February 25, 2014

# ENERGY SAVINGS FROM AIR SEALING LARGE BUILDINGS

## Energy Design Conference & Expo, Duluth, MN


**Dave Bohac P.E.**

Director of Research

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# 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
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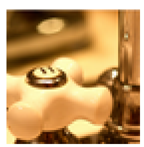
**Electric Thermal Storage vs. Heat Pump Water Heaters**



Which residential water heating technology is best for meeting electricity energy saving goals? It will depend if the goal is reducing total consumption or lowering peak demand.

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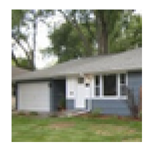
**CEE Housing Solutions Home Sells**



November 4, 2013 This past Friday, November 1st, the CEE Housing Solutions home in Richfield sold.

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**CEE Staff Member Presents on Energy Audits and Retro-Commissioning Webinar**

October 28, 2013 Chris is presenting on the outcomes and benefits of PBEEEP, Minnesota's Public Building Retro-Commissioning Program.

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### Featured Staff

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**Mark Hancock, P.E.**
Senior Mechanical Engineer
Full Bio

**Brenda Yaritz**
Senior Loan Officer
Full Bio

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# Project Team

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- Air Barrier Solutions
  - Larry Harmon
- The Energy Conservatory
  - Gary Nelson
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  - Peter Burns

Air Leakage Test Staff:
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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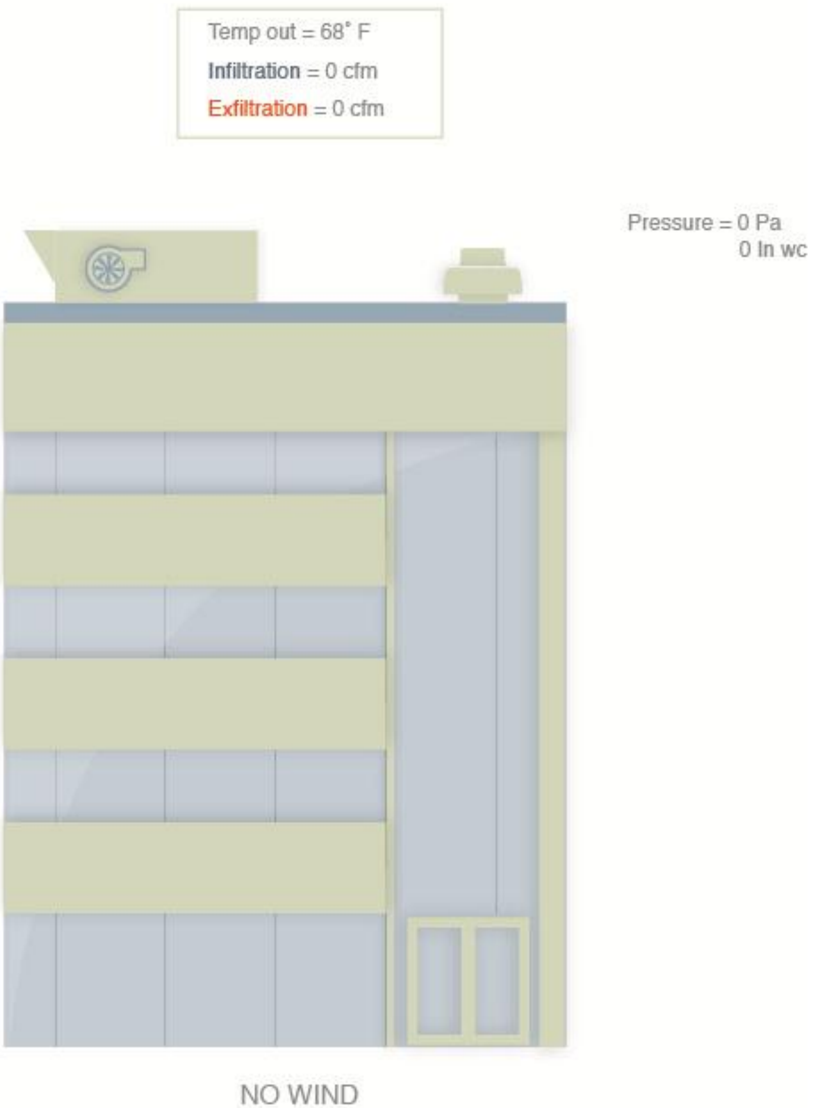
# Why do we care about building air leakage?

- 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

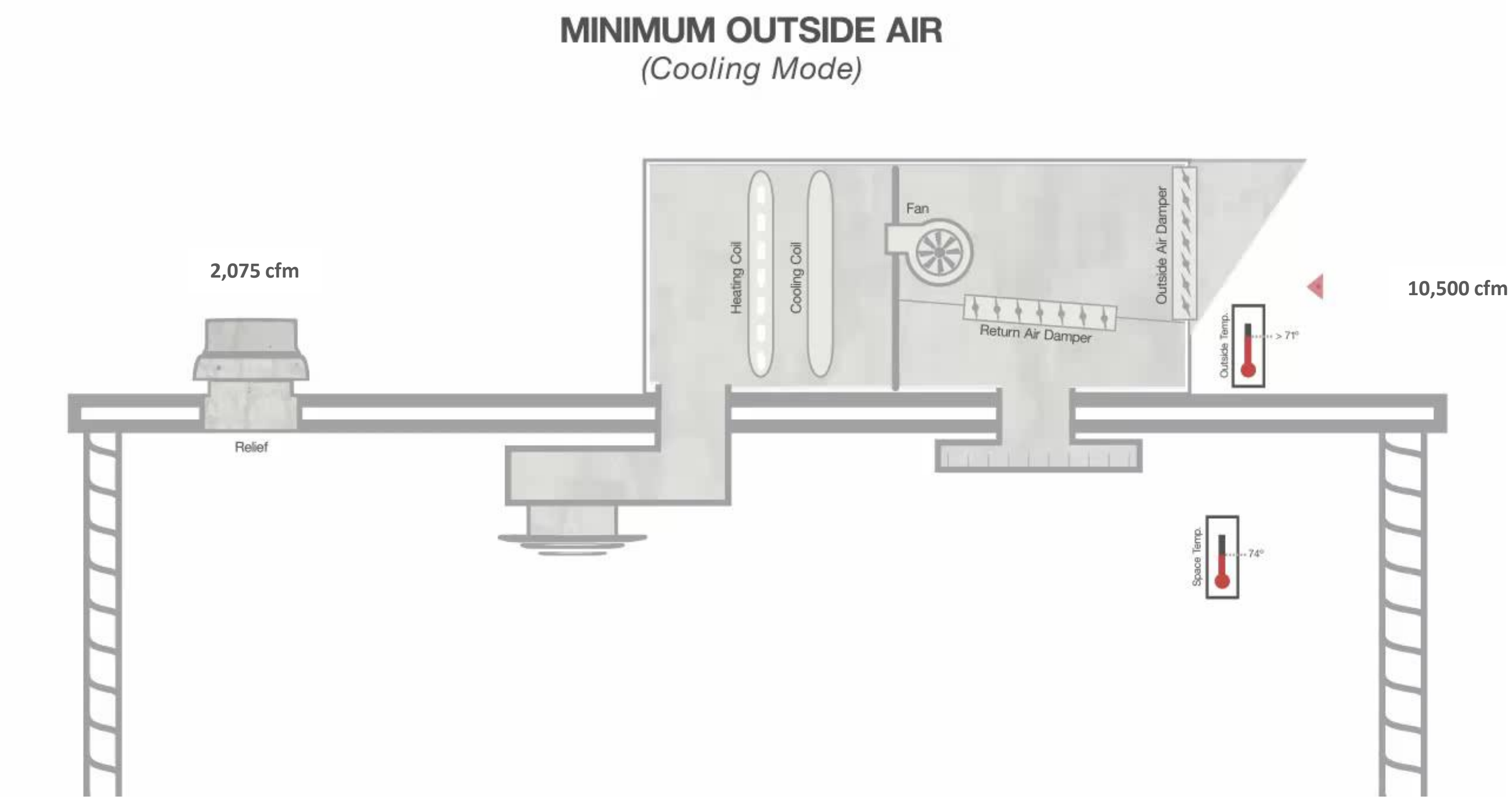
## WARM WEATHER - HVAC OFF




## WARM WEATHER - HVAC ON


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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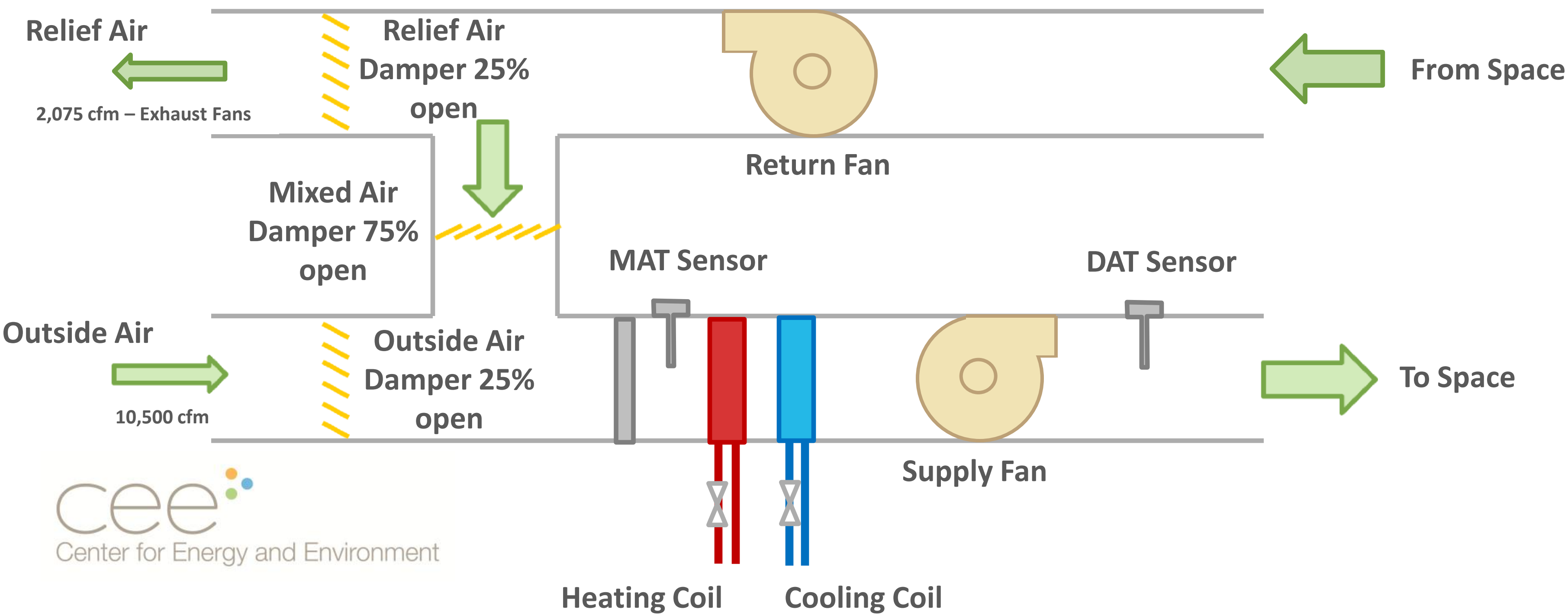
# Single-zone Constant Volume AHU

- 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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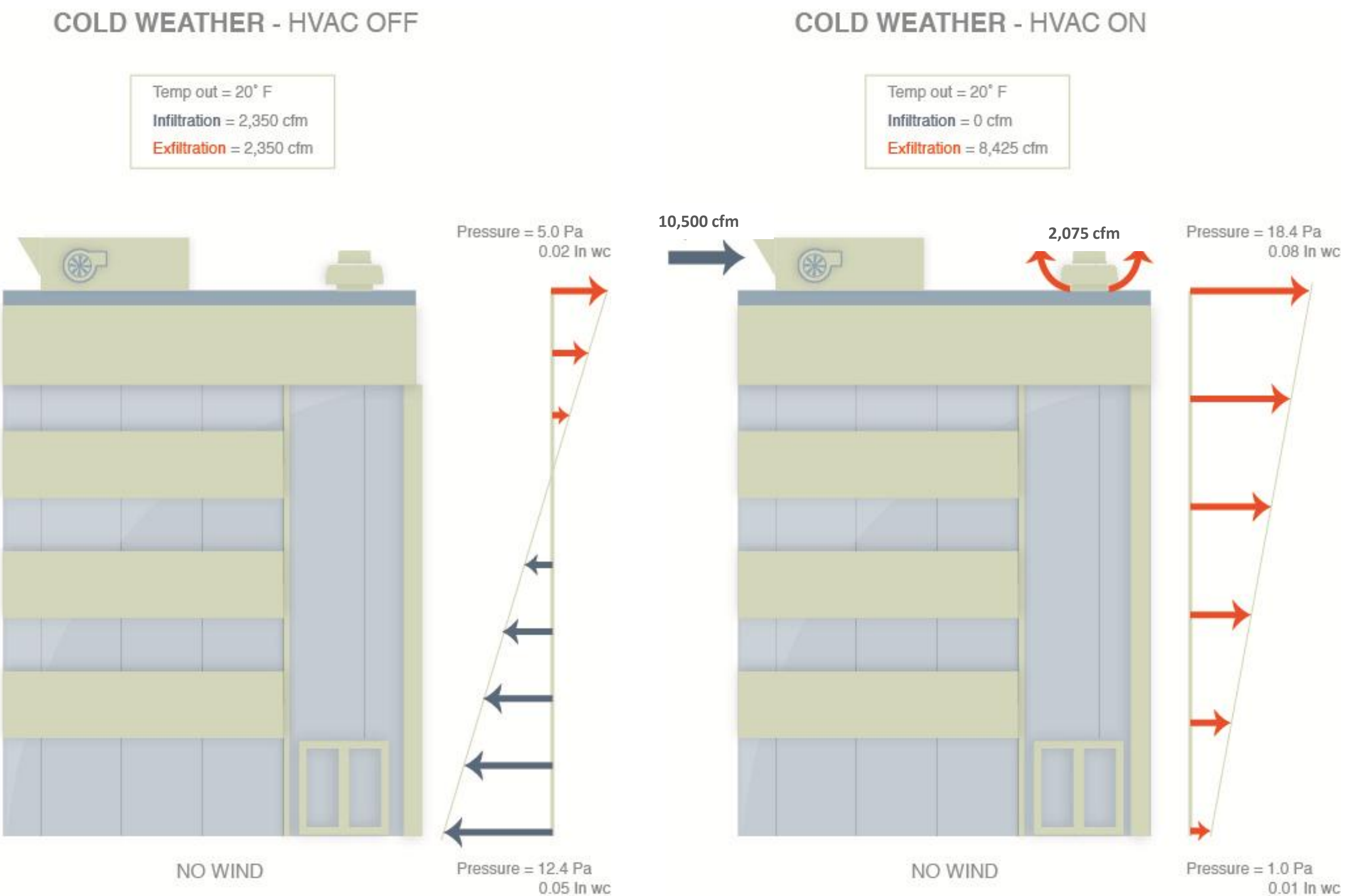
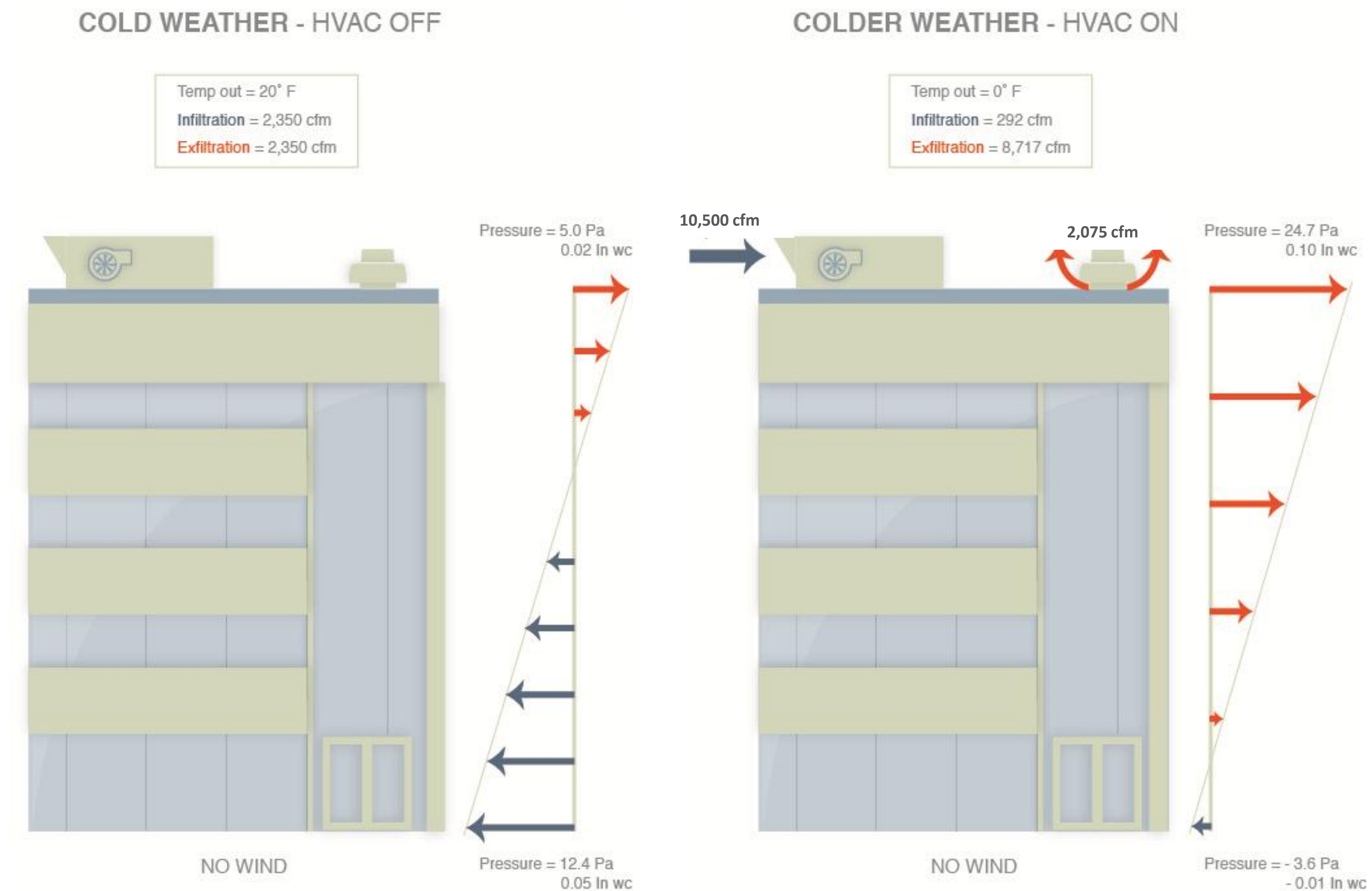
# Air Handler Pressurization




