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Leakage Reductions For Large Building Air Sealing and HVAC System Pressure Effects

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AIVC Airtightness Workshop

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Motivation For Project

Expand cost effective air sealing of existing buildings in Minnesota.

Add this to current recommissioning activities – much done through utility programs.

Need greater confidence in estimated leakage reduction and energy savings calculation.

Limited leakage measurements and savings calculations that do not include stack and mechanical system pressure effect.

Envelope Air Sealing Research Objectives

Air sealing toolkit for building recommissioning

- Develop screening protocol
- Refine investigation protocol
- Generate energy savings calculation procedures

- Measure change in building tightness due to air sealing
- Model effect of sealing on building infiltration and conditioning loads

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 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

Six Buildings In Minnesota

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

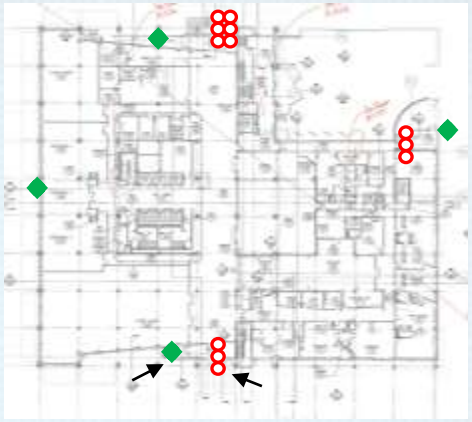
3 elementary & middle schools: 1936 to 1965 with additions
60,000 – 139,000sf

University Library 246,000sf

Small Office 27,000sf

Library/Office 55,000sf

Air Leakage Test Protocol



- ASTM E779-10
- Ground level pressures on 4 sides
- 5 minute baselines before & after
- Pressurization and depressurization tests
- 13 to 16 pressure levels from 15 to 75Pa at 5Pa increments; 1 minute each
- Mechanical systems temporarily sealed
- Unseal at end of tests & one-point 75Pa to measure mechanical system increased leakage

