work Prep: black light photos



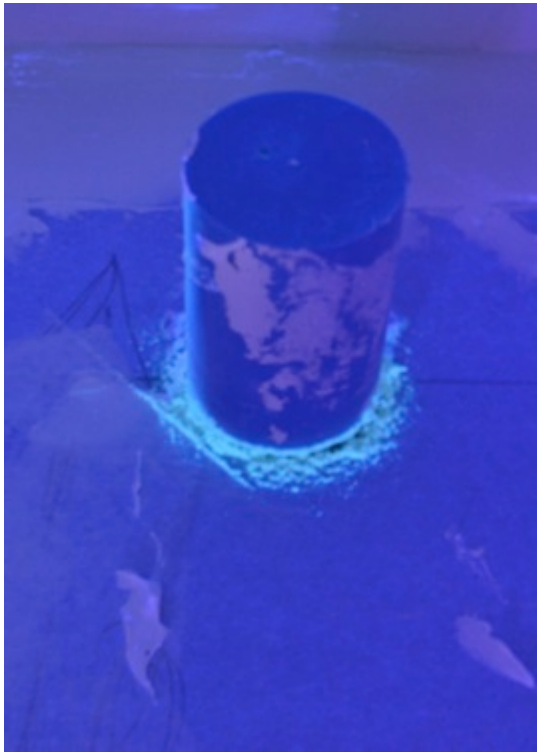
Electrical Boxes

Floor/wall Joint

Site Work Prep: black light photos

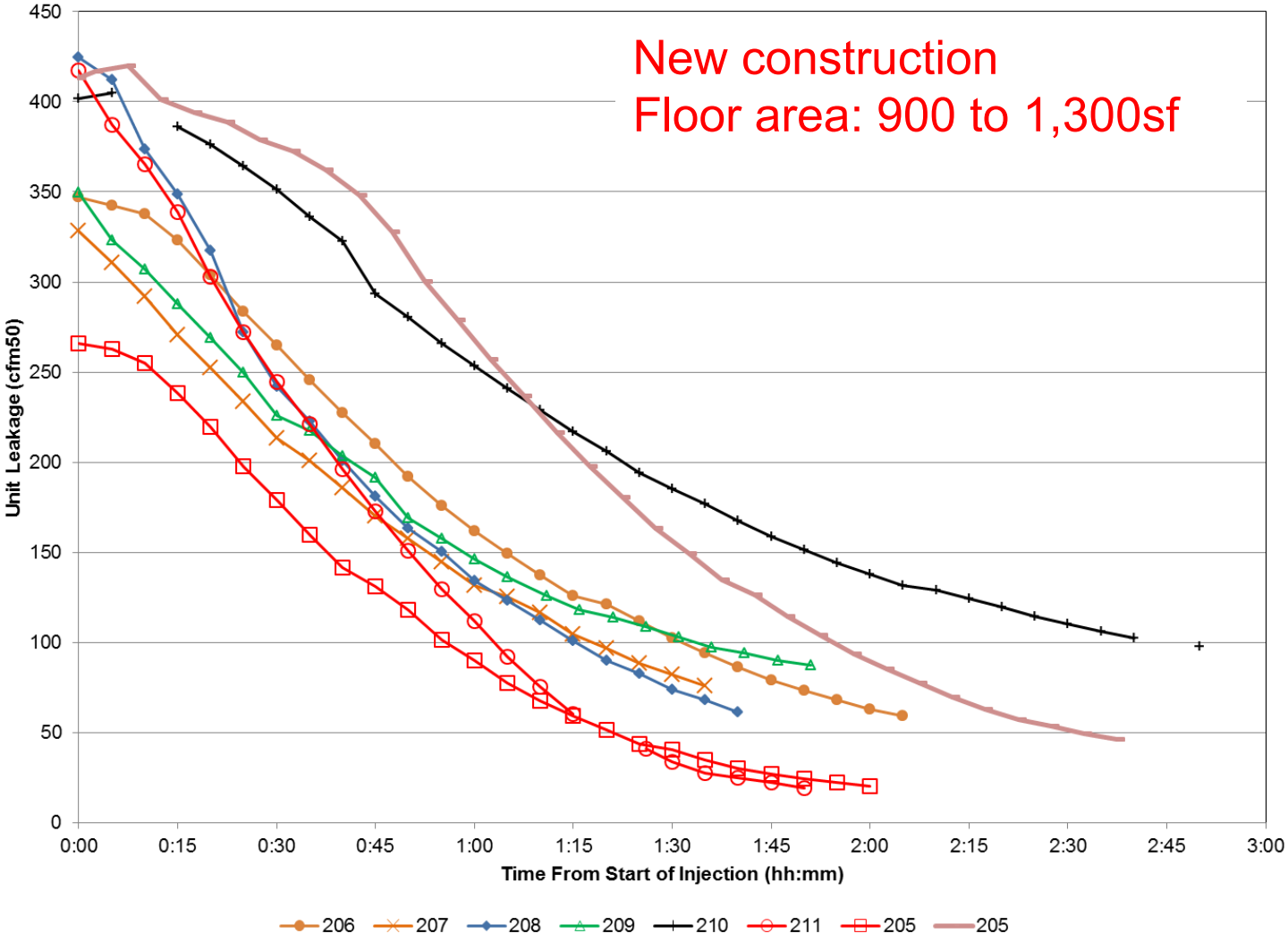


Recessed Light



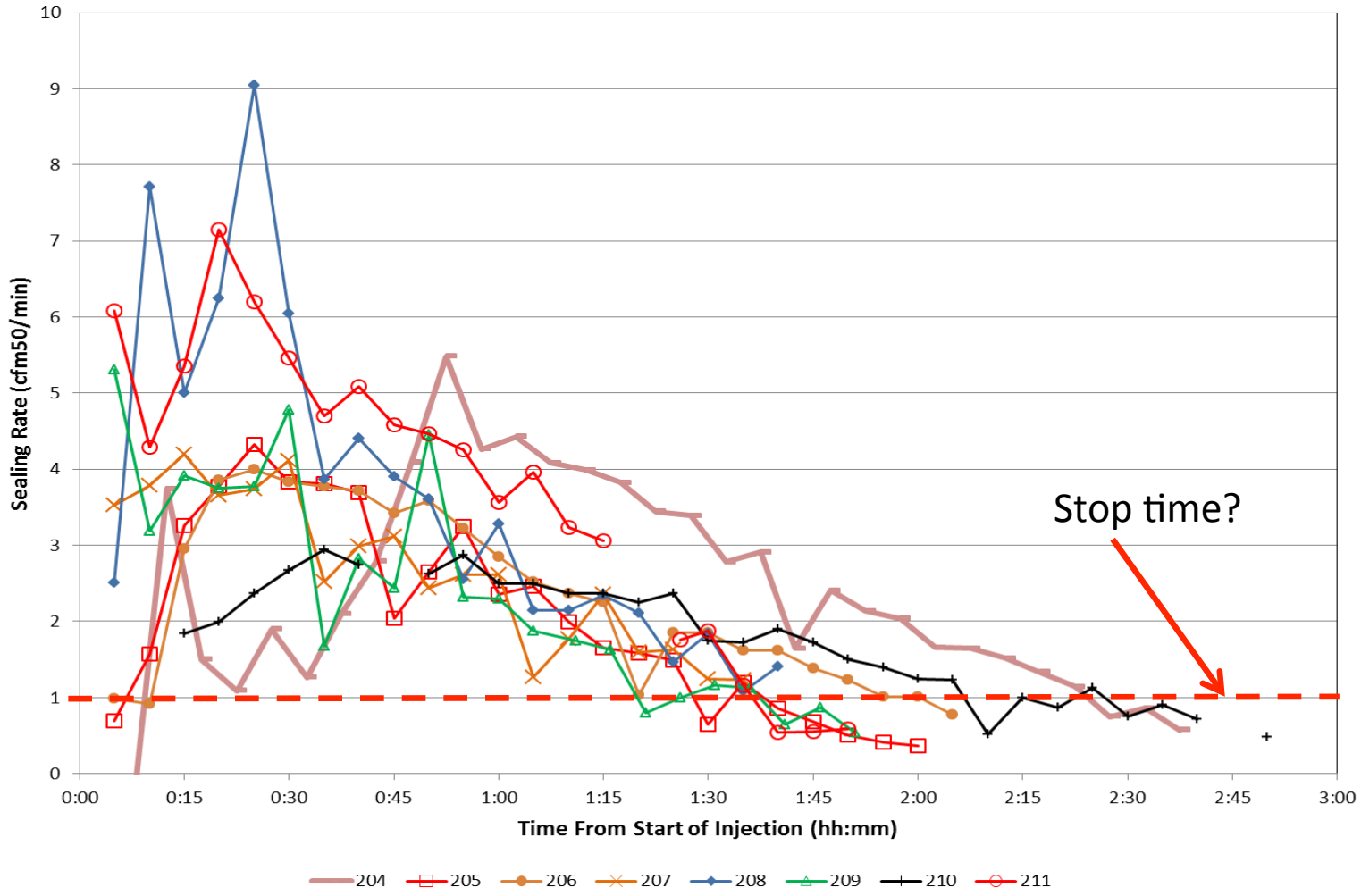
Sprinkler Head

Leakage Reduced Over Injection Period