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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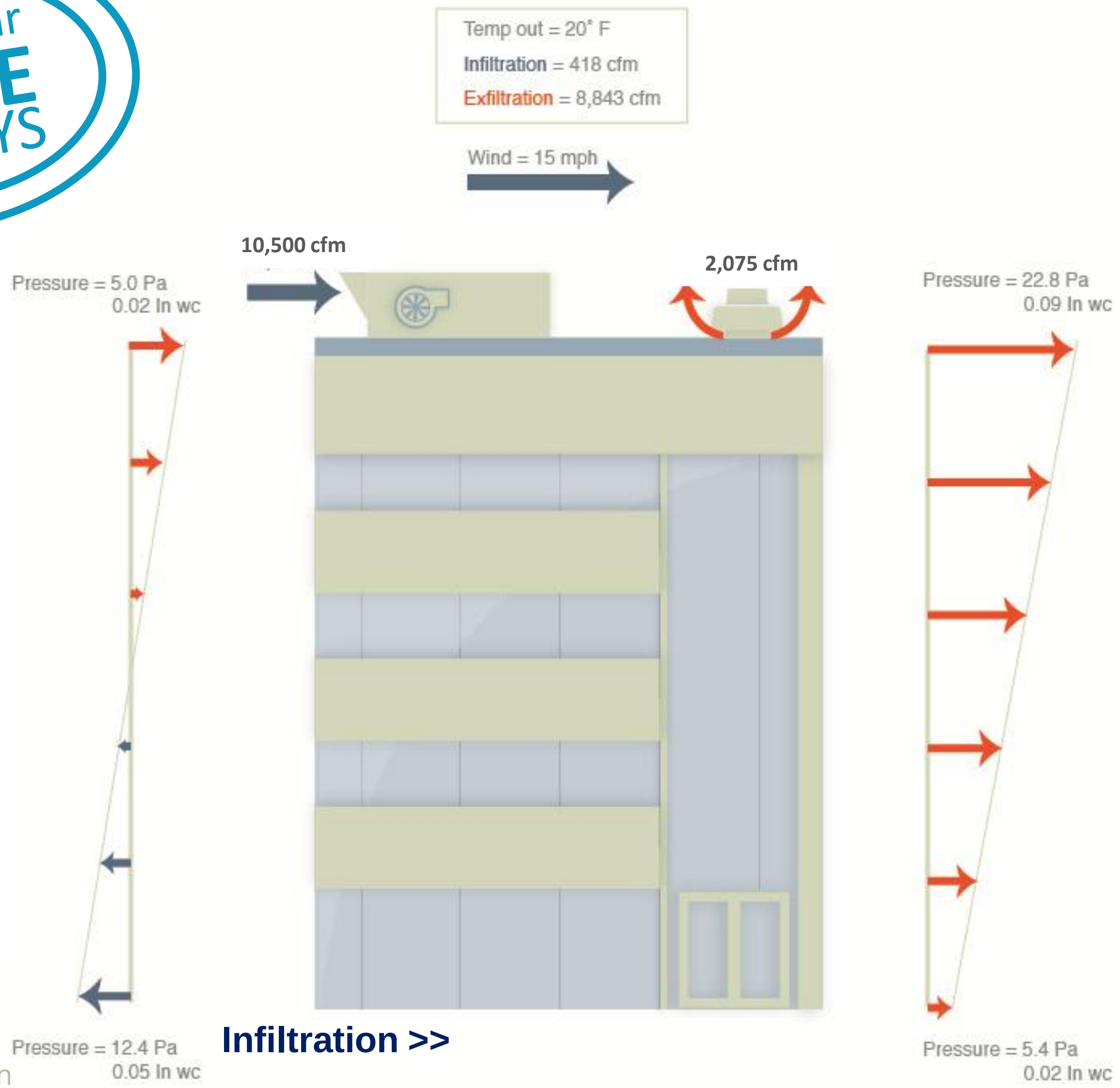


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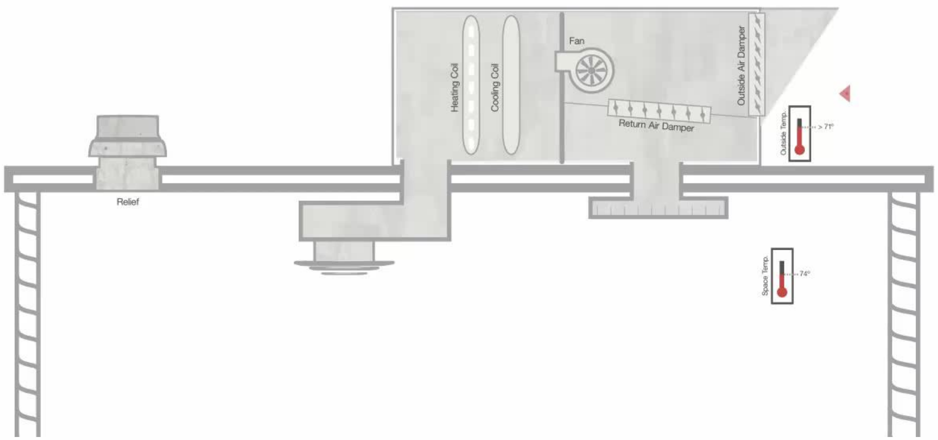
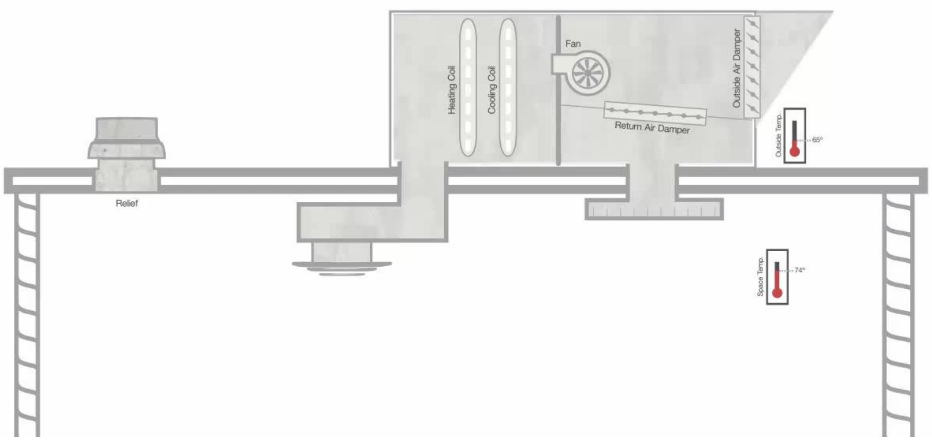
4 Story 60,000sf Office Building: leakage = 27,000 cfm@75Pa, 0.5 cfm@75/ft$^2$

# Roof Top Unit Operation

**MINIMUM OUTSIDE AIR**
*(Cooling Mode)*




**FULLY ECONOMIZED**

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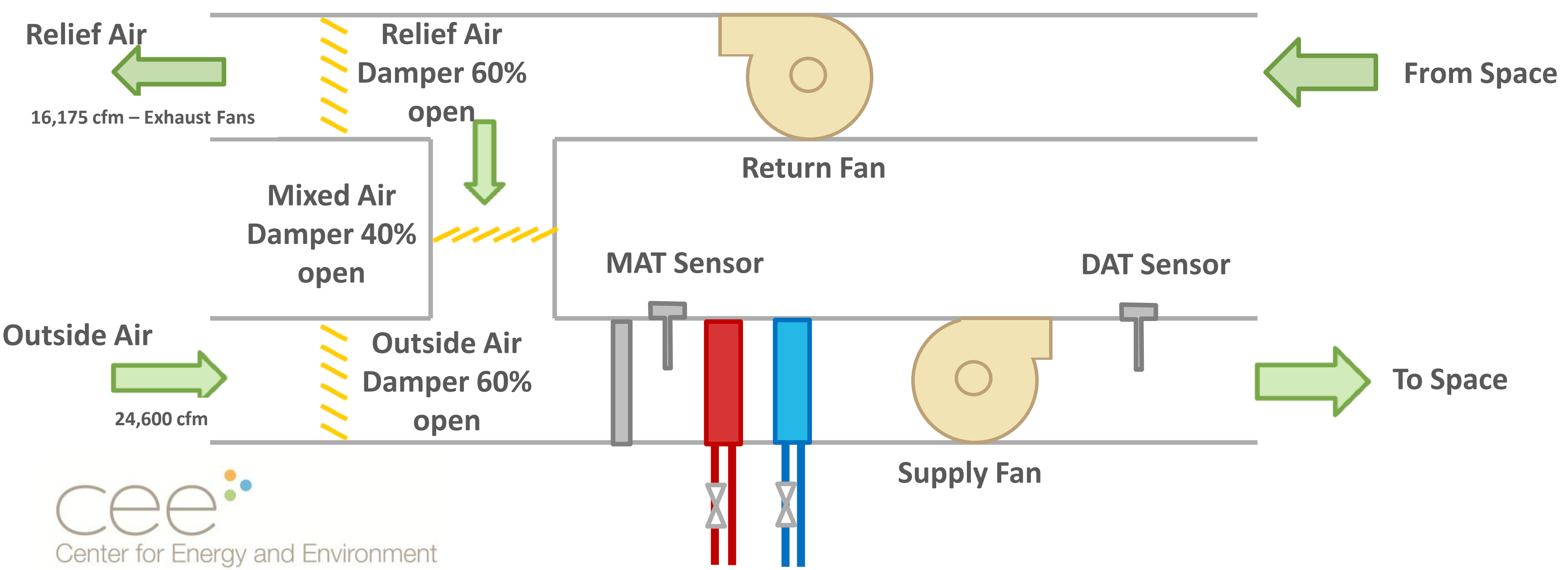
# Single-zone Constant Volume AHU

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

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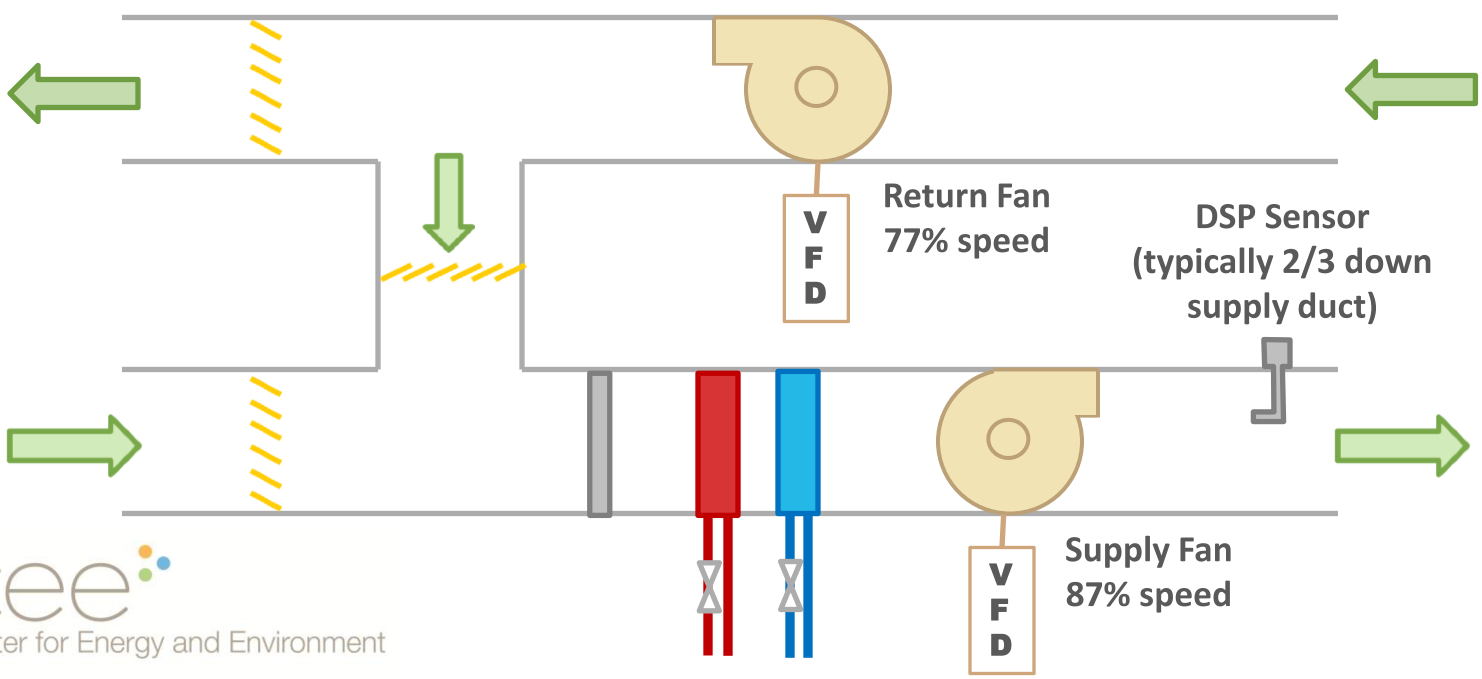
# Variable Volume AHU with VAV Boxes