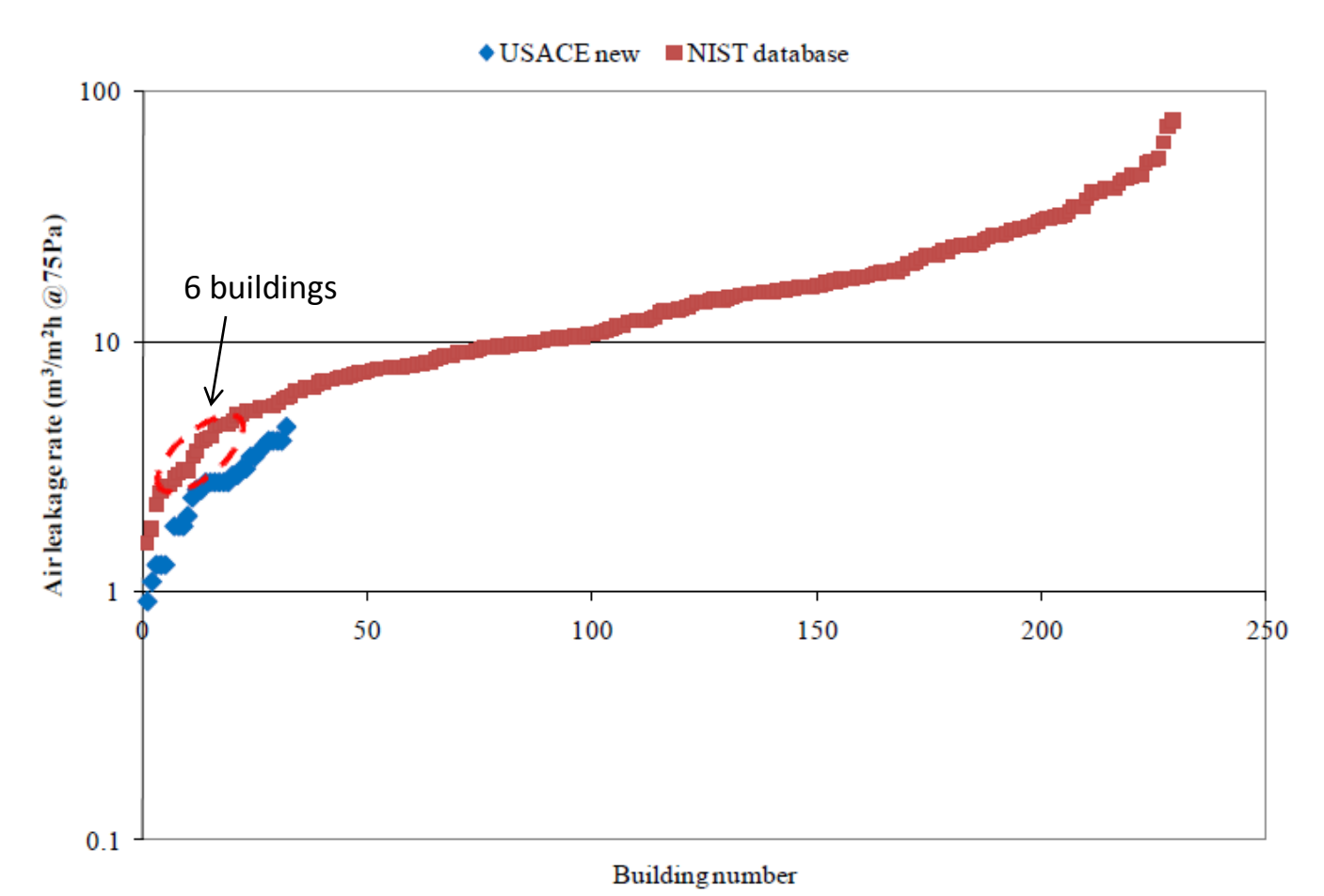
Air Leakage Test Results

	Envelope Area (ft^2)		Air Leakage at 75Pa				
				5 Sides		6 Sides	Constr
Building ID	5 Sides[1]	6 Sides[2]	(cfm)	(cfm/ft^2)	($m^3/h \cdot m^{2)}$	(cfm/ft^2)	Year
Elem School TF	87,419	146,977	27,425	0.31	5.7	0.19	1951
Middle School	130,318	208,733	32,818	0.25	4.6	0.16	1936
Small Office	38,340	65,267	9,177	0.24	4.4	0.14	1998
Univ Library	98,240	171,712	23,356	0.24	4.3	0.14	1967
Elem School PS	84,798	145,766	17,602	0.21	3.8	0.12	1965
Library/Office	84,558	139,965	12,321	0.15	2.6	0.09	2007
Minimum	38,340	65,267	9,177	0.15	2.6	0.09	
Mean	87,279	146,403	20,450	0.23	4.2	0.14	
Median	86,108	146,371	20,479	0.24	4.3	0.14	
Maximum	130,318	208,733	32,818	0.31	5.7	0.19	

All 6 buildings at least 25% tighter than U.S. Army Corp standard of 0.25 cfm/sf

Air Leakage Test Results

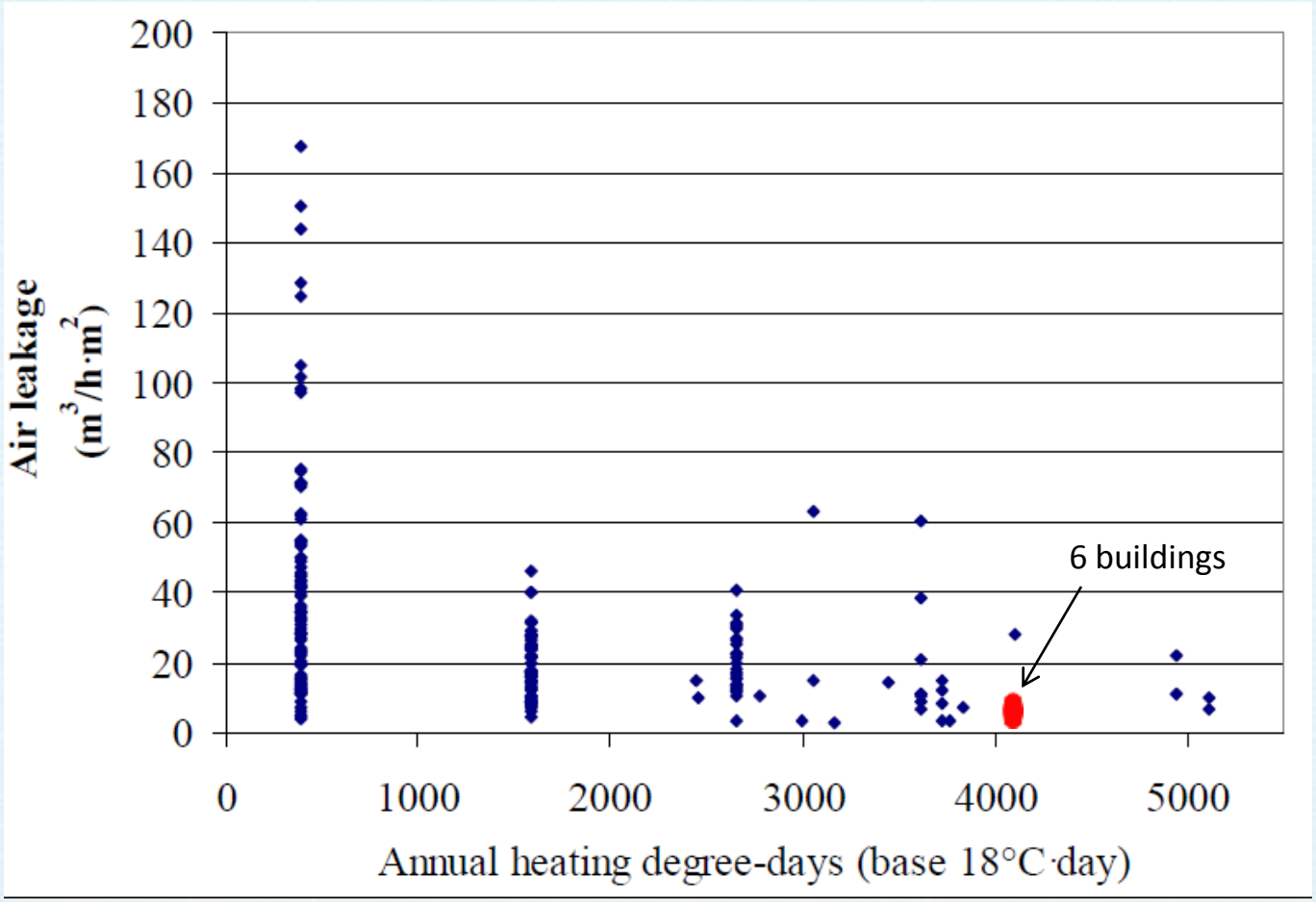
Average of 4.2 $m^3/h\ m^2$ = 83% less than average of 227 U.S. C&I