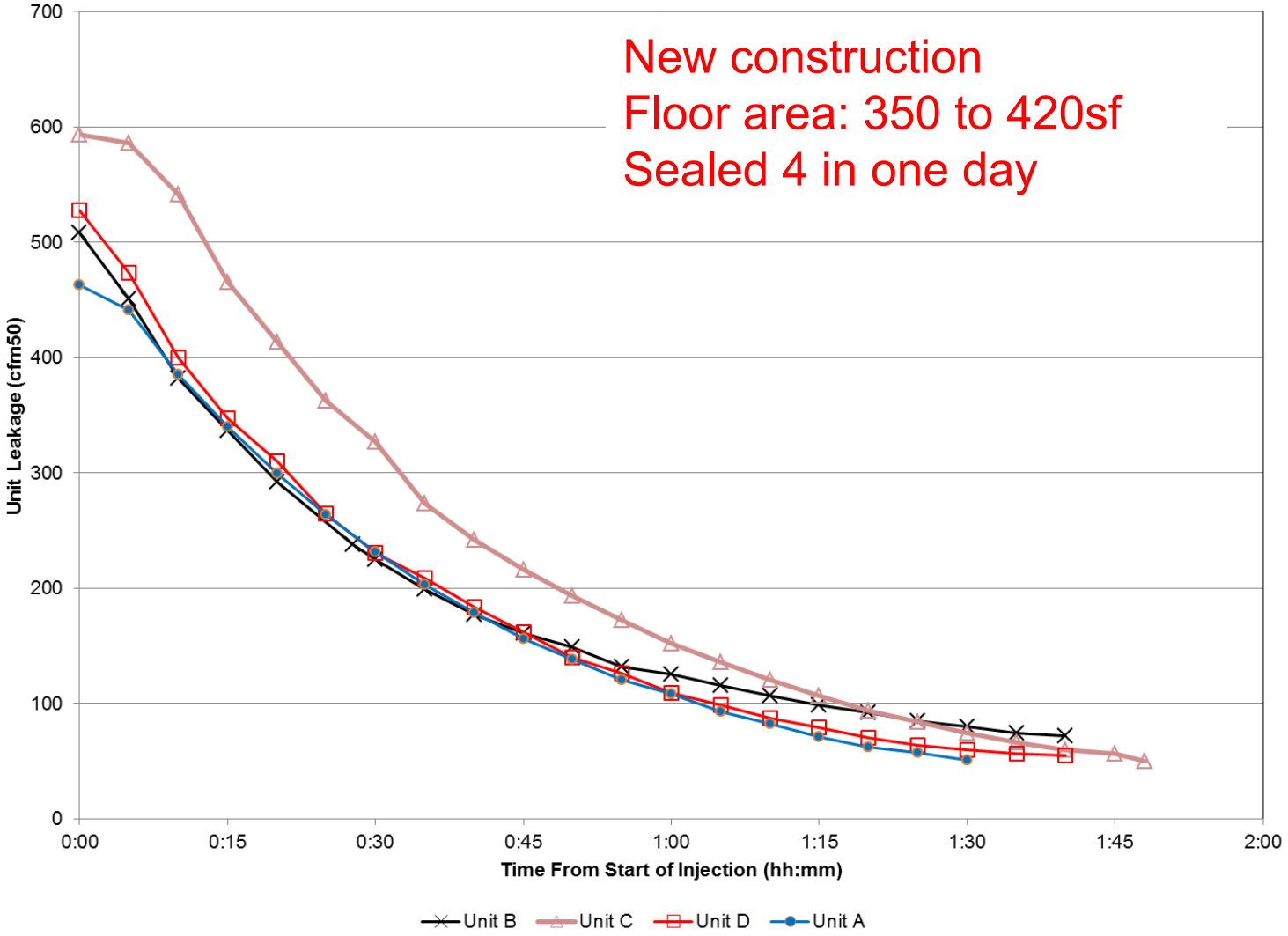


ACH50 pre: 2.0 – 2.9, post: 0.2 – 0.7; 71% to 94% reduction

Sealing Rate

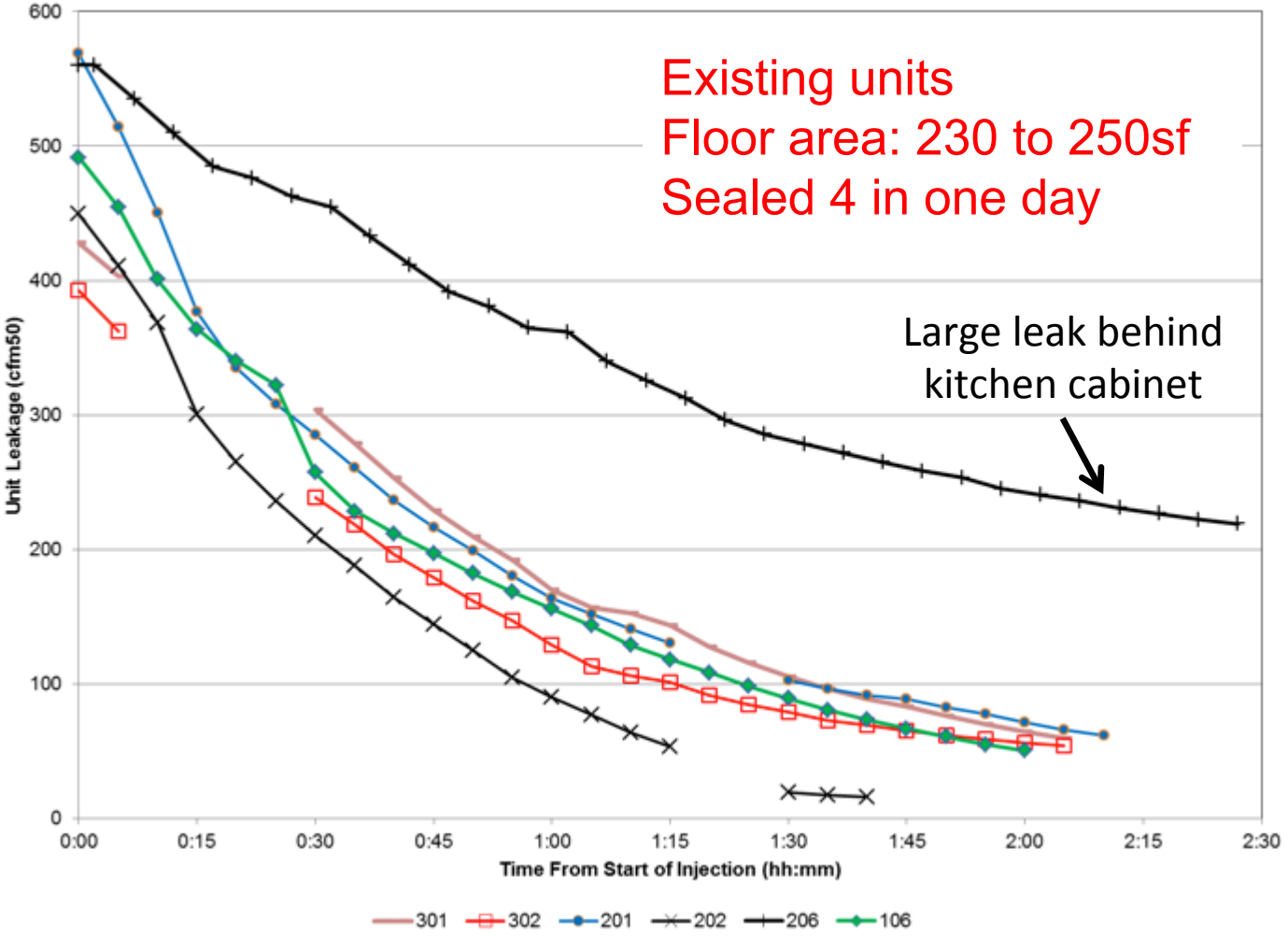


Leakage Reduced Over Injection Period



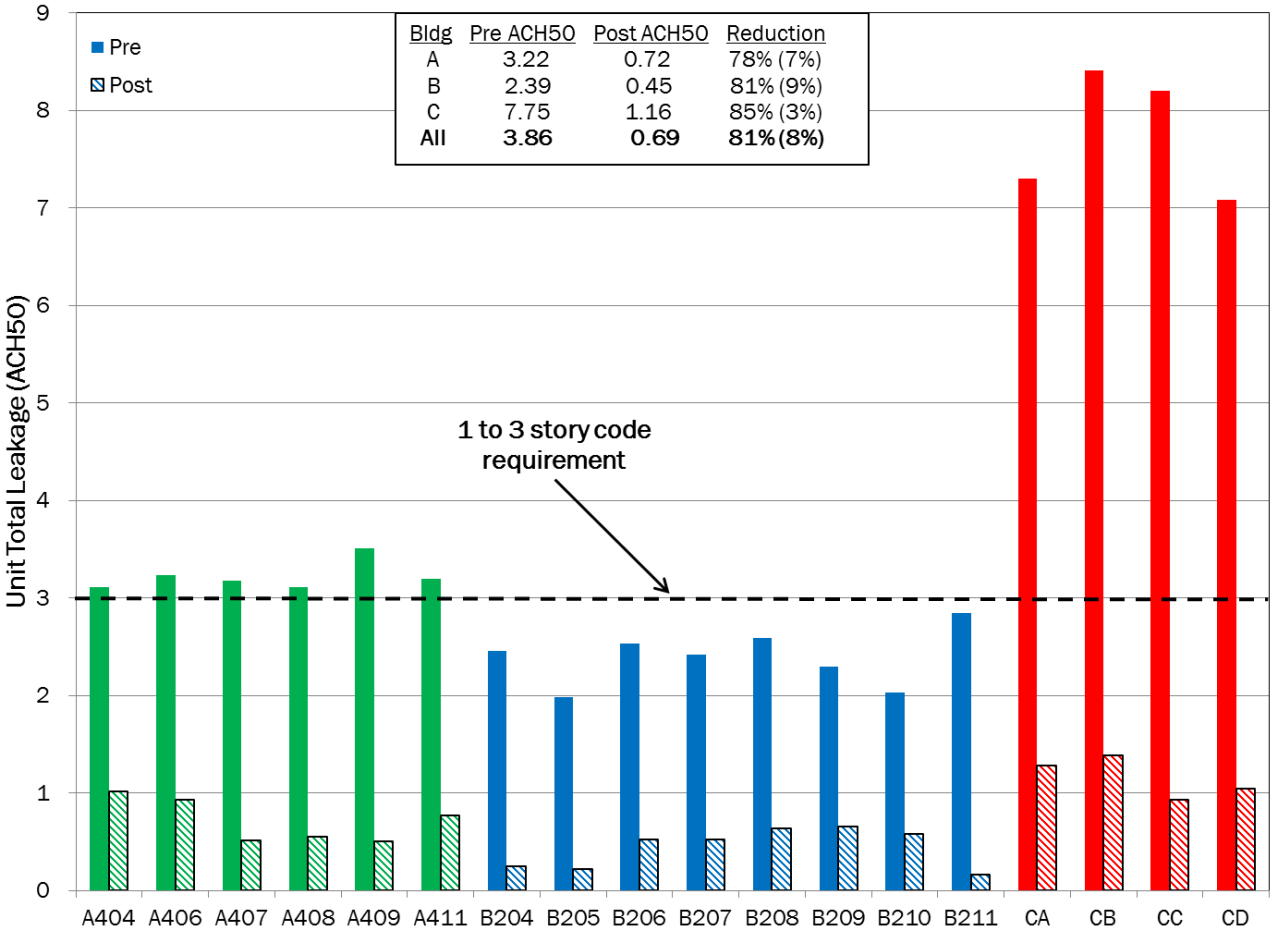
ACH50 pre: 7.1 – 8.4, post: 0.9 – 1.4; 82% to 89% reduction