- 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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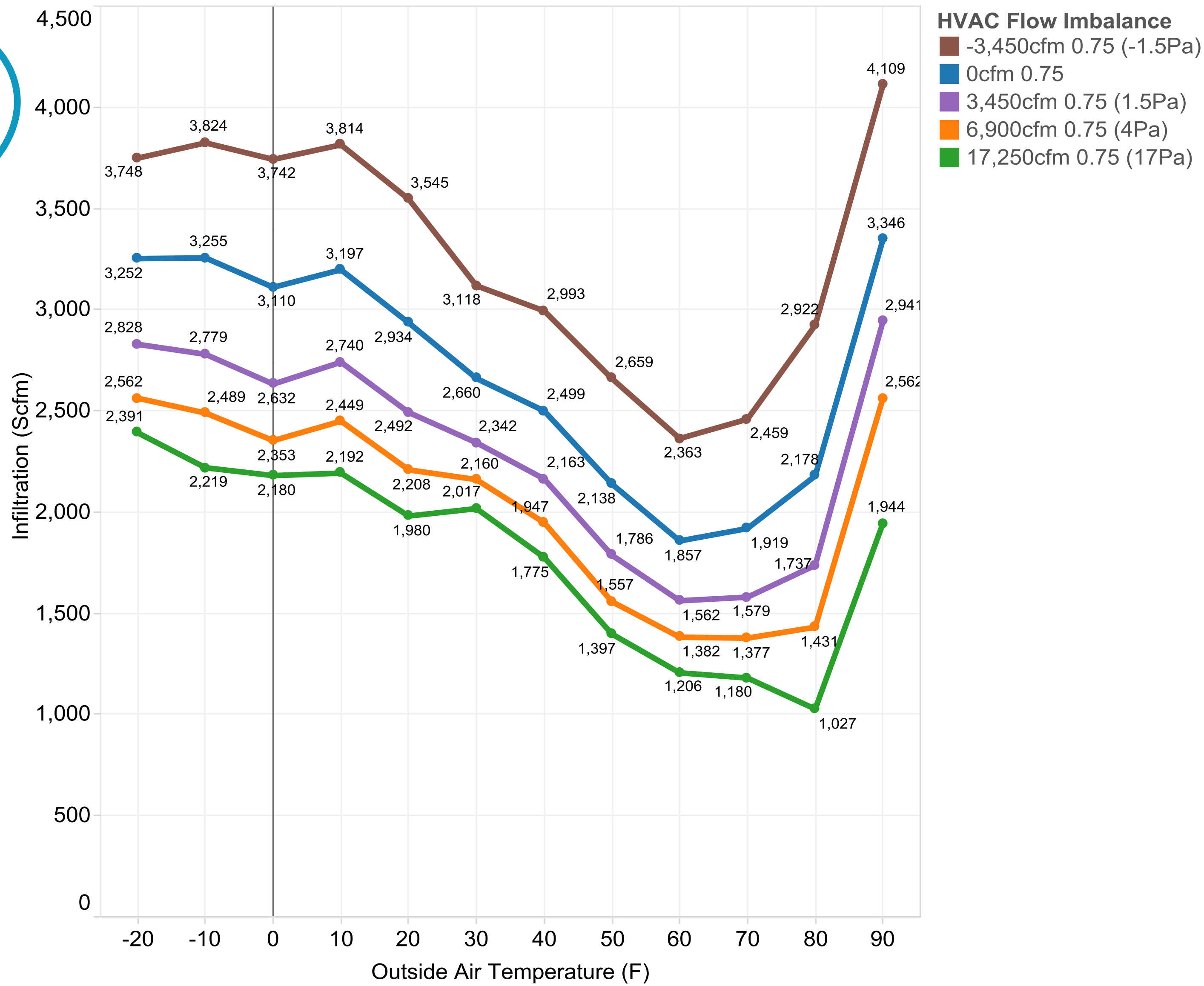
# Model Infiltration: Range of Flow Imbalance

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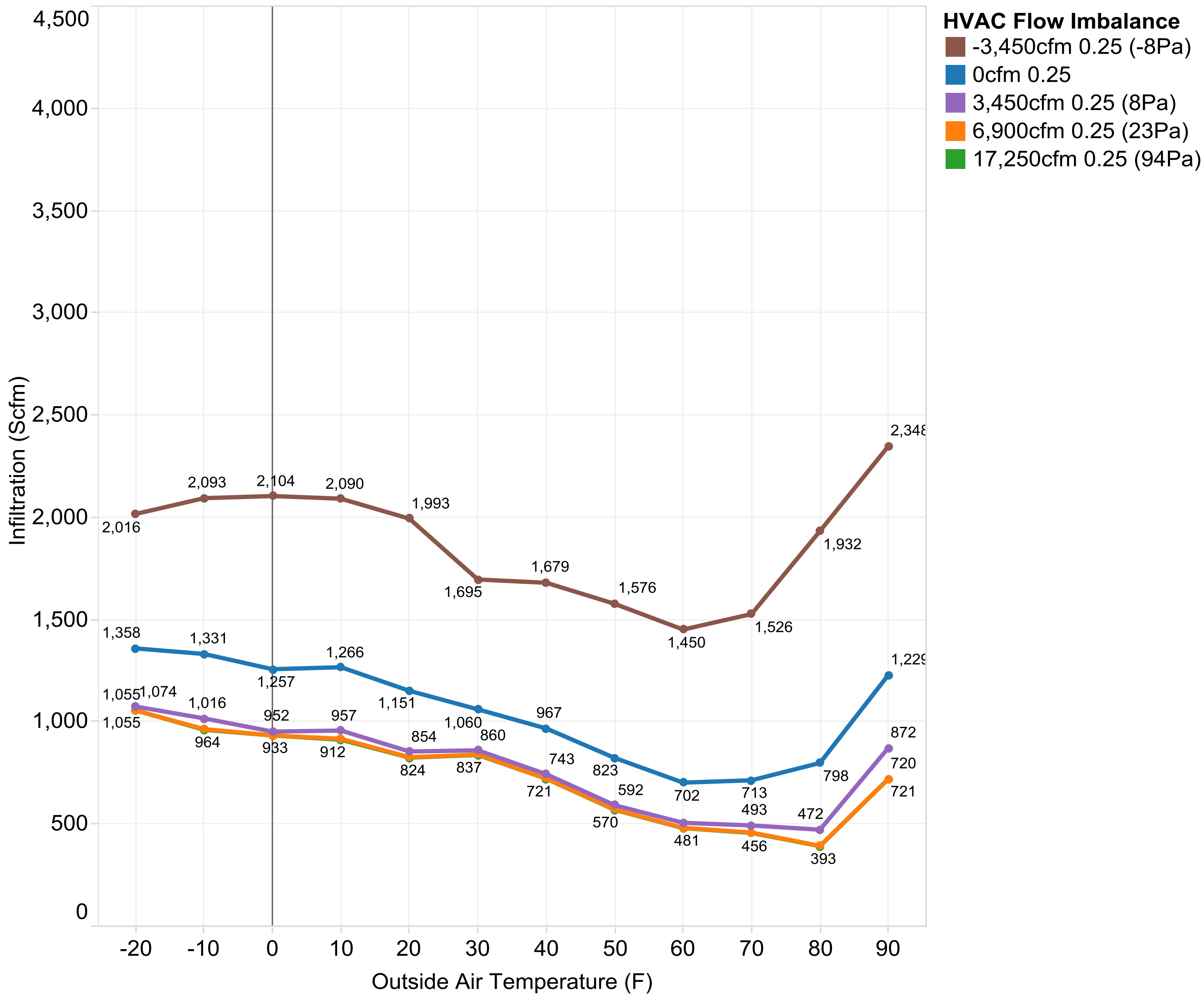
1 Story 60,560ft² Elementary School: leakage = 44,670 cfm@75Pa (0.75cfm@75/ft²)

# Model Infiltration: Range of Flow Imbalance

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1 Story 60,560ft$^2$ Elementary School: leakage = 14,890 cfm@75Pa (0.25cfm@75/ft$^2$)

# 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 |

# Model Infiltration: Range of Flow Imbalance

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

| | HVAC Flow Imbalance, OA - EA (cfm) | | | | |
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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

# Air Leakage Test Video

This slide contains a 5 minute video that provides an overview of the whole building air leakage test process.

The video can be found on CEE's web site at:

www.mncee.org/Innovation-Exchange/Projects/Current/Capturing-energy-Savings-from-Large-Building-Envel/

# 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

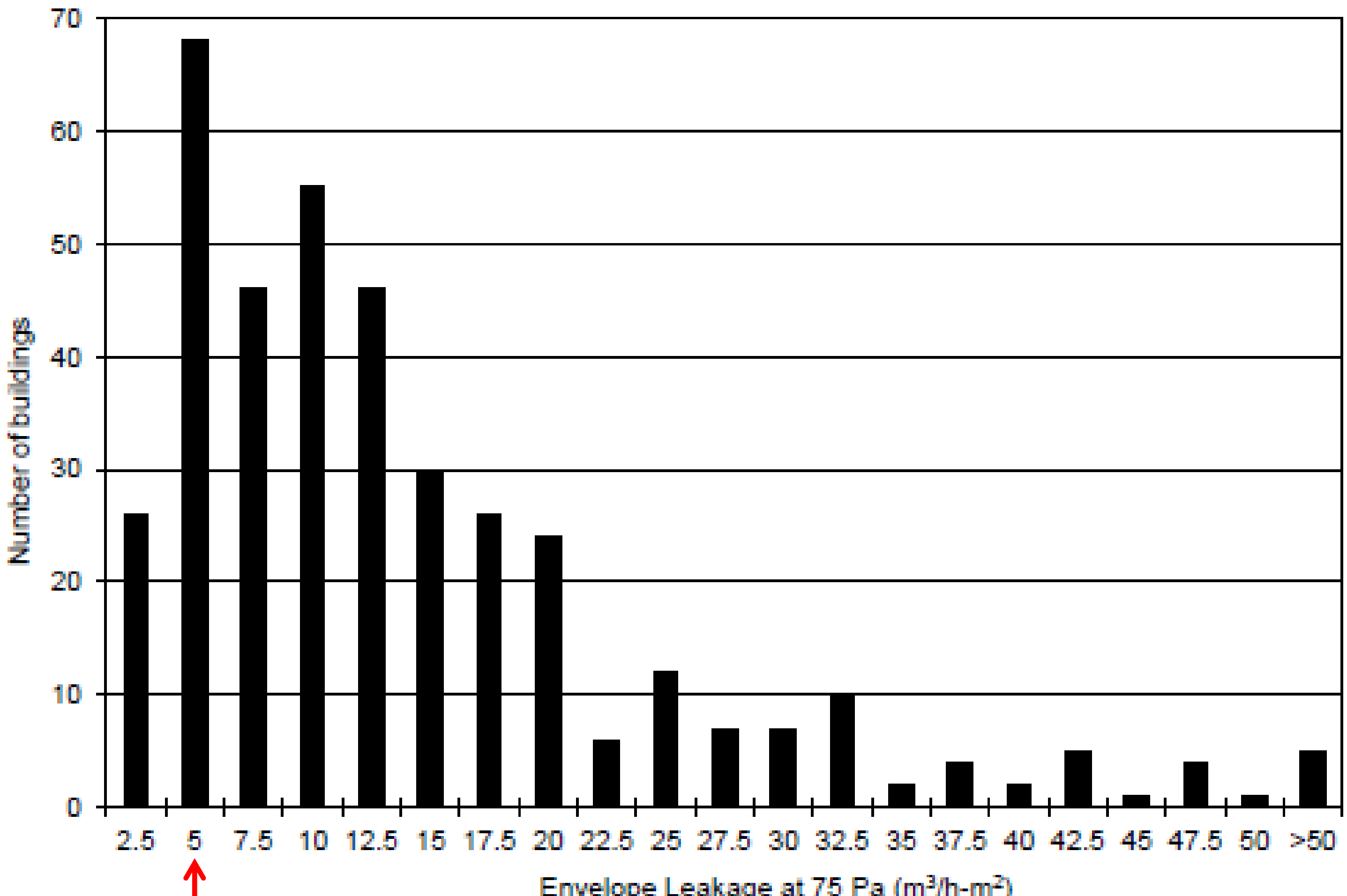
# NIST Results from US whole building tests

| 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** |
| **All Buildings** | **387** | **0.72** | **0.63** | **0.03** | **4.28** |
| **USACE & Navy** | **300** | **0.16** | | | |

USACE Std = 0.25

Emmerich and Persily 2013

# NIST Results: Frequency Histogram




USACE Std = 4.5

20-25% meet Std

Multiply by 0.055 >> cfm/ft²

Emmerich and Persily 2013

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# 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

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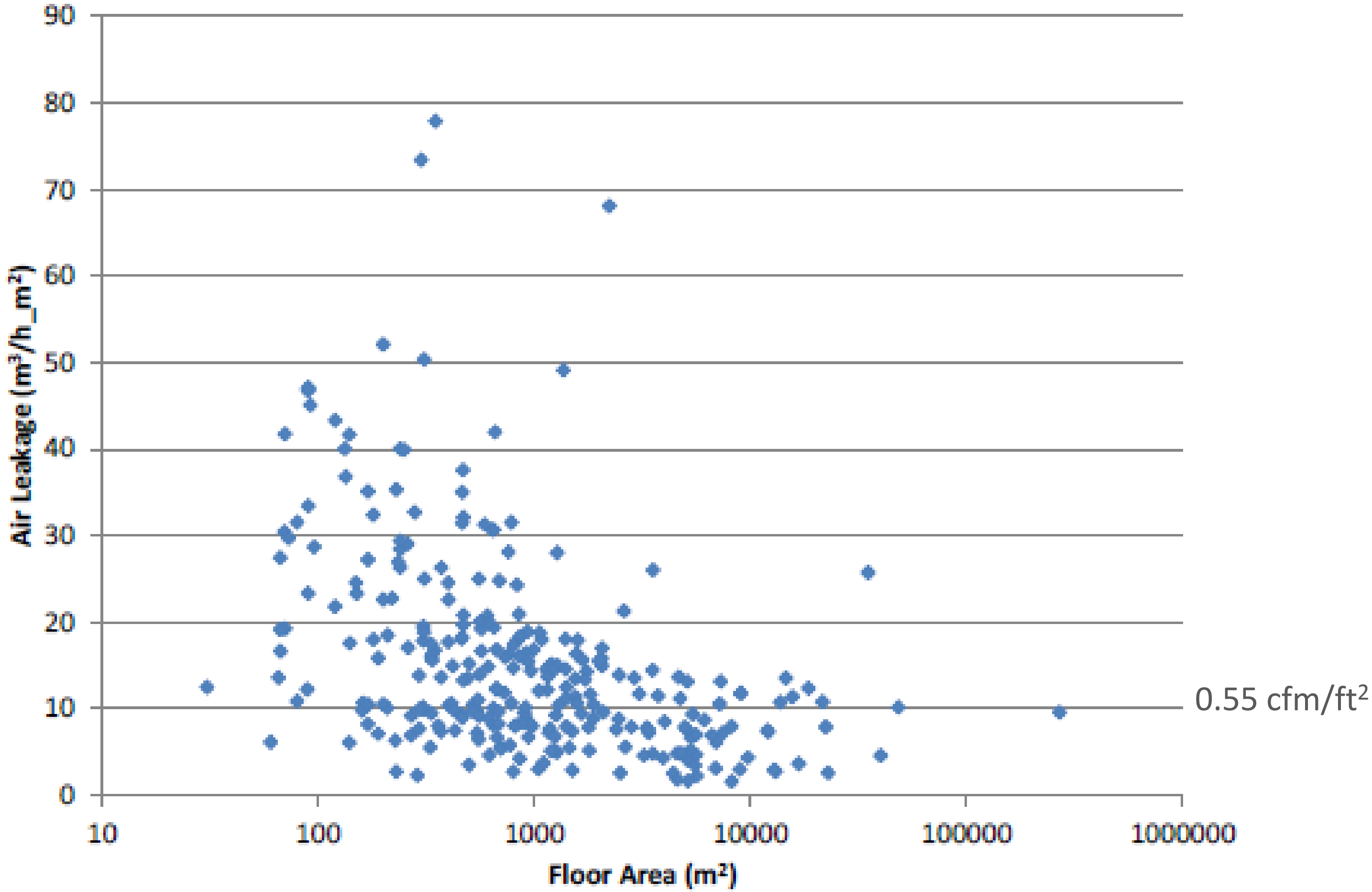
# NIST Results: Effect of Building Size