Emmerich and Persily, AIVC 2011

Air Leakage Test Results

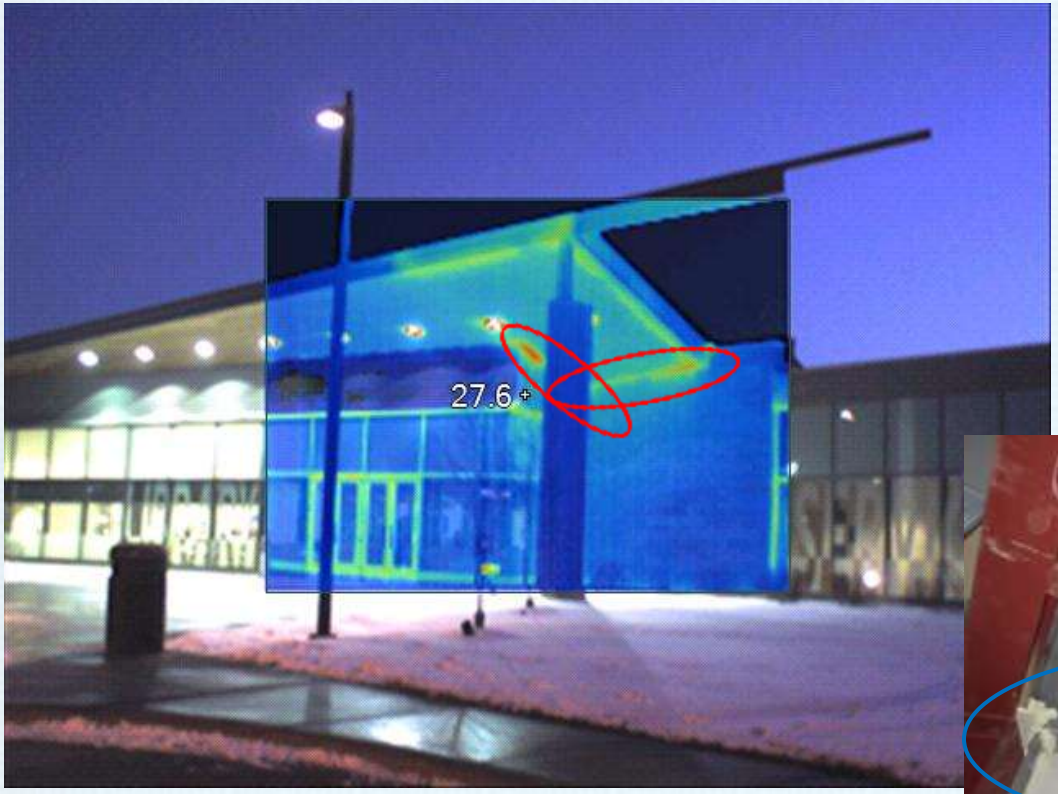
Colder climate = tighter????



Emmerich and Persily, AIVC 2005

Air Sealing Focused on Wall/Roof Joint

Canopy leakage at exterior wall



Air Sealing Reduction

"Tight" buildings tightened by 10%

	Air Leakage at 75Pa			
	(cfm)		Reduction	
Building ID	Pre	Post	(cfm)	(%)
Elem School TF	27,425	22,699	4,726	17%
Middle School	32,818	28,872	3,947	12%
Small Office	9,177	8,470	708	8%
Univ Library	23,356	21,963	1,392	6%
Elem School PS	17,602	15,837	1,765	10%
Library/Office	12,321	11,369	953	8%
Minimum	9,177	8,470	708	6%
Mean	20,450	18,201	2,249	10%
Median	20,479	18,900	1,579	9%
Maximum	32,818	28,872	4,726	17%

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
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
Minimum	$ 1,152	$ 1.21	$ 1,297
Mean	$ 15,131	$ 7.41	$ 21,650
Median	$ 17,234	$ 6.37	$ 9,246
Maximum	$ 26,700	$ 15.13	$ 65,159

Cost effectiveness to be determined with modeling

Air Sealing Reduction

Contractor estimates better for leakier buildings??

