



Building Leakage Test Results

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NIST Results from US whole building tests


- ❖ 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
- ❖ Includes information on year built, building type, floor area, # stories, location, & wall type
- ❖ Used to model air infiltration energy loads and help establish leakage standards

NIST Results from US whole building tests

Dataset	Qty	6-sided at 75Pa (cfm/ft ²)			
		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
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All Buildings	387	0.72	0.63	0.03	4.28
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USACE & Navy	300	0.16		USACE Std = 0.25	
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Emmerich and Persily 2013: do not quote

NIST Results: IP and SI units

Dataset	Qty	6-sided at 75Pa (cfm/ft ²)				6-sided at 75Pa (m ³ /h*m ²)			
		Mean	Std Dev	Min	Max	Mean	Std Dev	Min	Max
Efficiency Vermont	36	0.35	0.38	0.03	1.78	6.4	6.9	0.5	32.3
ASHRAE RP 1478	16	0.29	0.20	0.06	0.75	5.3	3.7	1.0	13.6
Washington	18	0.40	0.15	0.11	0.64	7.2	2.8	2.0	11.6
Other VT/NH	79	0.54	0.40	0.05	1.73	9.8	7.3	0.9	31.5
Other	10	0.30	0.23	0.09	0.75	5.4	4.1	1.6	13.6
All new data	159	0.36	0.30	0.03	1.78	6.6	5.4	0.5	32.3

All previous data	228	0.92	0.70	0.09	4.28	16.7	12.7	1.6	77.9
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All Buildings	387	0.72	0.63	0.03	4.28	13.1	11.4	0.5	77.9
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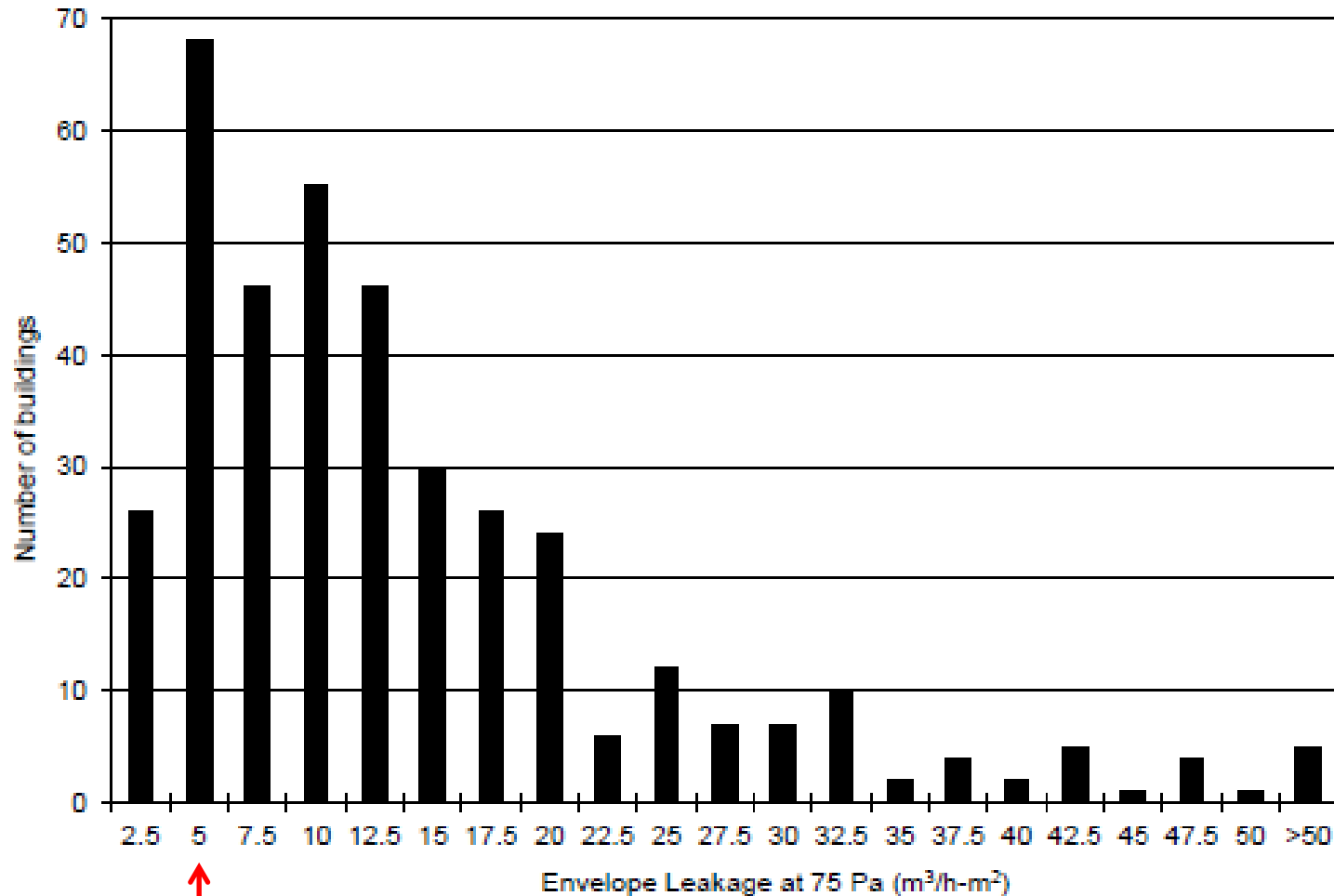
USACE & Navy	300	0.16
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USACE Std = 4.5