Buildings > 54,000ft$^2$ twice as tight

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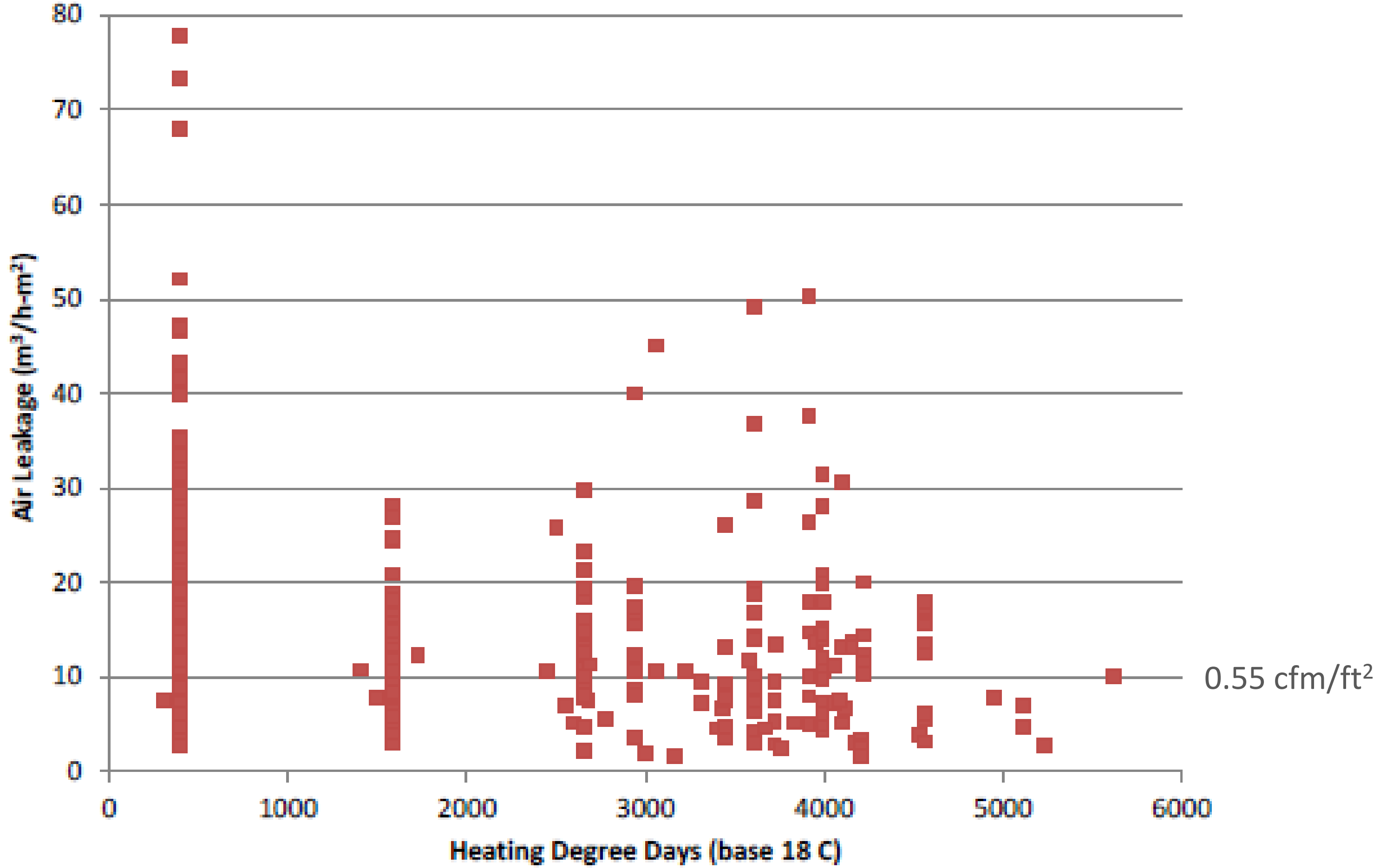
# NIST Results: Effect of Climate

Heating degree days > 3,600 one third tighter

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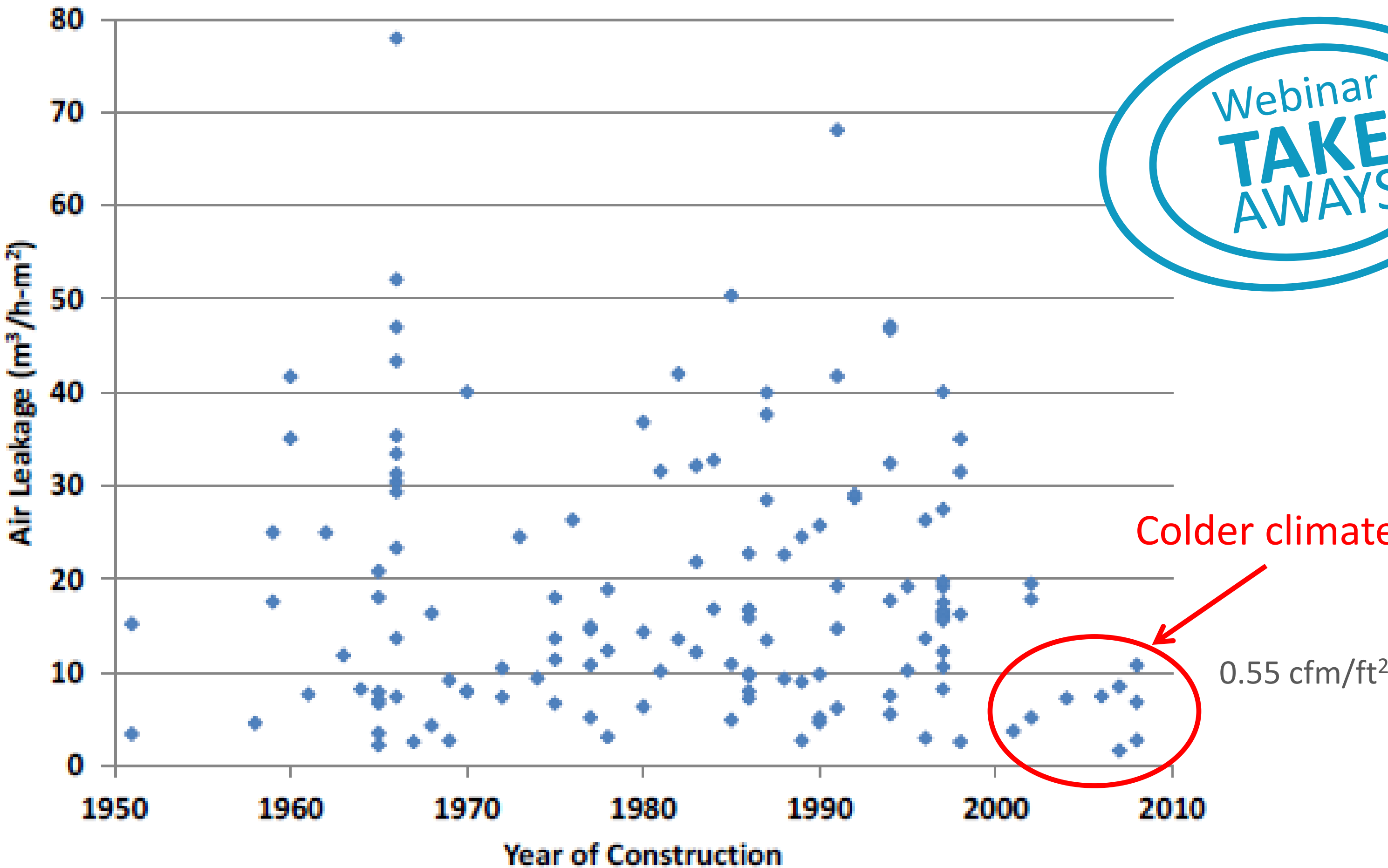
# NIST Results: Effect of Age

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

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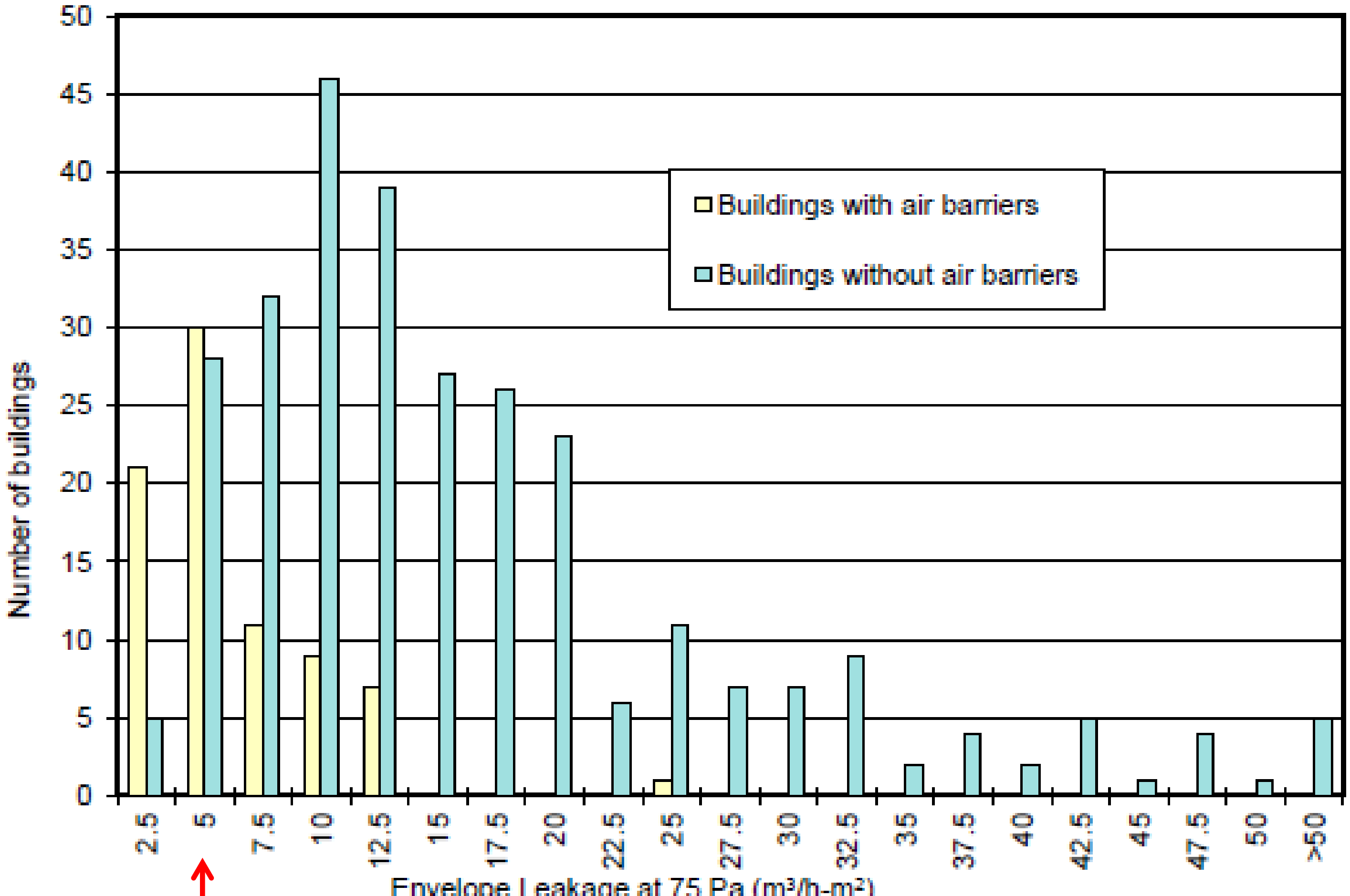
# NIST Results: LEED Buildings

- 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

# 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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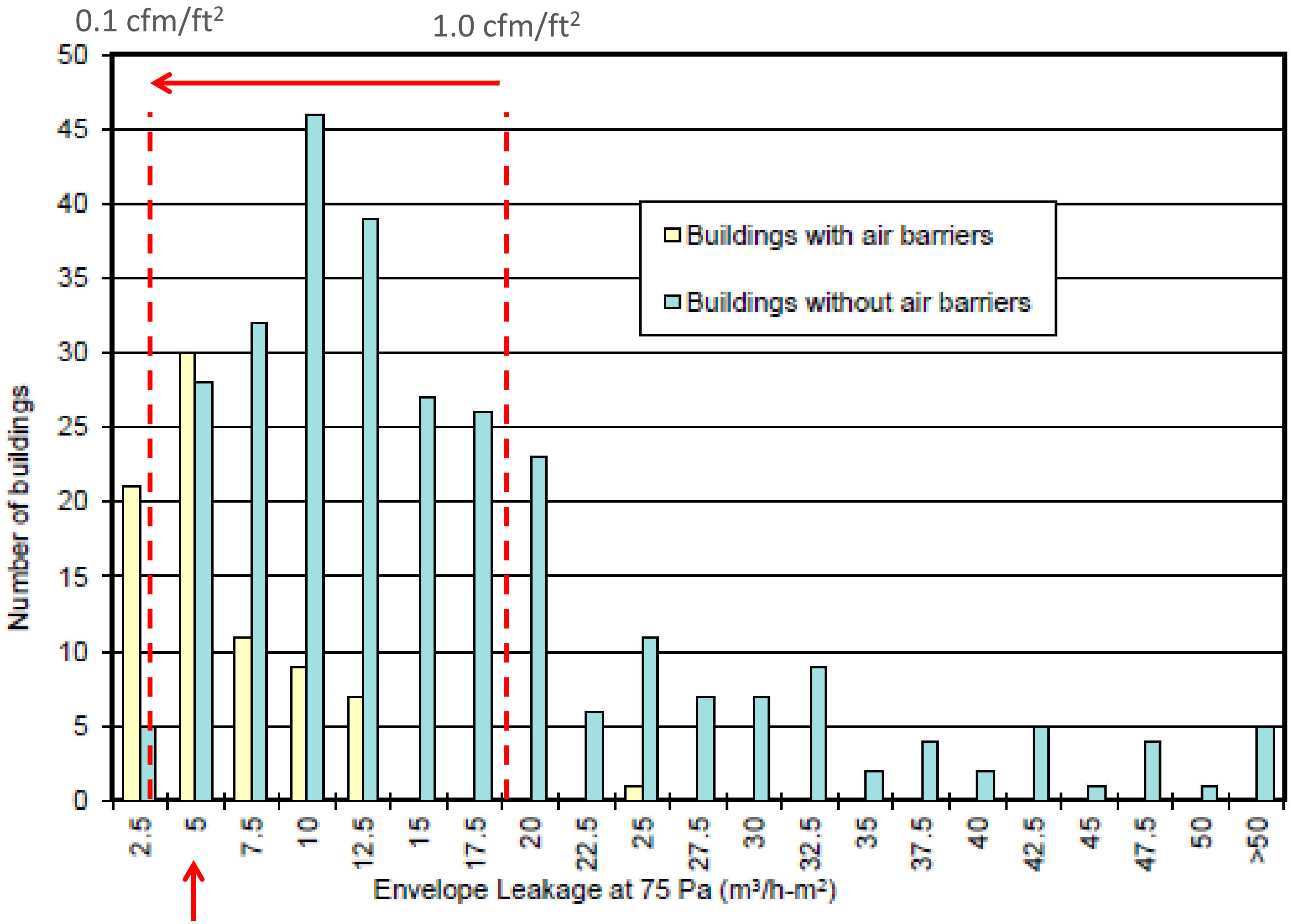
# NIST Results: Effect of Air Barrier