Leakage Reduced Over Injection Period



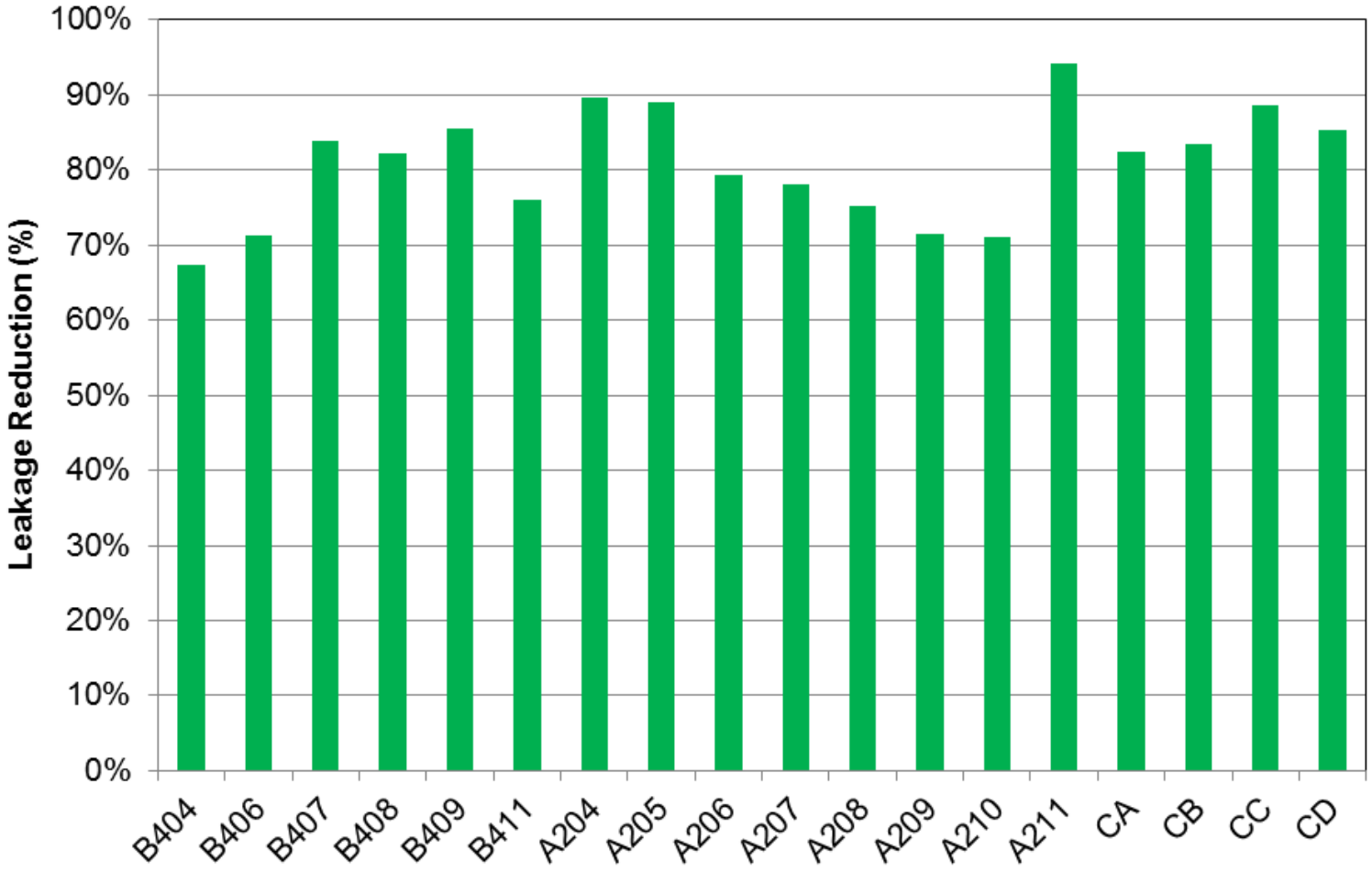
ACH50 pre: 12.0 – 17.2, post: 1.4 – 10.5; 39% to 88% reduction

Leakage Results: 18 New Construction Units



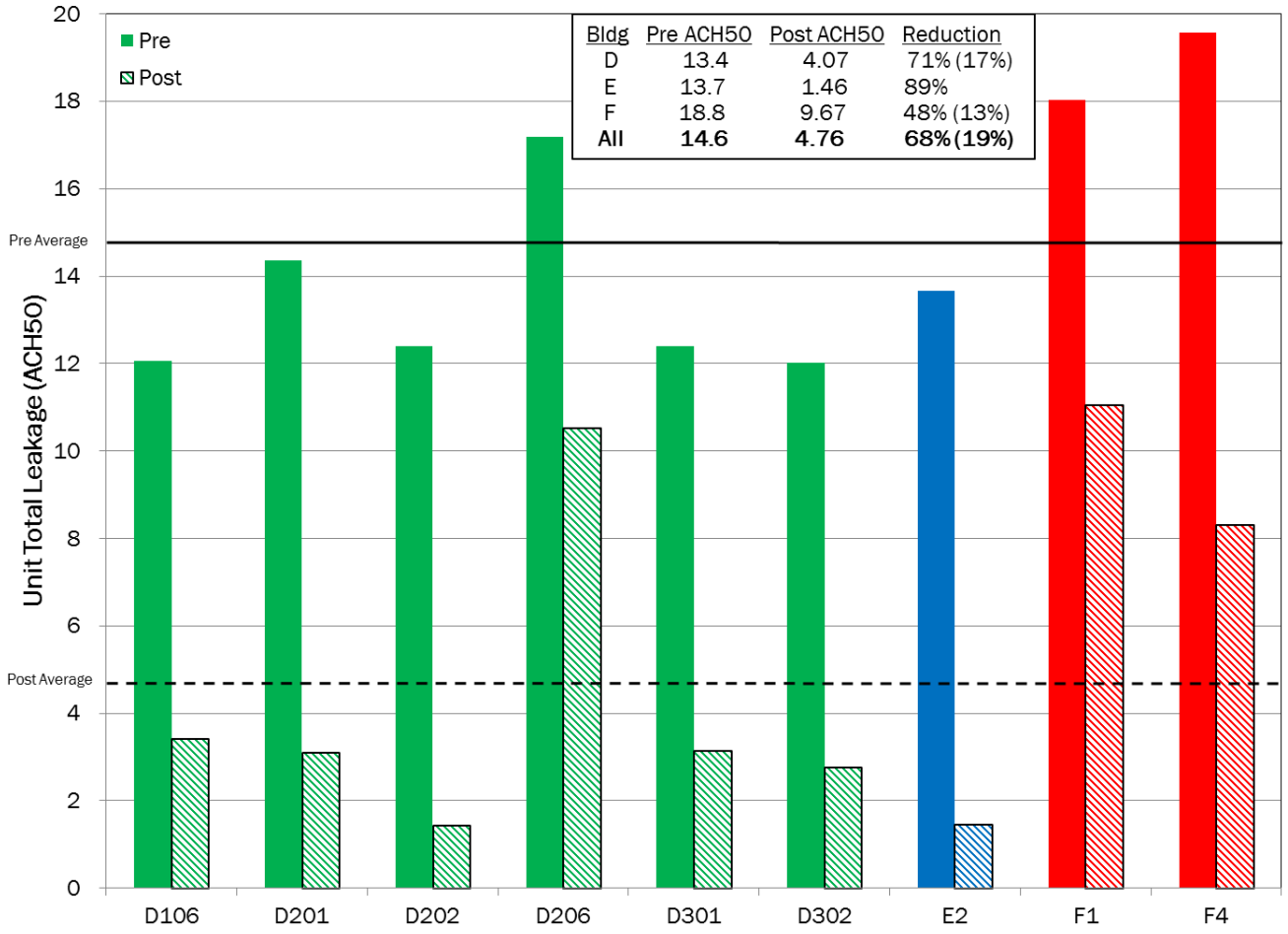
Average leakage: pre= 3.9 ACH50, post= 0.7 ACH50
54% to 95% below code requirement, average= 77%

Leakage Results: New Construction



Reduction: 67% to 94%, average = 81%

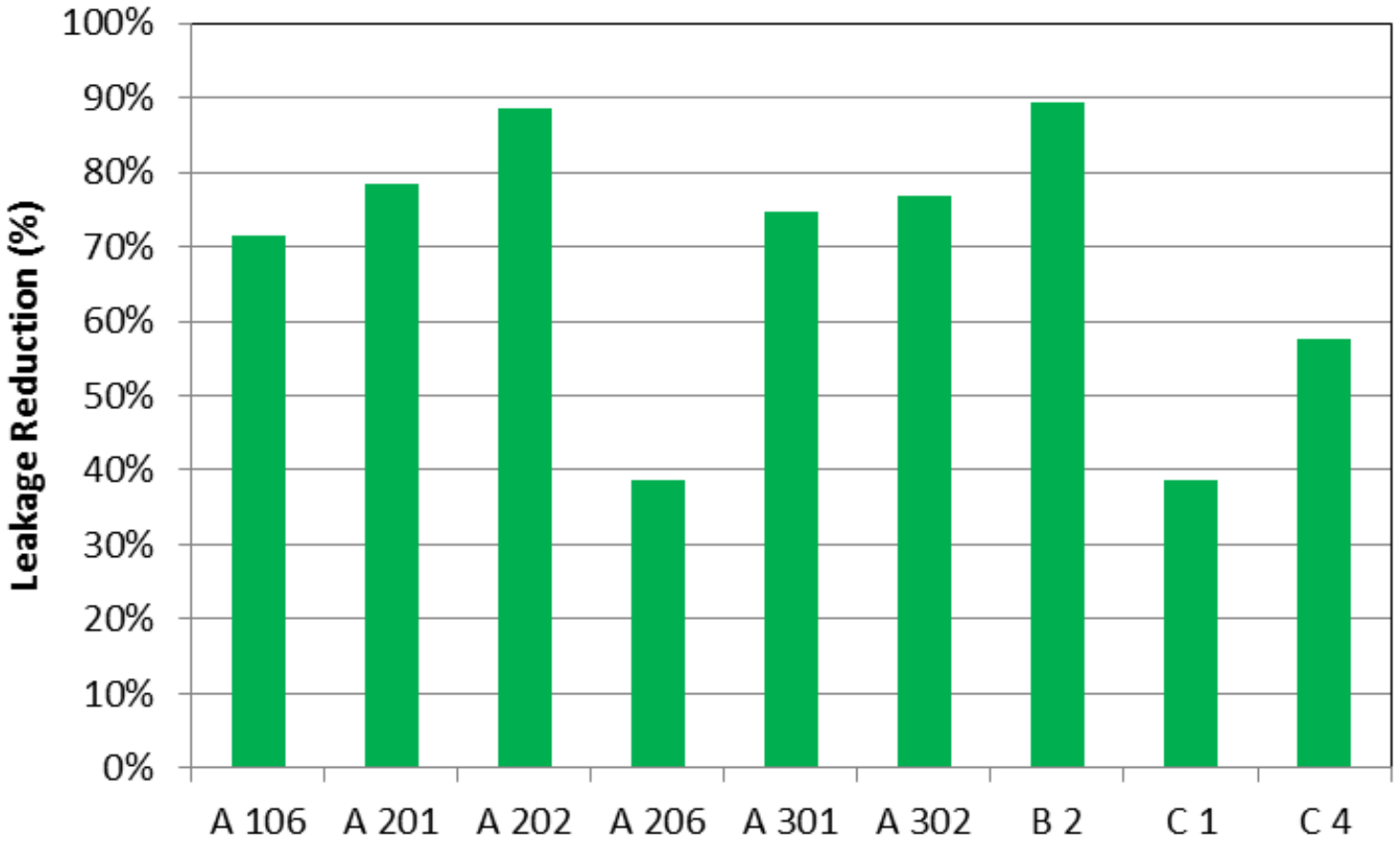
Leakage Results: 9 Existing Units



Average leakage: pre= 14.6 ACH50, post= 4.8 ACH50

6 of 9 within 15% of new construction code requirement

Leakage Results: Existing Units



Reduction: 39% to 89%, average = 68%

Leakage Results: Where Are the Leaks?