Emmerich and Persily 2013: do not quote

Multiply by 18.2 >>

NIST Results: Frequency Histogram



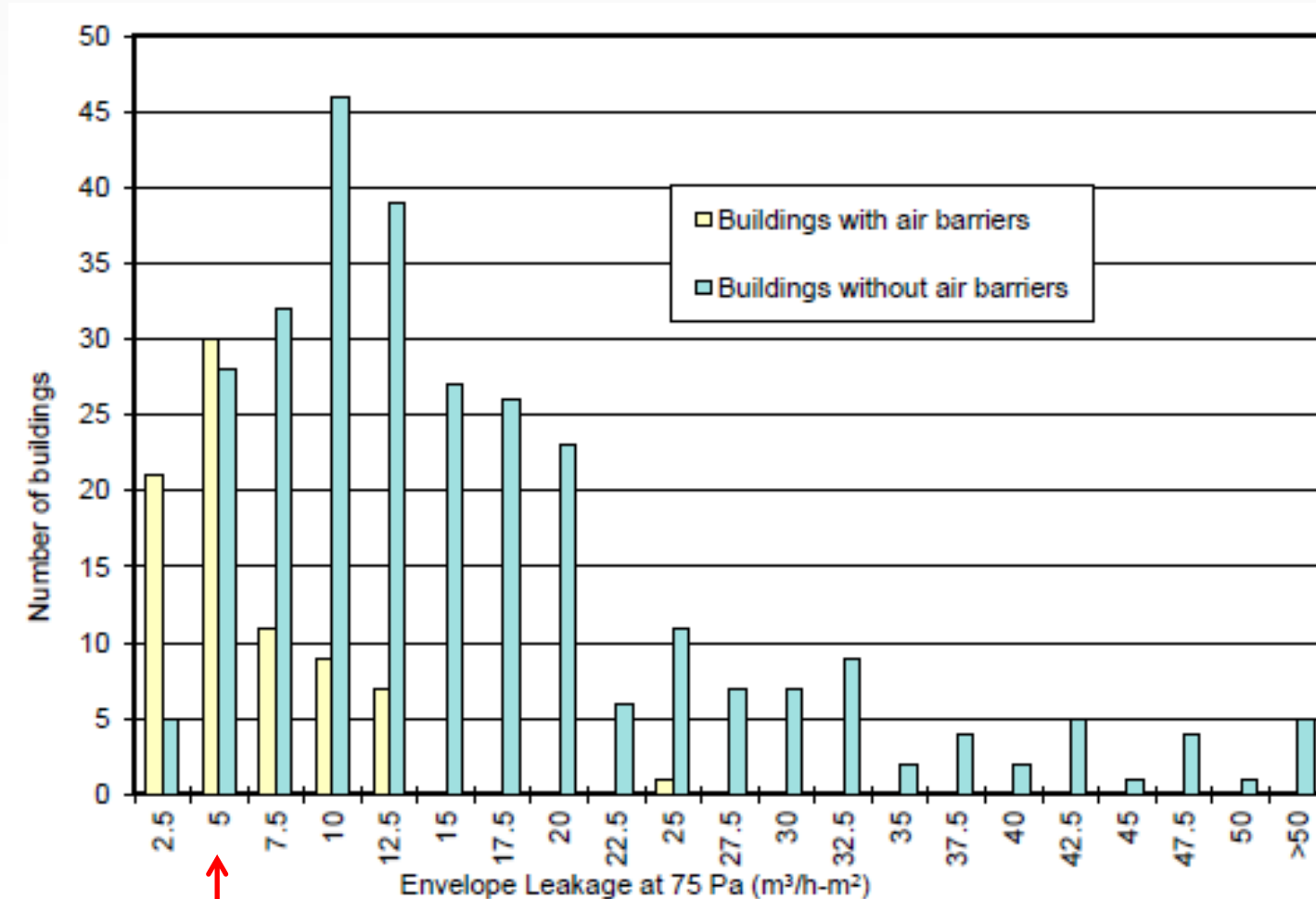
USACE Std = 4.5
20-25% meet Std

Multiply by 0.055 >> cfm/sf

Emmerich and Persily 2013: do not quote

NIST Results: Effect of Air Barrier

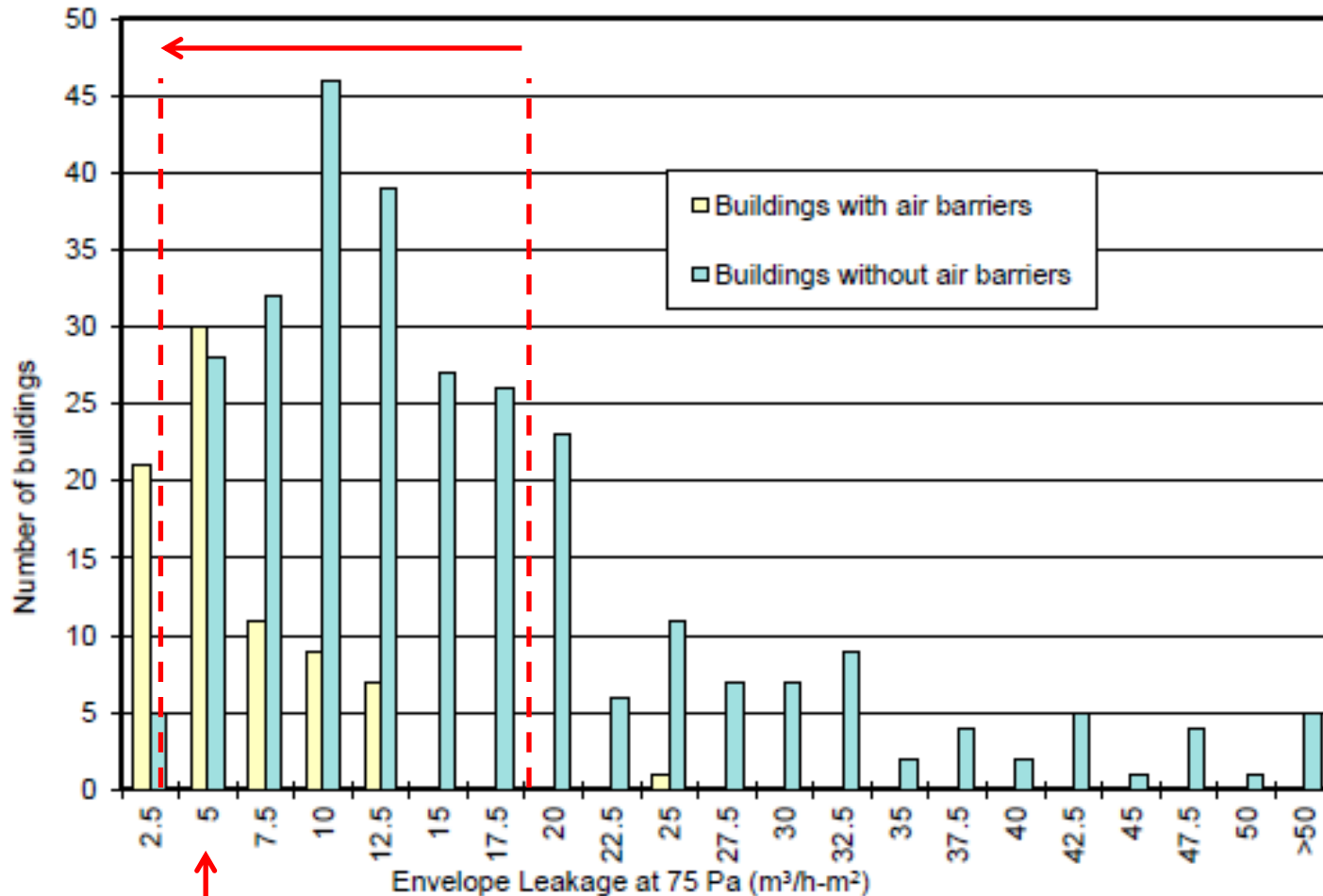
Buildings with air barrier are 70% tighter