Compare no air barrier to tight construction




USACE Std = 4.5, 0.25cfm/ft$^2$

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# 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

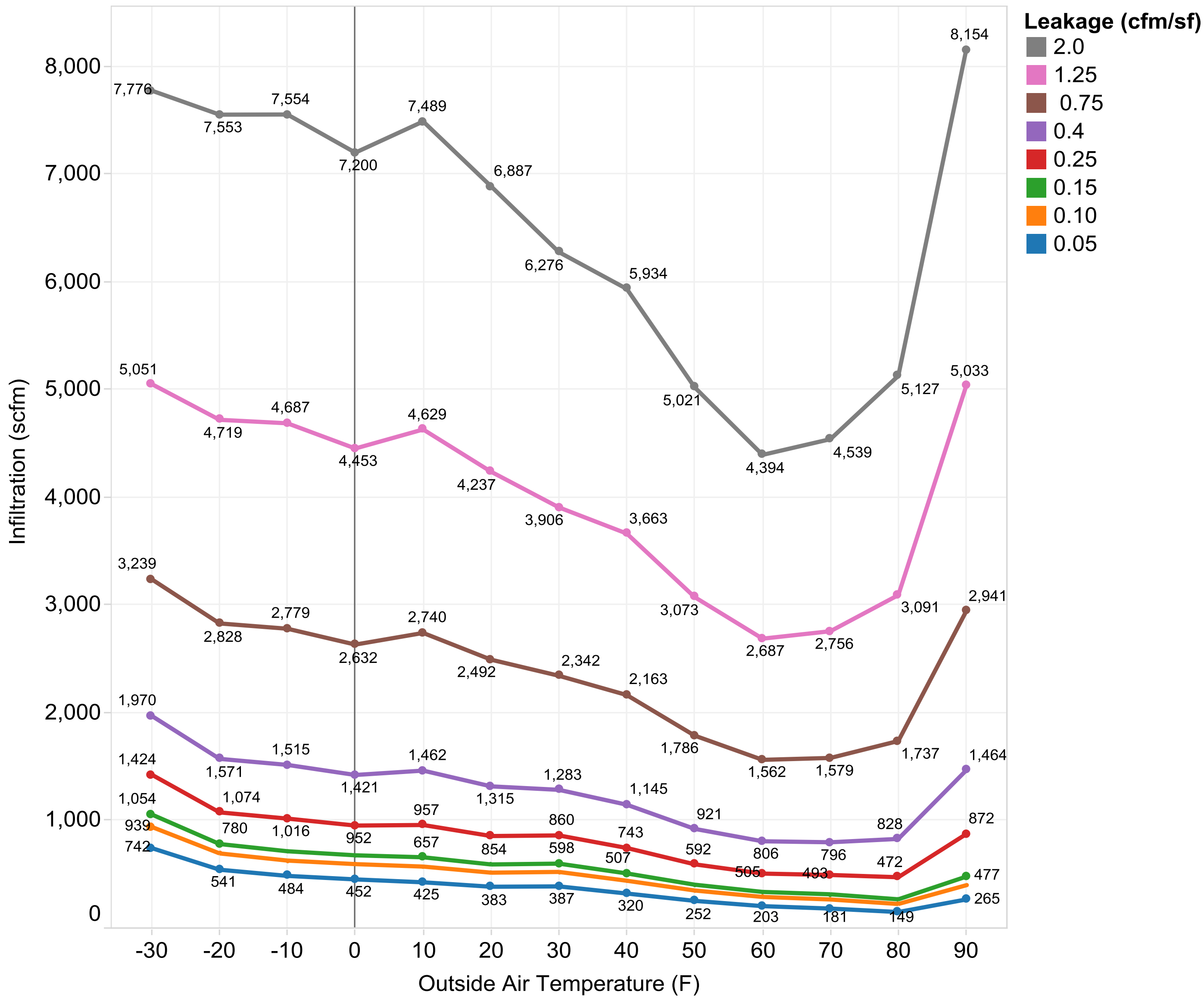
| City | Annual Average Infiltration ($h^{-1}$) Baseline | Target | Gas Savings | | Electrical Savings | | Total Savings |
|---|---|---|---|---|---|---|---|
| Bismarck | 0.22 | 0.05 | $1,854 | 42% | $1,340 | 26% | $3,195 |
| Minneapolis | 0.23 | 0.05 | $1,872 | 43% | $1,811 | 33% | $3,683 |
| St. Louis | 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

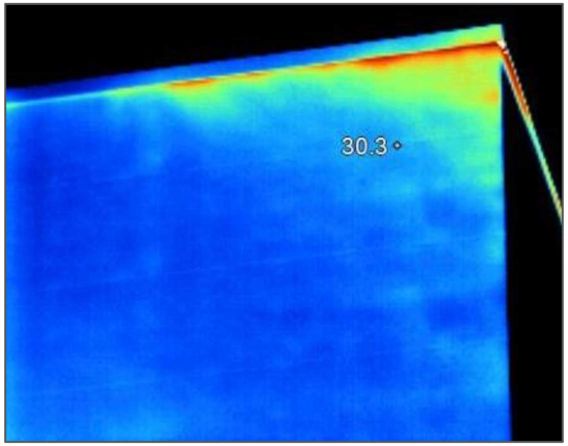
- Goal: 24 to 36 existing mid- and high-rise buildings (16 Completed)
- Non-residential
- 4 stories or higher
- Sustainability certification (14 of 16)
- Built after the year 2000
- Climate zones 2-7 (All 6 Zones Represented)

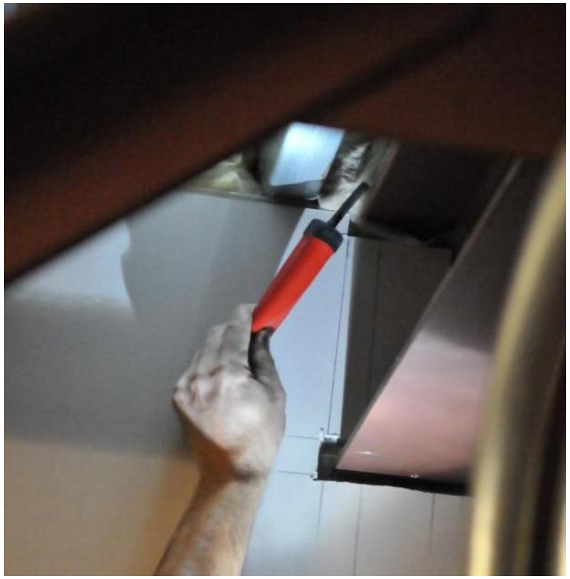
# ASHRAE Research Project: leakage results

- 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

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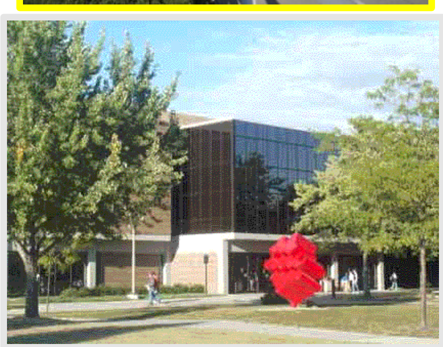
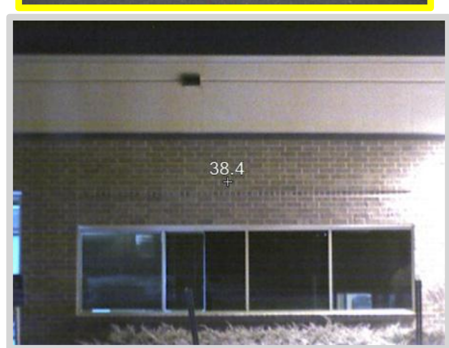
# Building Characteristics

| 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 |

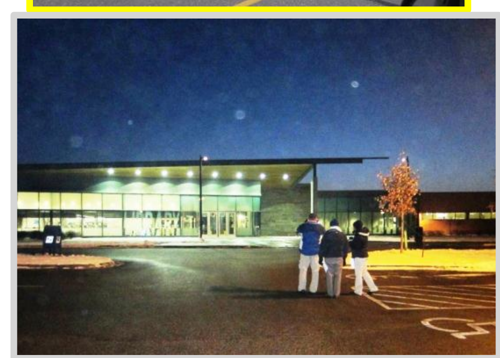
3 elementary & middle schools: 1936 to 1965 with additions 60,000 – 139,000sf



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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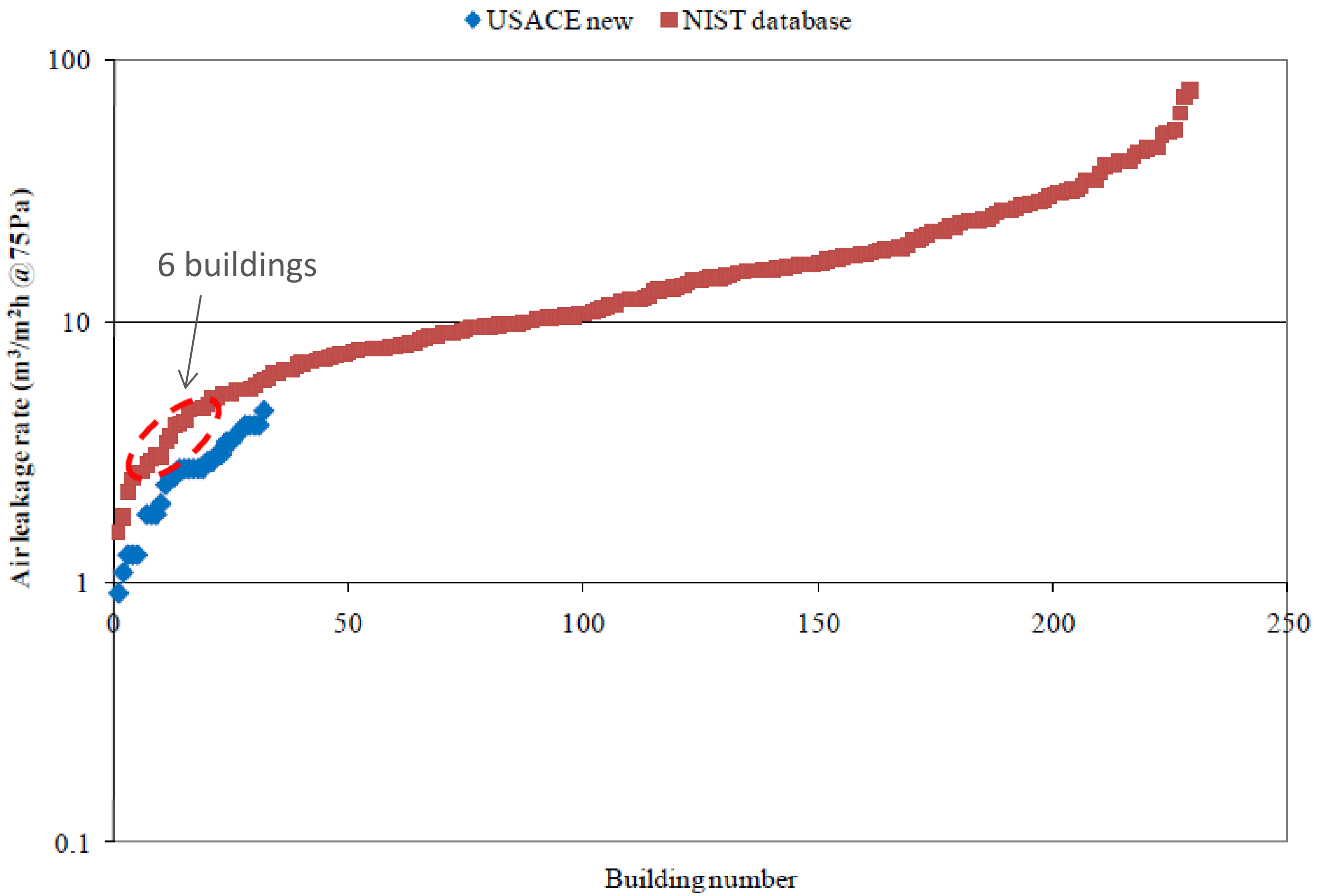
# Comparison to US Buildings

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

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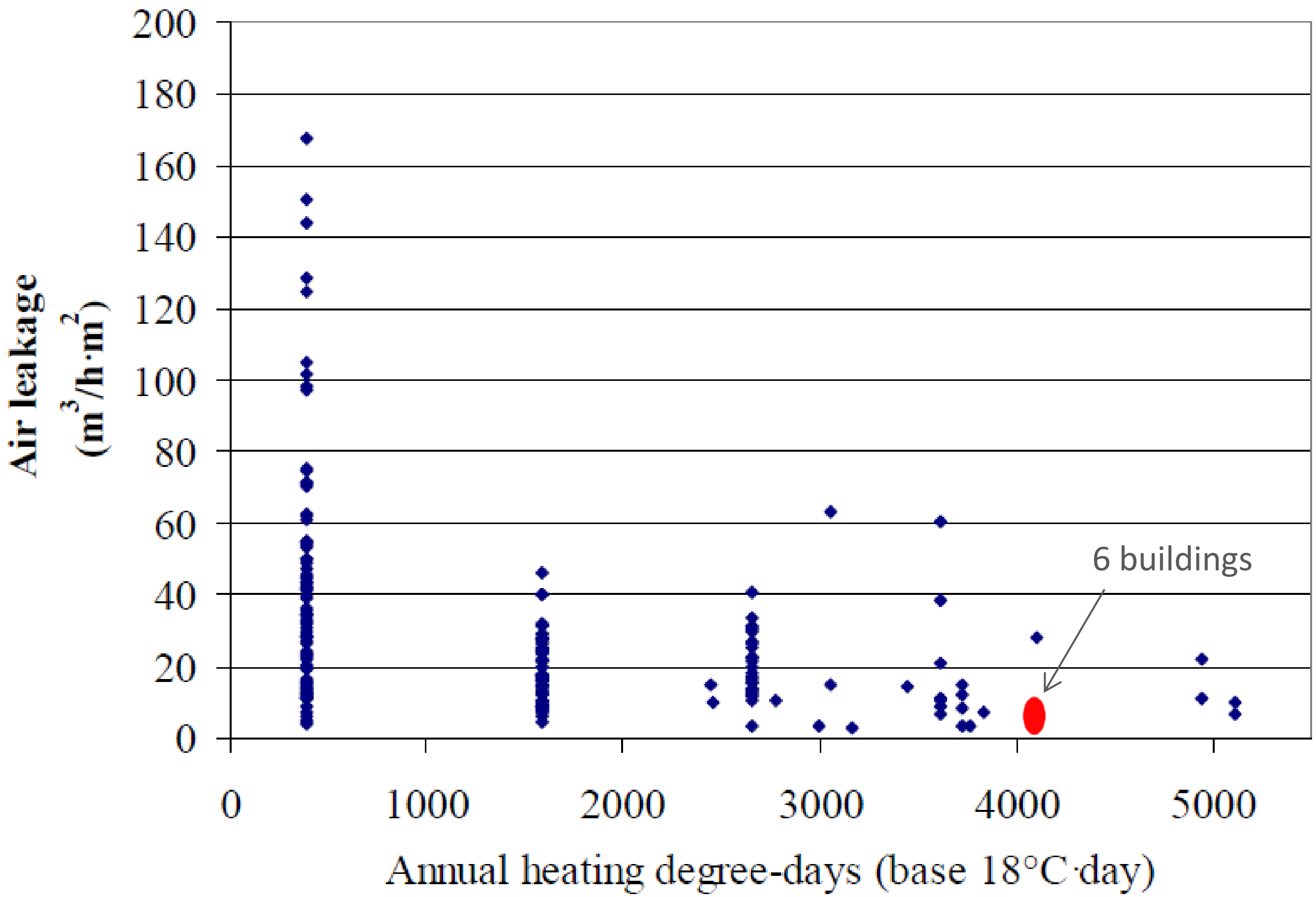
# Tighter Buildings in Colder Climates?