New Construction Building A

	(cfm50)			(cfm50/ft²)			Percent of Total		
ID	Ext & Below	Adj Units	Comm	Ext & Below	Adj Units	Comm	Ext & Below	Adj Units	Comm
A404	93	42	63	0.09	0.08	0.49	47%	21%	32%
A406	94	30	83	0.09	0.06	0.64	45%	15%	40%
A407	88	48	63	0.09	0.10	0.49	44%	24%	32%
A408	98	53	47	0.09	0.11	0.37	49%	27%	24%
A409	87	47	86	0.09	0.10	0.67	40%	21%	39%
A411	105	58	38	0.10	0.12	0.29	52%	29%	19%
Average	94	46	63	0.09	0.09	0.49	46%	23%	31%

About a quarter of leakage to adjoining units and a third to common space (hallways)

Leakage Results: Where Are the Leaks?

New Construction Building B

	Total	(ACH50)		Percentage of Total Leakage						Floor
ID	(cfm50)	Total	Exter	Exter	Comm	Left	Right	Up	Down	Red.
B206	494	3.58	0.28	8%	46%	19%	9%	12%	7%	29%
B207	580	4.21	0.73	17%	51%	12%	2%	12%	6%	43%
B208	957	5.97	0.46	8%	76%	4%	5%	4%	3%	57%
B209	648	3.97	0.99	25%	58%	2%	0%	11%	5%	42%
B210	784	4.04	0.33	8%	58%	7%	9%	12%	6%	50%
B211	757	4.98	1.07	22%	45%	9%	0%	13%	11%	43%
Average	703	4.46	0.64	15%	56%	9%	4%	11%	6%	44%

Over half of the leakage is to the hallway

Leakage Results: Where Are the Leaks?

New Construction Building C

	Total	Adjacent Unit		Remainder	
ID	(cfm50/ft^2)	(cfm50/ft^2)	(%)	(cfm50/ft^2)	(%)
CA	0.29	0.12	8%	0.33	92%
CB	0.33	0.12	7%	0.39	93%
CC	0.34	0.12	7%	0.39	93%
CD	0.29	0.12	8%	0.33	92%
Min	0.29	0.12	7%	0.33	92%
Average	0.31	0.12	8%	0.36	92%

8% of leakage to units on same floor

Leakage Results: Where Are the Leaks?

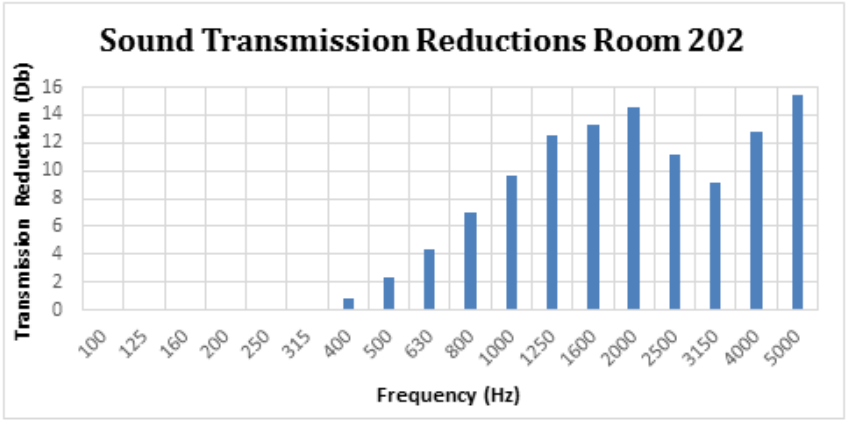
Existing Building D

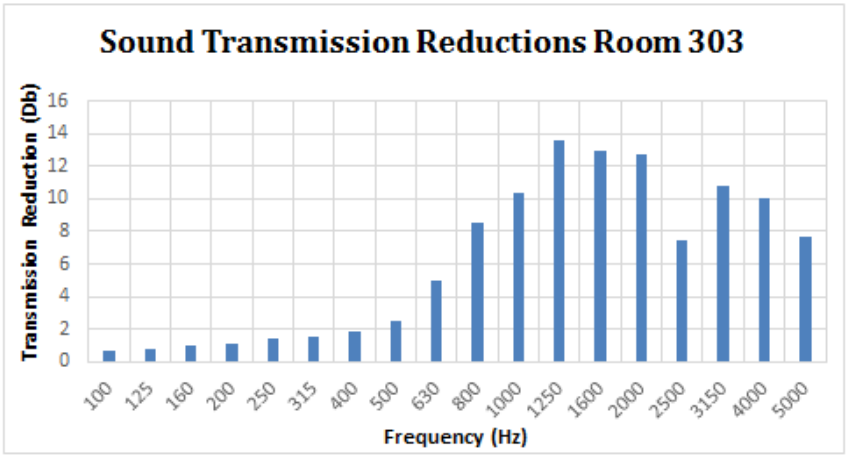
	(ACH50)			(cfm50/ft^2)			% of Total	
ID	Total	Ext.	Int.	Total	Ext.	Int.	Ext.	Int.
D 106	12.1	7.3	4.7	0.40	1.10	0.20	61%	39%
D 201	14.4	9.7	4.6	0.53	1.37	0.23	68%	32%
D 202	12.4	6.8	5.6	0.38	1.25	0.21	55%	45%
D 206	17.2	10.2	7.0	0.58	1.53	0.31	59%	41%
D 301	12.4	10.4	2.0	0.40	0.67	0.13	84%	16%
D 302	12.0	9.9	2.2	0.37	0.67	0.12	82%	18%
Average	13.4	9.0	4.4	0.44	1.10	0.20	68%	32%

Exterior is 5x leakier than interior

Reduced Noise Transmission

- Sound transmission testing was conducted in a MF building in NY
- Protocol based on ASTM E90
- Seal was an effective sound barrier between 800-5000 Hz
- Human voice frequency falls between 300-3000 HZ
- Helps to meet Building Code (IBC) requirement of 50 STC





Model

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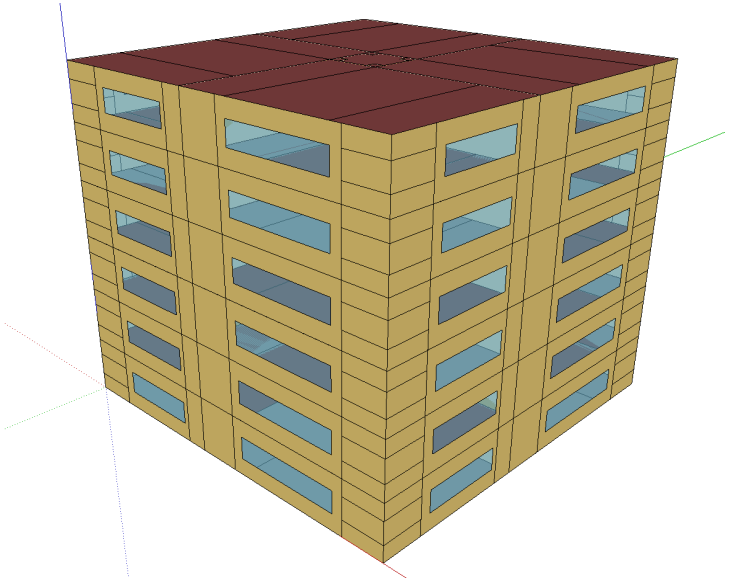
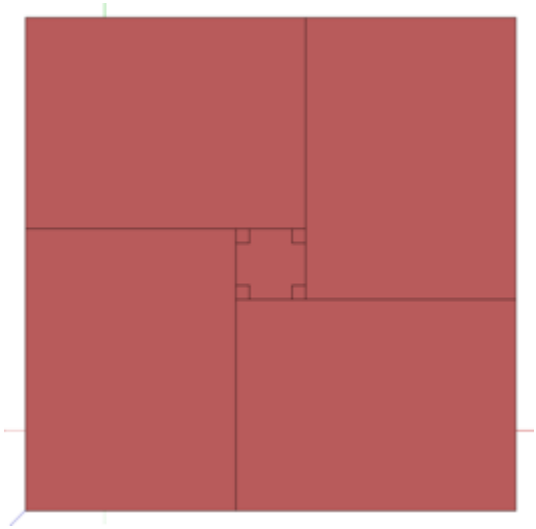
- **Ventilation model**: Airflow network
  - Calculates inter-zone flows
  - Accounts for wind and stack effects

- **HVAC Equipment:**
  - Based on MN multifamily building stock
    - Heating provided by baseboard radiant heaters
    - Cooling provided by window air conditioners

Model - Construction

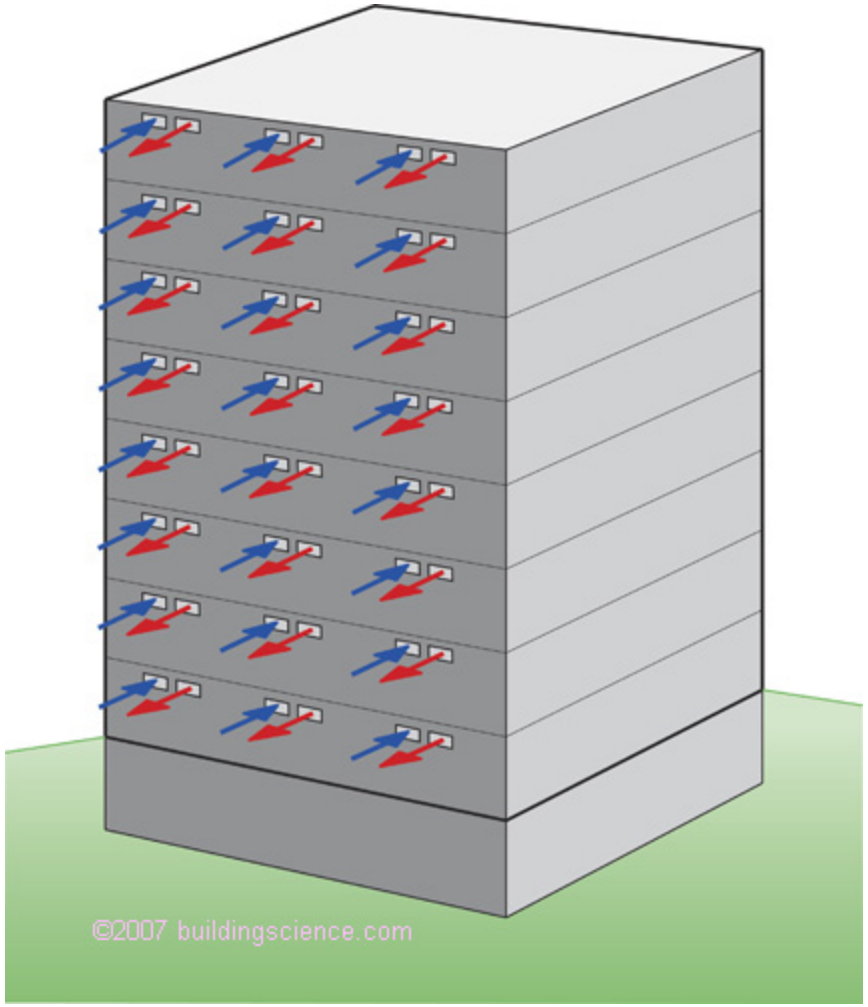
- 6-Story building model
- Floor plan:
  - 4 Units per floor
  - 1 Elevator shaft
  - 1,200sf floor area
- Construction:
  - DOE reference model construction
  - Window to wall ratio: 20%





