February 23, 2016

ENERGY SAVINGS FROM AIR SEALING COMMERCIAL BUILDINGS

2016 Energy Design Conference

Dave Bohac P.E.

Director of Research

Center for Energy and Environment

Continuing Education Credit Information

- In accordance with the Department of Labor and Industry's statute 326.0981, Subd. 11,

  "This educational offering is recognized by the Minnesota Department of Labor and Industry as satisfying **1.5 hours** of credit toward **Building Officials** continuing education requirements."

  For additional continuing education approvals, please see your credit tracking card.

Acknowledgements

This project was supported in part by a grant from the Minnesota Department of Commerce, Division of Energy Resources through a Conservation Applied Research and Development (CARD) program

Minnesota Department of Commerce
Division of Energy Resources

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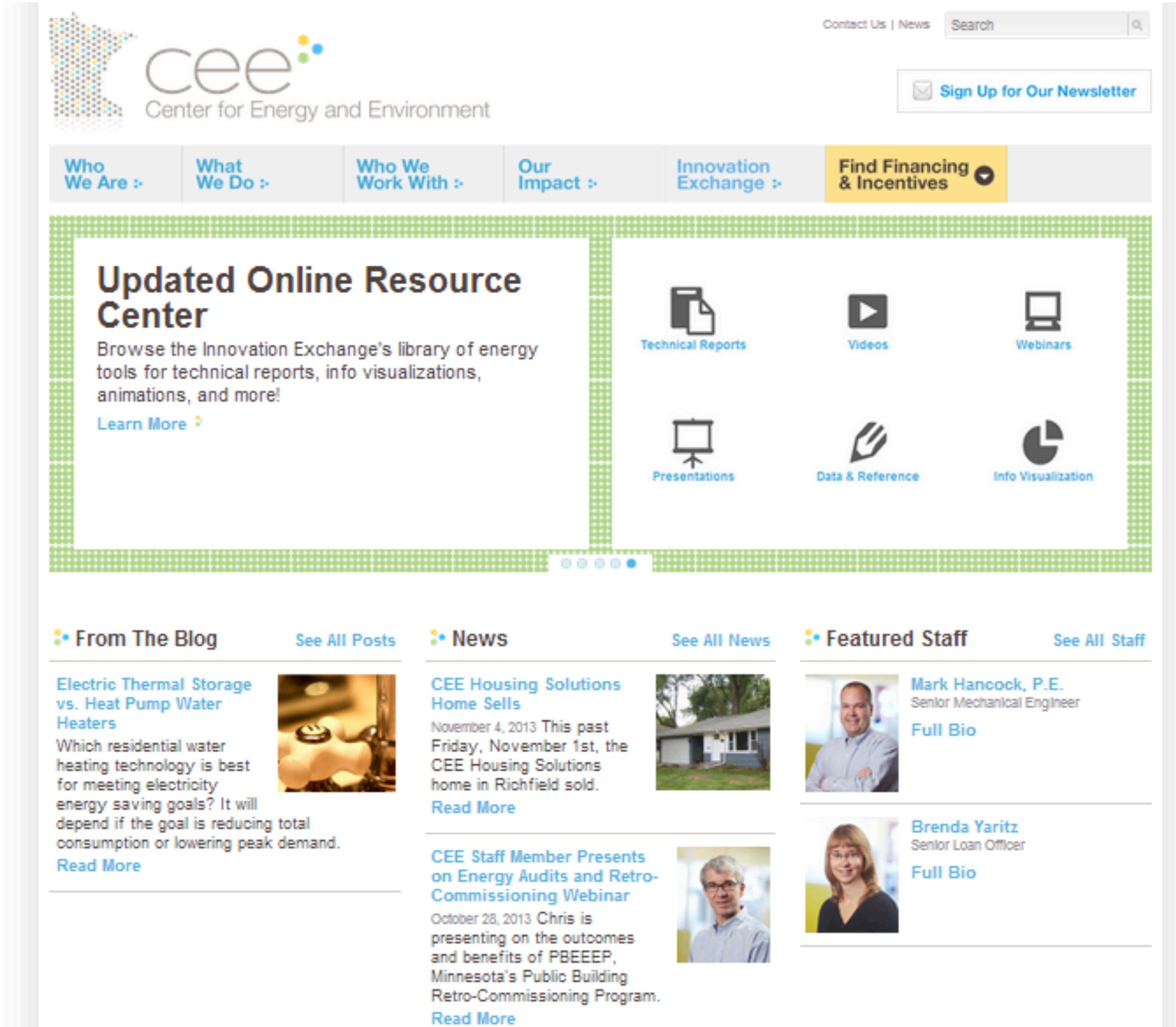
What we do

- Program Design and Delivery
- Lending Center
- Engineering Services
- Public Policy
- Innovation Exchange
    - Research
    - Education and Outreach



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Project Team

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  - Martha Hewett
  - Andrew Lutz
  - Kirk Kholehma
- Air Barrier Solutions
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- The Energy Conservatory
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  - Peter Burns

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CEE - Alex Haynor, Jerry Kimmen,
Joel Lafontaine, Dan May,
Erik Moe, Tom Prebich,
and Isaac Smith

Bruce Stahlberg of Affordable Energy Solutions

Large Building Tightness Specification

- Measure the air flow rate needed to pressurize & depressurize the building by 75Pa (0.3 in. wc.)

- Divide by the building envelope area – typically the exterior walls + roof + floor (6 sides)

- Results from 387 US C&I buildings
  - Average = 0.72 cfm/ft^2
  - Range 0.03 – 4.3 cfm/ft^2

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Code Requirements

- US Army Corp Engineers = 0.25 cfm/ft^2
  - Tested over 300 buildings
  - Average = 0.16 cfm/ft^2
- IECC 2012 (7 states) whole building compliance path = 0.40 cfm/ft^2
- Washington State: Buildings over five stories require a whole building test, but do not have to pass a prescribed value.
- City of Seattle : All buildings require a whole building test, but do not have to pass a prescribed value.

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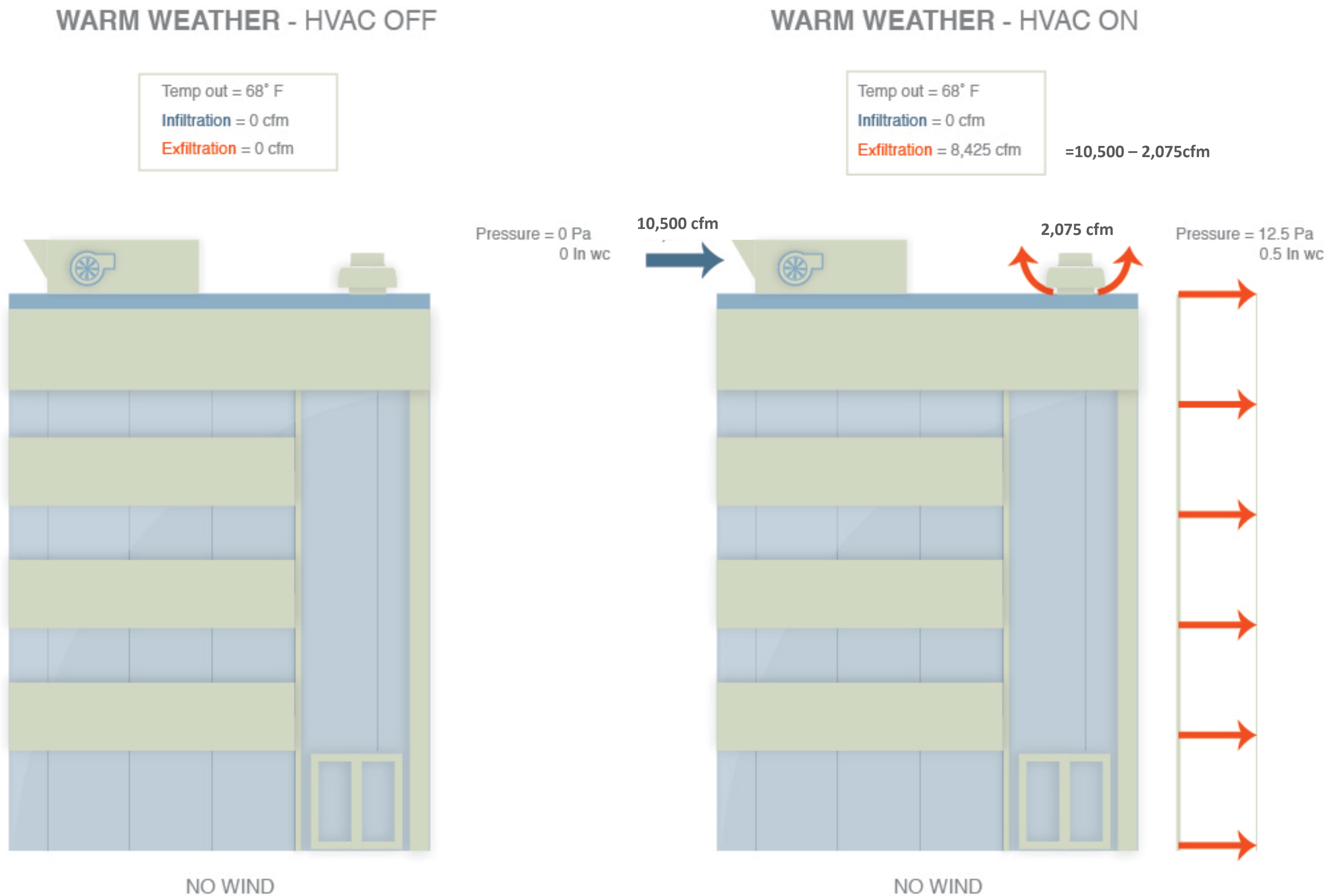
Why do we care about building air leakage?

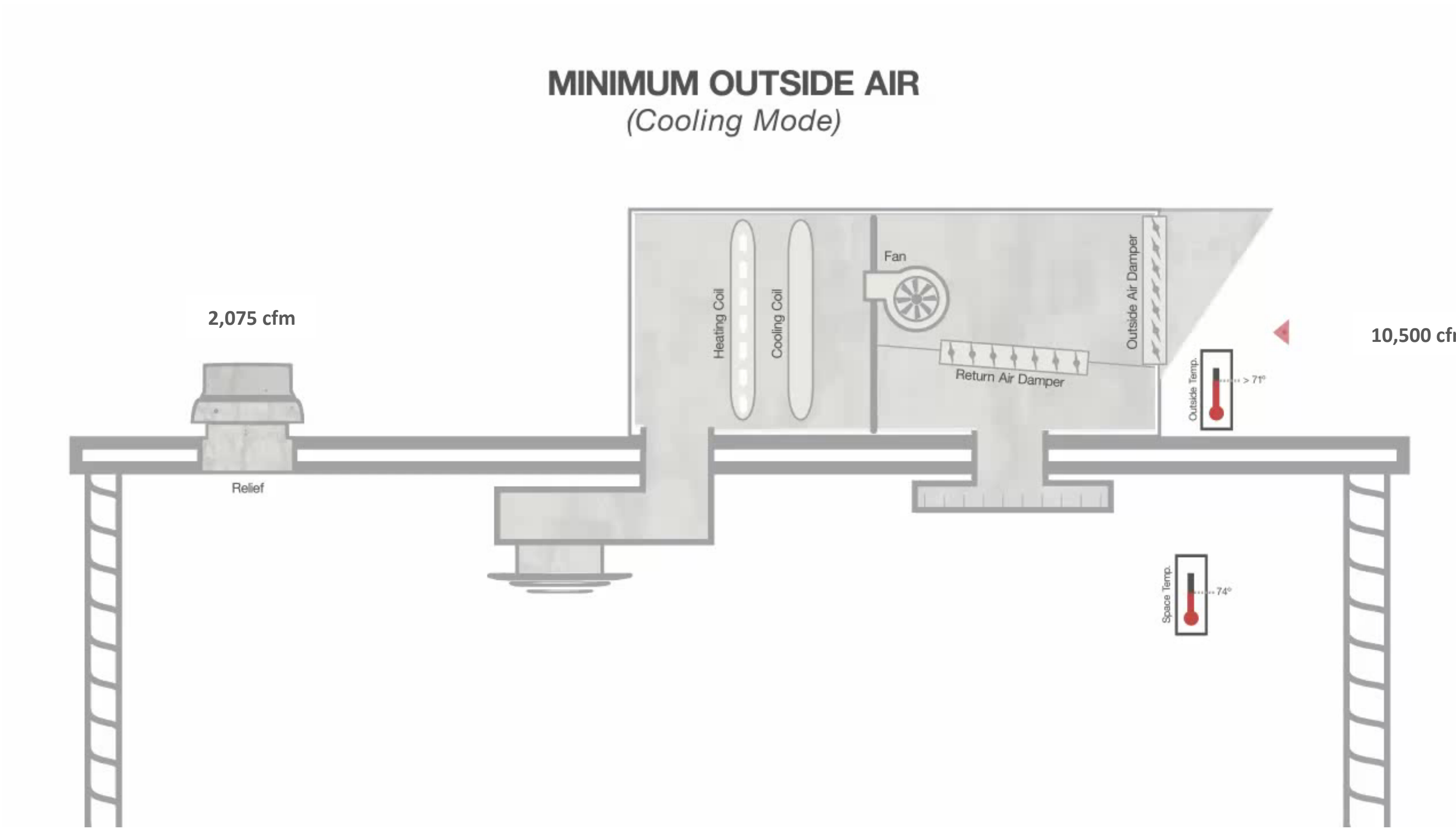
- HVAC systems pressurize buildings to eliminate infiltration – don’t they?
- When HVAC is off => air infiltration
- Pressurization not always effective or implemented correctly
- NIST/Persily tracer gas results – infiltration can be significant

Air Handler Pressurization



4 Story 60,000sf Office Building: leakage = 27,000 cfm@75Pa, 0.5 cfm@75/ft^2

Roof Top Unit Operation



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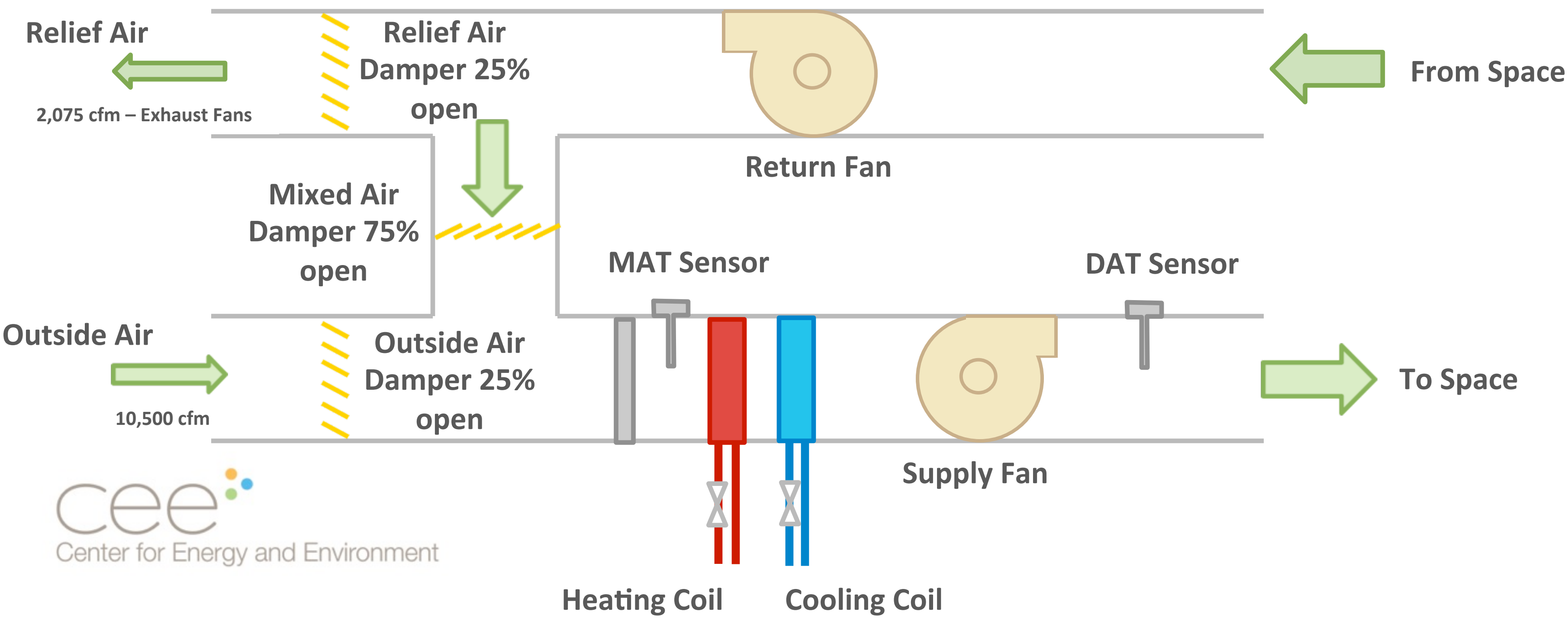
Single-zone Constant Volume AHU

- Supply and Return Fans turn on/off by schedule
- Outside Air Damper has a minimum position setpoint for ventilation
- Relief Damper controls air exhausted from the building