USACE Std = 4.5

NIST Results: Model Air Barrier Effect

Compare no air barrier to good construction



USACE Std = 4.5

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, 24,000sf Office Building

g

City	Annual Average Infiltration (h^{-1})		Gas Savings		Electrical Savings		Total Savings
	Baseline	Target					
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, 12,000sf Retail

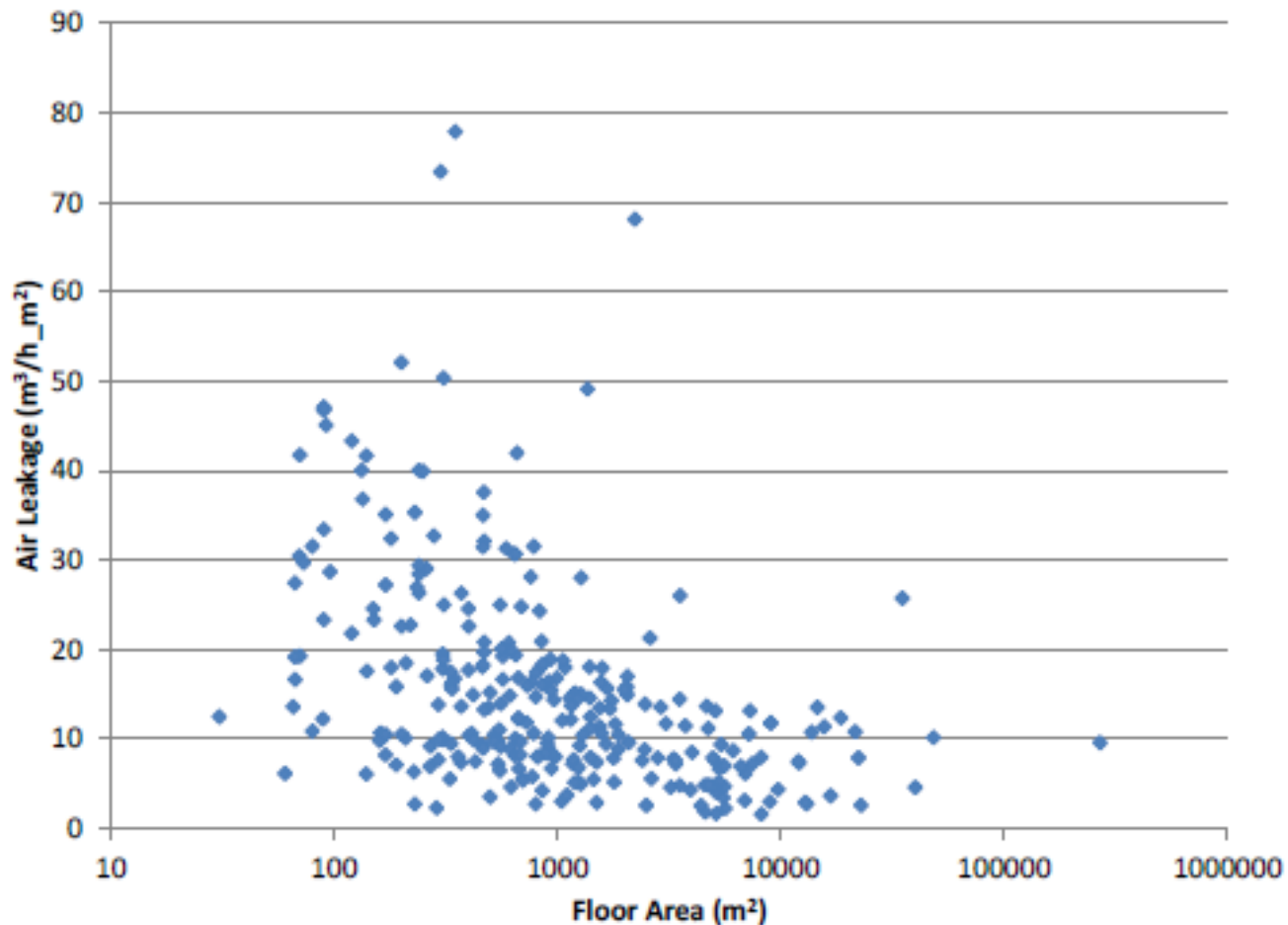
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City	Annual Average Infiltration (h^{-1})		Gas Savings		Electrical Savings		Total Savings
	Baseline	Target					
Bismarck	0.20	0.02	\$1,835	26 %	\$33	2 %	\$1,869
Minneapolis	0.22	0.02	\$1,908	28 %	\$364	18 %	\$2,272
St. Louis	0.24	0.01	\$1,450	38 %	\$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: do not quote