Model – Ventilation Method

- Four ventilation strategies investigated
  - Exhaust only
  - Exhaust with some supply
  - Balanced
  - No ventilation
- Individual unit exhaust fans and balanced ventilators



Model – Leakage

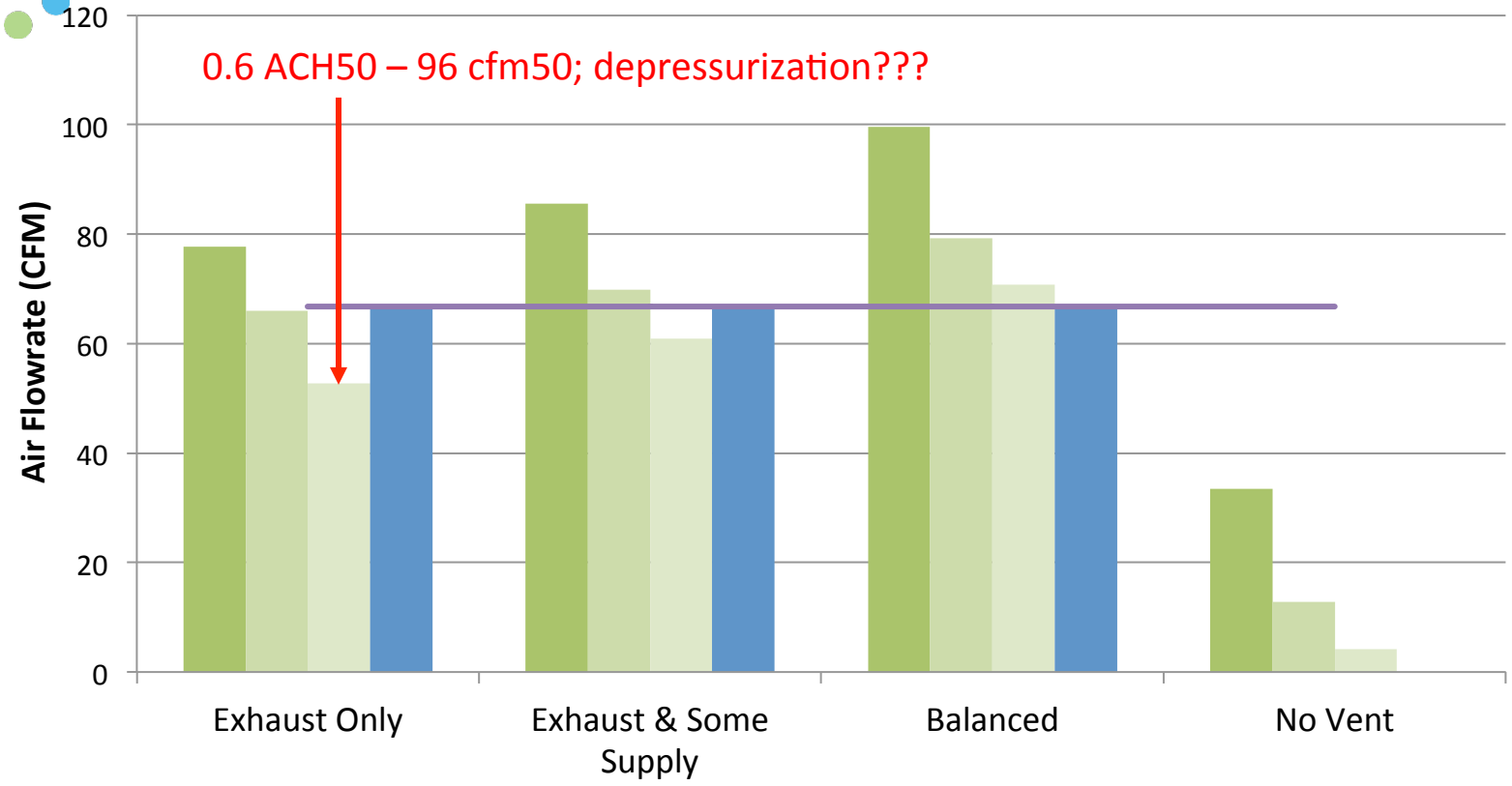
Envelope leakage (total):

- Existing Building
  - Leaky: 9.5 ACH50 (existing data)
  - Sealed: 3 ACH50 (MN code?)
- New Building
  - Compliant: 3 ACH50 (MN code?)
  - Tight: 0.6 ACH50 (Passive House)

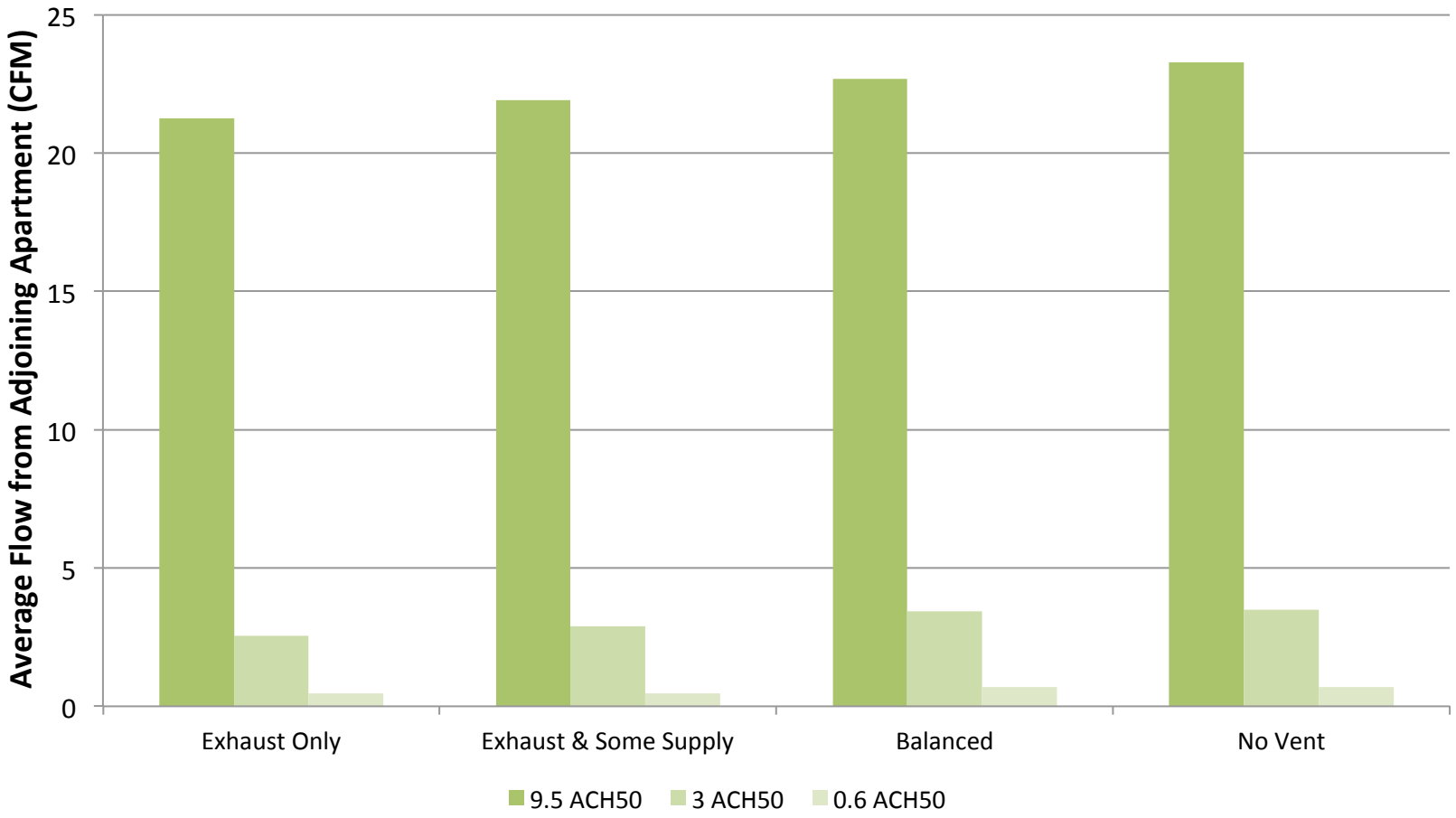
ACH50	Exterior	Interior	Floor/Ceiling	Door
9.5	43%	34%	13%	9%
3	47%	18%	5%	29%
0.6	47%	18%	5%	29%

Table 1: Leakage distribution used in models

Results – Ventilation Flows



Results – Interior Flows



Results – Summary Table

- Impact of sealing air leaks in apartment buildings in Minneapolis

	New Buildings 80% reduction	Existing Buildings 68% Reduction
Heating Savings (therms/year)	60 - 75	40 - 200
Heating Savings ($/year)	$33 - $44	$23 - $120

Exterior leakage reduced from 3.0 ACH50 to 0.6 ACH50

Low savings: Total leakage reduced from 9.5 ACH50 to 3 ACH50

Little or negative impact on cooling energy

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New construction: balanced ventilation
Existing buildings: exhaust only typically acceptable

Convert Blower Door Results to Infiltration?

Air Sealing

- Leaky with no or balanced = divide by 25
- Leaky with exhaust ventilation = divide by 40

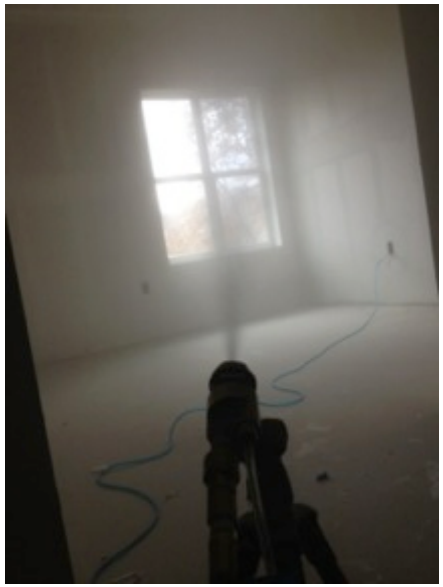
Considerations

- Need **exterior leakage**
- Interior sealing >> less impact on energy
- Depends on type/amount of mechanical ventilation
- Impacted by wind shielding and building height

Air Sealing at Lower Cost?

Aerosol

- Prep
- Sealing process
- Simultaneous air leakage testing ensures results



Vs.

Manual air sealing

i.e. caulking/foaming

- Architectural specification
- Labor
- Air leakage test

=> Uncertain results

Conclusions

- Not a solution for large air leak gaps
- When aerosol envelope sealing can be used
  - New construction
  - Rehab
  - Change in occupancy (higher cost)
- New construction
  - 81% reduction & 77% below code
  - Reduce to below code w/o excessive QC
  - Comply with code reliably
- Existing units
  - 68% reduction & 6 of 9 within 15% new code
  - Heating savings= 67 therms/yr, 19%
  - 85% reduction in flows from adjacent units
- Balanced ventilation is crucial for new construction, exhaust or supply OK for existing
- Can you eliminate some “conventional” sealing? If not, too costly?