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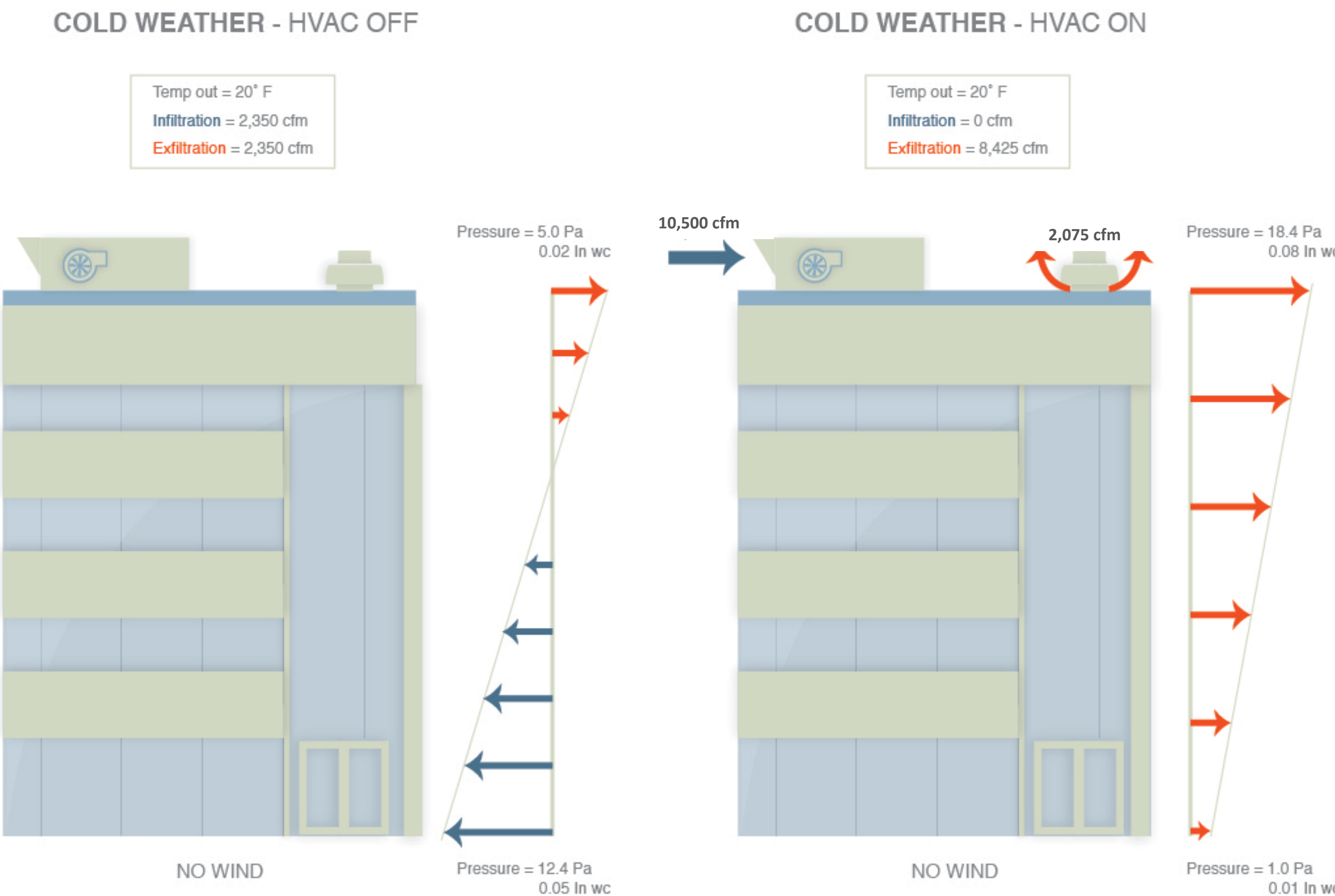
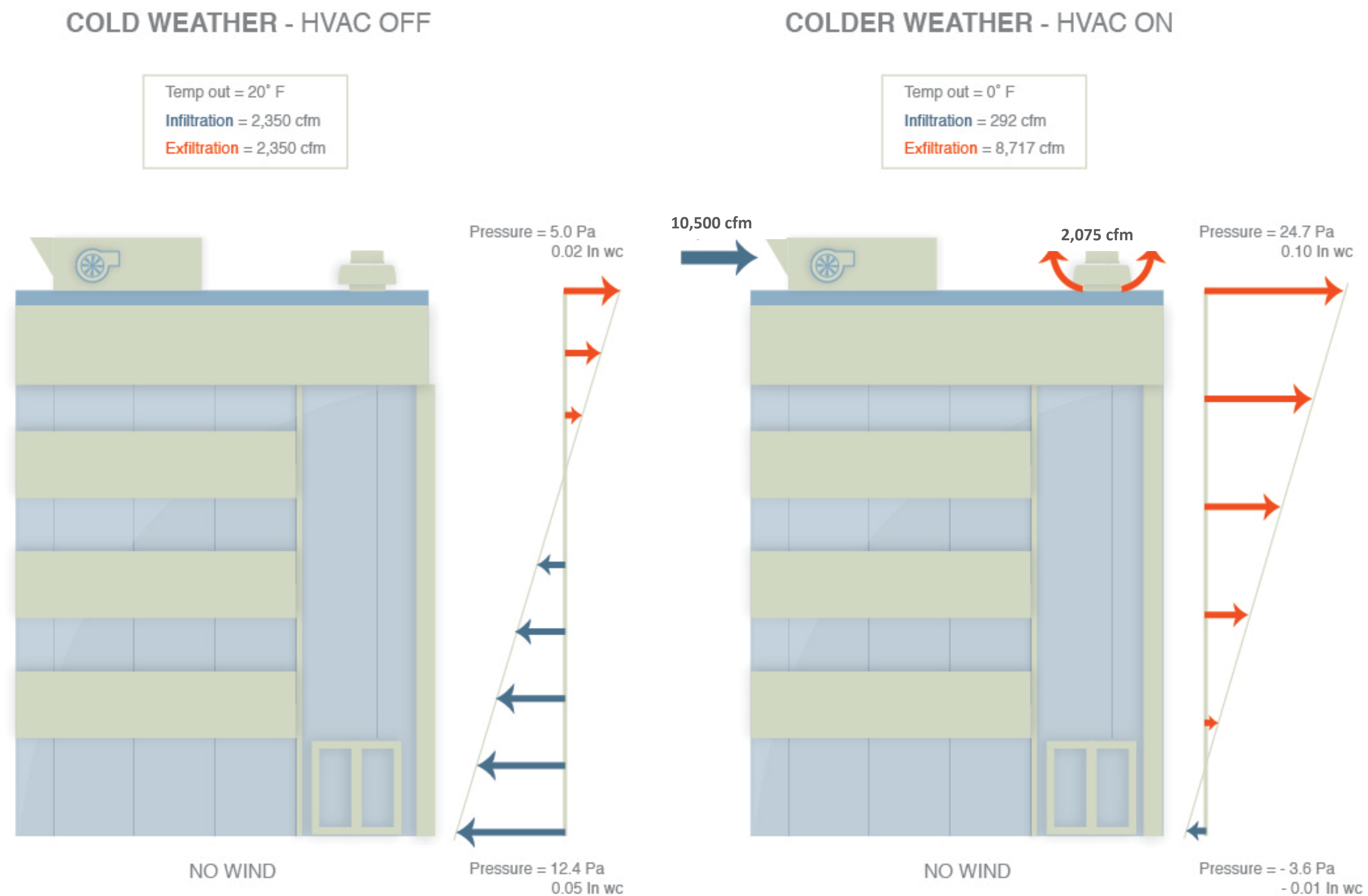
Air Handler Pressurization



4 Story 60,000sf Office Building: leakage = 27,000 cfm@75Pa, 0.5 cfm@75/ft^2

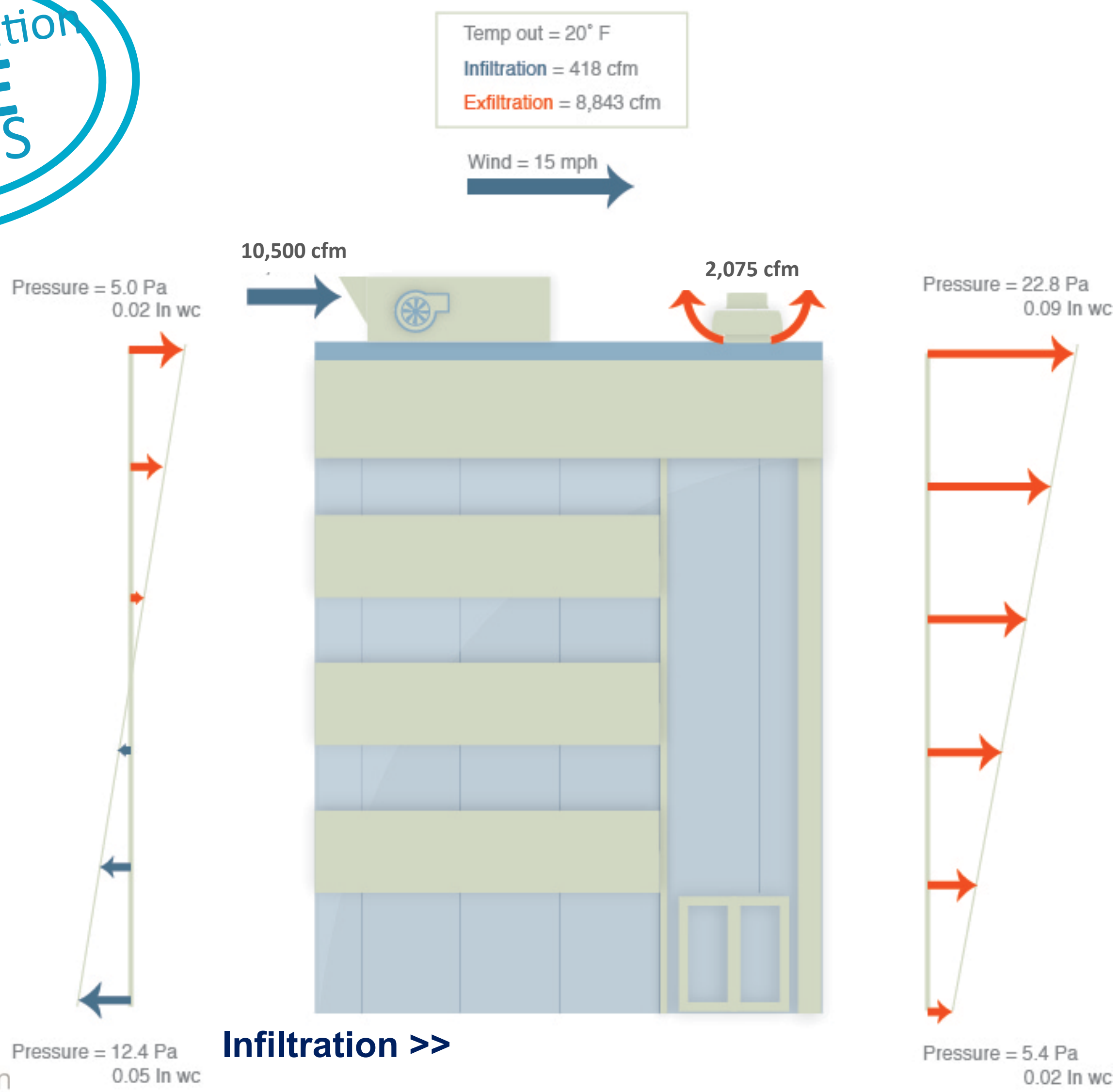
Air Handler Pressurization



4 Story 60,000sf Office Building: leakage = 27,000 cfm@75Pa, 0.5 cfm@75/ft^2

Air Handler Pressurization

COLD WEATHER - HVAC ON



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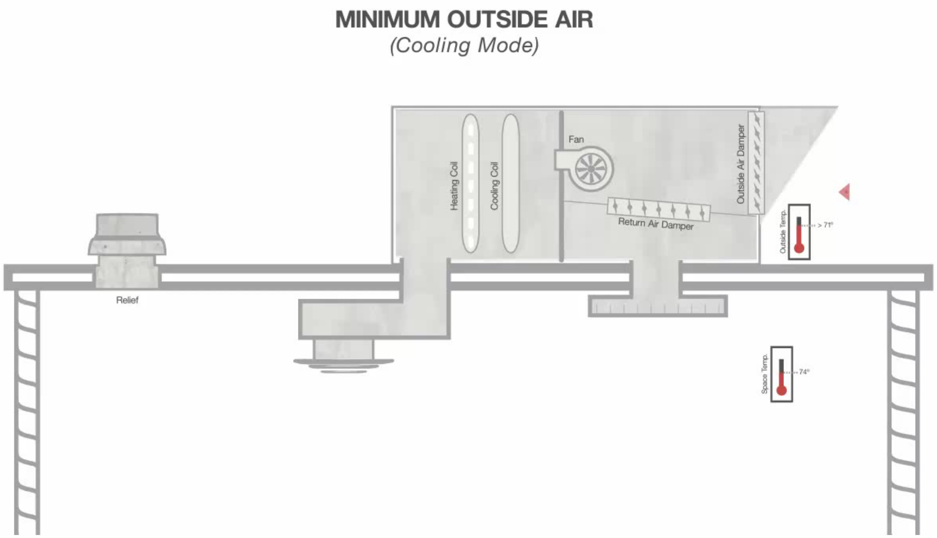
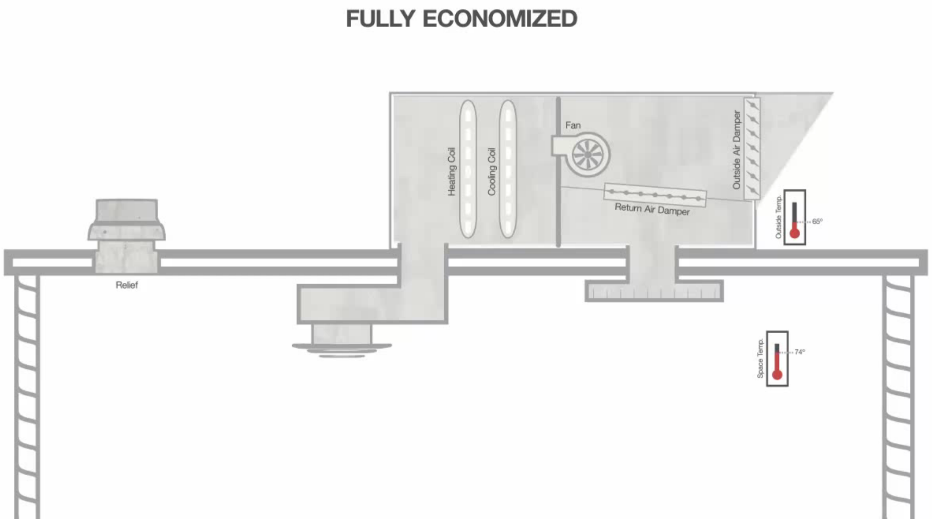
Roof Top Unit Operation





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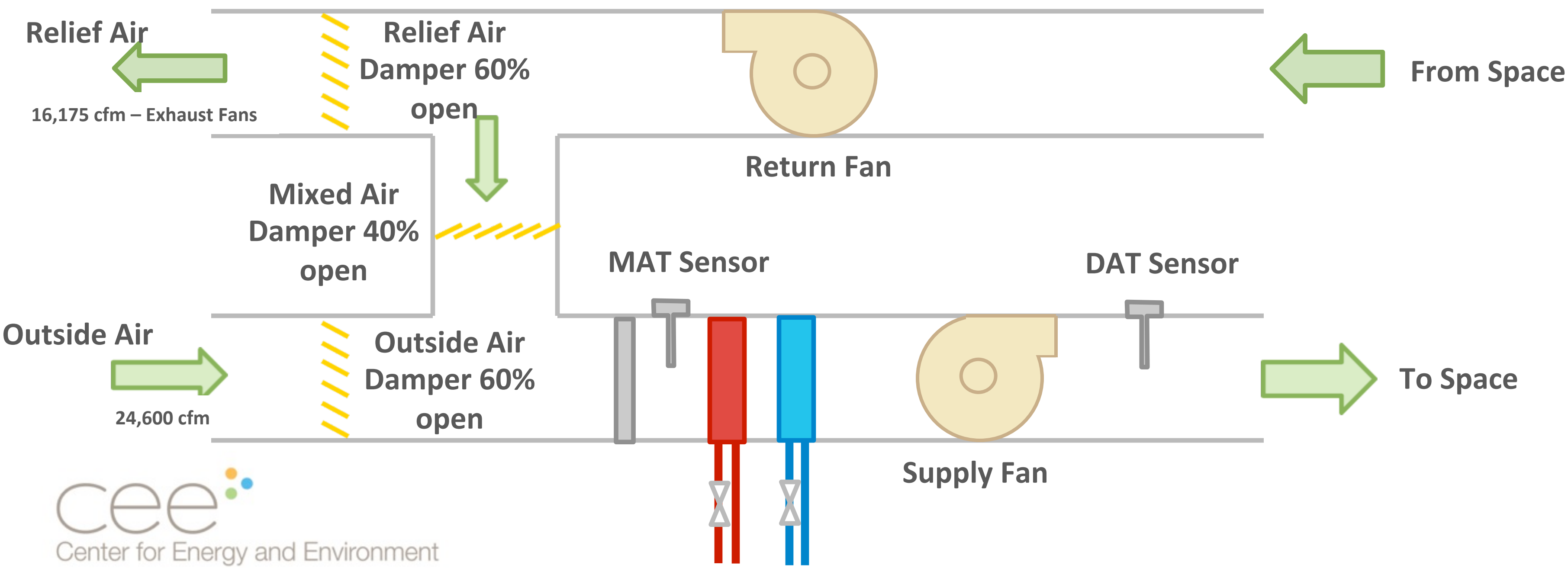
Single-zone Constant Volume AHU

- Economizer operation
  - Mild weather when building needs cooling
  - Open outdoor air dampers, exhaust dampers follow; OA – EA stays the same?