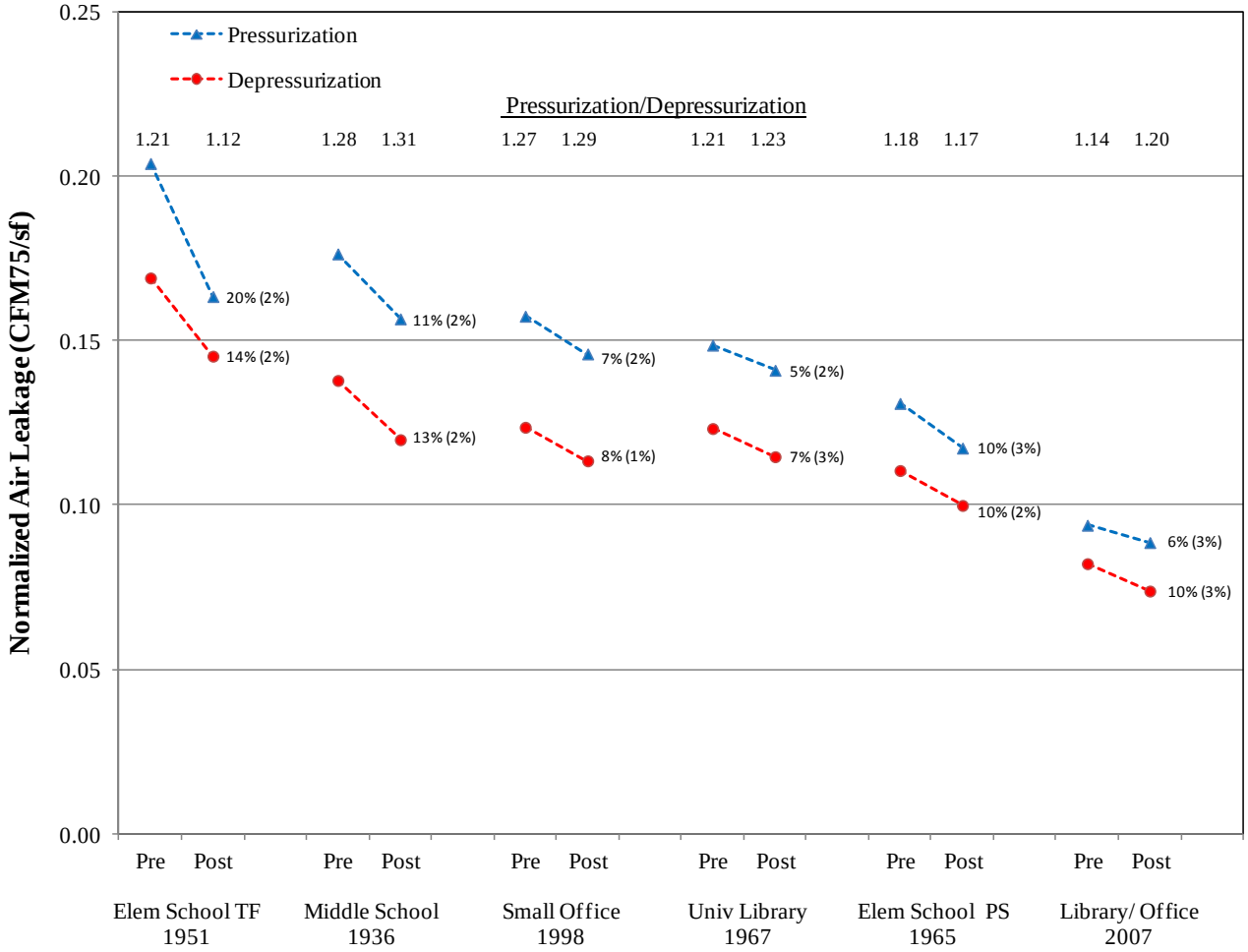
	Leakage Area				Sealed Area (sf)		
	EqLA (ft^2)		Reduction		Contractor Estimated		
Building ID	Pre	Post	(ft^2)	(%)	Roof/Wall	Total	Meas/Est
Elem School TF	15.2	12.5	2.7	18%	8.84	11.49	**0.31**
Middle School	16.6	13.8	2.8	17%	11.73	14.98	**0.24**
Small Office	4.6	4.1	0.5	10%			
Univ Library	13.1	12.8	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