NIST Results: Effect of Building Size

Buildings > 54,000sf twice as tight



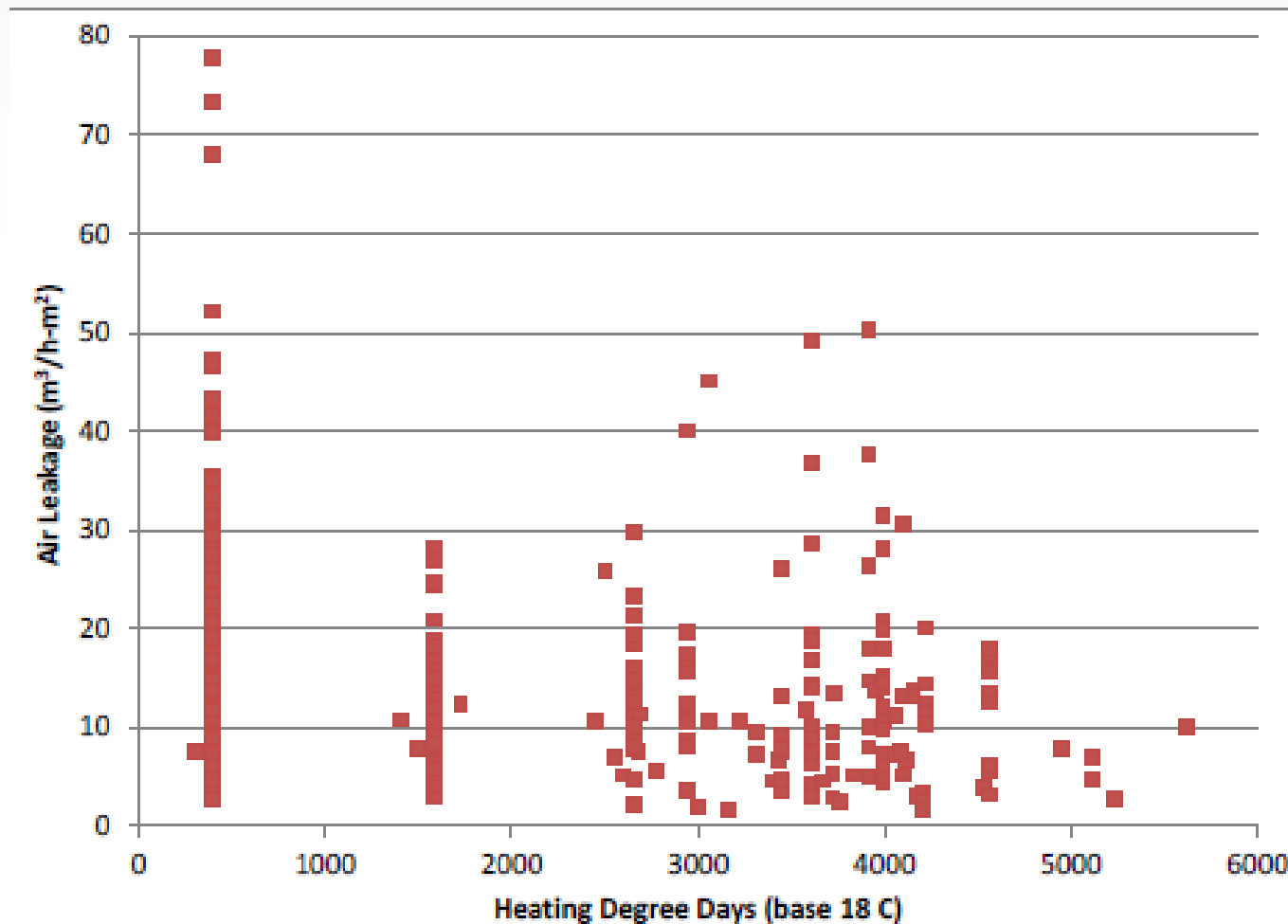
NIST Results: weak trends

- ❖ Tighter – office, education, public assembly & long-term health care
- ❖ Leakier – retail, restaurants, industrial