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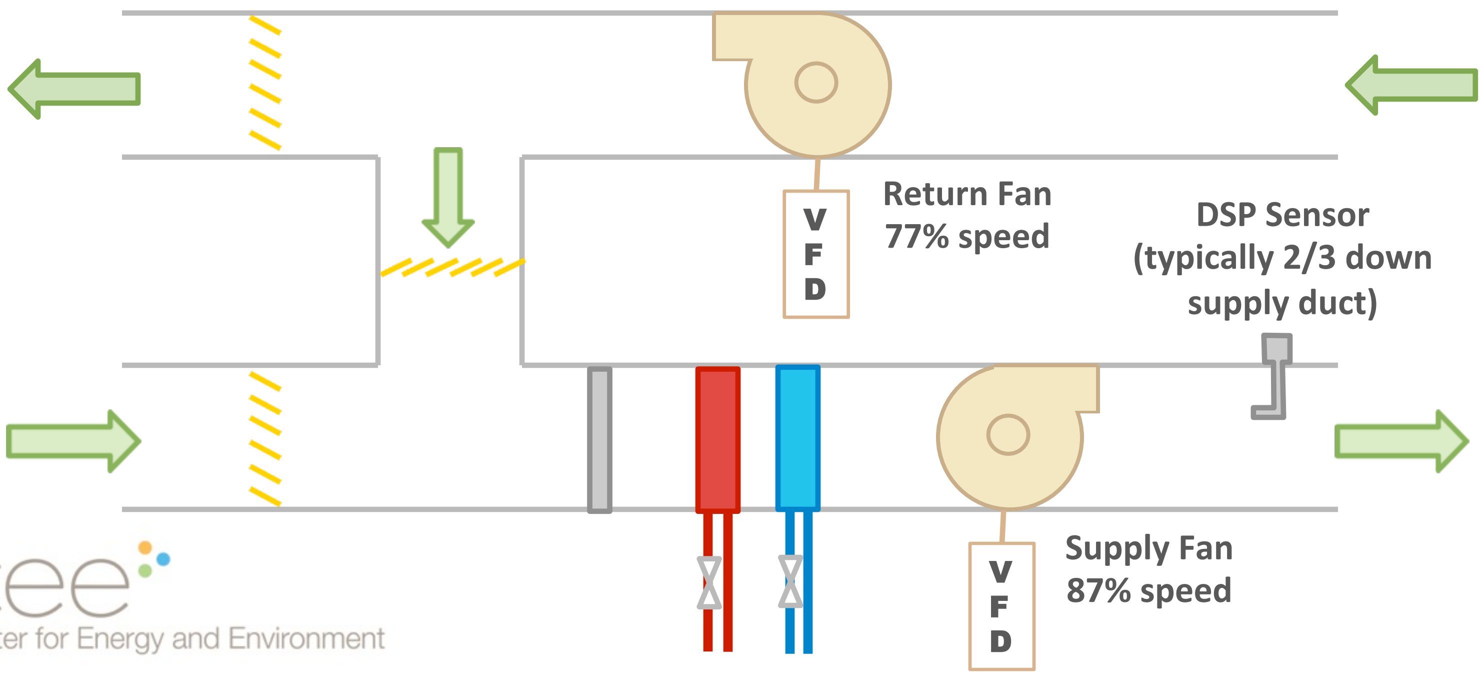
Variable Volume AHU with VAV Boxes

- Supply and Return Fans
  - Supply fan VFD modulates to meet Duct Static Pressure (DSP) Setpoint
  - Return fan lags supply fan to maintain positive pressure



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Model Infiltration: Range of Flow Imbalance

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TAKE
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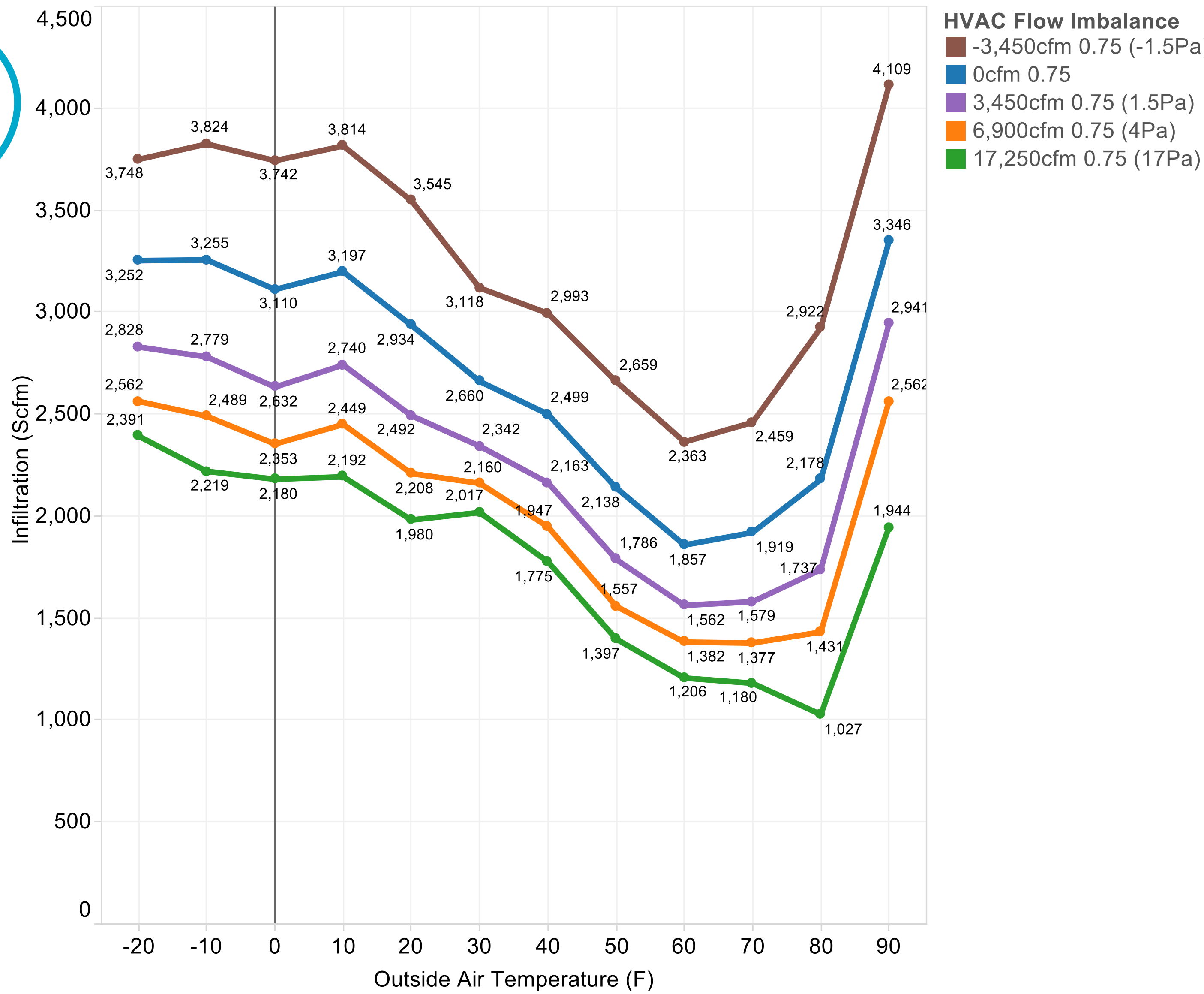

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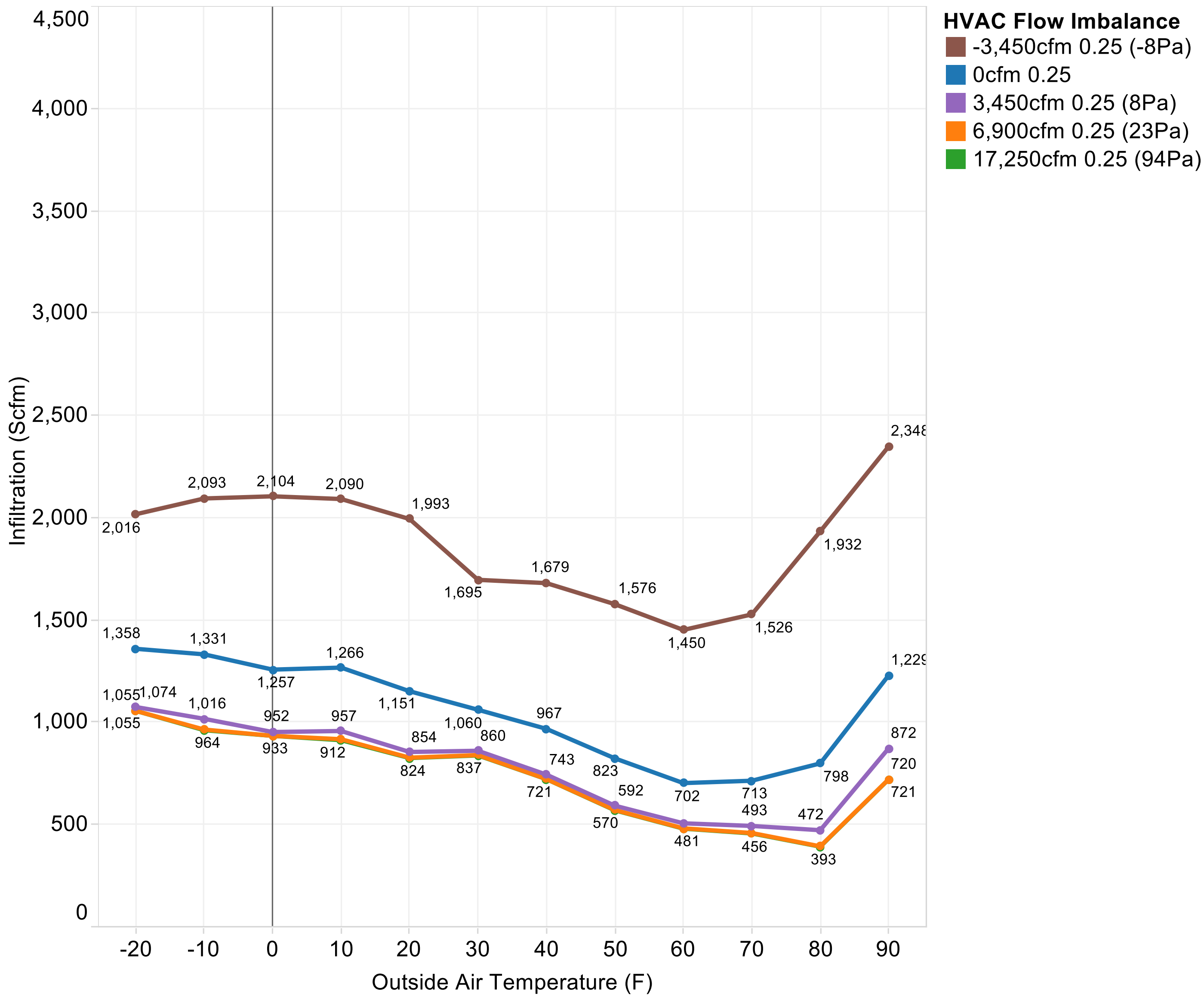
1 Story 60,560ft^2 Elementary School: leakage = 44,670 cfm@75Pa (0.75cfm@75/ft^2)

Model Infiltration: Range of Flow Imbalance



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1 Story 60,560ft² Elementary School: leakage = 14,890 cfm@75Pa (0.25cfm@75/ft²)

Model Infiltration: Range of Flow Imbalance

Envelope Leakage= 0.75 cfm@75Pa/ft^2

	HVAC Flow Imbalance, OA - EA (cfm)				
	-3,450	0	3,450	6,900	17,250
Avg Infil. (cfm)	2,986	2,444	2,077	1,849	1,652
Avg Infil. (ach)	0.25	0.20	0.17	0.15	0.14
Heat Load (therms/yr)	7,264	6,114	5,260	4,732	4,308
% Space Heating	19%	16%	14%	12%	11%
Cost ($)	$4,213	$3,546	$3,051	$2,745	$2,499

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Model Infiltration: Range of Flow Imbalance

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Envelope Leakage= 0.25 cfm@75Pa/ft^2

	HVAC Flow Imbalance, OA - EA (cfm)				
	-3,450	0	3,450	6,900	17,250
Avg Infil. (cfm)	1,725	951	708	678	676
Avg Infil. (ach)	0.14	0.08	0.06	0.06	0.06
Heat Load (therms/yr)	4,004	2,439	1,875	1,813	1,809
% Space Heating	10%	6%	5%	5%	5%
Cost ($)	$2,322	$1,414	$1,087	$1,052	$1,049

What about Energy Recovery Ventilators?

- Why not run the exhaust air through an ERV to recovery some of that energy instead of forcing it out through the envelope?

- Need a tighter envelope to accomplish ERVs with infiltration control


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How leaky or tight are US buildings?

- Test results compiled by the National Institute of Standards and Technology (NIST) – Emmerich and Persily – over the past 15 years
- 387 commercial and institutional buildings
- NOT RANDOM: researchers, low-energy programs, private testing firms
- Used to model air infiltration energy loads and help establish leakage standards

NIST Results from US whole building tests

		6-sided at 75Pa (cfm/ft^2)			
Dataset	**Qty**	**Mean**	**Std Dev**	**Min**	**Max**
Efficiency Vermont	36	0.35	0.38	0.03	1.78
ASHRAE RP 1478	16	0.29	0.20	0.06	0.75
Washington	18	0.40	0.15	0.11	0.64
Other VT/NH	79	0.54	0.40	0.05	1.73
Other	10	0.30	0.23	0.09	0.75
All new data	**159**	**0.36**	**0.30**	**0.03**	**1.78**
All previous data	**228**	**0.92**	**0.70**	**0.09**	**4.28**
All Buildings	**387**	**0.72**	**0.63**	**0.03**	**4.28**
USACE & Navy	**300**	**0.16**			

USACE Std = 0.25

Emmerich and Persily 2013

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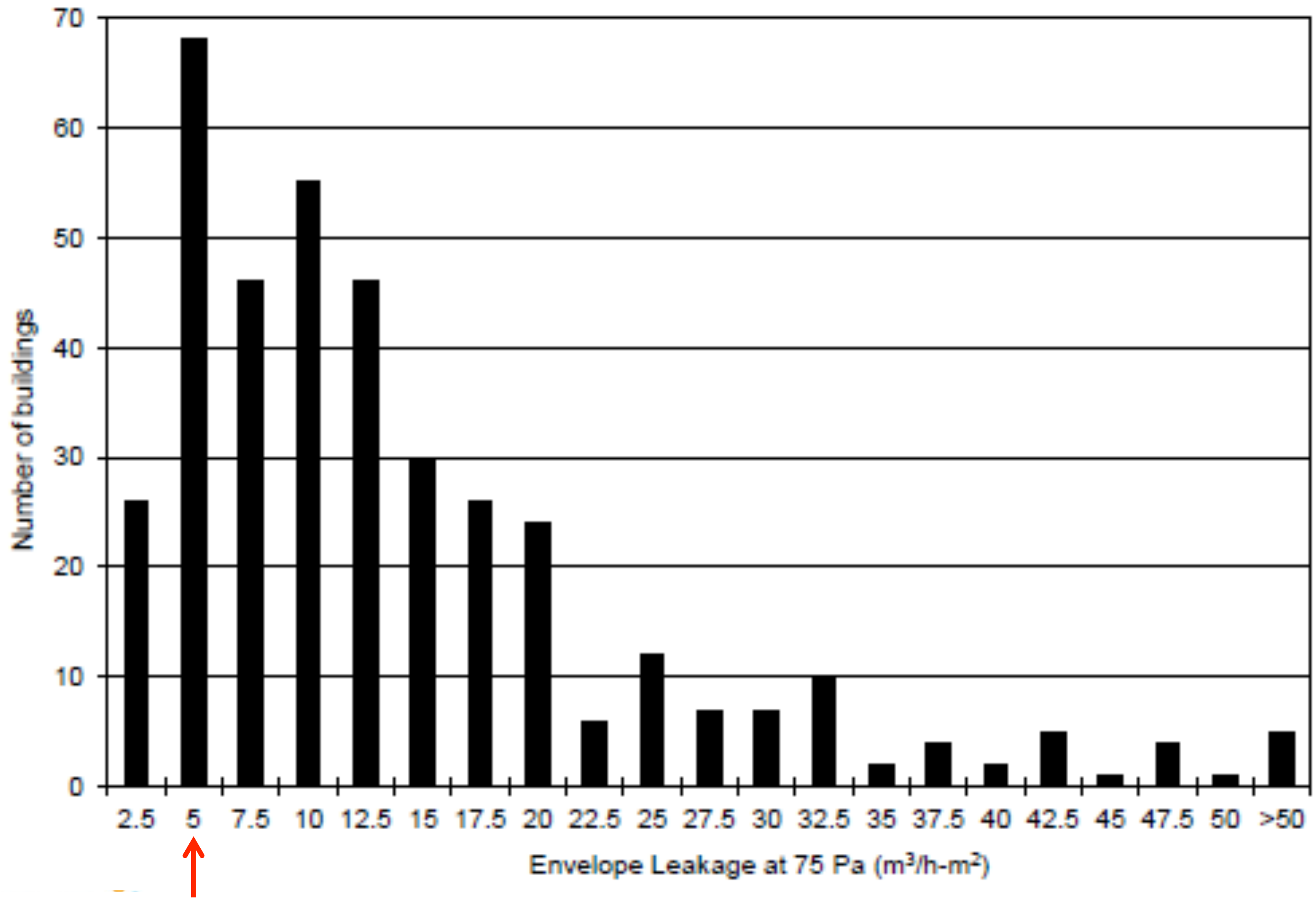
NIST Results: Frequency Histogram