EqLA < Estimated sealing

Comparison of Pressurization and Depressurization

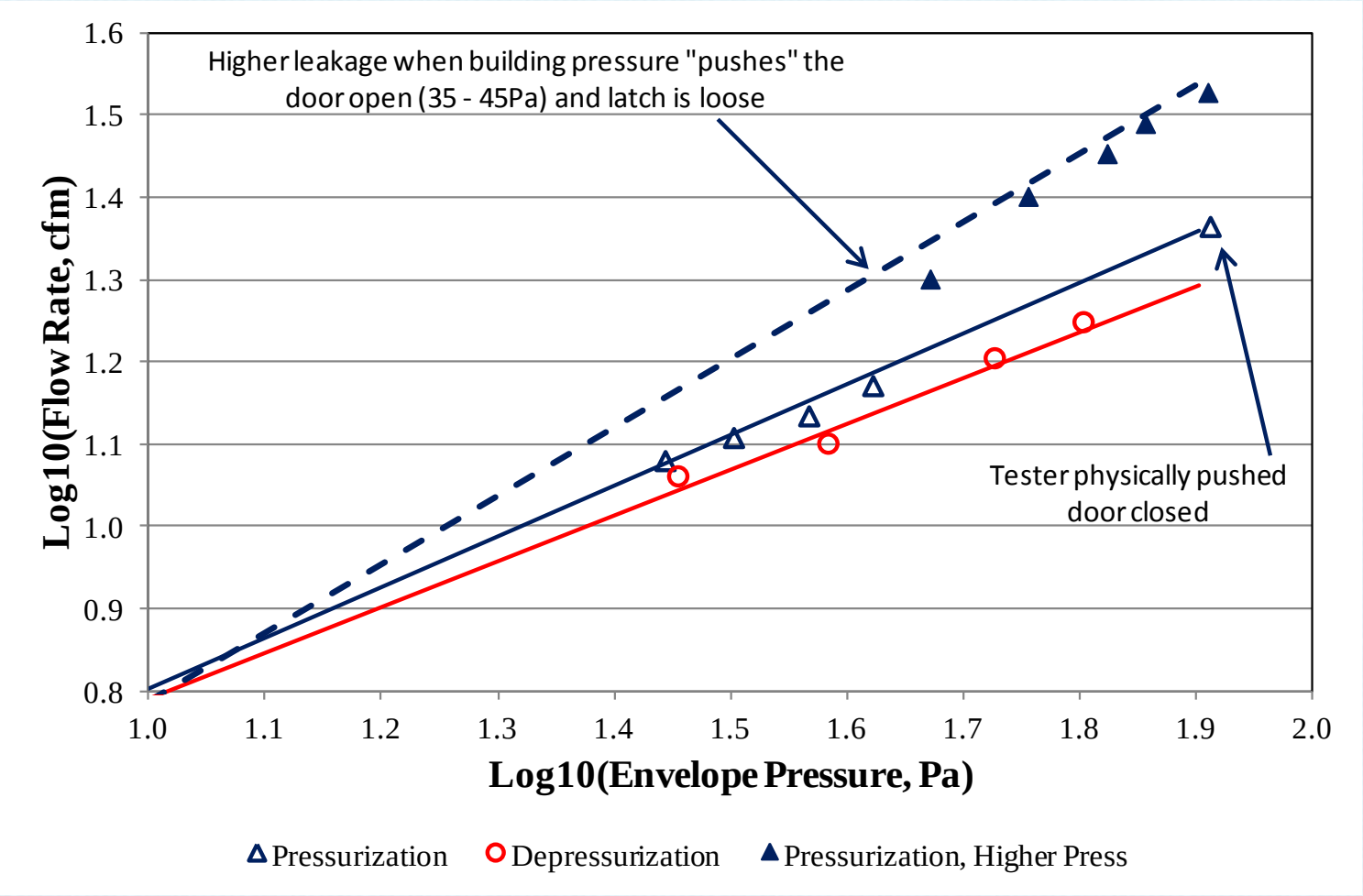


Pressure/Depress.
Mean = 1.22
Range: 1.12 – 1.31

For only 1 building the difference in percent CFM75 reduction > uncertainty

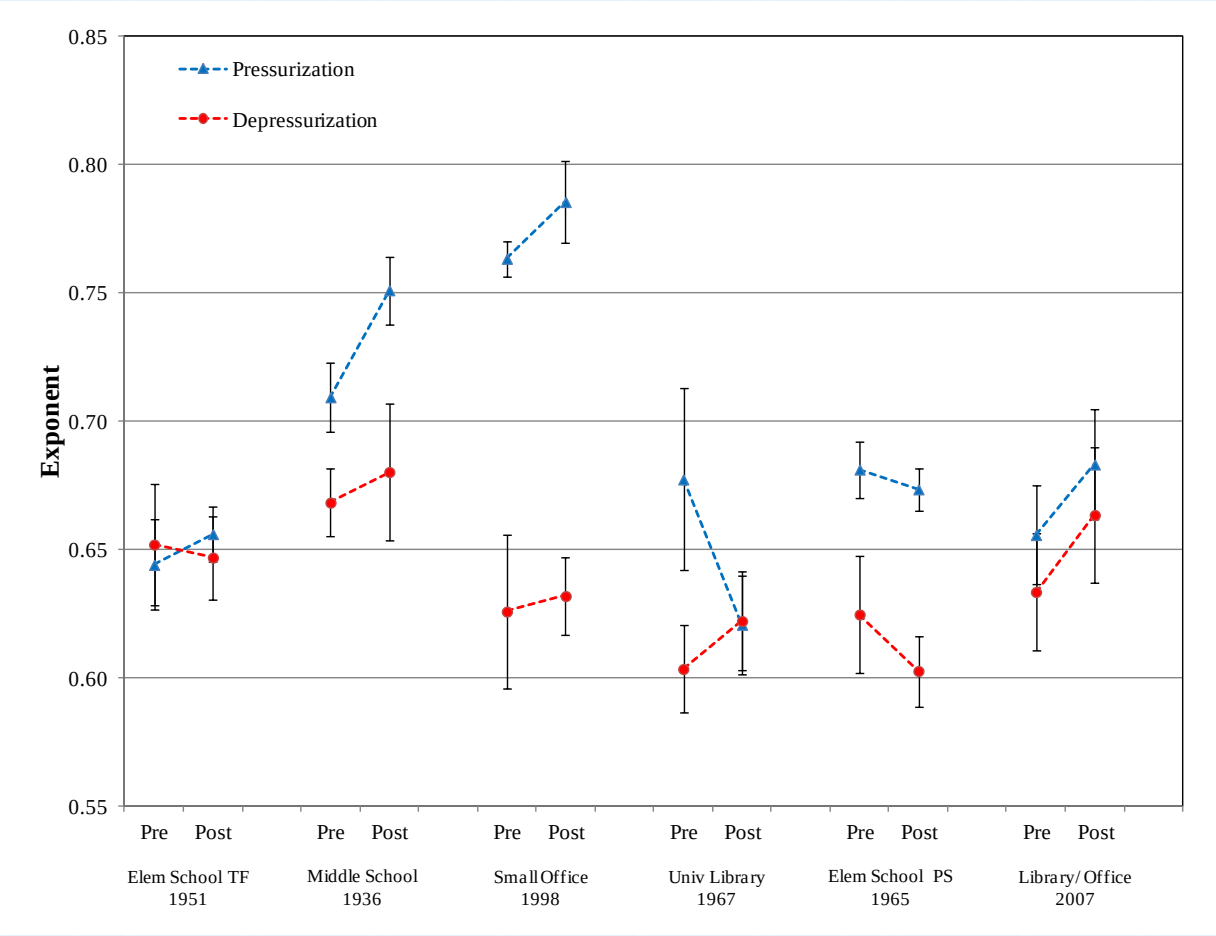
Doors Leakier Under Pressurization

Due to loose latches



For elementary school doors could explain 17% of difference (26 doors)