Future Work

Large Building Sealing with Department of Defense

- Sealing existing commercial buildings on military bases
- Lab testing of seal strength and durability
- Modeling energy savings due to large-building sealing

Building America

- Integrate sealing process into construction schedule
- Work with developers in CA and MN
- Test multiple options

Aeroseal Commercialization

- Has started commercial service (limited)
- Developing contractor network – end of 2017

THANK *you!*

Dave Bohac
dbohac@mncee.org

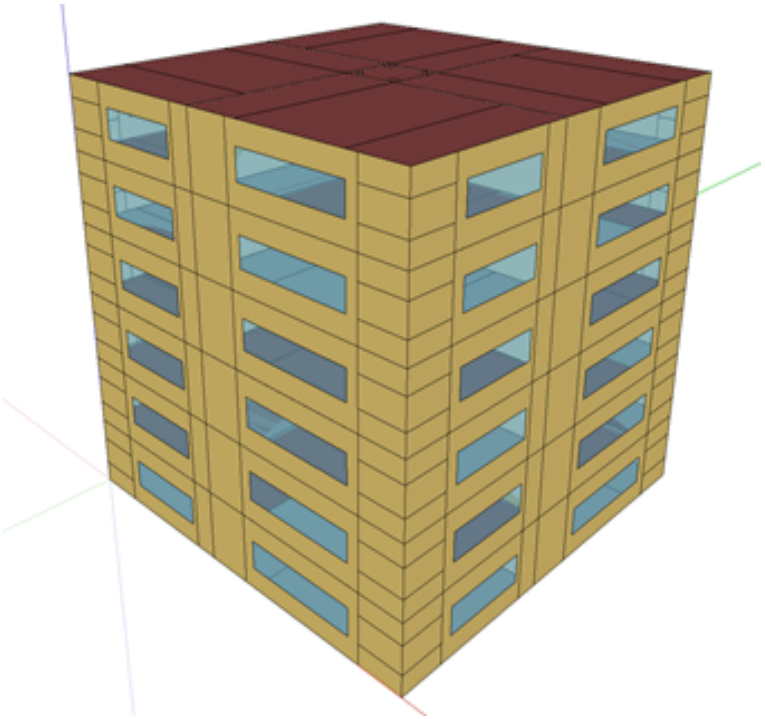
Ben Shoenbauer
bshoenbauer@mncee.org

cee
Center for Energy and Environment

Energy & Ventilation Modeling

- EnergyPlus model: air flows **computed** from leakage paths and wind/stack/ventilation imbalance
- Three levels of tightness:
  - 9.5 ACH50 (leaky/existing)
  - 3.0 ACH50 (new code)
  - 0.6 ACH50 (aerosol sealed)
- Ventilation systems (0.35ach = 70cfm rqd):
  - balanced
  - exhaust only
  - supply = half of exhaust
  - none

6 story, 4 units/floor
1,200sf/unit

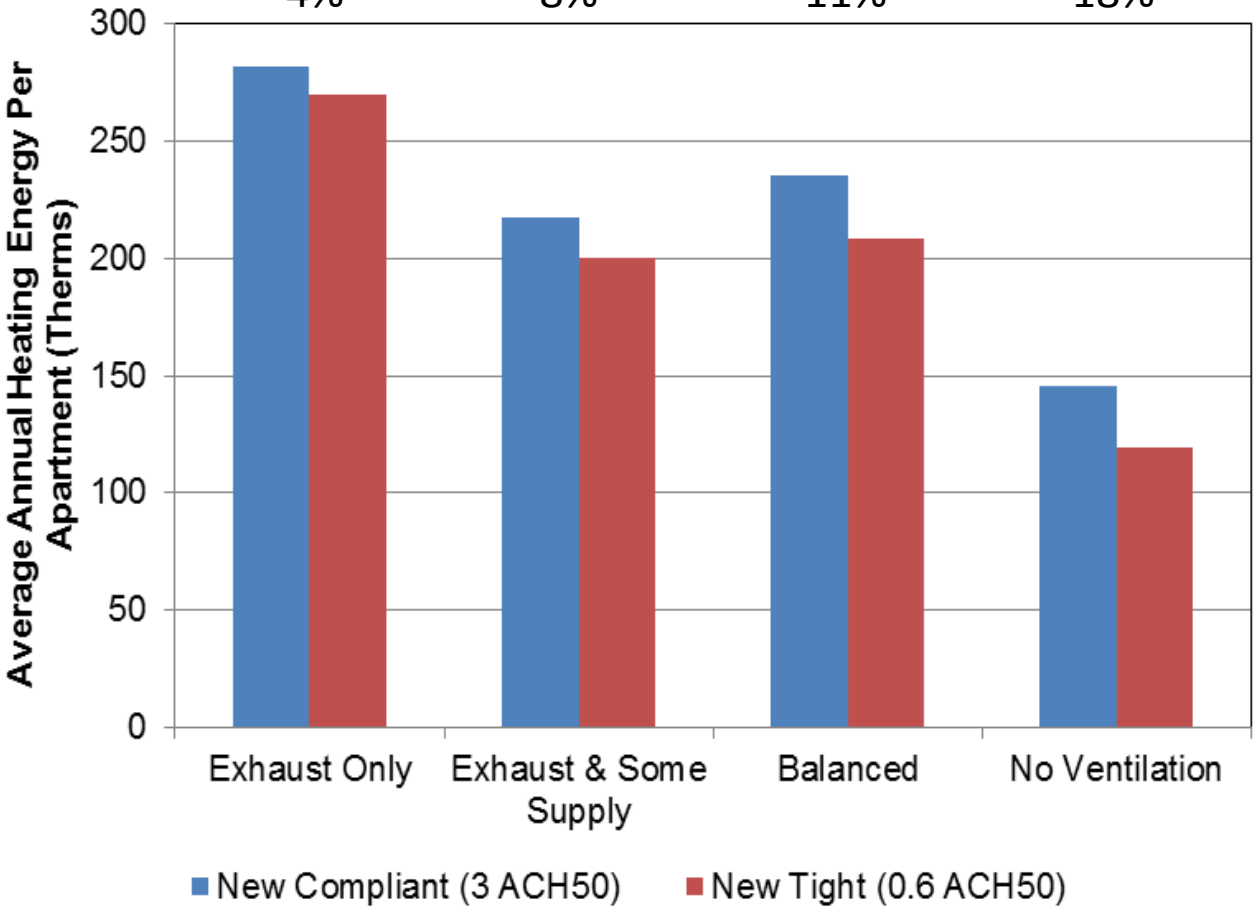


Leakage Distribution
Exterior = 28%
Hallway = 51%
Adj Unit = 16%
Ceiling = 5%

Energy & Ventilation Modeling

New Construction

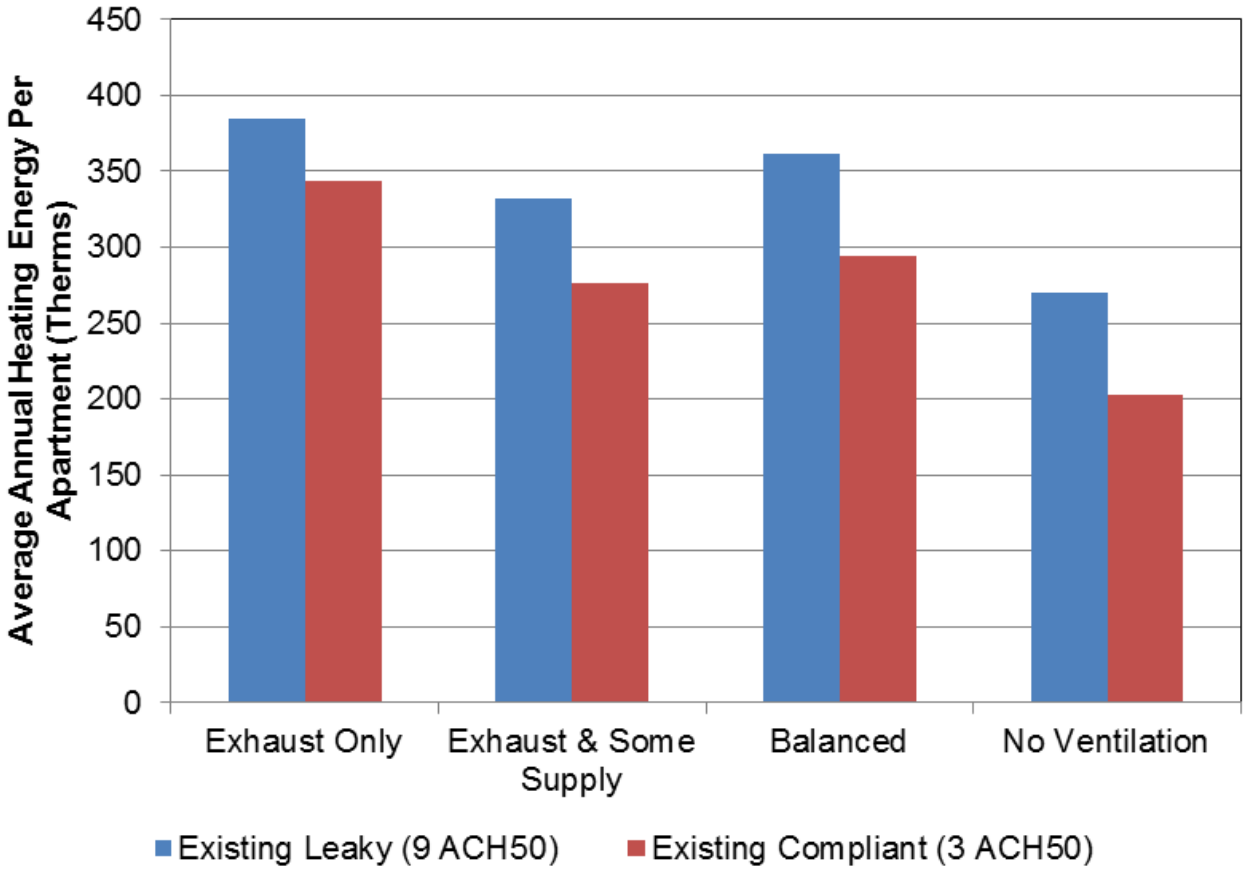
Therm/yr	12	17	27	26
$/yr	$7	$10	$16	$15
	4%	8%	11%	18%