USACE Std = 4.5
20-25% meet Std

Multiply by 0.055 >> cfm/ft^2

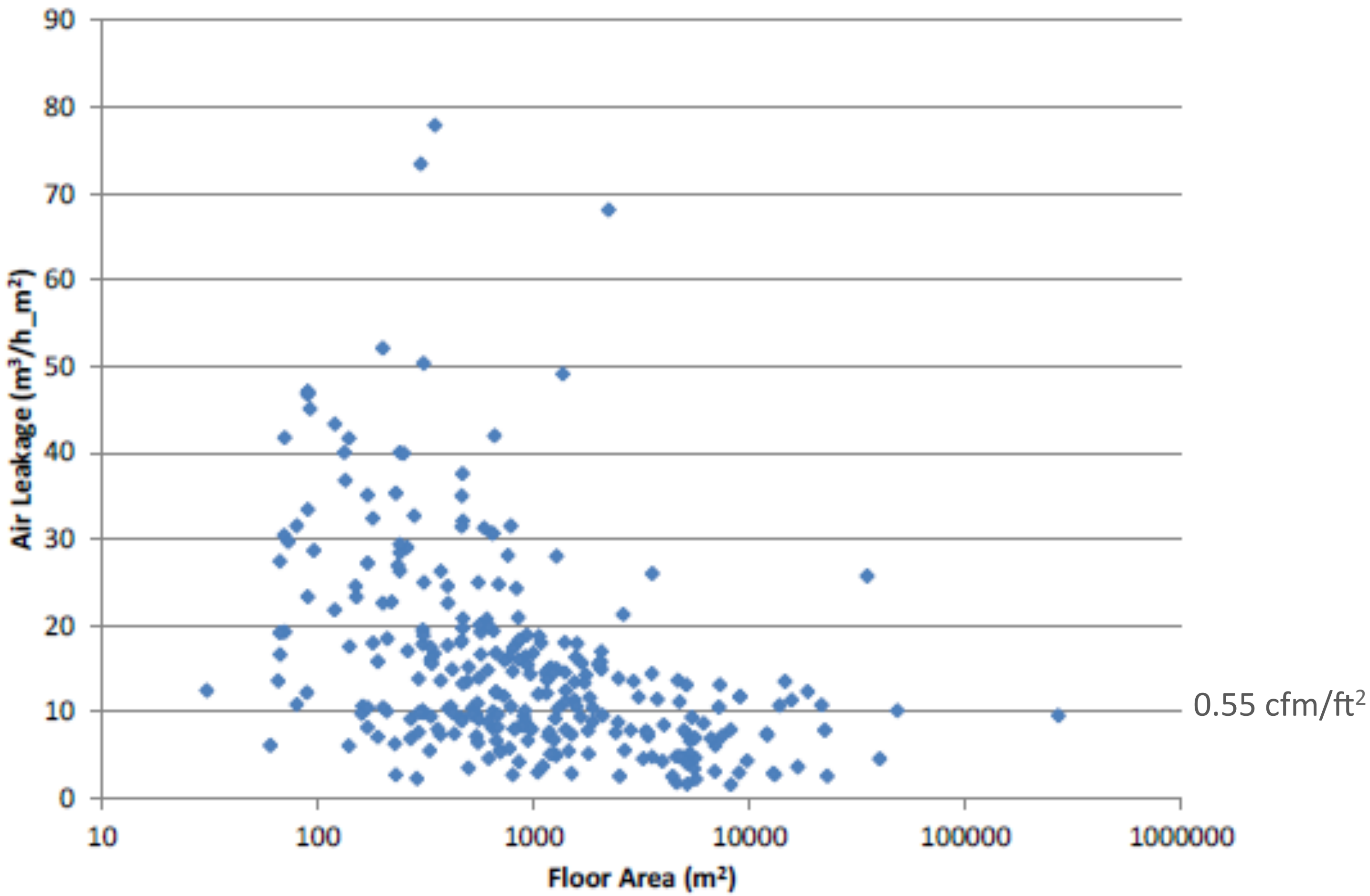
Emmerich and Persily 2013

NIST Results: Weak Trends

- Tighter – office, education, public assembly & long-term health care
- Leakier – retail, restaurants, industrial
- Leakier exterior walls – frame, masonry/metal, & frame/masonry

NIST Results: Effect of Building Size

Buildings > 54,000ft^2 twice as tight



Emmerich and Persily 2013

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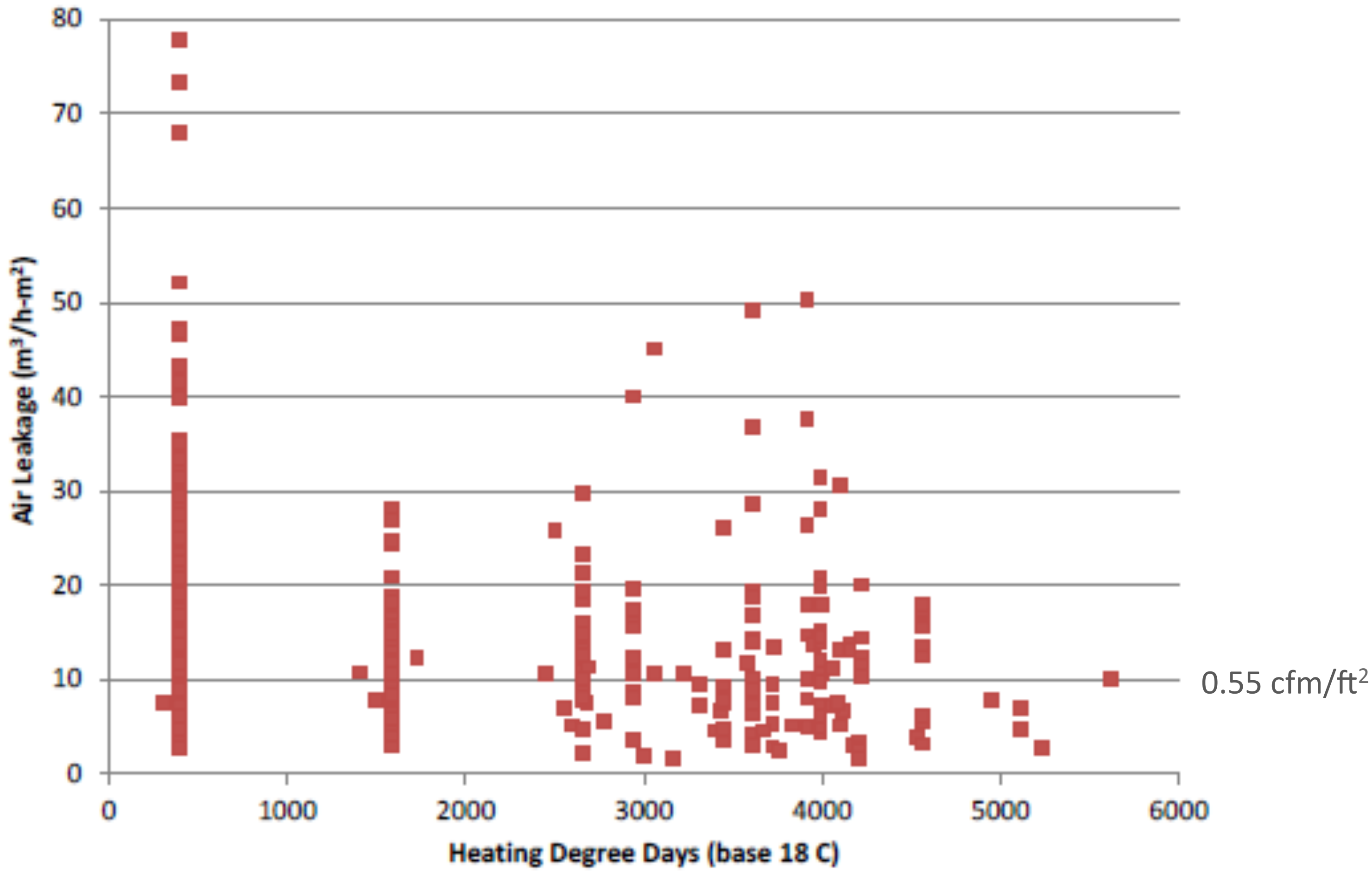
NIST Results: Effect of Climate

Heating degree days > 3,600 one third tighter



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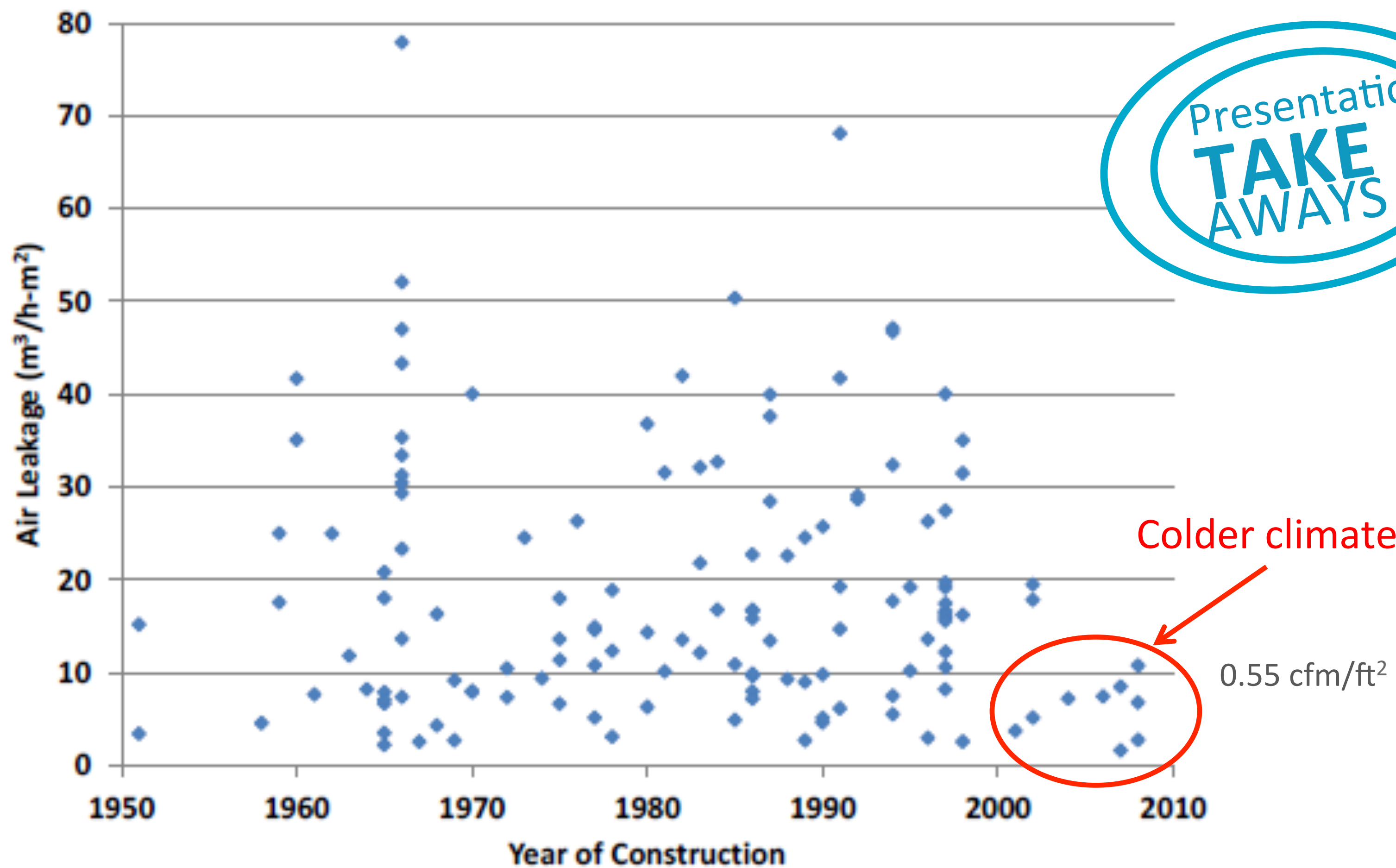
NIST Results: Effect of Age

138 buildings with no air barriers built since 1950 – no strong trend



Presentation TAKE AWAYS

Emmerich and Persily 2013

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NIST Results: LEED Buildings

- 23 LEED buildings; average = 0.29 cfm/ft^2
- Significantly tighter than average of other 364 buildings
- Slightly (5%) leakier than other 56 buildings with an air barrier

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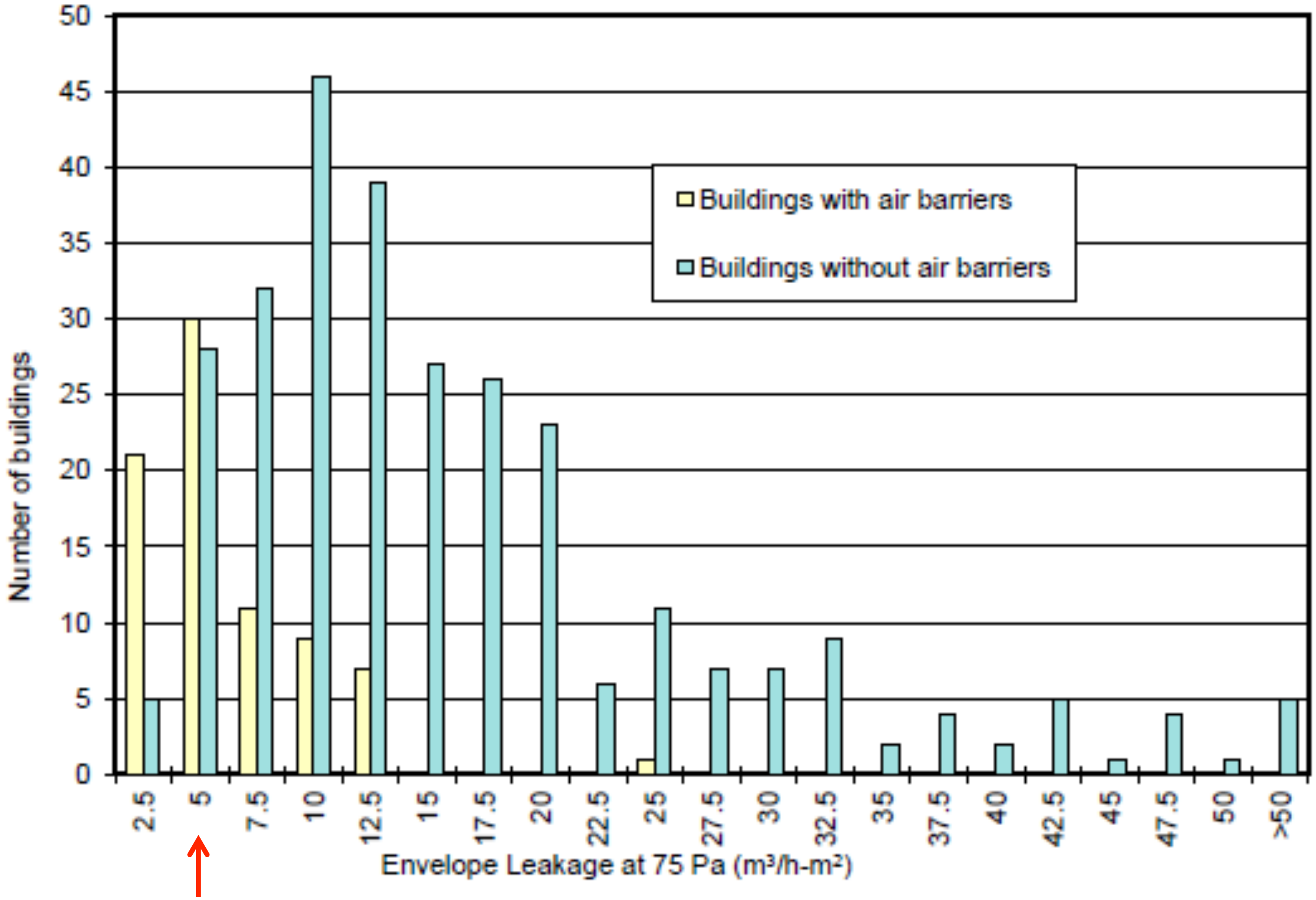
NIST Results: Effect of Air Barrier

Buildings with air barrier are 70% tighter



USACE Std = 4.5, 0.25cfm/ft^2

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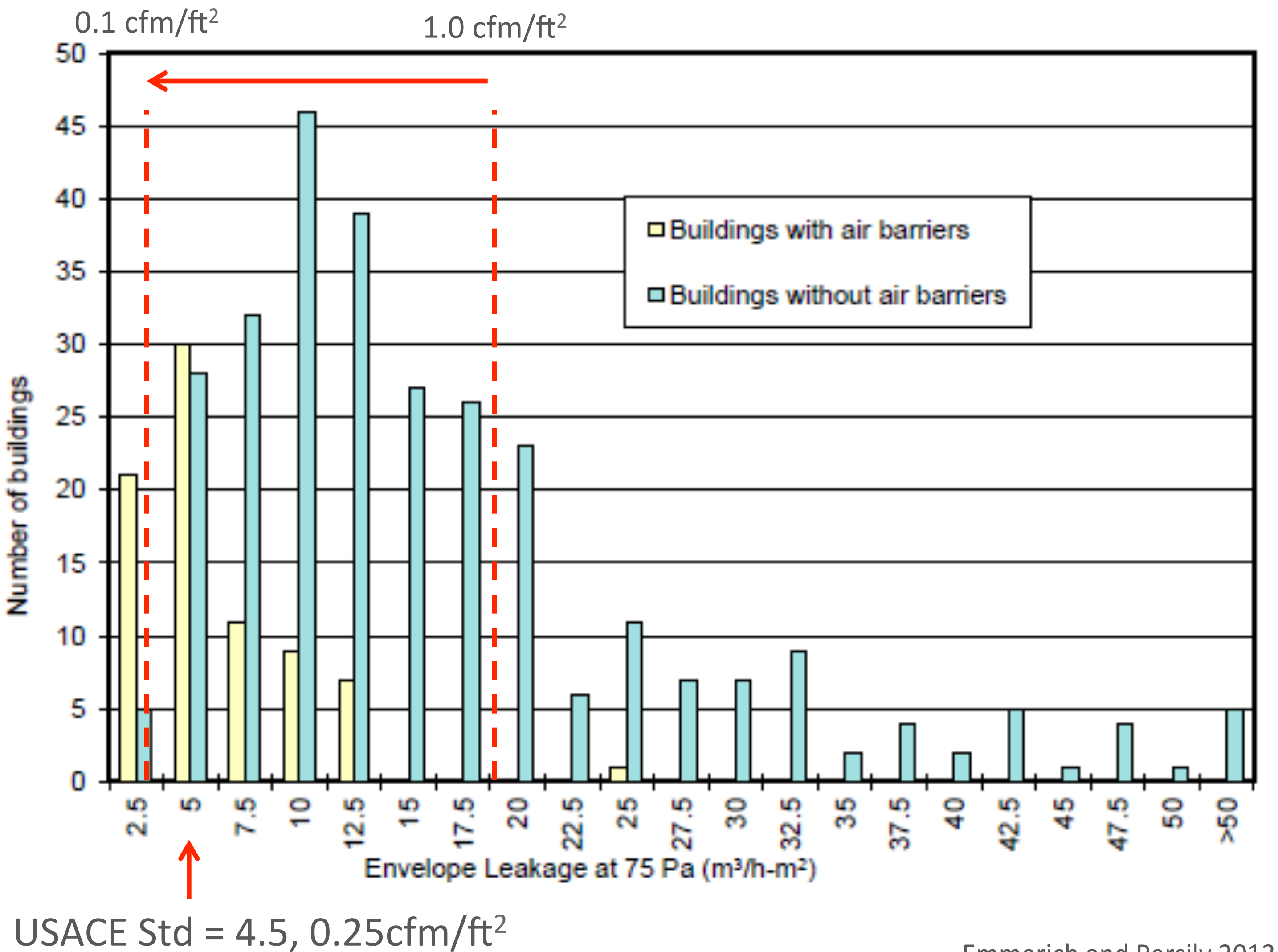
NIST Results: Effect of Air Barrier