Comparison of Power Law Exponents

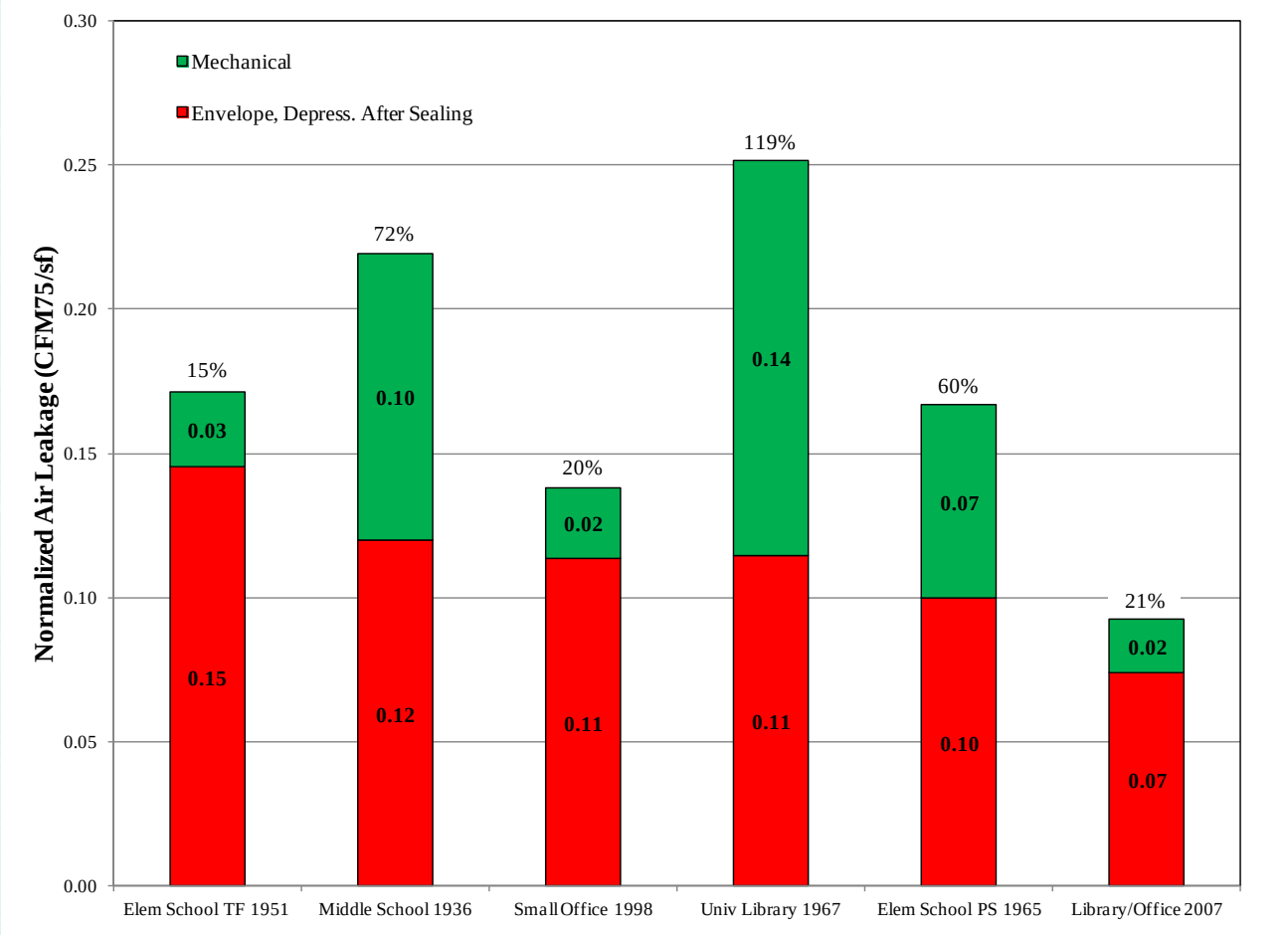


Pressurization > Depressurization for 10 of 12

For 7 of 12 difference > sum of uncertainties

Mechanical System Leakage

Part of building envelope when not operating