- ❖ Leakier exterior walls – frame, masonry/metal, & frame/masonry

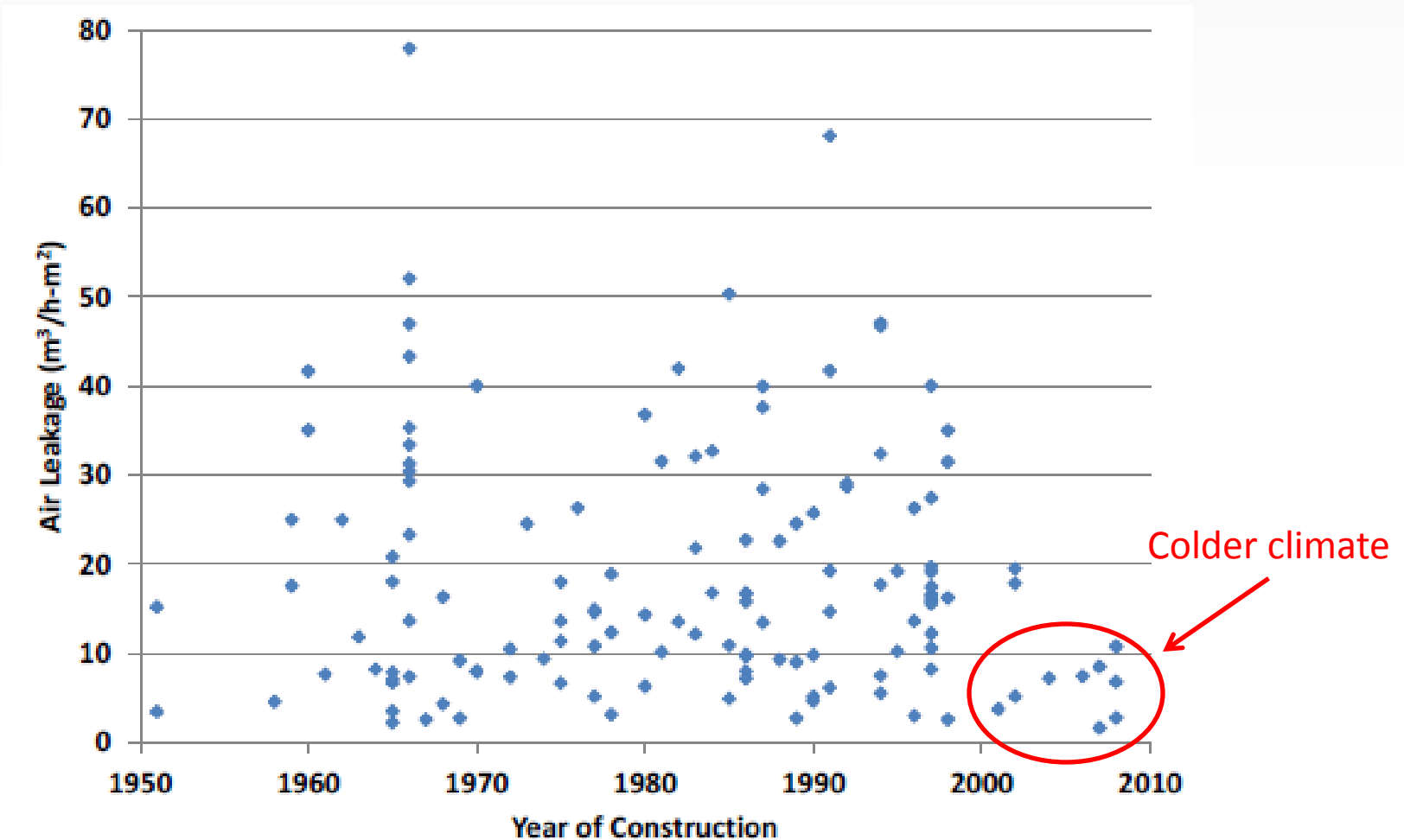
NIST Results: Effect of Climate

Heating degree days > 3,600 one third tighter



NIST Results: Effect of Age

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

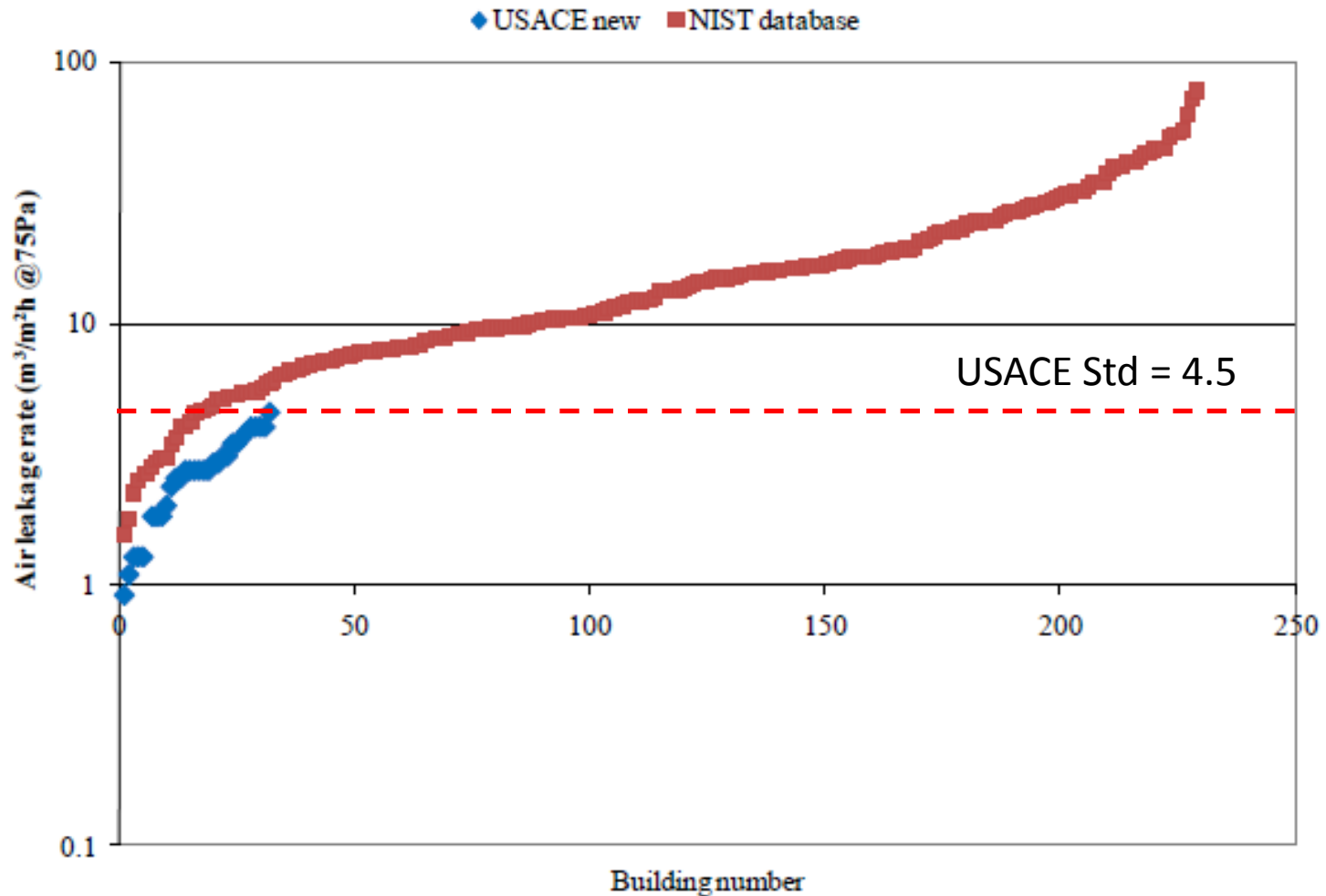


NIST Results: LEED buildings

- ❖ 23 LEED buildings; average = 0.29 cfm/ft²
- ❖ Significantly tighter than average of other 364 buildings
- ❖ Slightly (5%) leakier than other 56 buildings with an air barrier

USACE Results: significantly tighter

2011 database > only 10 – 15% pass USACE Std



ASHRAE Research Project: goals

- ❖ Collect whole building leakage results on newer, tall commercial and institutional buildings
- ❖ Identify test protocol issues and propose solutions for testing larger buildings
- ❖ Collect data on HVAC penetration (e.g. damper) leakage

ASHRAE Research: key players

- ❖ Wiss, Janney, Elstner, Associates, Inc. Principal Researcher
- ❖ Terry Brennan, Camroden Associates
- ❖ Gary Nelson and Collin Olson, The Energy Conservatory
- ❖ Dave Bohac, Center for Energy and Environment
- ❖ Larry Harmon, Air Barrier Solutions
- ❖ Jim Cummings and Chuck Withers, FSEC

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)