Compare no air barrier to tight construction



Emmerich and Persily 2013

NIST Building Infiltration & Energy Models

- Multizone infiltration and energy model
- Compared air infiltration and energy use for:
  - "typical" - no air barrier reported leakage (4x USACE)
  - "target" – good practice (40% below USACE)
- Five cities in different climate zones

NIST Building Infiltration & Energy Models

Two-Story, 24,000ft^2 Office Building

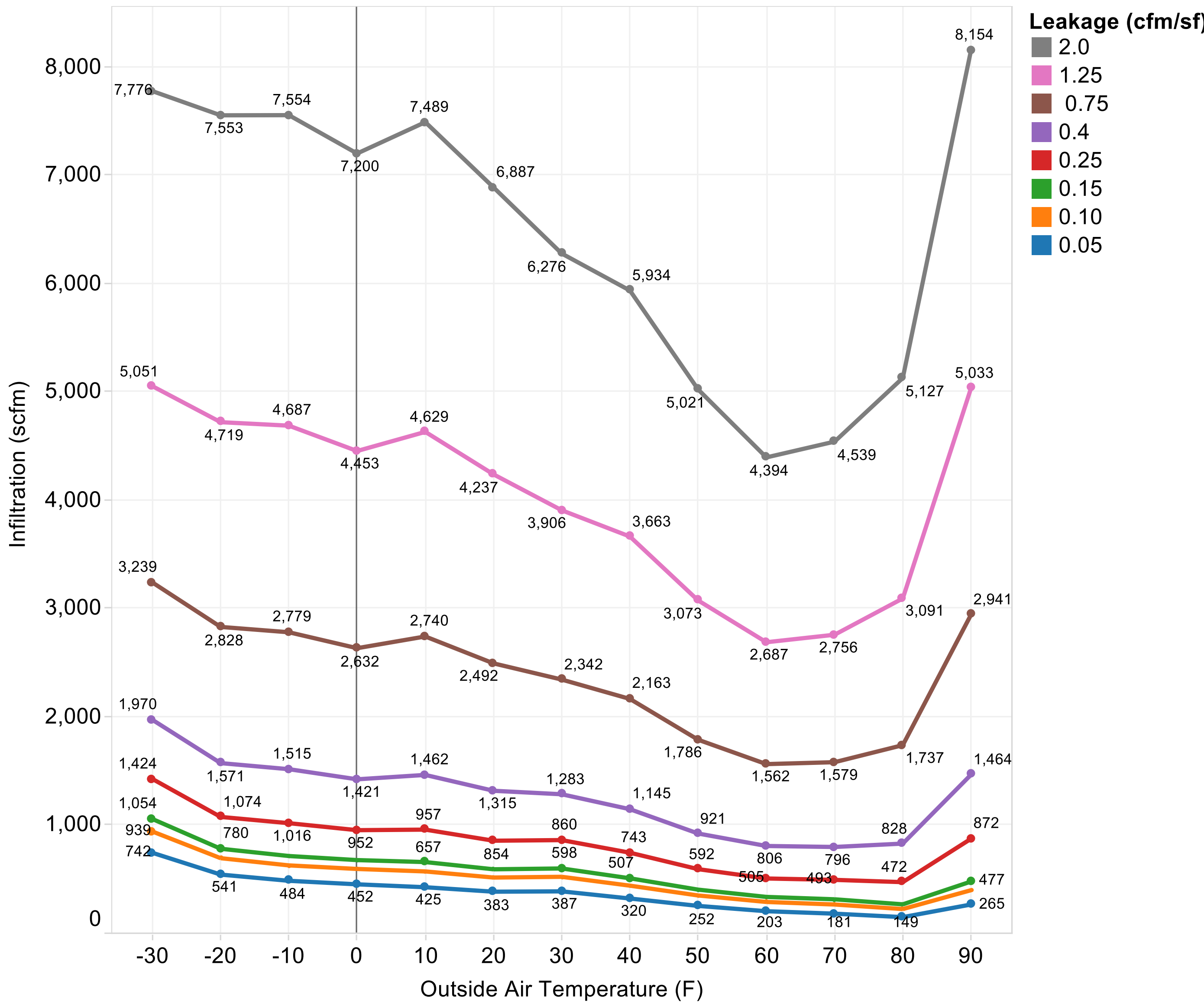
City	Annual Average Infiltration (h^{-1}) Baseline	Target	Gas Savings		Electrical Savings		Total Savings
Bismarck	0.22	0.05	$1,854	42%	$1,340	26%	$3,195
Minneapolis	0.23	0.05	$1,872	43%	$1,811	33%	$3,683
St. Louis	0.26	0.04	$1,460	57%	$1,555	28%	$3,016
Phoenix	0.17	0.02	$124	77%	$620	9%	$745
Miami	0.26	0.03	$0	0%	$769	10%	$769

One-Story, 12,000ft^2 Retail Building

City	Annual Average Infiltration (h^{-1}) Baseline	Target	Gas Savings		Electrical Savings		Total Savings
Bismarck	0.20	0.02	$1,835	26 %	$33	2 %	$1,869
Minneapolis	0.22	0.02	$1,908	28 %	$364	18 %	$2,272
St. Louis	0.24	0.01	$1,450	38 %	$298	9 %	$1,748
Phoenix	0.13	0.00	$176	64 %	$992	14 %	$1,169
Miami	0.21	0.01	$6	98 %	$1,224	14 %	$1,231

Emmerich and Persily 2013

Model Infiltration: Range of Envelope Leakage



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1 Story 60,560ft^2 Elementary School: HVAC Imbalance = 3,450 cfm

Model Infiltration: Range of Envelope Leakage

1 Story 60,560ft^2 Elementary School: HVAC Imbalance = 3,450 cfm

	Building Envelope Leakage (cfm@75/ft^2)							
	0.05	0.1	0.15	0.25	0.4	0.75	1.25	2
Avg Infil. (cfm)	305	417	481	708	1,094	2,077	3,539	5,751
Avg Infil. (ach)	0.03	0.03	0.04	0.06	0.09	0.17	0.29	0.47
Heat Load (therms/yr)	855	1,139	1,305	1,875	2,832	5,260	8,867	14,322
% Space Heating	2%	3%	3%	5%	7%	14%	23%	37%
Cost ($)	$496	$661	$757	$1,087	$1,643	$3,051	$5,143	$8,306

NIST office building model:

1.0 cfm/ft^2 = 0.23 ach

0.1cfm/ft^2 = 0.05 ach

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ASHRAE Research: selection criteria

- Goal: 24 to 36 existing mid- and high-rise buildings (16 Completed)
- Non-residential
- 4 stories or higher
- Sustainability certification (14 of 16)
- Built after the year 2000
- Climate zones 2-7 (All 6 Zones Represented)

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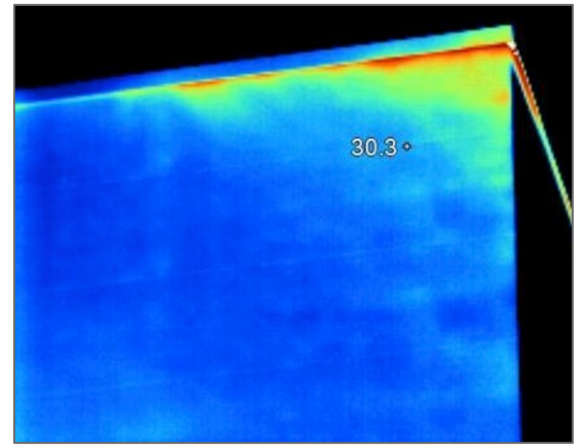
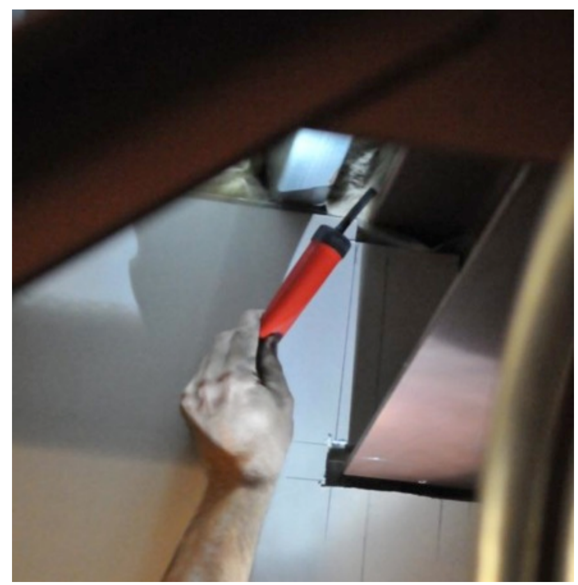
ASHRAE Research Project: leakage results

- Average = 0.29 cfm/ft^2
- Green building = 0.32 cfm/ft^2; others = 0.22 cfm/ft^2
- Air barrier specified and envelope expert = 0.13 cfm/ft^2; others = 0.39 cfm/ft^2
- Unsealing HVAC penetrations increased leakage by average of 27% with range of 2% to 51%

ASHRAE Research Project: leakage sites

- Roof/wall intersection
- Soffits and overhangs
- Mechanical rooms, garages, basements, loading docks
- Roll-up and overhead doors





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Minnesota Leakage Study: work scope

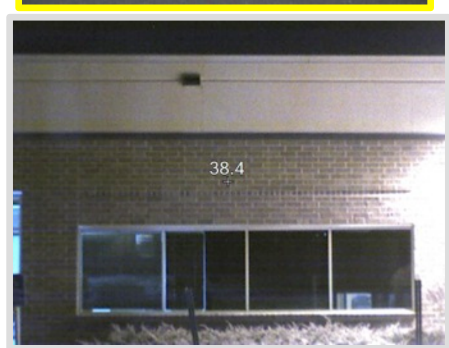
- Conduct investigations on 25 buildings: floor area of 25,000 to 500,000 ft^2
- Air seal and pre/post leakage tests on ~~6~~ 7 buildings
- Continuous building pressure and HVAC operation data for 50 to 200 days
- CONTAM pre/post air flow models that include mechanical system leakage and pressure effects
- Compute infiltration/energy reductions

Building Characteristics

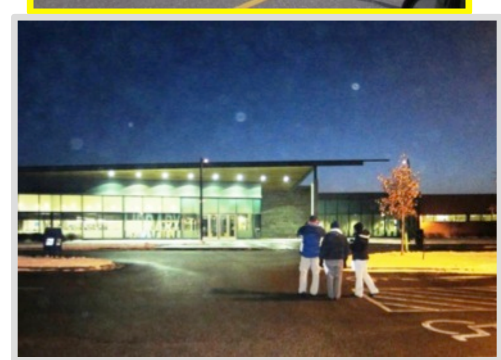
Building ID	Floor Area (sf)	# Stories	Constr Year	Wall Type
Elem School TF	59,558	1	1951	Masonry & corrugated metal panel
Middle School	138,887	3	1936	Cast concrete w/CMU infill
Small Office	26,927	1	1998	EFIS tip up (3 walls) and CMU block
Univ Library	246,365	3	1967	Cast concrete w/CMU infill & brick ext
Elem School PS	60,968	1	1965	CMU w/brick exterior
Library/Office	55,407	1	2007	Steel studs & brick or stone cladding

3 elementary & middle schools: 1936 to 1965 with additions 60,000 – 139,000sf

University Library 246,000sf



Small Office 27,000sf



Library/Office 55,000sf

Minnesota Leakage Study: leakage results

All 7 buildings at least 25% tighter than the US Army Corp standard of 0.25 cfm/ft^2

Building ID	Floor Area (ft^2)	Envelope Area (ft^2) 6 Sides^2	Air Leakage at 75Pa (cfm)	Air Leakage at 75Pa 6 Sides (cfm/ft^2)	EqLA (ft^2)	# Stories	Constr Year
Elem School TF	59,558	146,977	27,425	0.19	15.2	1	1951
Comm. College	95,000	164,844	28,881	0.18	17.2	2	1996
Middle School	138,887	208,733	32,818	0.16	16.6	3	1936
Small Office	26,927	65,267	9,177	0.14	4.6	1	1998
Univ Library	246,365	171,712	23,356	0.14	13.1	3	1967
Elem School PS	60,968	145,766	17,602	0.12	9.6	1	1965
Library/Office	55,407	139,965	12,321	0.09	6.9	1	2007
Minimum	26,927	65,267	9,177	0.09	4.6		
Mean	97,587	149,038	21,654	0.14	11.9		
Median	60,968	146,977	23,356	0.14	13.1		
Maximum	246,365	208,733	32,818	0.19	17.2		

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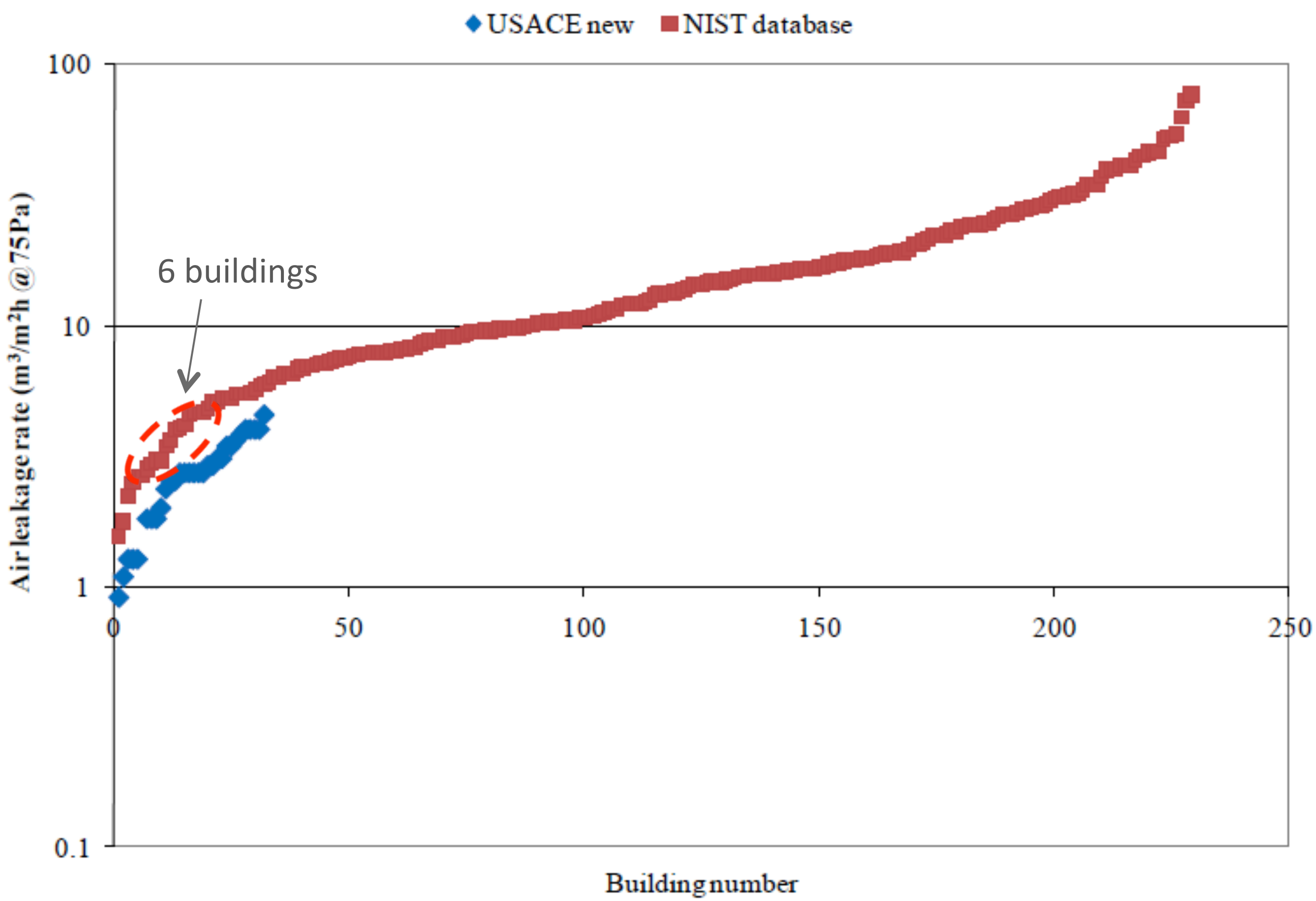
Comparison to US Buildings

7 building average is 85% less than the US average, slightly less than US Army Corp average



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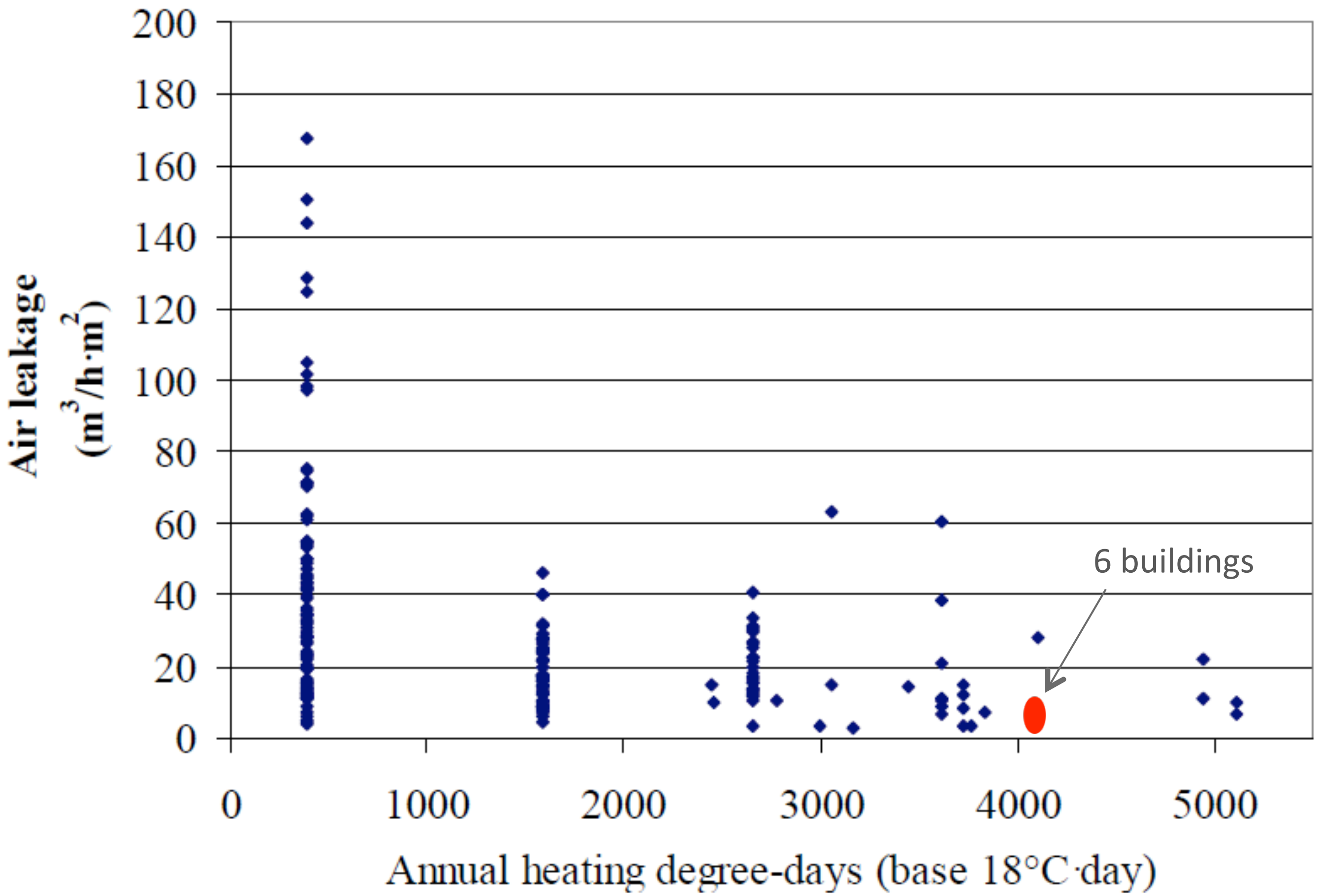
Tighter Buildings in Colder Climates?