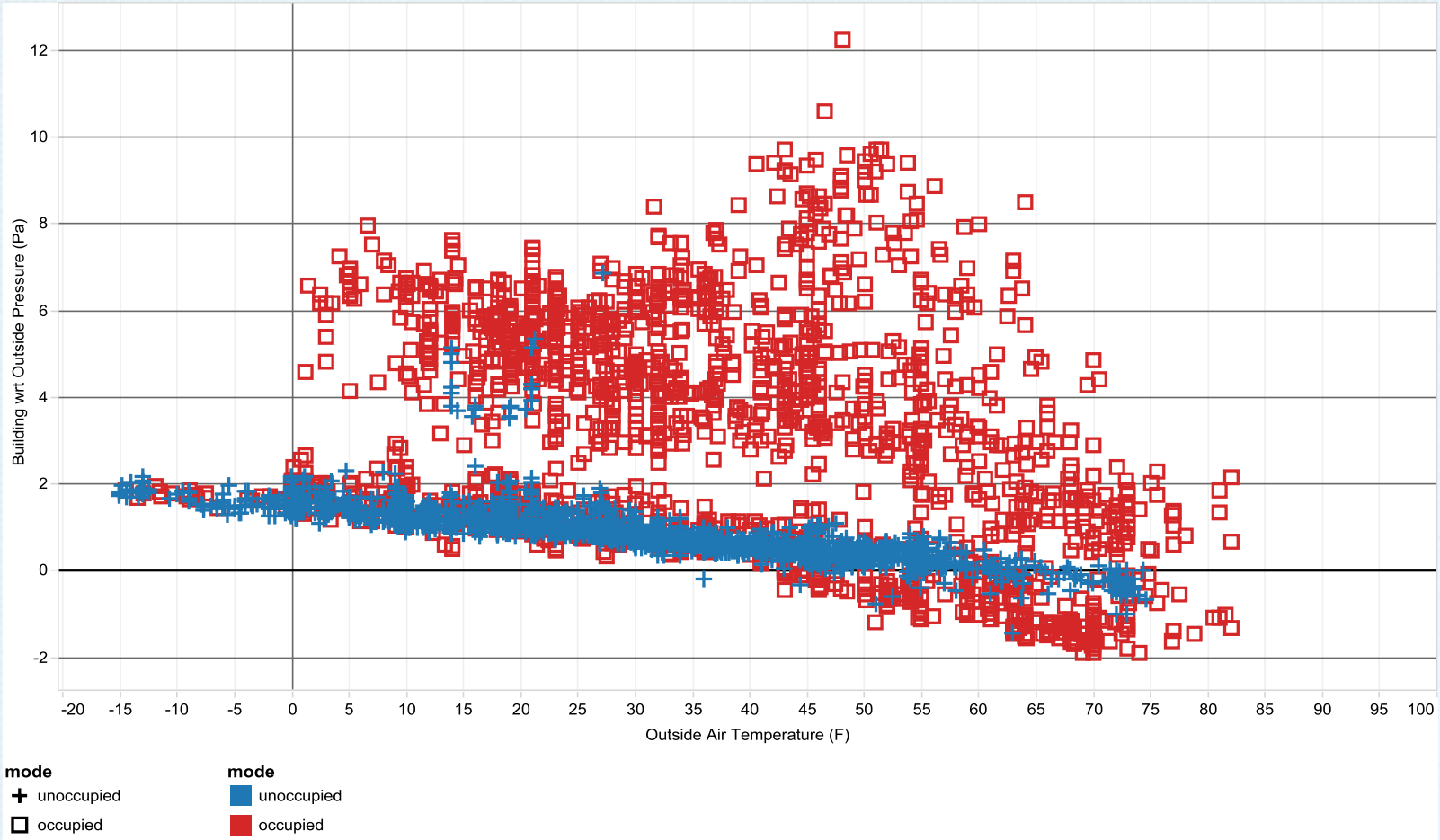


Mean
51%
0.05 cfm/ft^2
(6 sides)

Range
15% to 119%
0.02 to 0.14 cfm/ft^2

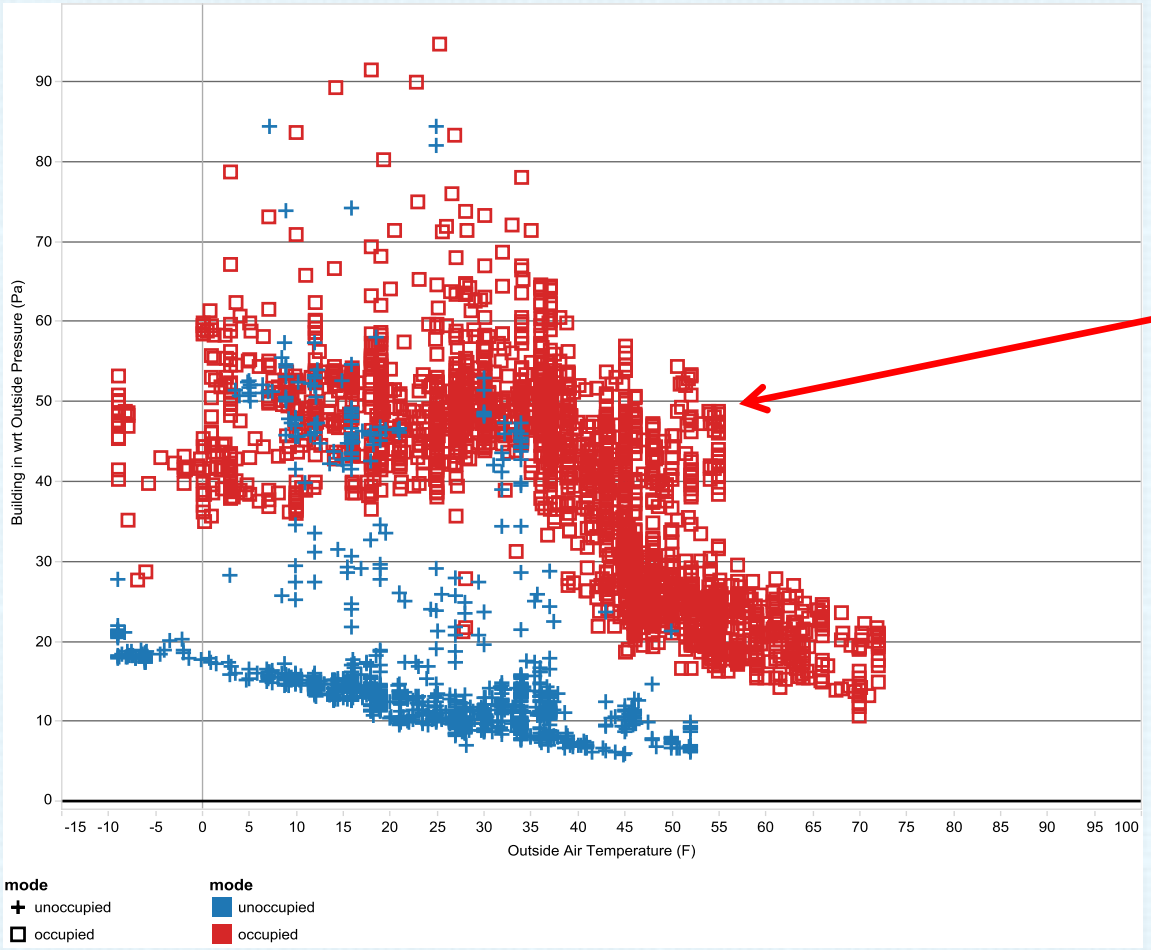
Two most recently built (1998 and 2007) had low leakage