Energy & Ventilation Modeling

Existing Units

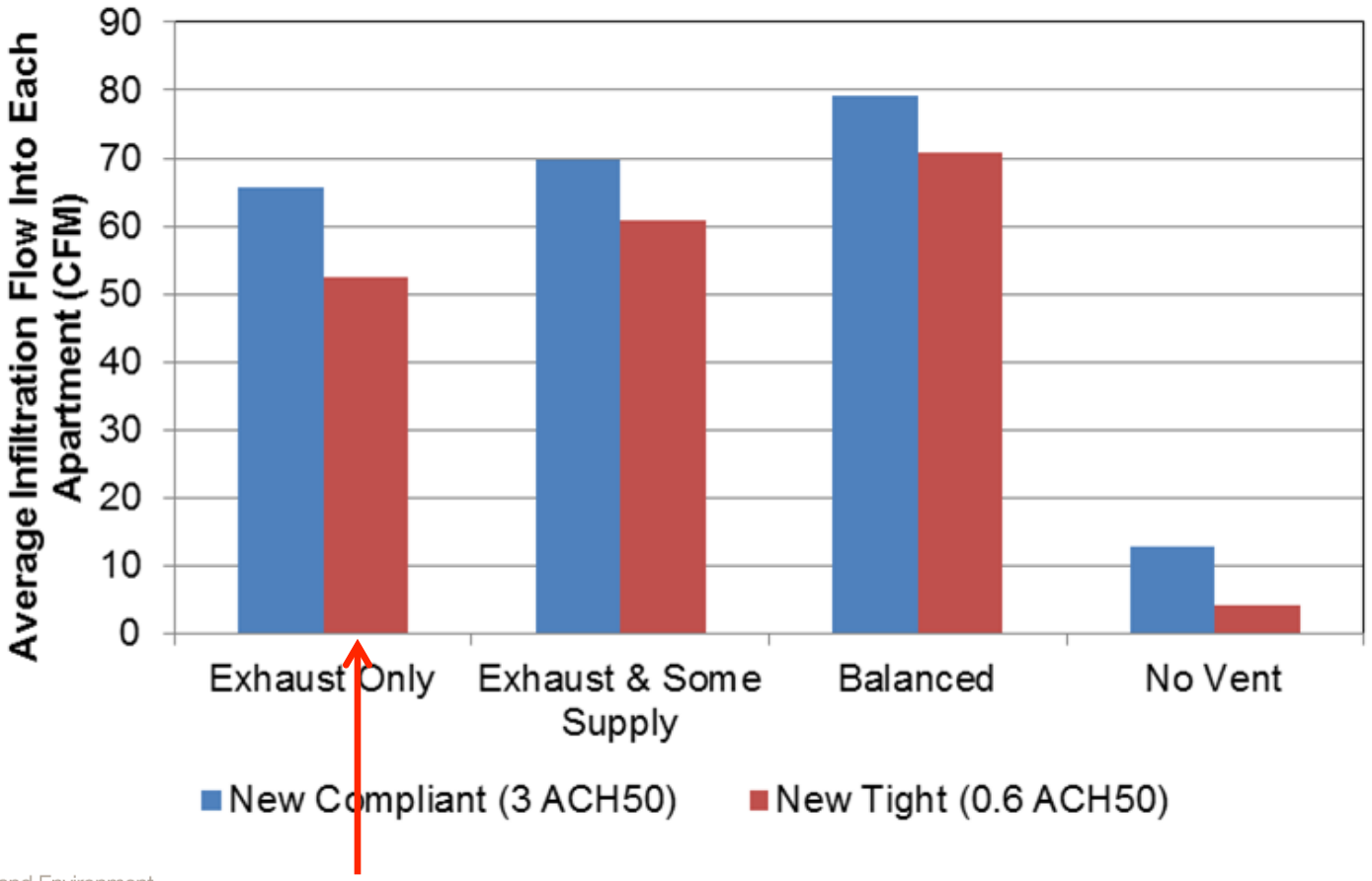
Therm/yr	41	56	67	68
$/yr	$24	$33	$39	$39
	11%	17%	19%	25%