7 building average is 85% less than the US average



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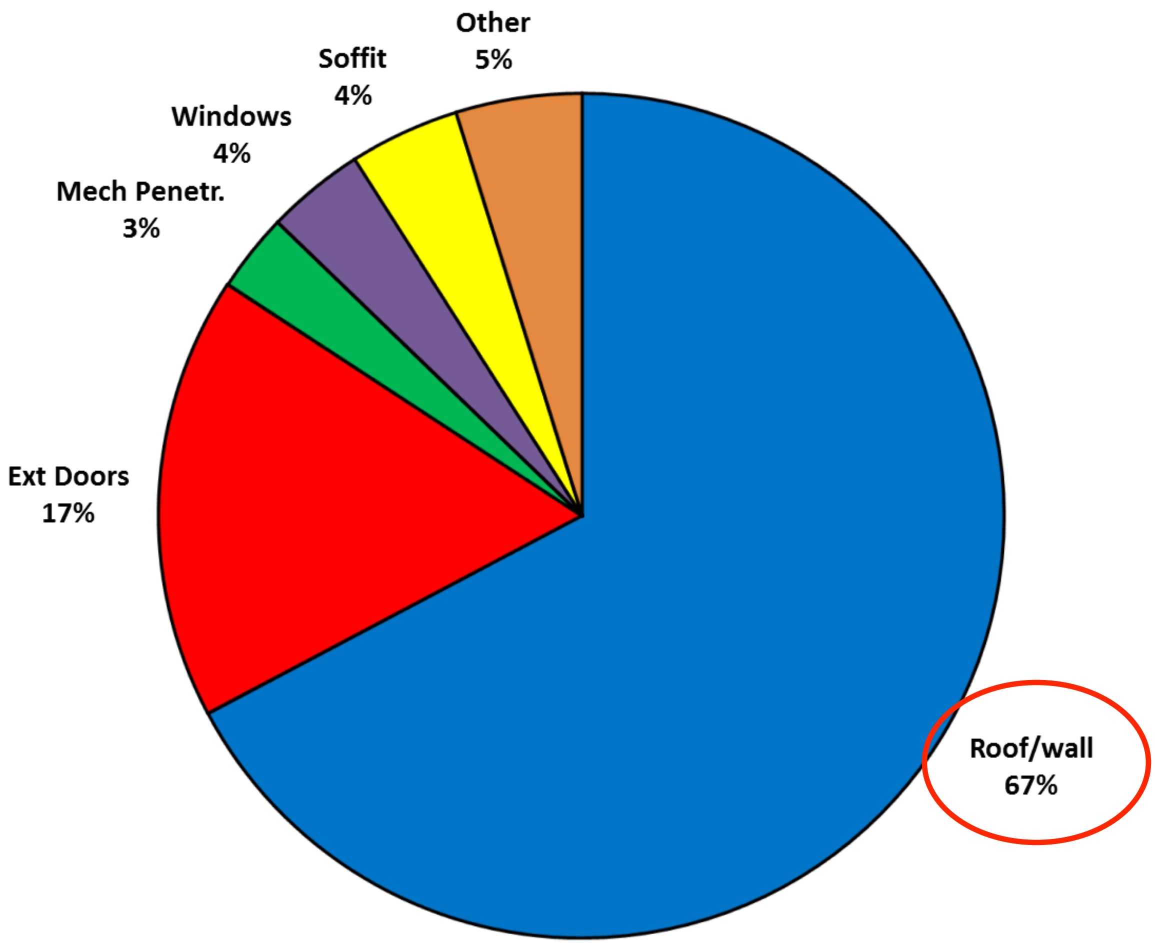
Where Were the Leaks?



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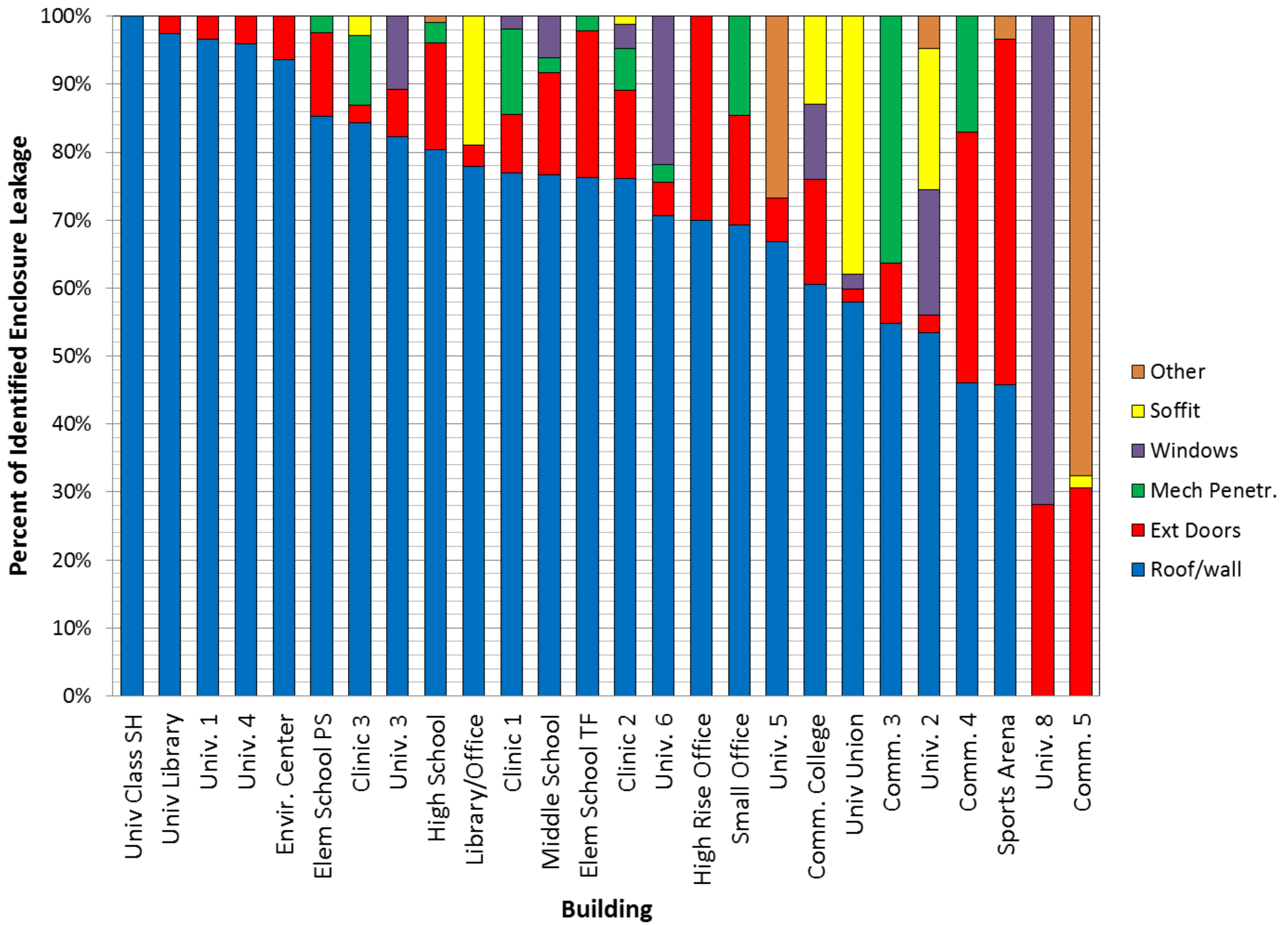

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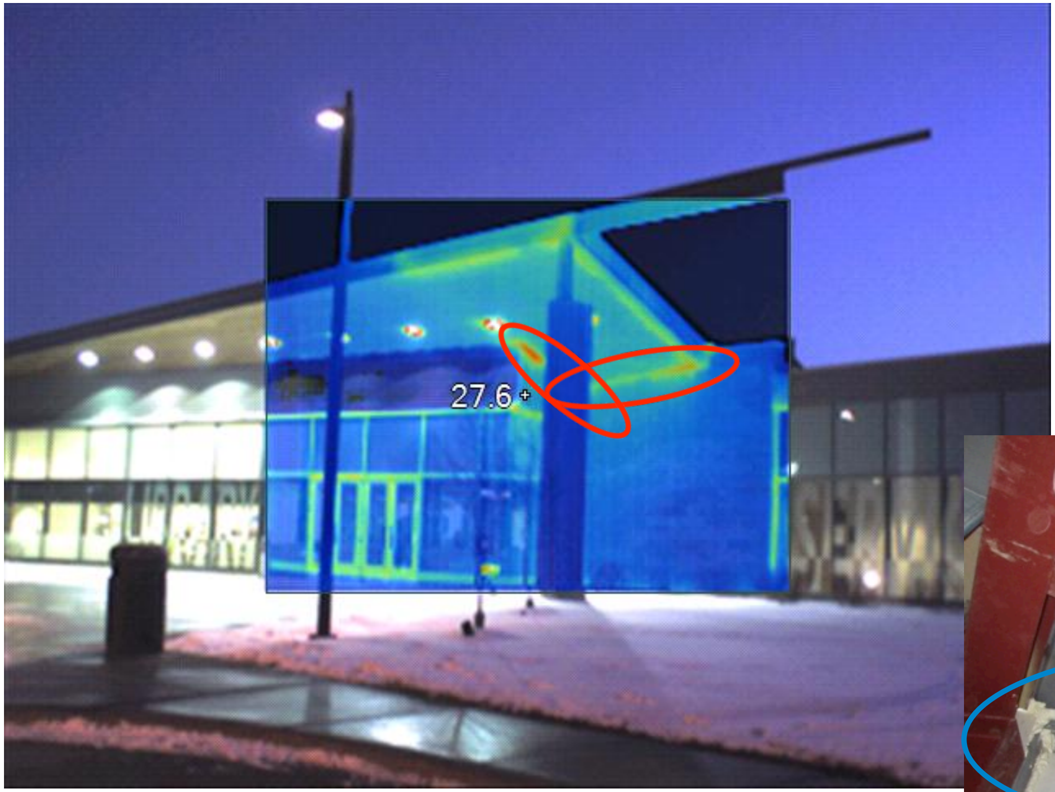
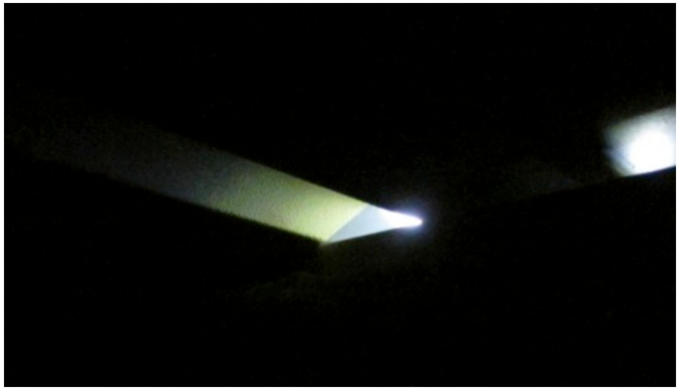
Air Sealing Focused on Roof/wall

Canopy leakage at exterior wall





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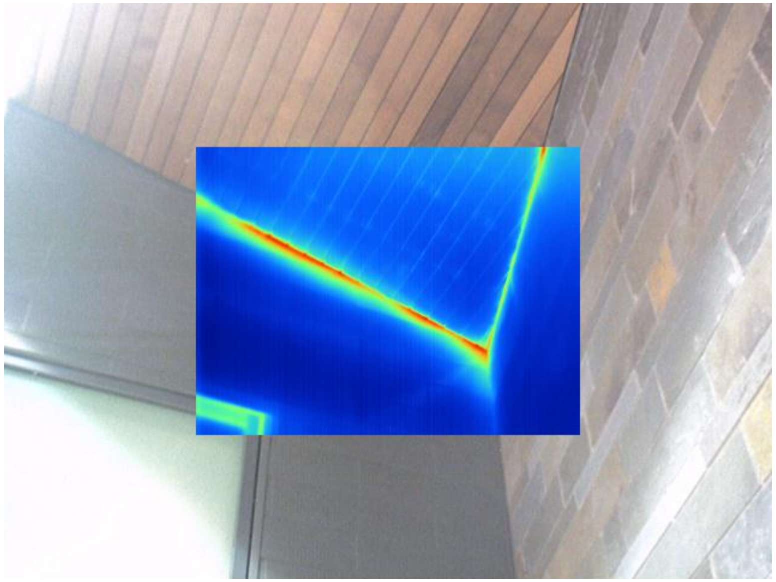
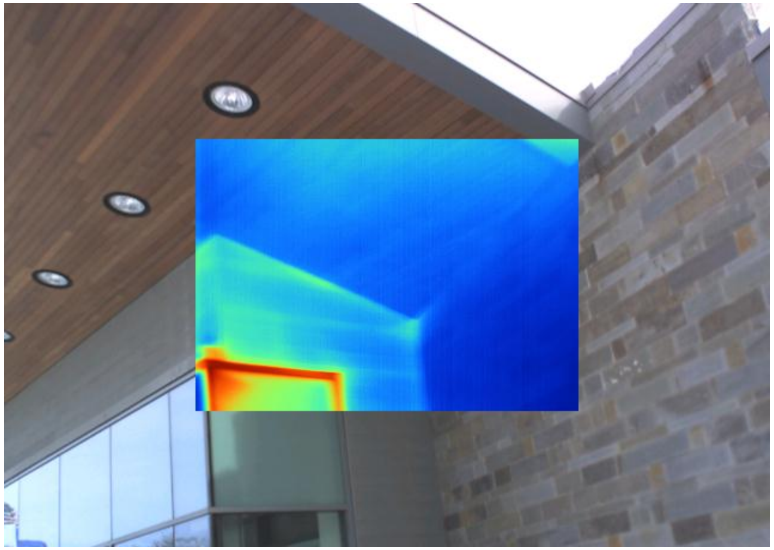
Air Sealing Focused on Roof/wall