Mechanical System Pressure Effects



Elementary School: 3 air handlers, 6 rooftops, and 6 fan coil units; combination of constant and variable air volume, most economize, no building pressure control

Mechanical System Pressure Effects



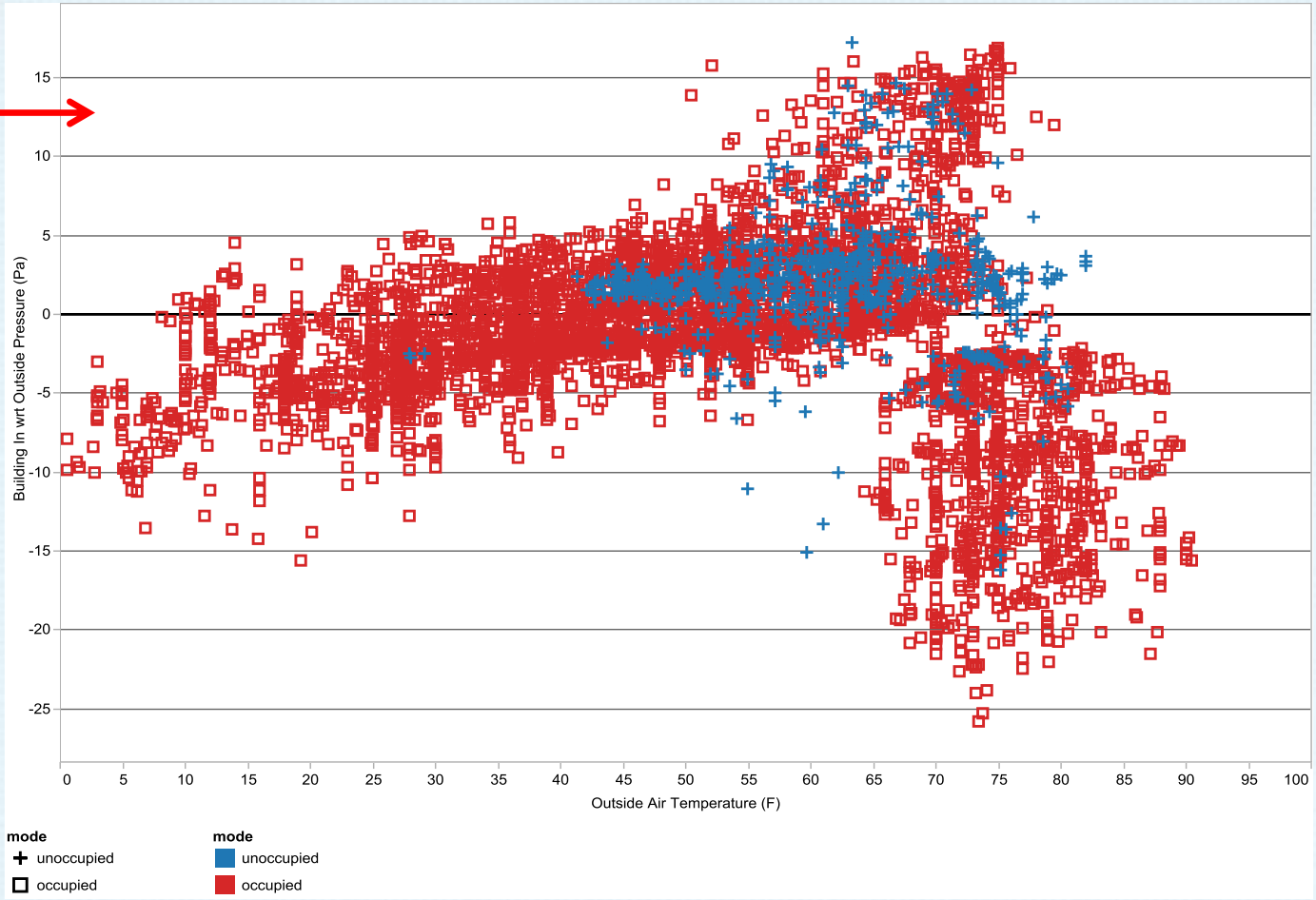
No/little infiltration, entry doors blow open

Stone at top of exterior wall replaced due to moisture damage

University Library: 246,000sf, 4 large air handlers that economize, two exhaust dampers not functioning, 1 of 4 air handlers off at night, no building pressure control

Mechanical System Pressure Effects

Control
Set point



Library/Office:1 constant and 4 variable volume air handlers, 1 of 5 operate during unoccupied mode, building pressure control (12.5Pa)- exhaust dampers (one sensor not functioning)

Summary

- Tight buildings: 84% tighter than U.S. average – due to cold climate location?
- Sealing = 10% reduction, more reduction and less expensive for leakier buildings
- Contractor over-estimated sealing area
- Pressurization leakiness greater by 22%, but gave similar percent sealing reductions
- Including mechanical systems increased leakage by 15 to 119% (0.02 to 0.14 cfm/ft^2)
- Mechanical systems have significant effect on building pressure and infiltration

Future Work

- Determine mechanical system pressure effect by outdoor air temperature and operating mode
- CONTAM models for pre & post sealing
- Develop simple methods for estimating mechanical pressure effect on infiltration reduction???

- Better methods for estimating air sealing leakage reduction