ASHRAE Research Project: buildings

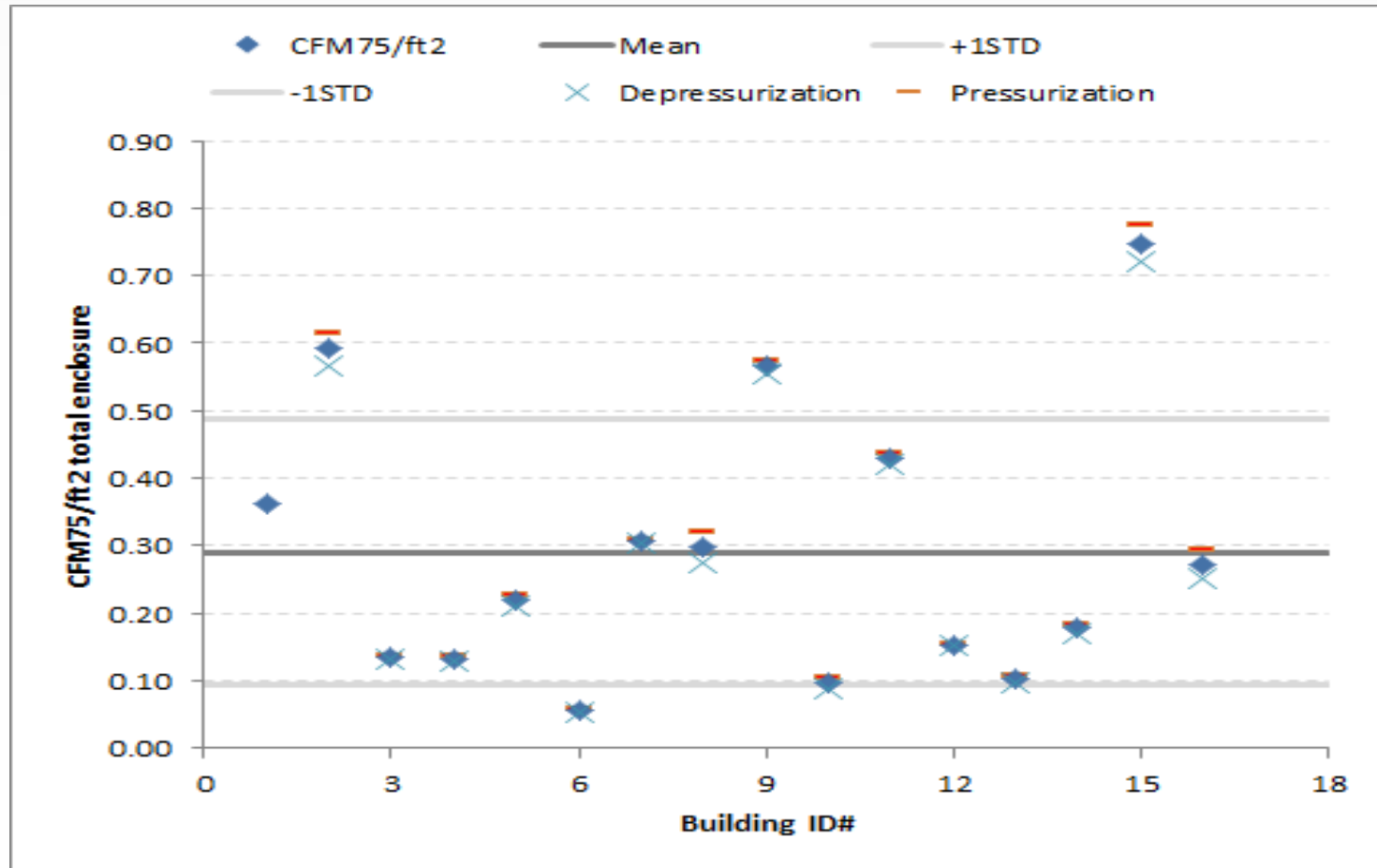


ASHRAE Research Project: buildings



ASHRAE Research Project: results

6-sides leakage average = 0.29 cfm/ft² (0.20 std. dev.), min= 0.06, max= 0.75



NIST Building Infiltration & Energy Models

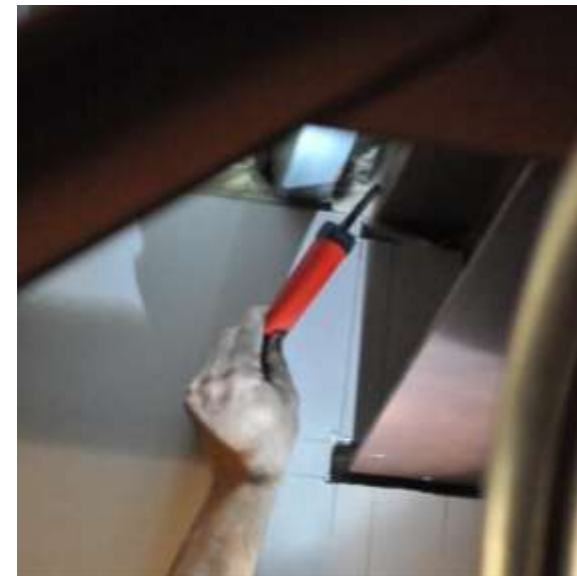
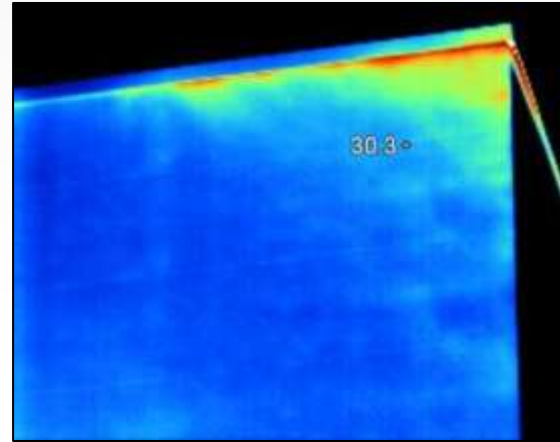
- ❖ TRNSYS multizone infiltration and energy model
- ❖ Includes weather and HVAC pressure effects
- ❖ Compared air infiltration and energy use for:
 - “typical” - no air barrier reported leakage (4x USACE)
 - “target” – good practice (40% below USACE)
- ❖ Five US cities representing different climate zones
- ❖ Two-story, 24,000sf office and one-story 12,000sf retail

ASHRAE Research Project: leakage results

- ❖ Average = 0.29 cfm/ft²
- ❖ Green building = 0.32 cfm/ft²; others = 0.22 cfm/ft²
- ❖ Air barrier specified and envelope expert = 0.13 cfm/ft²; others = 0.39 cfm/ft²
- ❖ 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