Canopy leakage at exterior wall



IR Before



IR After

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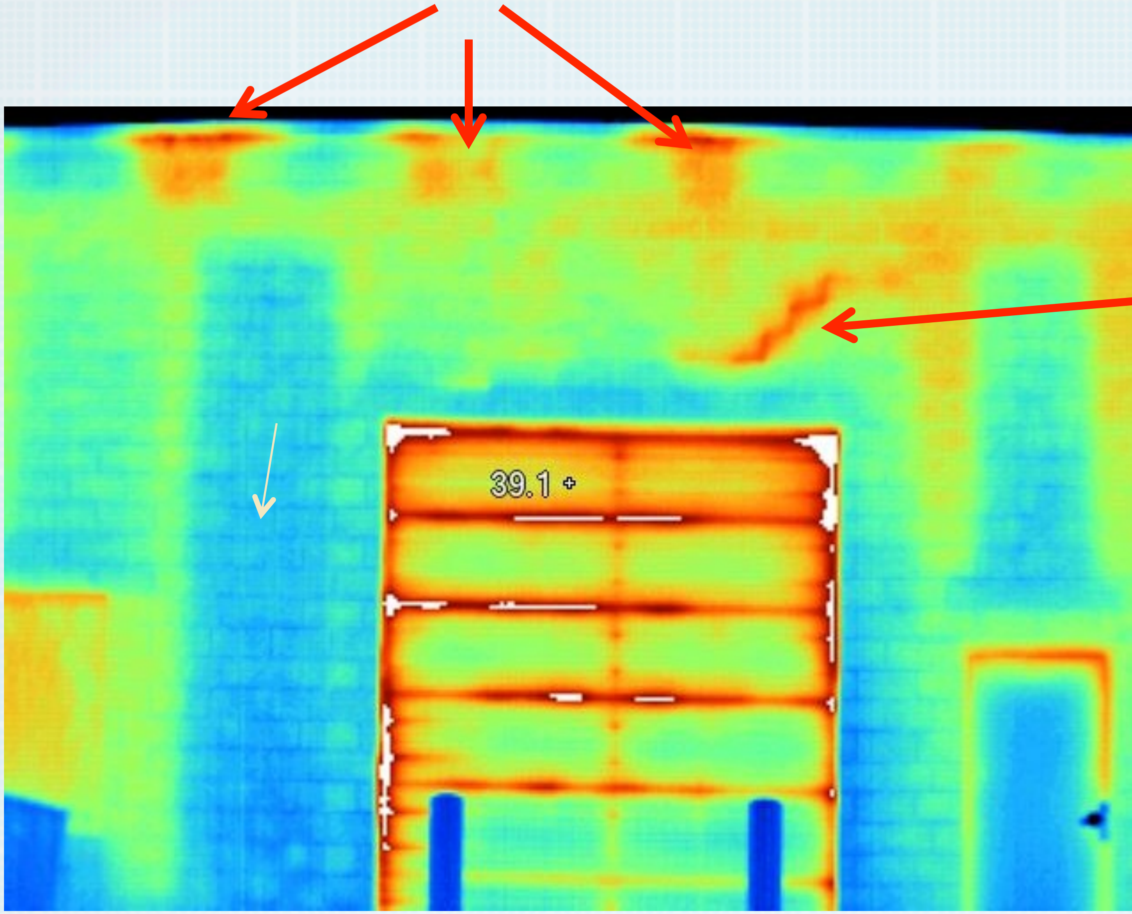
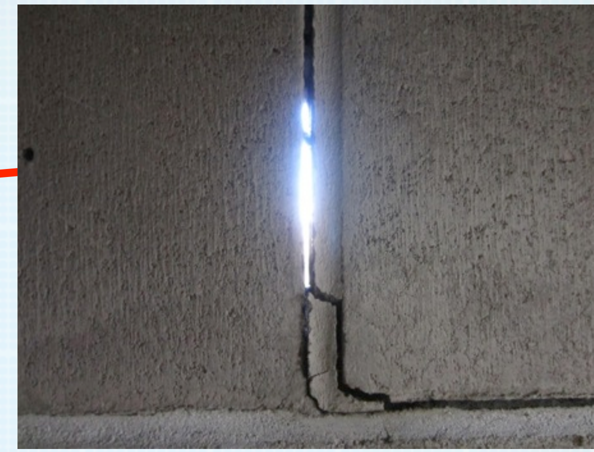
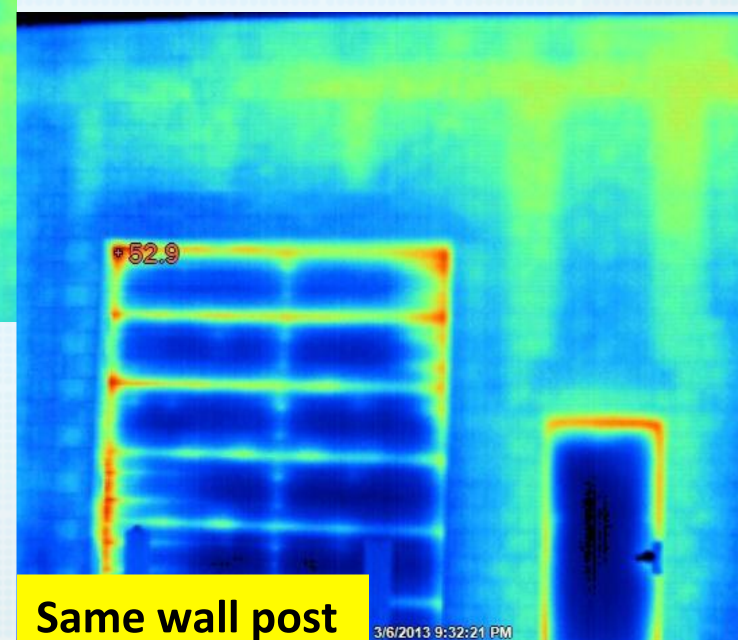
Where to look: IR view of rear CMU wall pre







Look inside: 10 beam pockets

Open to inside

Open above to parapet cap

Smoke shows airflow

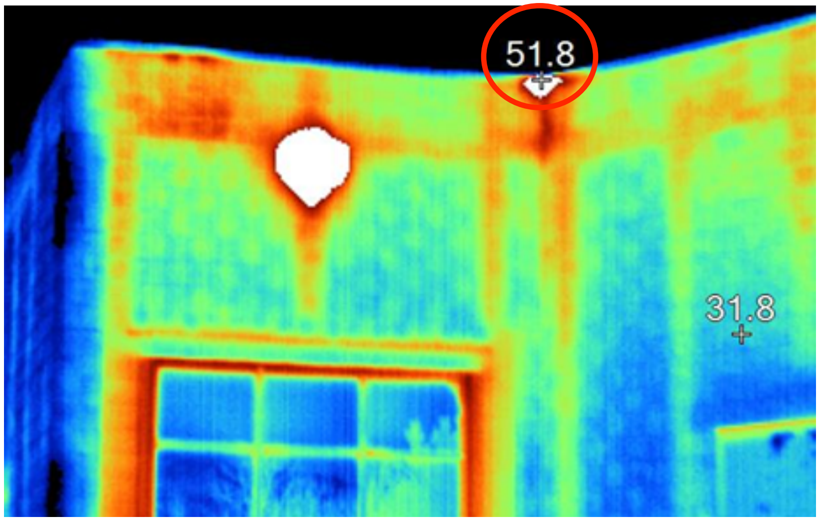
Closed cell foam fill, don't create fire hazard

See ICC ES 3228 approvals.
maintain exhaust on work space adj. to occupied office
Sample MDI < 5ppb
Manage exposure

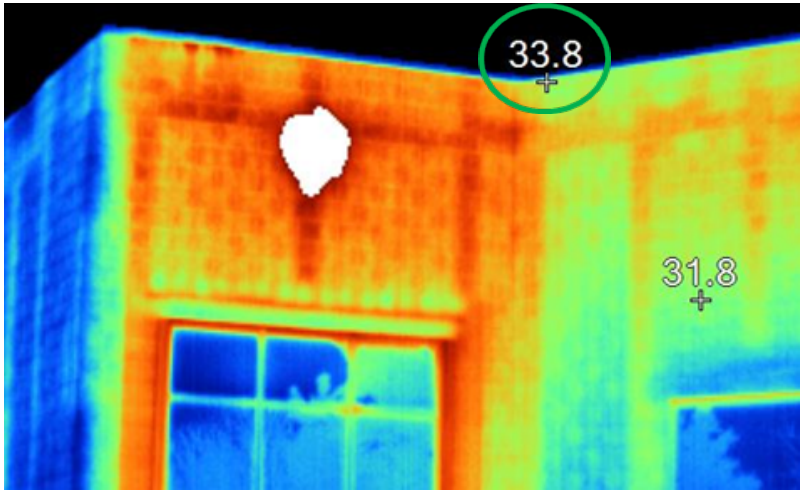
¾ cu ft foam block max temp rise check for building official and owner before injection.

Don't start a fire

Beam Pockets



IR Before



IR After

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Air Sealing Reduction

"Tight" buildings tightened by 9%

	Leakage at	Air Leakage at 75Pa			
	6 Sides	(cfm)		Reduction	
Building ID	(cfm/ft^2)	Pre	Post	(cfm)	(%)
Elem School TF	0.19	27,425	22,699	4,726	17%
Comm. College	0.18	28,881	28,133	748	3%
Middle School	0.16	32,818	28,872	3,947	12%
Small Office	0.14	9,177	8,470	708	8%
Univ Library	0.14	23,356	21,963	1,392	6%
Elem School PS	0.12	17,602	15,837	1,765	10%
Library/Office	0.09	12,321	11,369	953	8%
Minimum	0.09	9,177	8,470	708	3%
Mean	0.14	21,654	19,620	2,034	9%
Median	0.14	23,356	21,963	1,392	8%
Maximum	0.19	32,818	28,872	4,726	17%

Leakier

Tighter

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Air sealing work confirmed by visual, smoke puffer, and IR inspections

Air Sealing Reduction

More expensive to seal tighter buildings?

	Air Sealing Cost		
Building ID	Total	($/CFM75)	($/ft^2)
Elem School TF	$ 18,550	$ 3.92	$ 6,822
Comm. College	$ 17,845	$ 23.86	$ 17,273
Middle School	$ 23,700	$ 6.00	$ 8,434
Small Office	$ 4,768	$ 6.73	$ 10,058
Univ Library	$ 15,918	$ 11.43	$ 65,159
Elem School PS	$ 26,700	$ 15.13	$ 38,132
Library/Office	$ 1,152	$ 1.21	$ 1,297
Median	$ 17,845	$ 6.73	$ 10,058

Leakier

Tighter

Cost per sq ft
of sealing

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Air Sealing Reduction

Contractor estimates better for leakier buildings?

	Leakage Area				Sealed Area (sf)		
	EqLA (ft^2)		Reduction		Contractor Estimated		
Building ID	Pre	Post	(ft^2)	(%)	Roof/Wall	Total	Meas/Est
Elem School TF	15.2	12.5	2.7	18%	8.84	11.49	**0.31**
Comm. College	17.2	16.2	1.0	6%	5.47	5.47	**0.19**
Middle School	16.6	13.8	2.8	17%	11.73	14.98	**0.24**
Small Office	4.6	4.1	0.5	10%			
Univ Library	13.1	12.8	0.2	2%			
Elem School PS	9.6	8.9	0.7	7%	14.45	16.94	**0.05**
Library/Office	6.9	6.0	0.9	13%			

Leakier

Tighter

Building Leakage < Estimated sealing

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Air Sealing Energy Savings

Modeled Infiltration and Energy Savings

	Space Heat Gas Use (Therms/yr)		
Building ID	Total	Infiltration	Infil/Total
Elem School TF	40,224	2,389	6%
Comm. College	32,095	3,402	11%
Middle School	44,469	7,779	17%
Small Office		684	
Univ Library		192	
Elem School PS	26,563	2,387	9%
Library/Office	18,108	2,829	16%
Minimum			6%
Mean			12%
Median			11%
Maximum			17%

Air Sealing Energy Savings

Modeled Infiltration and Energy Savings

	Space Heat Gas Use (Therms/yr)			Gas Savings		Avg	Leakage
Building ID	Total	Infiltration	Infil/Total	(Therm/yr)	($/yr)	Infil (cfm)	Red. (%)
Elem School TF	40,224	2,389	6%	549	$319	1,296	17%
Comm. College	32,095	3,402	11%	174	$105	1,730	3%
Middle School	44,469	7,779	17%	905	$525	4,330	12%
Small Office		684		39	$24	964	8%
Univ Library		192		11	$6	249	6%
Elem School PS	26,563	2,387	9%	223	$129	1,453	10%
Library/Office	18,108	2,829	16%	107	$68	1,477	8%
Minimum			6%	11	$6	249	3%
Mean			12%	287	$168	1,643	9%
Median			11%	174	$105	1,453	8%
Maximum			17%	905	$525	4,330	17%

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Air Sealing Energy Savings

Presentation TAKE AWAYS

Modeled Infiltration and Energy Savings

Building ID	Gas Savings (Therm/yr)	Gas Savings ($/yr)	Electric Savings (kWh/yr)	Electric Savings ($/yr)	Total ($/yr)	Leakage Red. (%)	Cost ($)	Payback (years)
Elem School TF	549	$319	1,034	$101	$419	17%	$18,550	44
Comm. College	174	$105	232	$23	$127	3%	$17,845	140
Middle School	905	$525	2,523	$246	$771	12%	$23,700	31
Small Office	39	$24	18	$2	$26	8%	$4,768	182
Univ Library	11	$6	79	$0	$6	6%	$15,918	2,872
Elem School PS	223	$129	487	$47	$177	10%	$26,700	151
Library/Office	107	$68	-232	-$24	$44	8%	$1,152	26
Minimum	11	$6	-232	-$24	$6	3%	$1,152	26
Mean	287	$168	592	$56	$224	9%	$15,519	492
Median	174	$105	232	$23	$127	8%	$17,845	140
Maximum	905	$525	2,523	$246	$771	17%	$26,700	2,872

Able to seal “tight” buildings, but work was not cost effective

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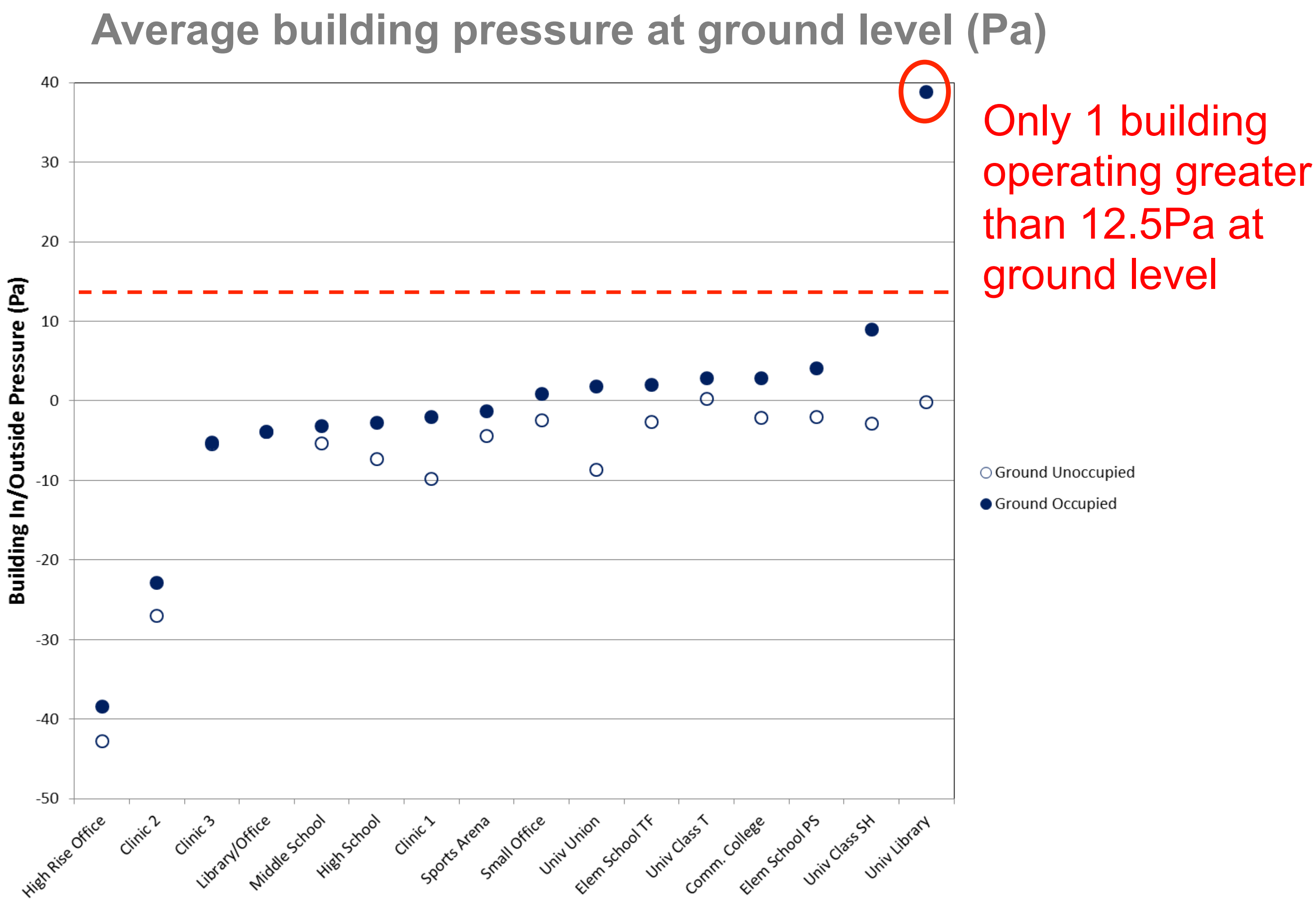
Building Pressure Measurements



20F < outside temp <= 45F

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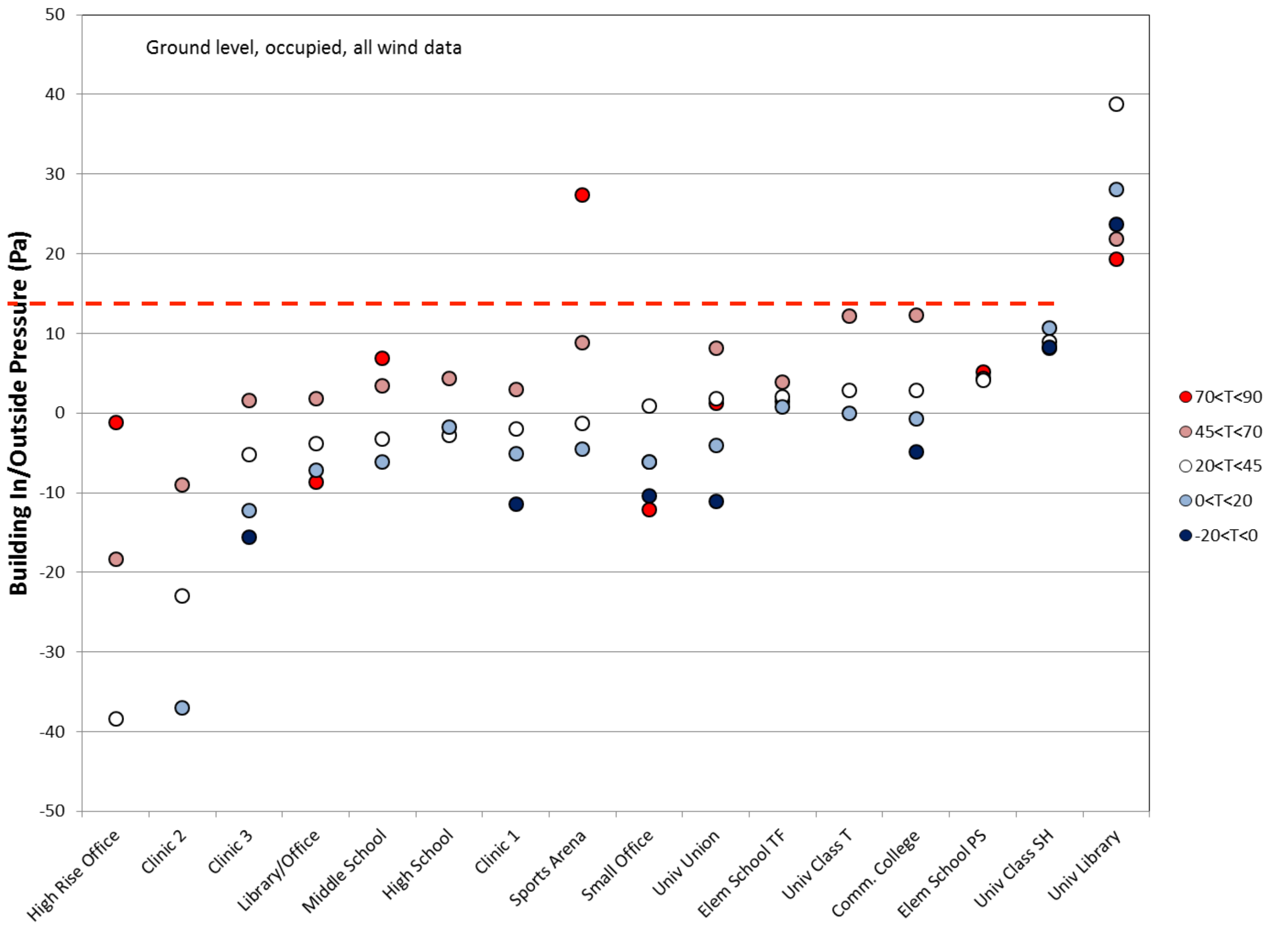
Building Pressure Measurements