Energy & Ventilation Modeling

New Construction

Outside Air Ventilation & Infiltration

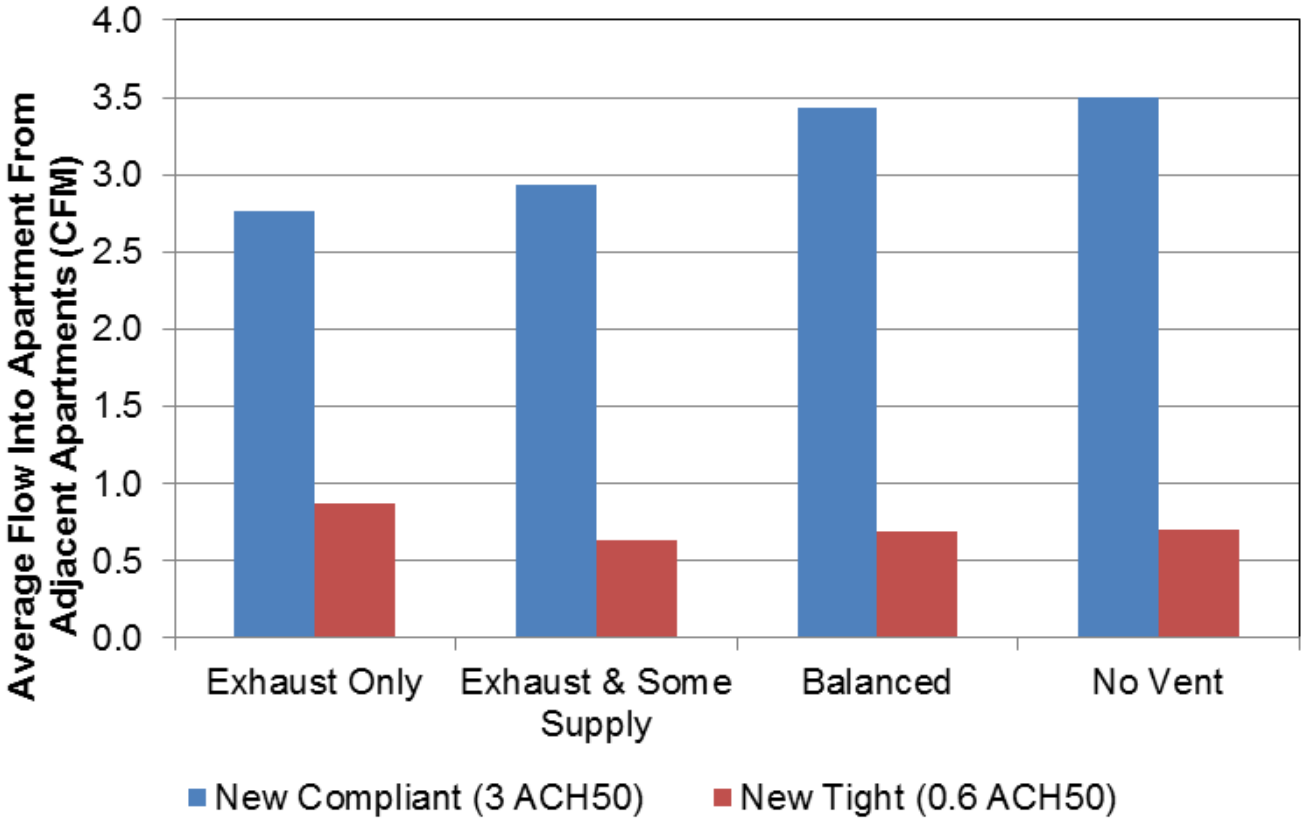


0.6 ACH50 = 96 cfm50; depressurization???

Energy & Ventilation Modeling

New Construction

Flow From Adjacent Apartment

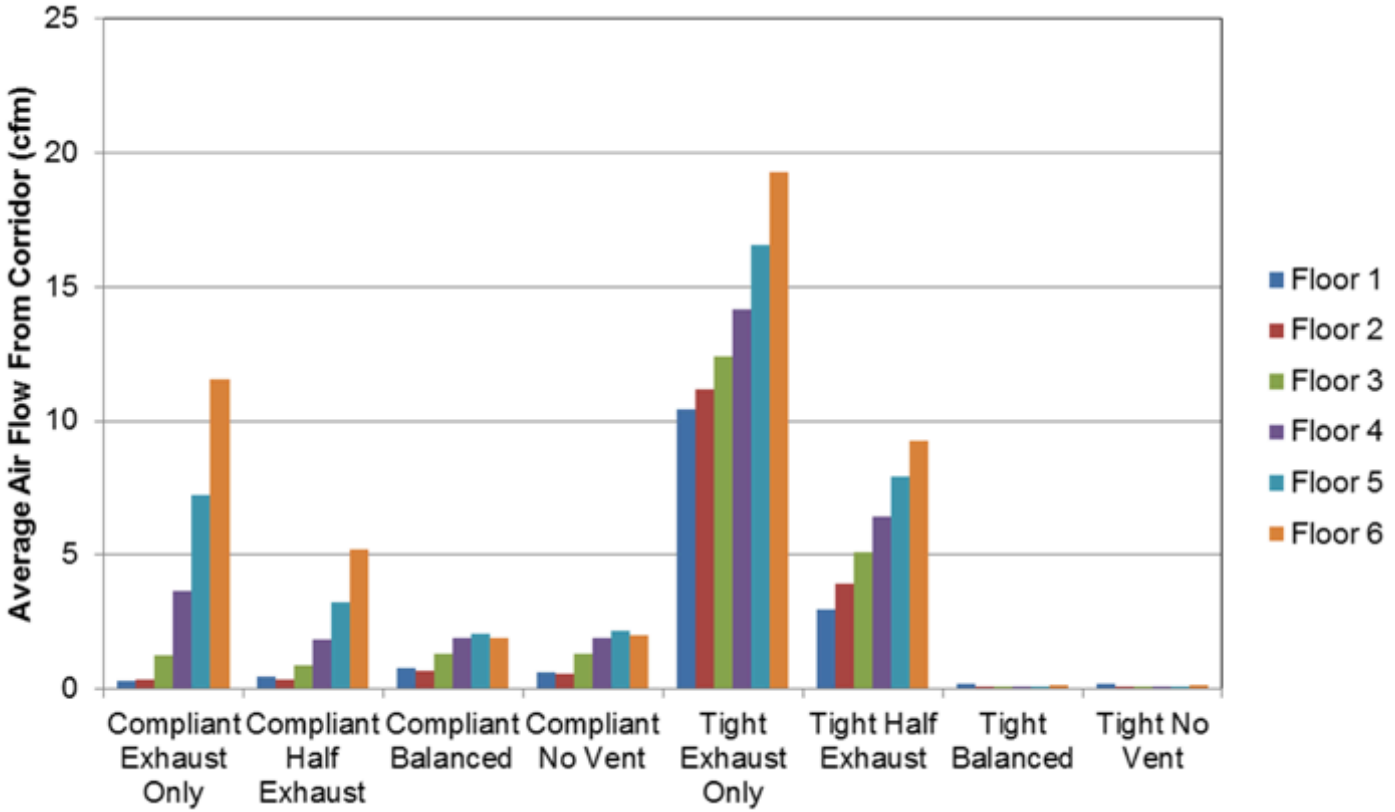


68 to 80% Reduction

Energy & Ventilation Modeling

New Construction

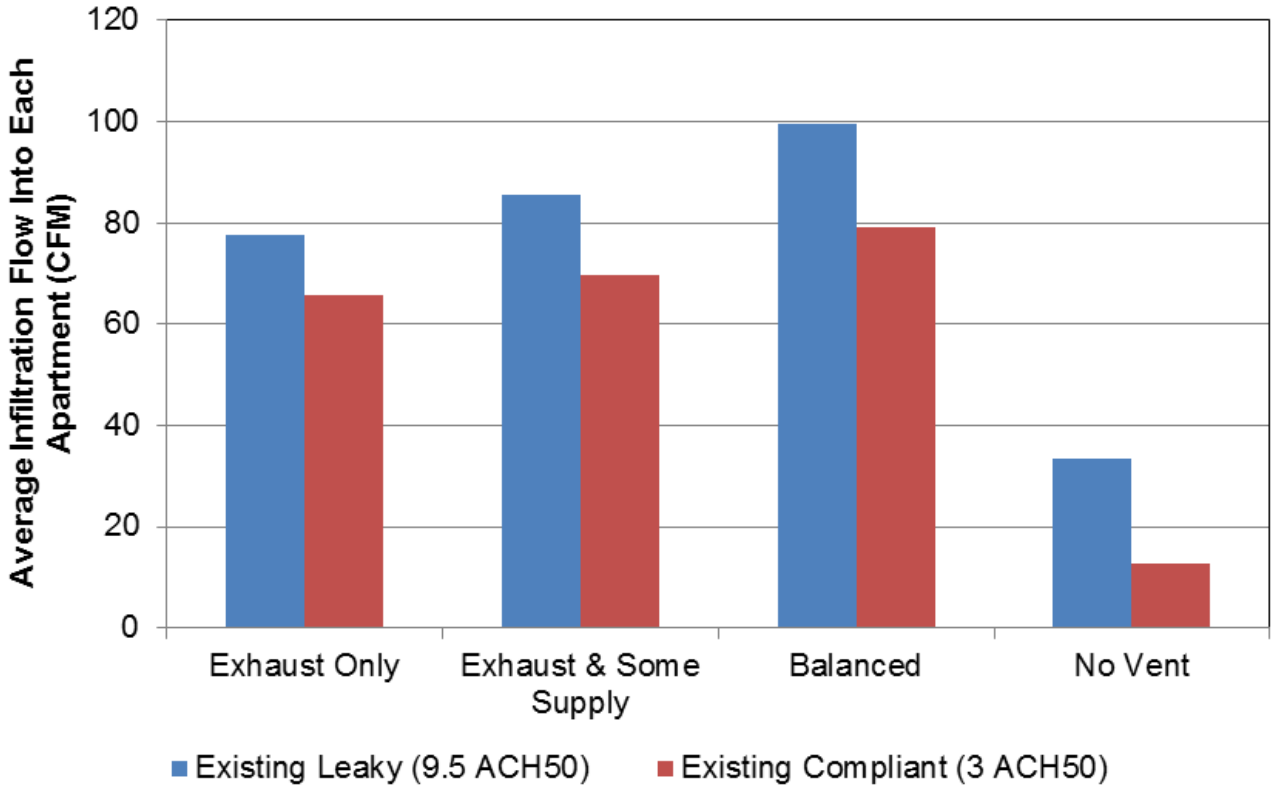
Flow From Corridor



Energy & Ventilation Modeling

Existing Units

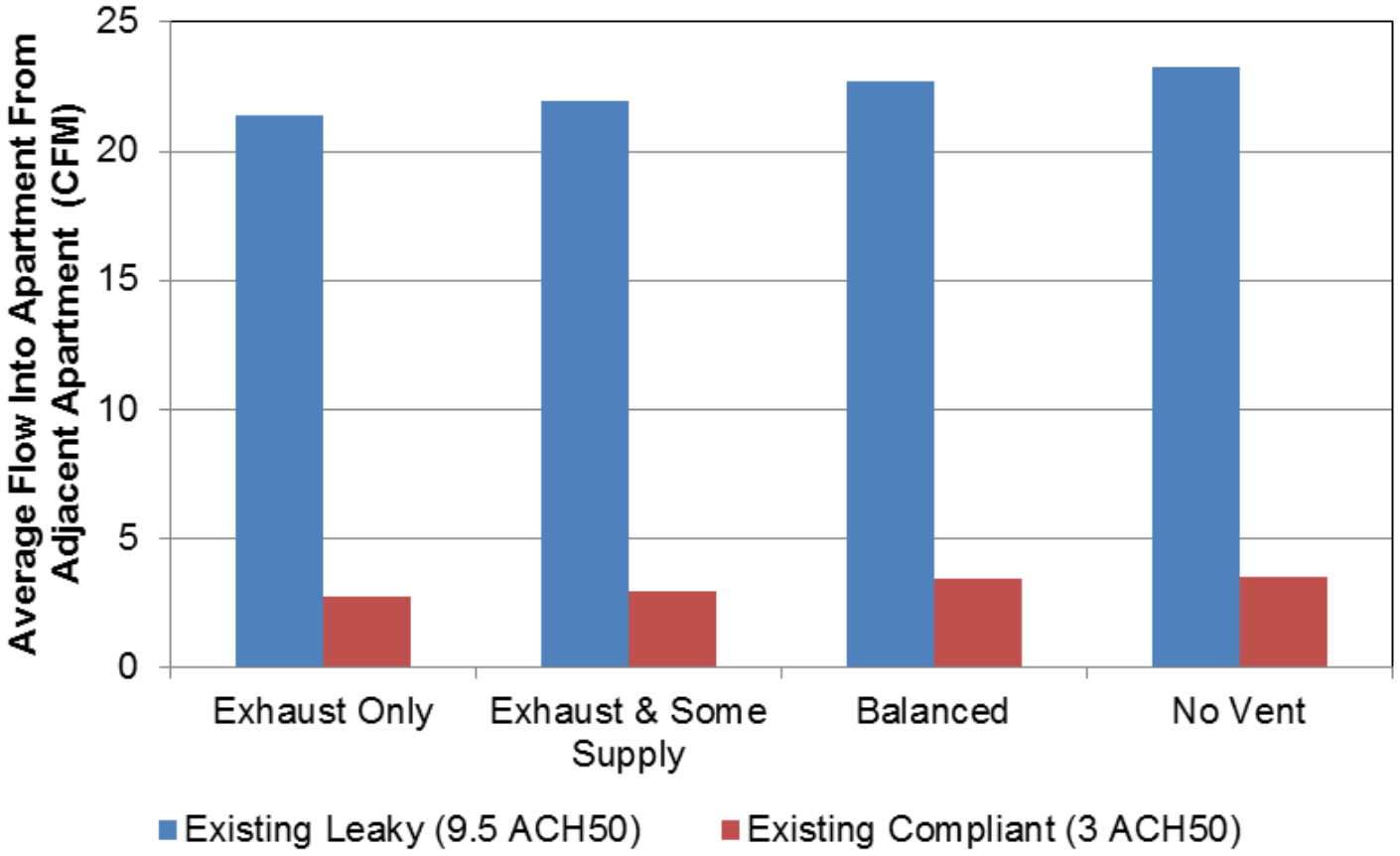
Outside Air Ventilation & Infiltration



Energy & Ventilation Modeling

Existing Units

Flow From Adjacent Apartment



85% to 87% Reduction

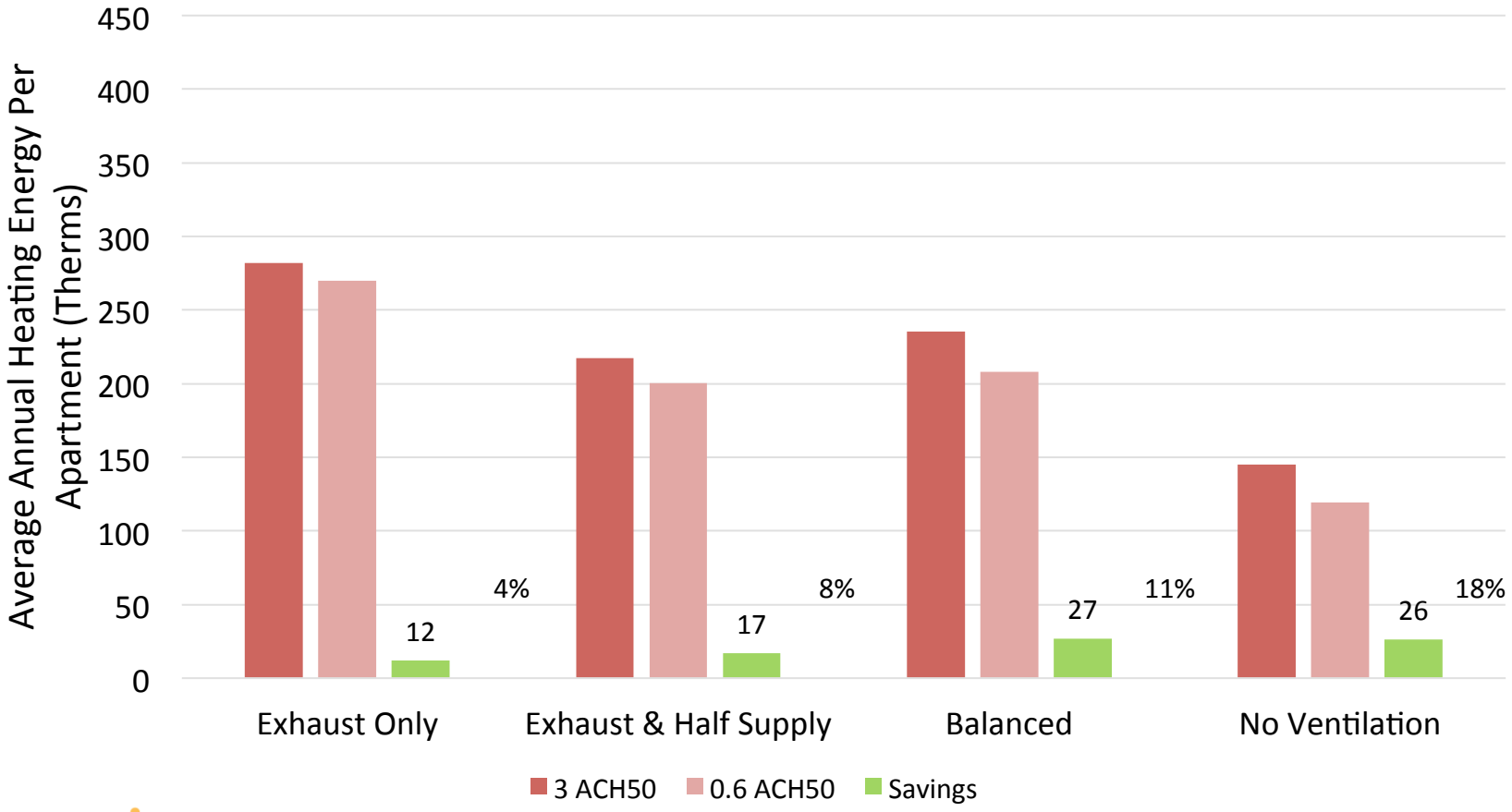
Aerosol Sealing Process:

Design Visit – Before Construction

1. Identify air tightness goal
2. Describe aerosol sealing process
3. Review air barrier details
4. Specify that leaks with gap width > 3/8” must be sealed or reduced to 3/8”
5. Determine when aerosol sealing will be applied in construction process
6. Discuss “conventional” sealing that may not be necessary (consider fire code)

This is ideal process

Results - Annual HVAC Energy Use (New Buildings)



Results - Annual HVAC Energy Use (Existing Buildings)