Minnesota Leakage Study: work scope

- ❖ Conduct investigations on 25 buildings: floor area of 25,000 to 500,000 ft²
- ❖ 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

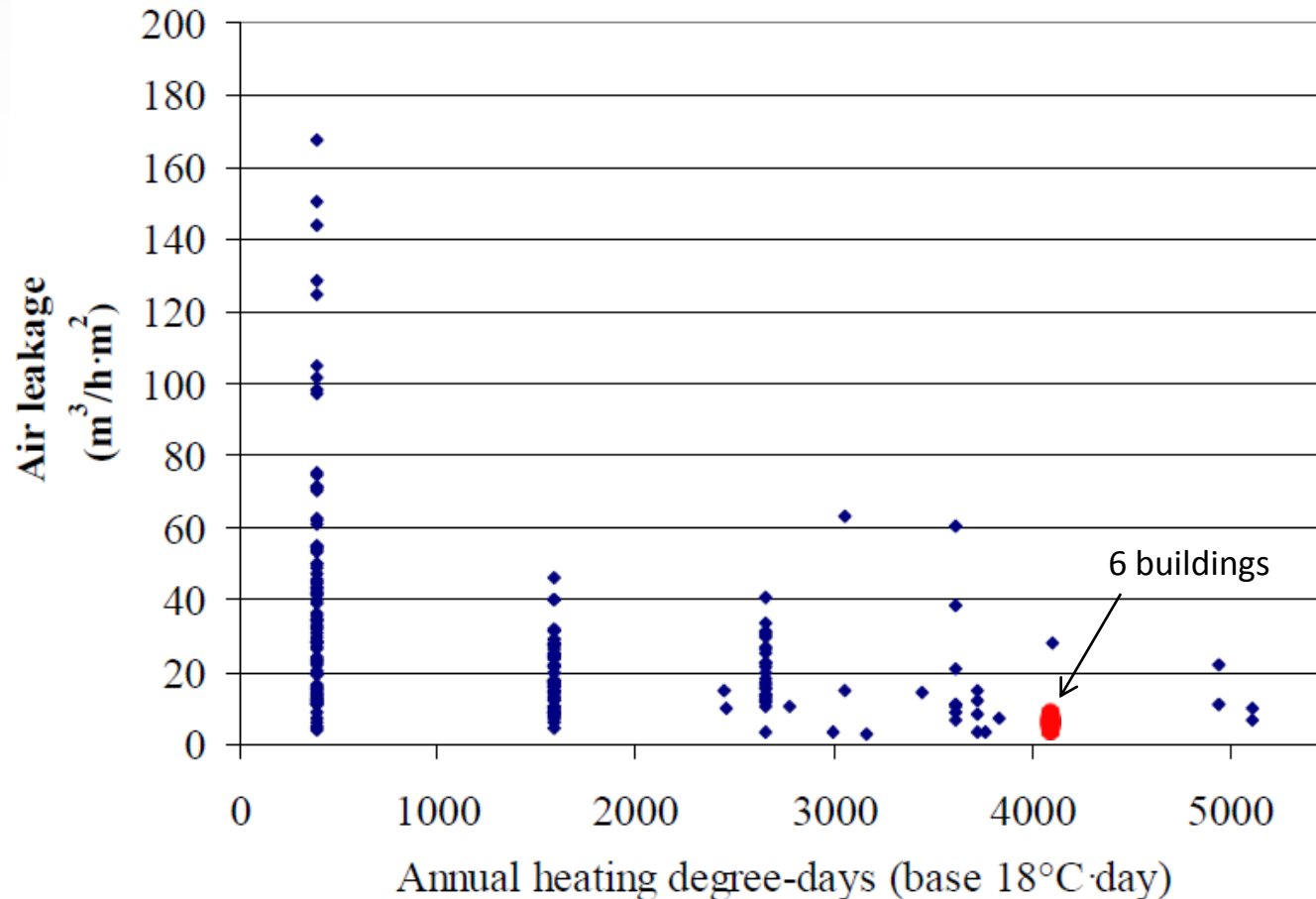
Minnesota Leakage Study: leakage results

Building ID	Envelope Area (ft ²)		Air Leakage at 75Pa				Constr Year
	5 Sides ¹	6 Sides ²	(cfm)	5 Sides		6 Sides	
				(cfm/ft ²)	(m ³ /h·m ²)	(cfm/ft ²)	
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/ft²

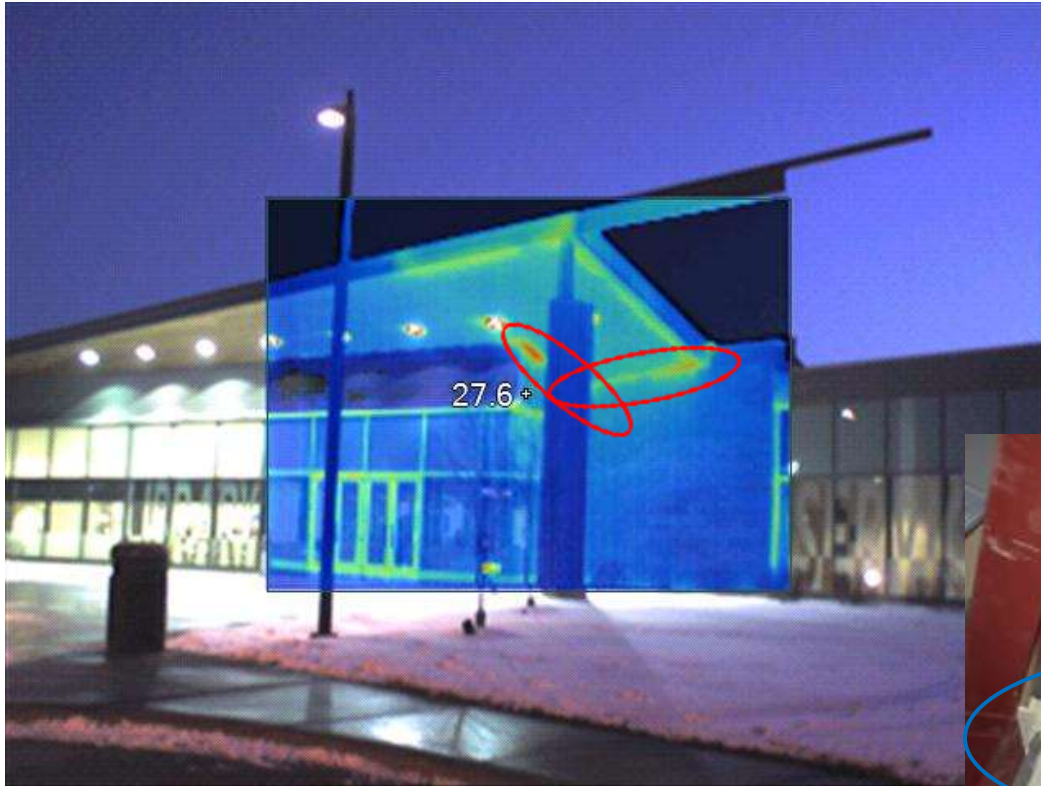
Minnesota Leakage Study: leakage results

Colder climate = tighter????