Average building pressure at ground level (Pa)



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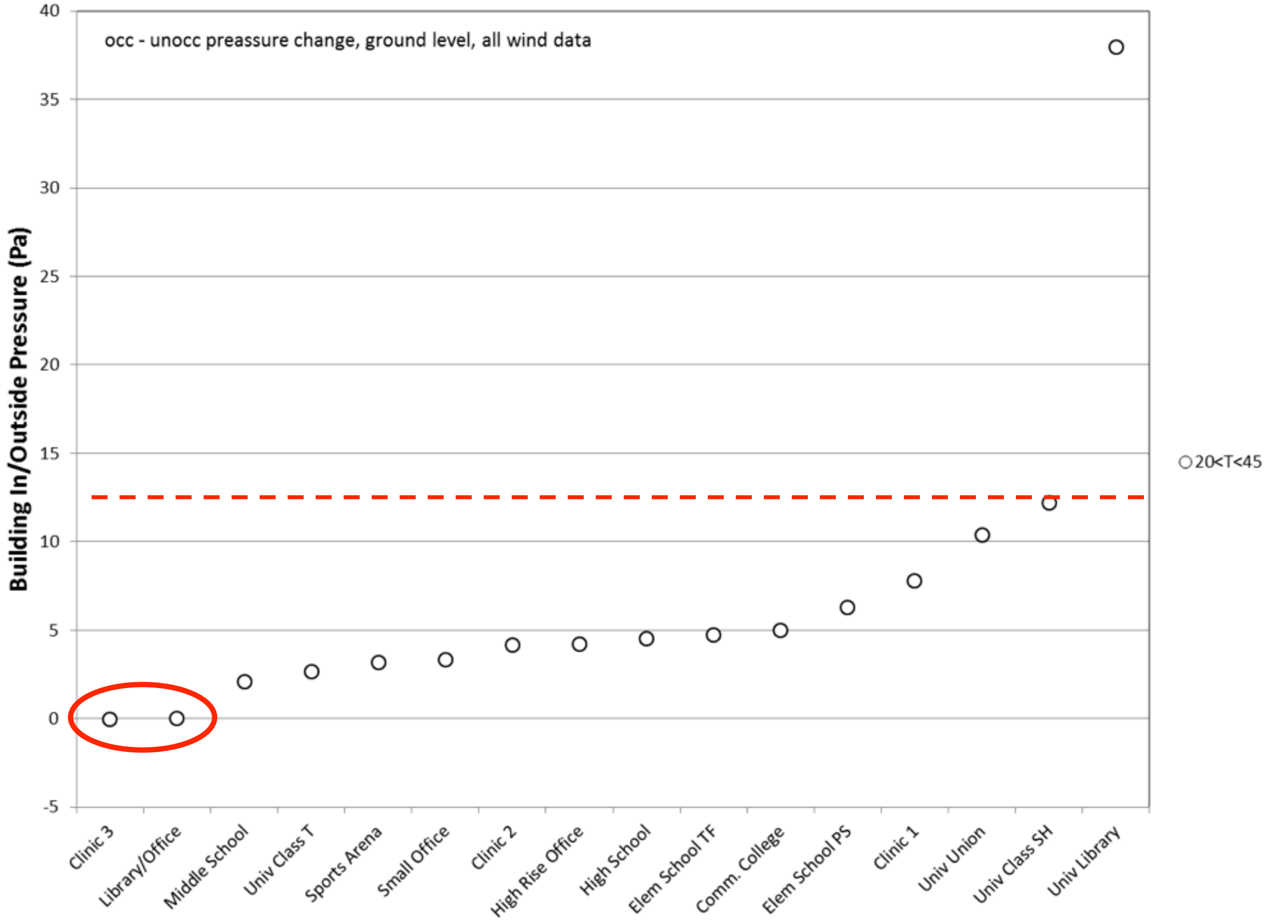
Building Pressure Measurements

Difference between occupied and unoccupied pressure (Pa)



Pressure increase for almost all buildings

20F < outside temp <= 45F

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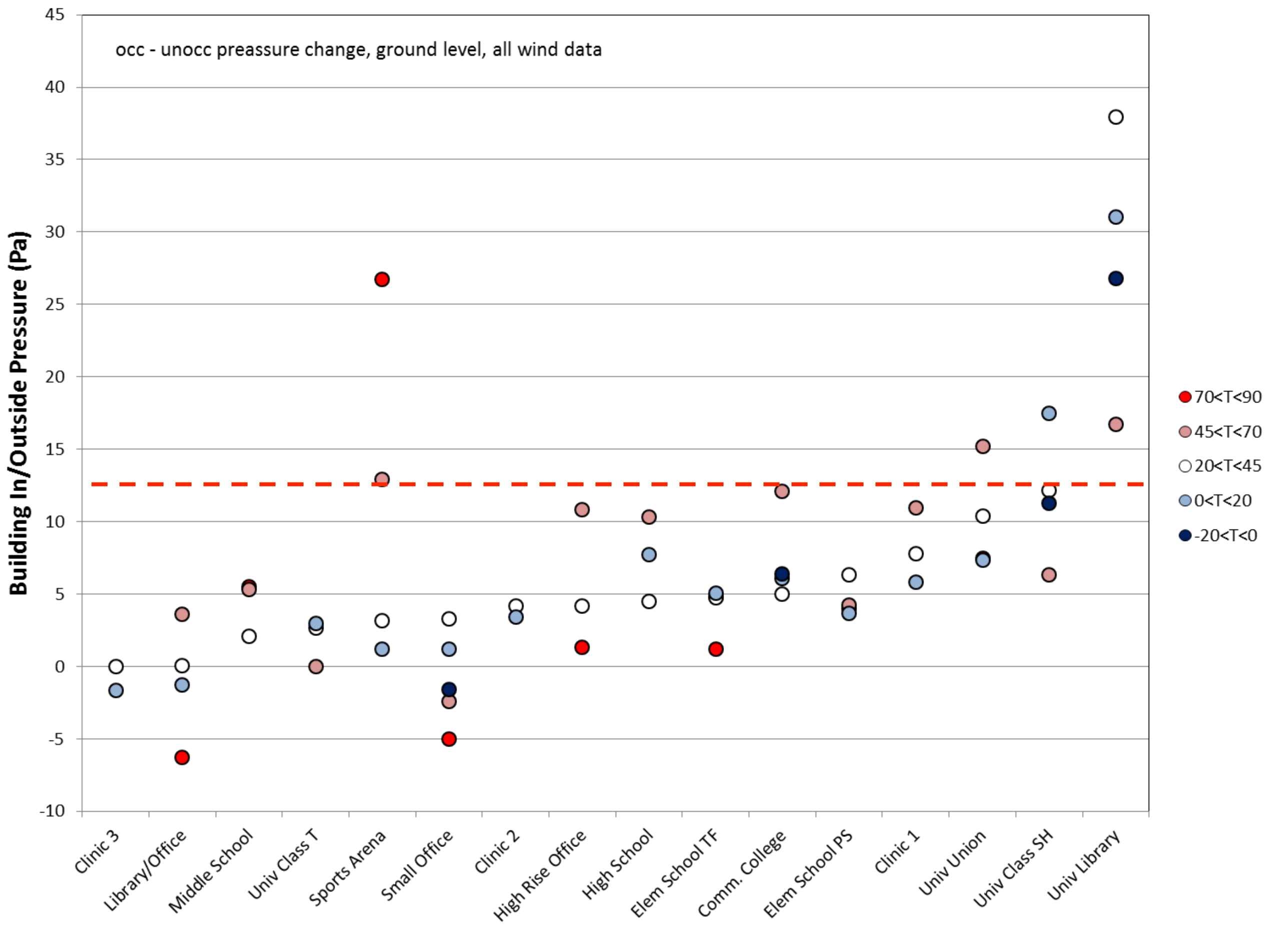
Building Pressure Measurements

Difference between occupied and unoccupied pressure (Pa)



20F < outside temp <= 45F

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Computing Savings For Your Project

- Can we divide cfm50 by 20 to get savings?
- It is not that simple for larger buildings
- HVAC pressurization effects savings
- Greater savings for taller buildings, open terrain, distance from neutral level, floor compartmentalization
- Internal heat gain = cooling more important
- Developing spreadsheets for savings calculations

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Computing Savings For Your Project

Three Story Commercial Building

- Typical pressurization = 10% less
  6Pa = 35% less
  12.5Pa = 60% less
- 1 story = 40% less; 5
  story = 30% more;
  10 story = 80% more
- Urban wind shielding = 35% less
  Open wind shielding = 70% more

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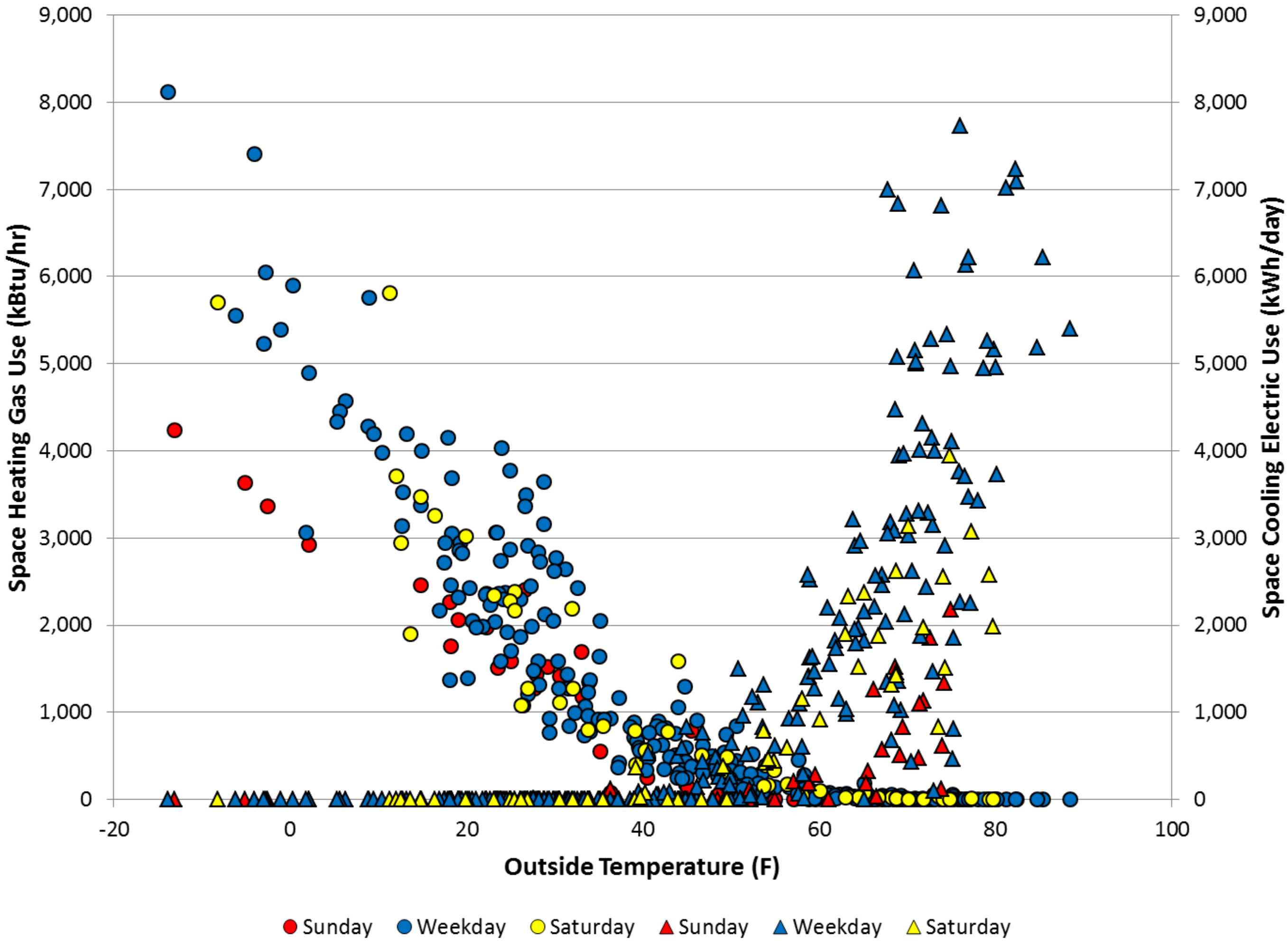
Office Building Model: Heating & Cooling



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Mechanical System Leakage

Part of building envelope when not operating

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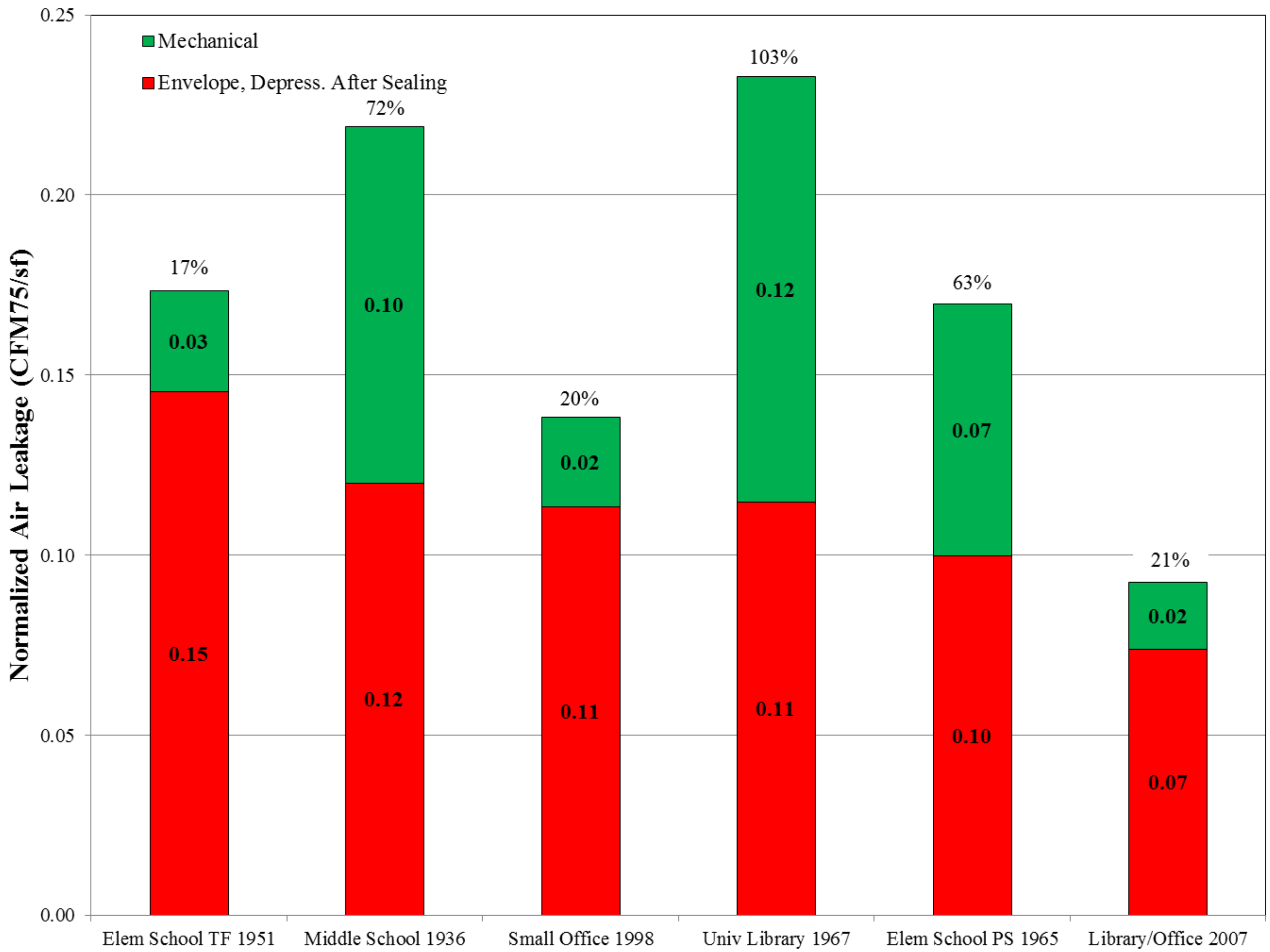
Mechanical System Leakage

Part of building envelope when not operating



Mean
49%
0.06 cfm/ft^2
(6 sides)

Range
17% to 103%
0.02 to 0.12 cfm/ft^2

Two most recently built (1998 and 2007) had low leakage

Summary

- Tight buildings: 85% tighter than U.S. average & at least 25% below Army Corp standard – due to cold climate location?
- Sealing = 9% reduction, more reduction and less expensive for leakier buildings
- Contractor over-estimated sealing area
- Long paybacks for air sealing work
- Including mechanical systems increased leakage by 17 to 103% (0.02 to 0.12 cfm/ft^2)
- HVAC systems tend to pressurize buildings. Not as great as typical design practice

When Is Air Sealing Worthwhile?

- You can see out the envelope gaps & leak is accessible
- Taller (5+ stories) in open terrain
- Reported problem that is likely to be caused by air leakage
- You live in portion of US that hasn't had to worry about infiltration

Other Opportunities

- Older/leaky dampers (cost?)
- Building pressure control

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Thank you!

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