7 building average is 85% less than the US average

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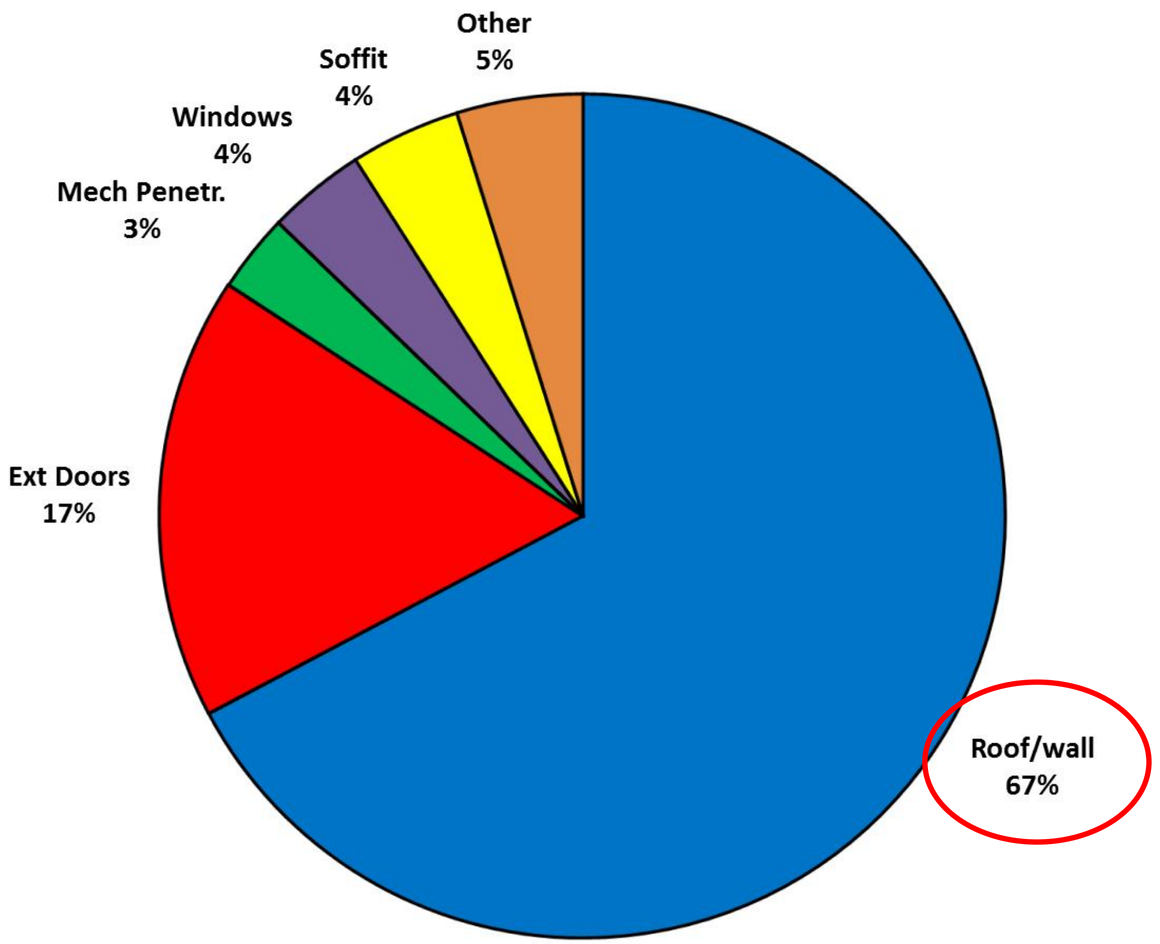
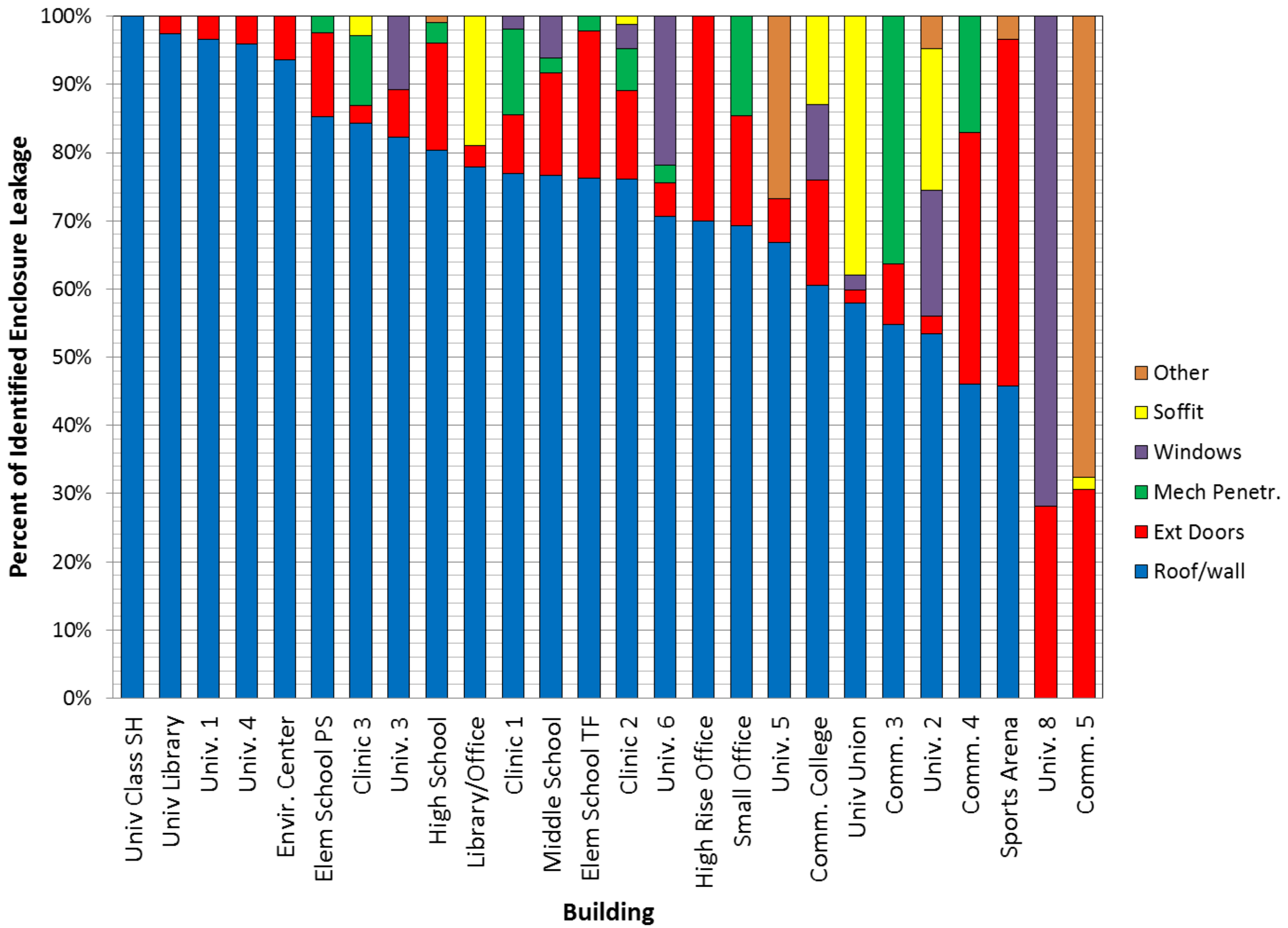
# Where Were the Leaks?



# Where Were the Leaks?

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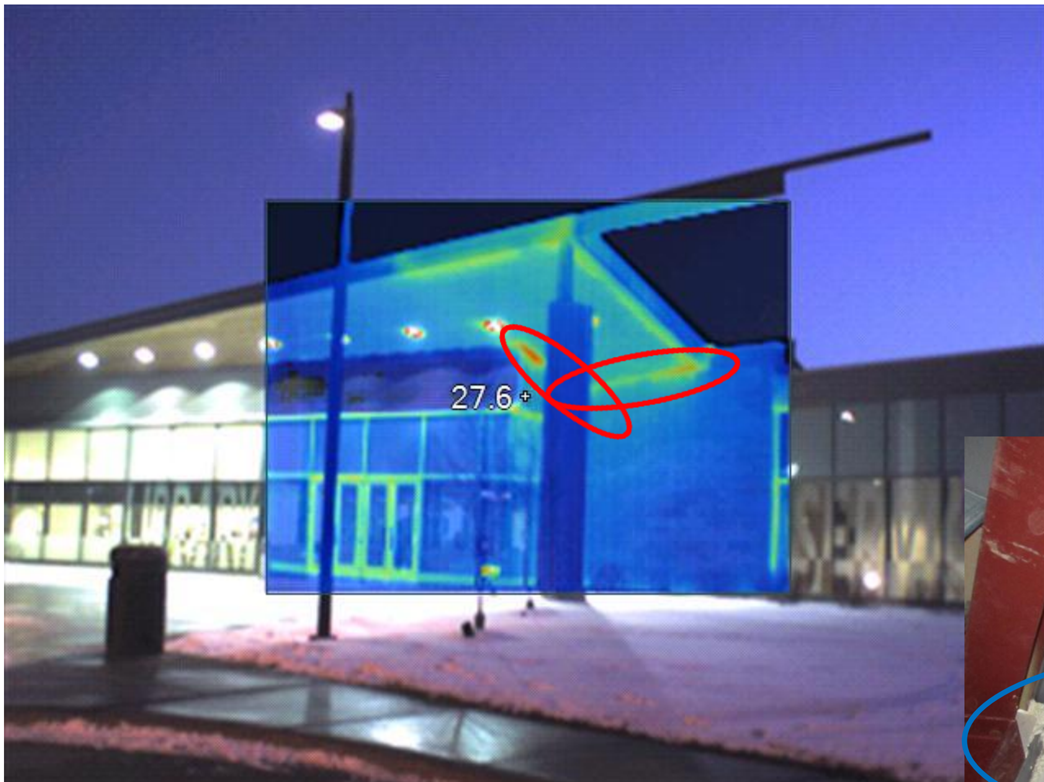
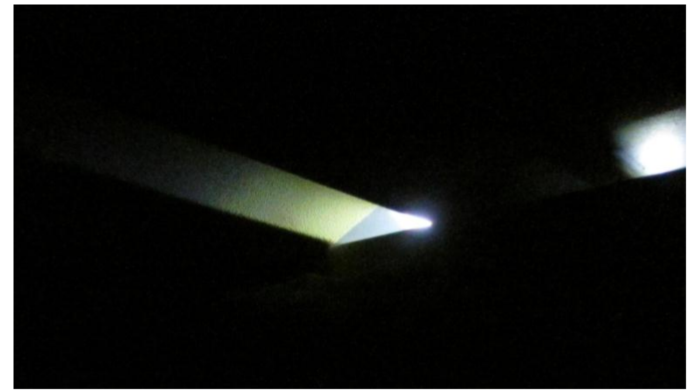
# Air Sealing Focused on Roof/wall

Canopy leakage at exterior wall



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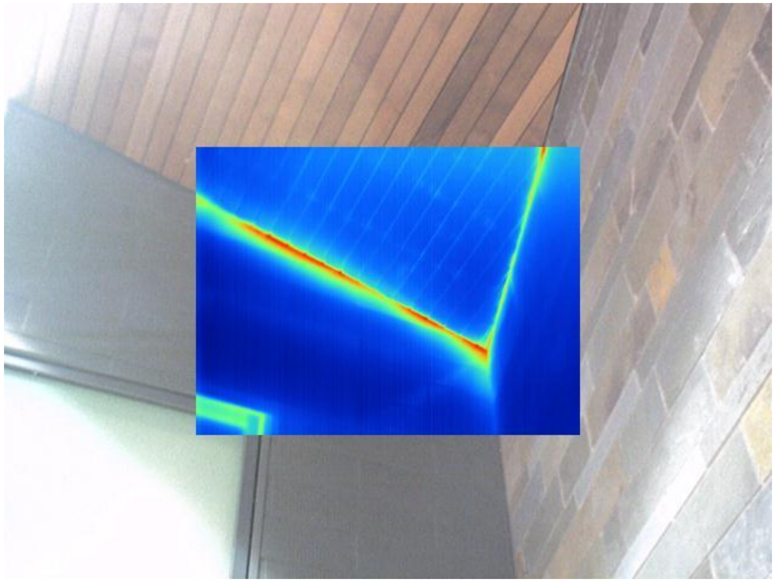
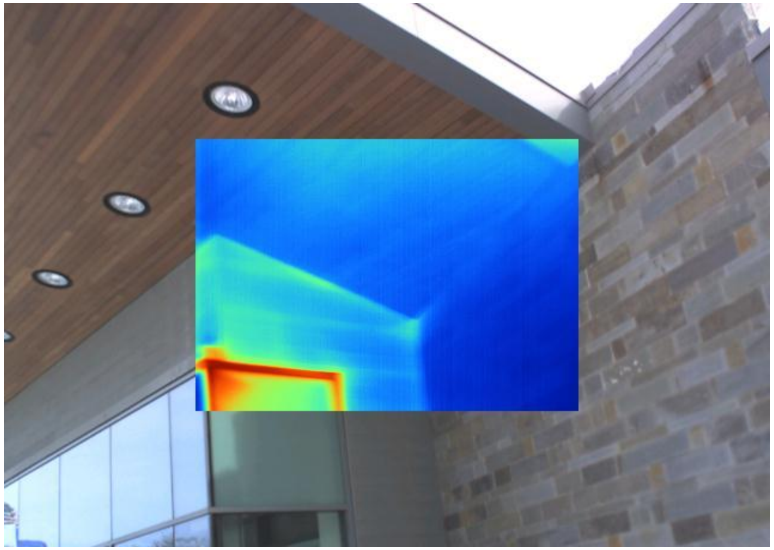
# Air Sealing Focused on Roof/wall