Minnesota: air sealing focused on roof/wall

Canopy leakage at exterior wall

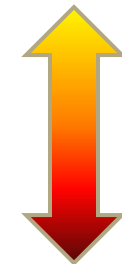


Minnesota: air sealing reduction

“Tight” buildings tightened by 10%

Building ID	Air Leakage at 75Pa			
	(cfm)		Reduction	
	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%

Leakier



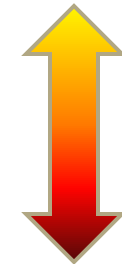
Tighter

Minnesota: air sealing reduction

More expensive to seal tighter buildings??

Building ID	Air Sealing Cost		
	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

Leakier

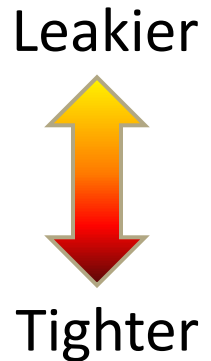


Tighter

Minnesota: air sealing reduction

Contractor estimates better for leakier buildings??

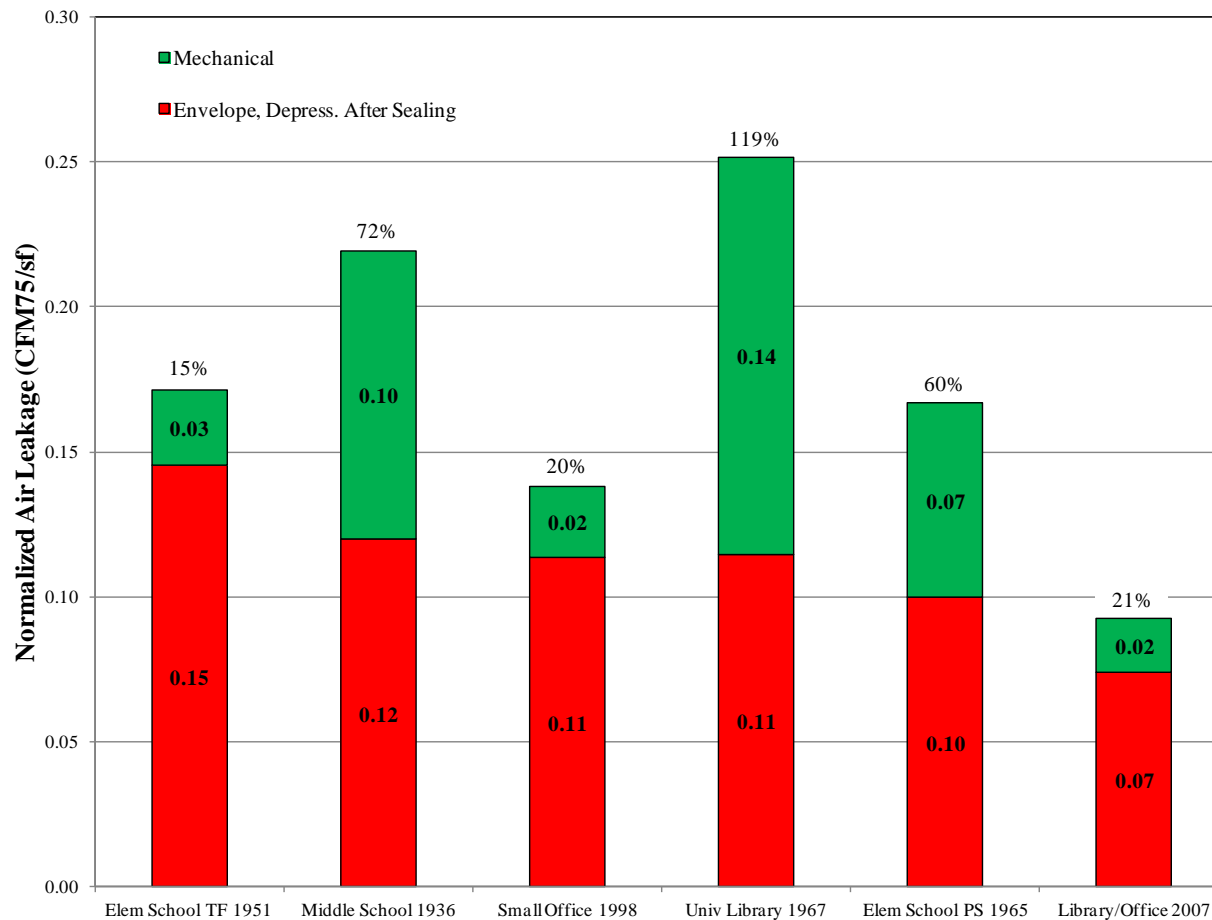
Building ID	Leakage Area				Sealed Area (sf)		
	EqLA (ft ²)		Reduction		Contractor Estimated		Meas/Est
	Pre	Post	(ft ²)	(%)	Roof/Wall	Total	
Elem School TF	15.2	12.5	2.7	18%	8.84	11.49	0.31
Middle School	16.6	13.8	2.8	17%	11.73	14.98	0.24
Small Office	4.6	4.1	0.5	10%			
Univ Library	13.1	12.8	0.2	2%			
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%			



EqLA < Estimated sealing

Minnesota: HVAC penetration leakage

Part of building envelope when not operating



Mean
51%
0.05 cfm/ft²
(6 sides)

Range
15% to 119%
0.02 to 0.14 cfm/ft²

Questions?