Canopy leakage at exterior wall



**IR Before**



**IR After**

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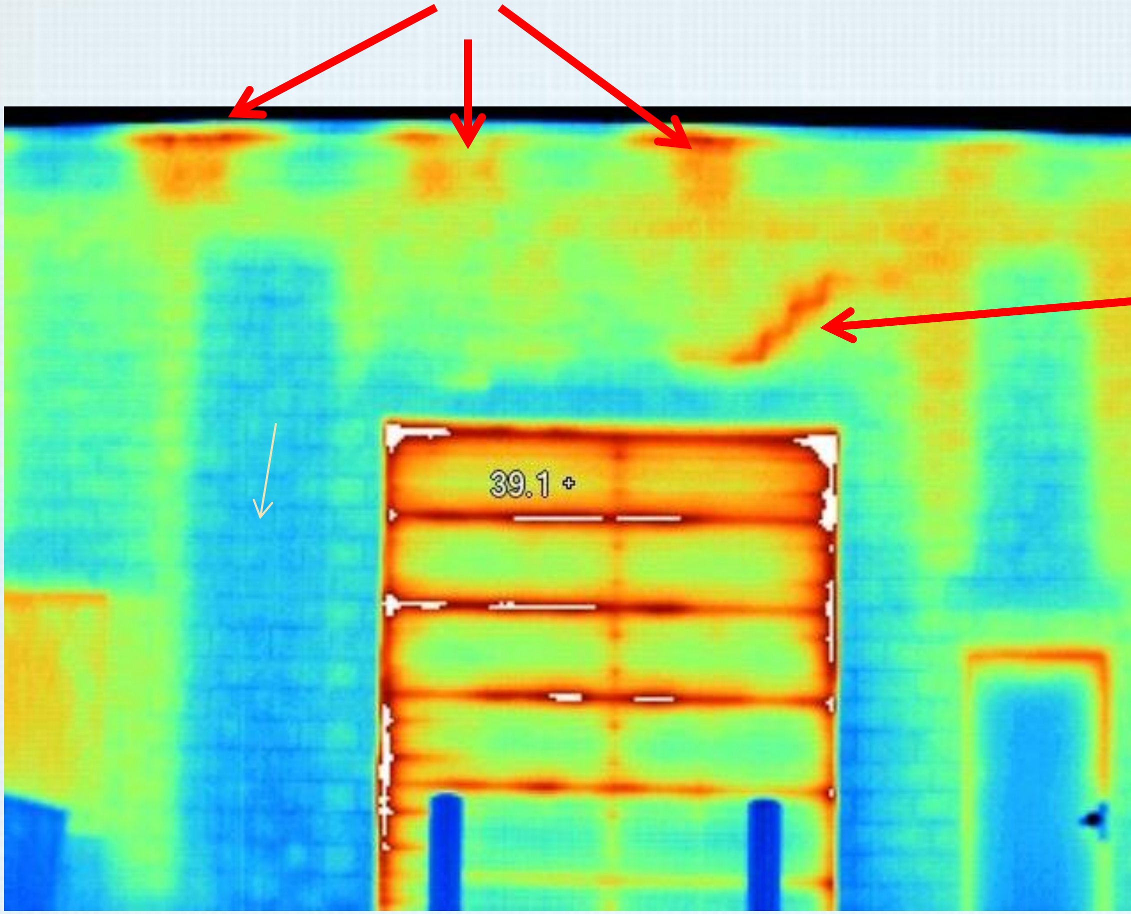
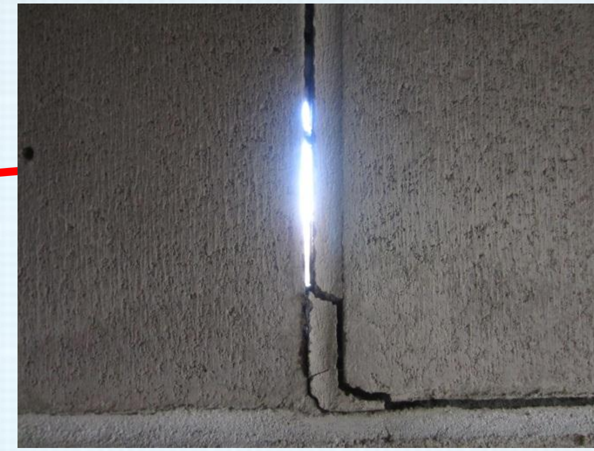
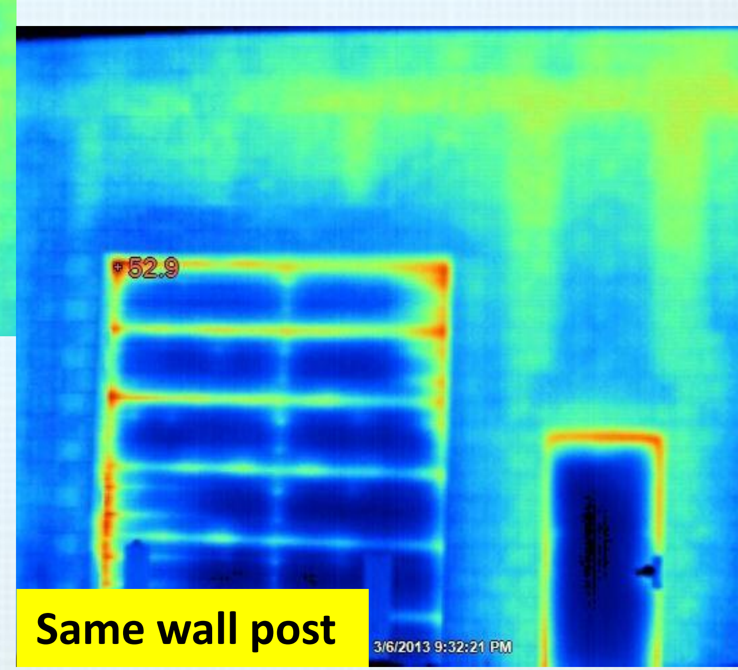
# Where to look: IR view of rear CMU wall pre





# Look inside: 10 beam pockets


Open above to parapet cap

Smoke shows airflow

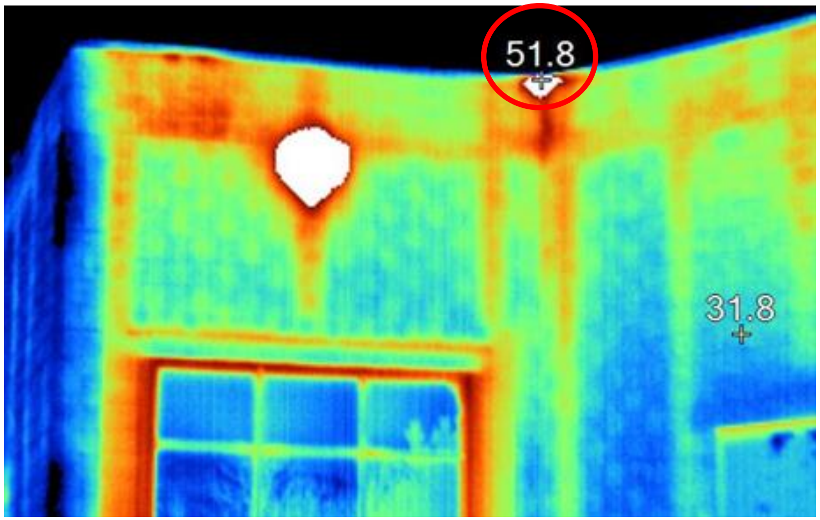
# Closed cell foam fill,  don’t create fire hazard

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 6 Sides | Air Leakage at 75Pa (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

# 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

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## Modeled Infiltration and Energy Savings

| | Gas Savings | | Electric Savings | | Total | Leakage | | Payback |
|---|---|---|---|---|---|---|---|---|
| Building ID | (Therm/yr) | ($/yr) | (kWh/yr) | ($/yr) | ($/yr) | Red. (%) | Cost ($) | (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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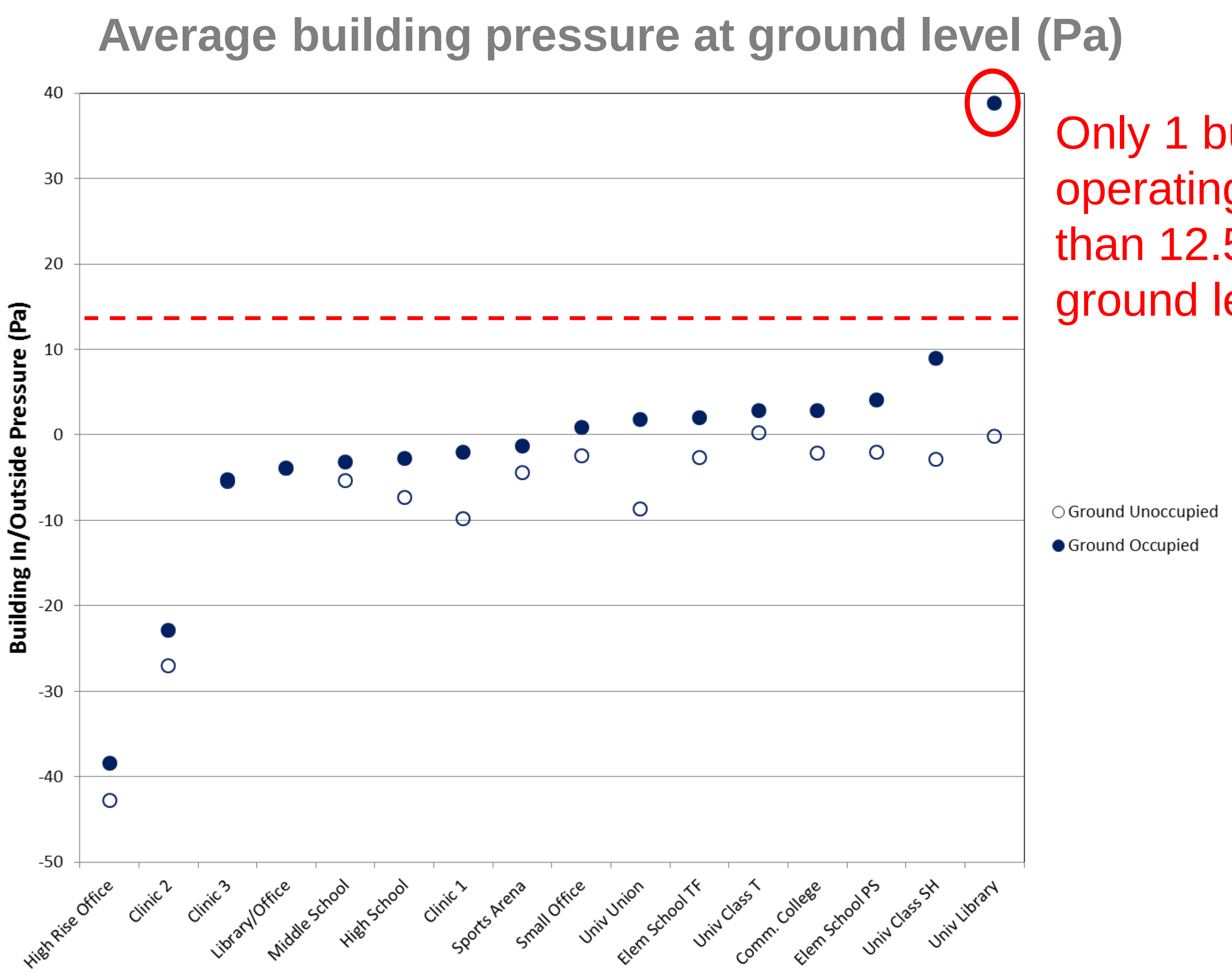
# Building Pressure Measurements




Only 1 building operating greater than 12.5Pa at ground level

20F < outside temp <= 45F

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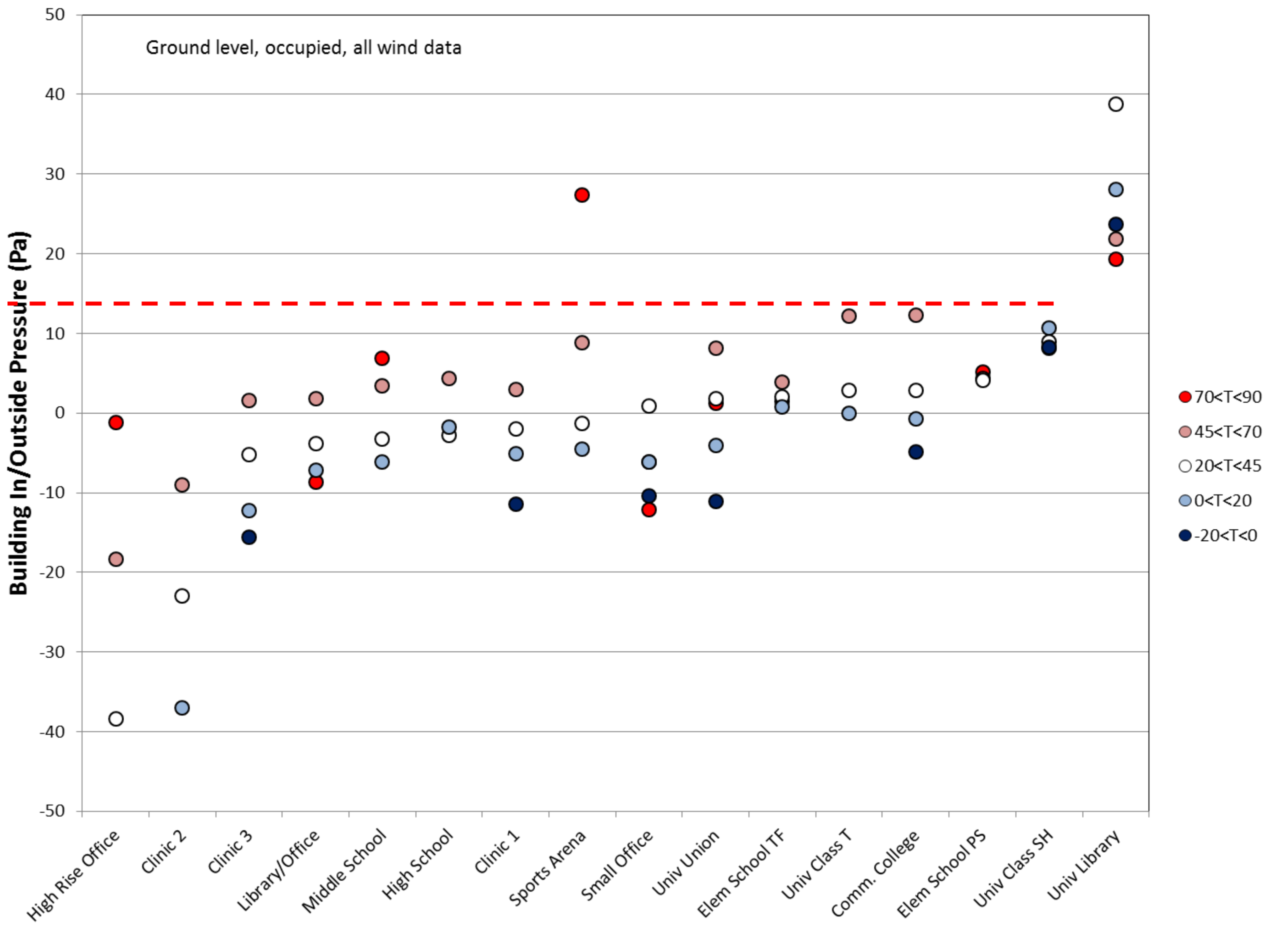
# Building Pressure Measurements

## Average building pressure at ground level (Pa)

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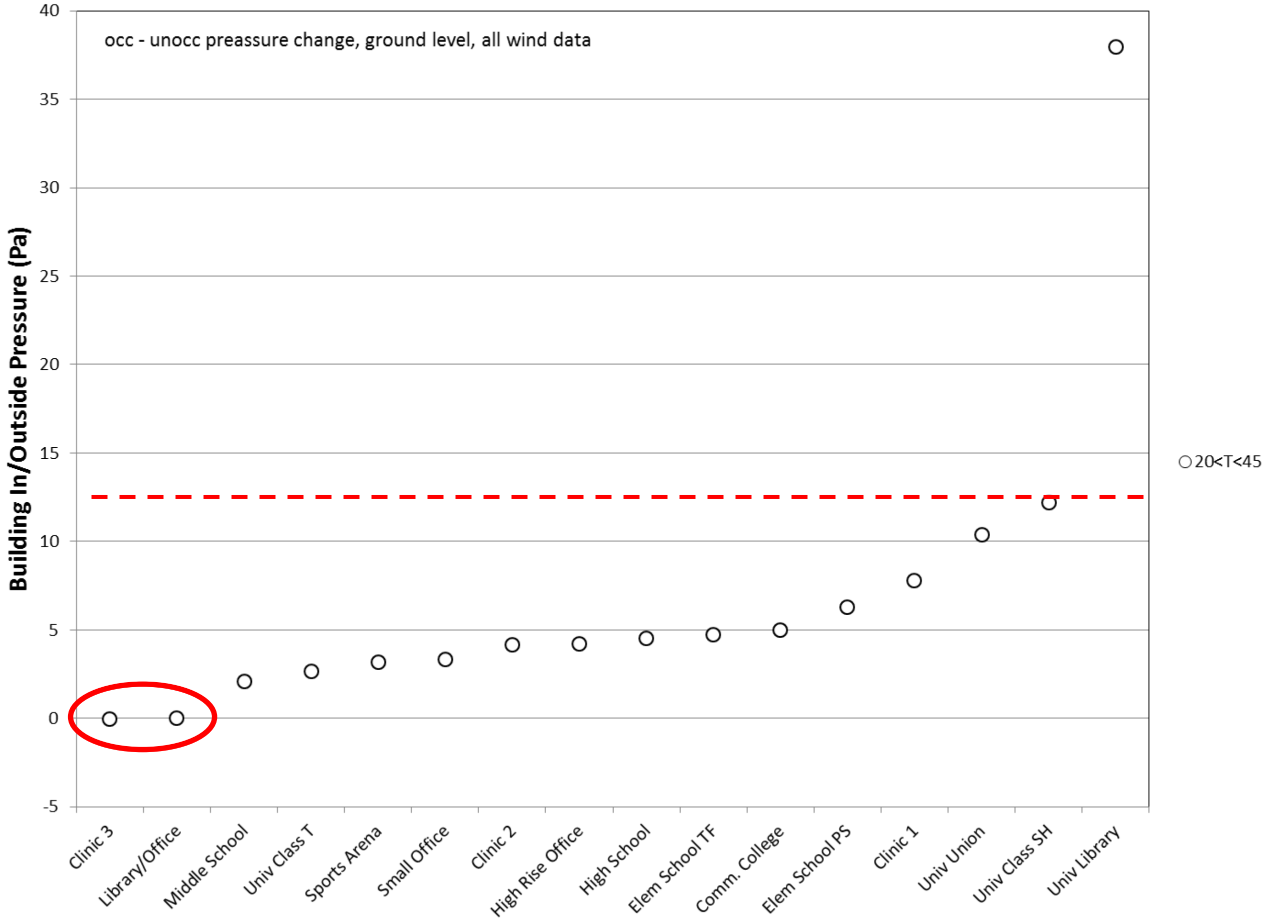
# Building Pressure Measurements

## Difference between occupied and unoccupied pressure (Pa)




Pressure increase for almost all buildings

20F < outside temp <= 45F

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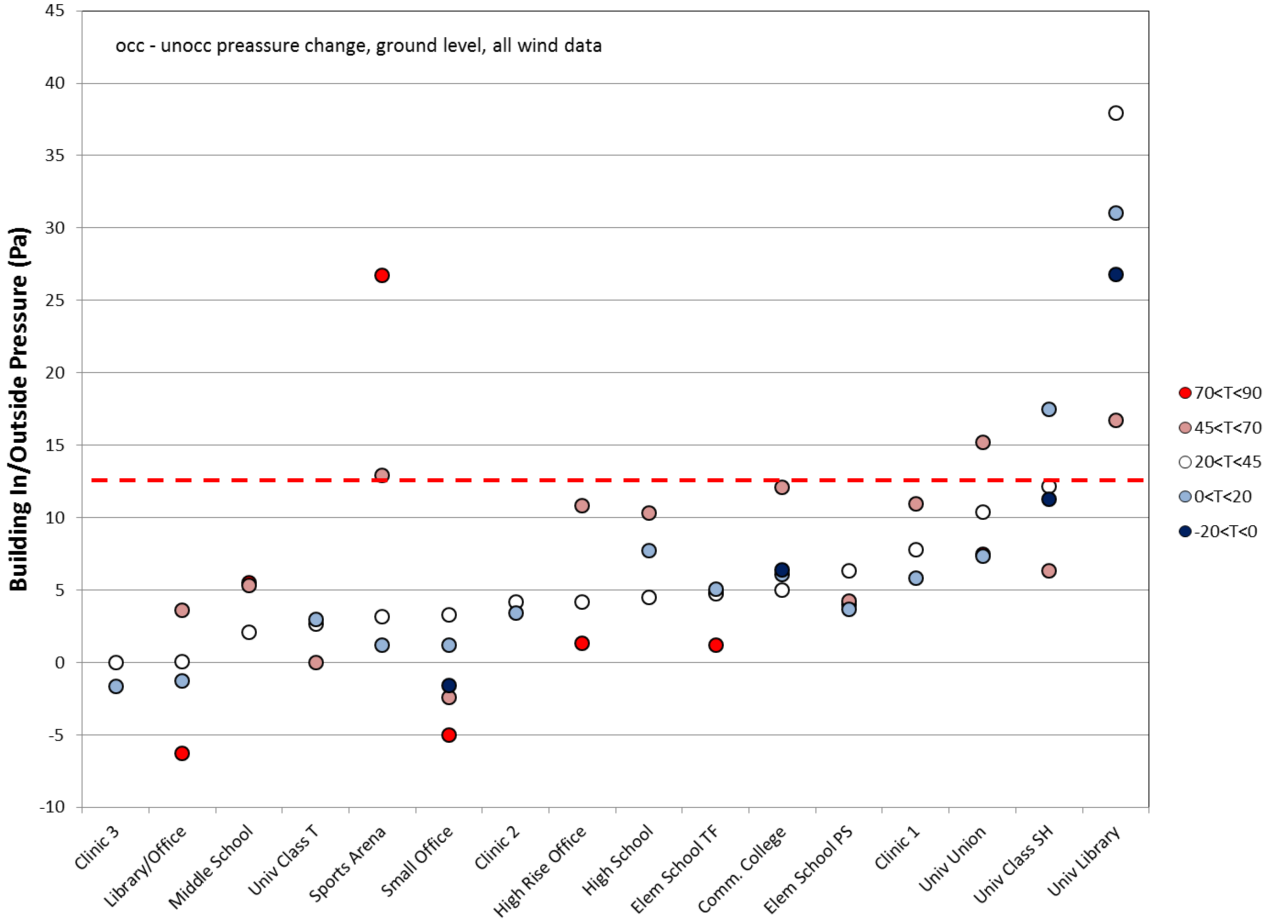
# Building Pressure Measurements

## 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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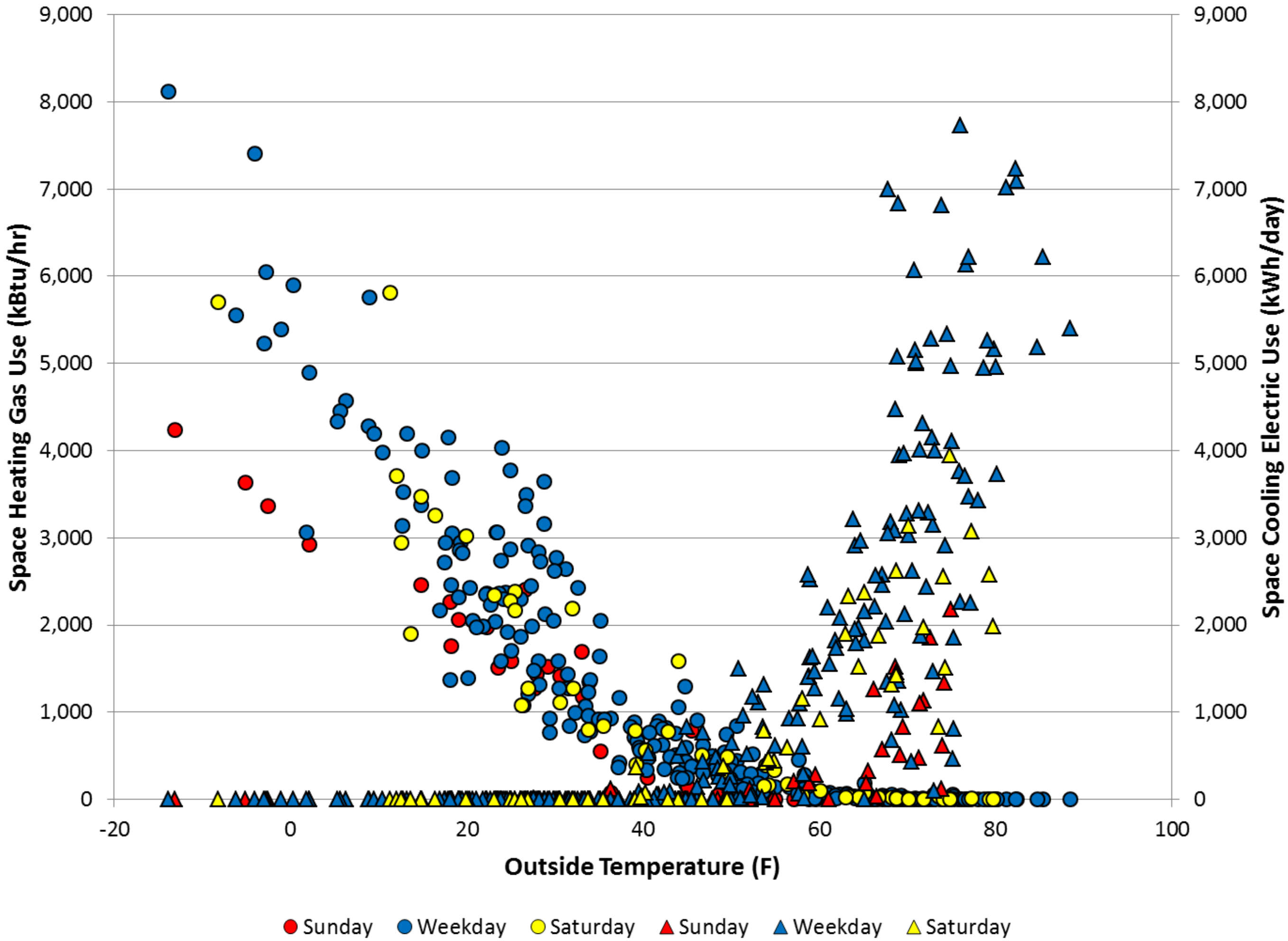
# Computing Savings For Your Project

### 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

# 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

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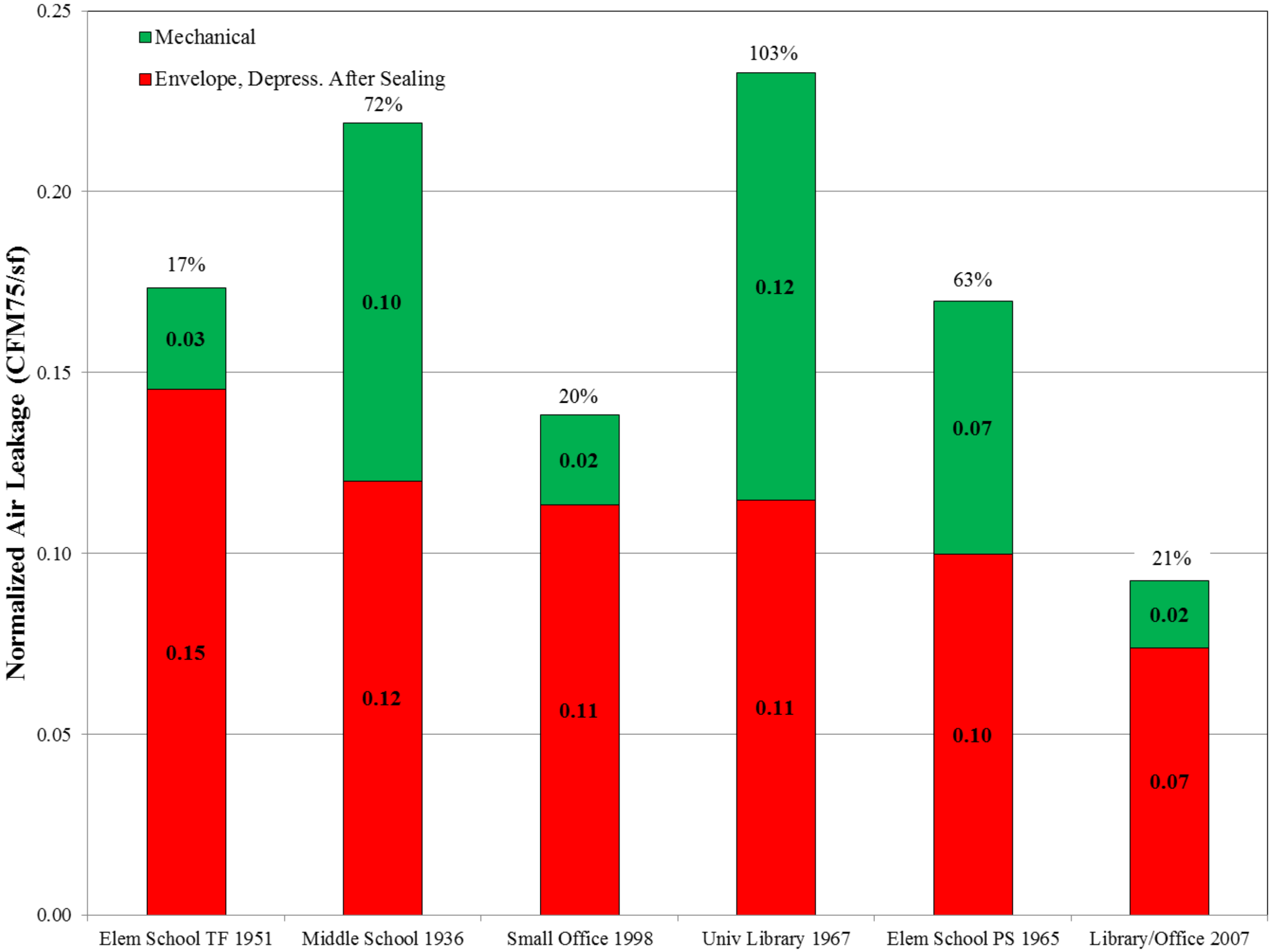


Mean
49%
0.06 cfm/ft$^2$
(6 sides)

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

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# 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

<u>Other Opportunities</u>

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

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# Thank you!

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