Low-Rise Multifamily Code Compliance Study Results

U.S. Department of Energy Building Energy Codes Program
NECC Webinar Series
AIA Provider #: I014 AIA Course #: BECPWS102020
ICC Provider Course #25989
October 20, 2020

DOE Low-Rise Multifamily Energy Code Field Studies

Presentation of Results

20 October 2020

Introduction & Overview

Robert Davis, Principal Investigator
Ecotope

Agenda

- Welcome & Context
- Overall Goals, Objectives
- Notable results from field data and simulations
- Q & A

Low-Rise MF Project Team

Why This Study?

Jeremy Williams, Building Technologies Office
U.S. Department of Energy

DOE Energy Code Field Studies

Single-Family Residential

Low-Rise Multifamily

Commercial

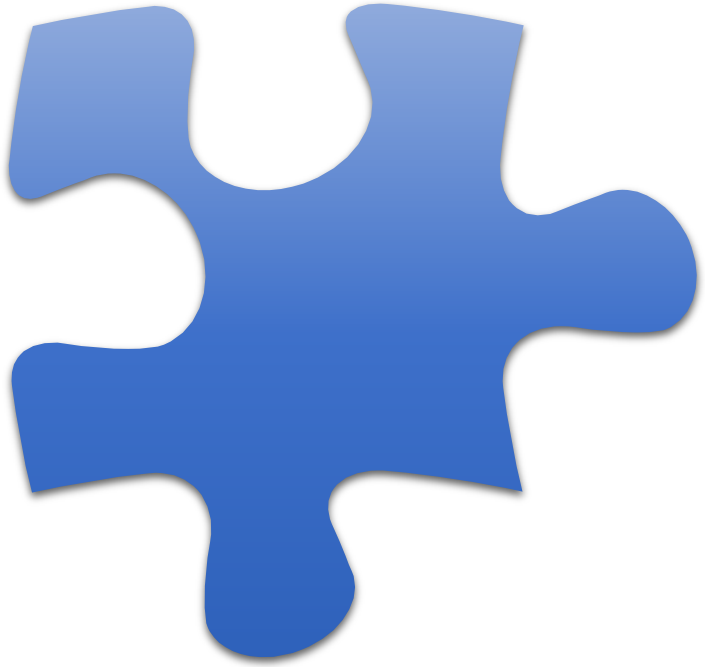
Collective LRMF Field Study Goals

- Estimate regulated energy use in typical low-rise multifamily buildings
- Identify opportunities for energy and cost savings by meeting energy code
- Improve understanding of building characteristics of this under-represented building type

LRMF Field Study Objectives Overview

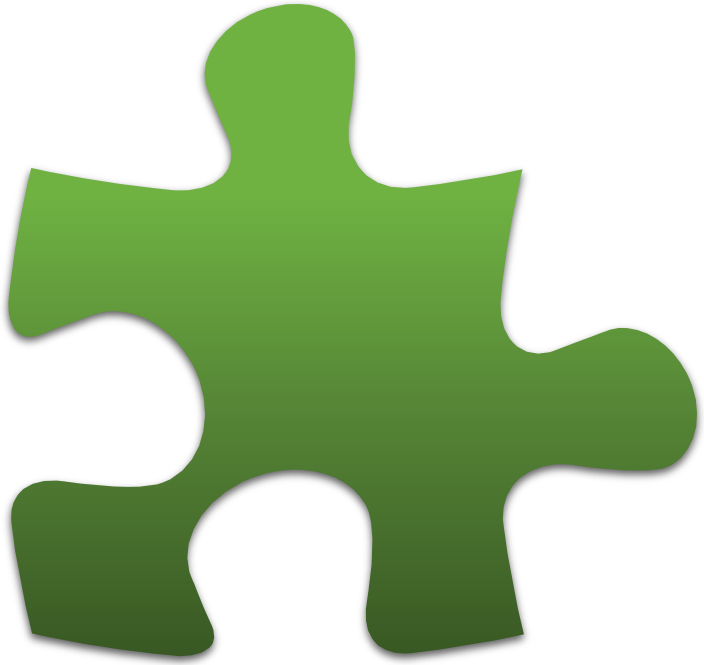
Characteristics Review and Energy Use Analysis

- Adapt SF protocol to low-rise MF
- Collect baseline and energy characteristics
- Model energy use



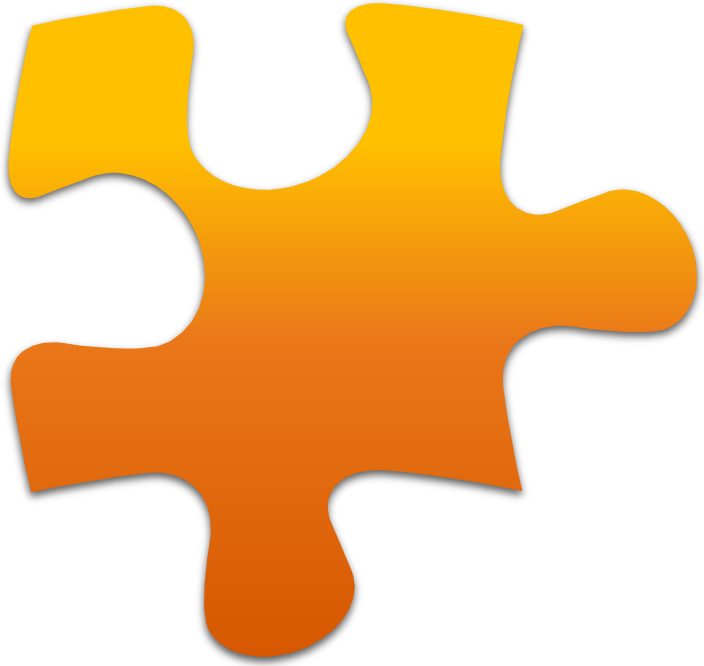
Air Tightness Testing

- Relationship between test types?
- Range of air leakage observed
- Recommendations for revising MF ATT protocols and requirements

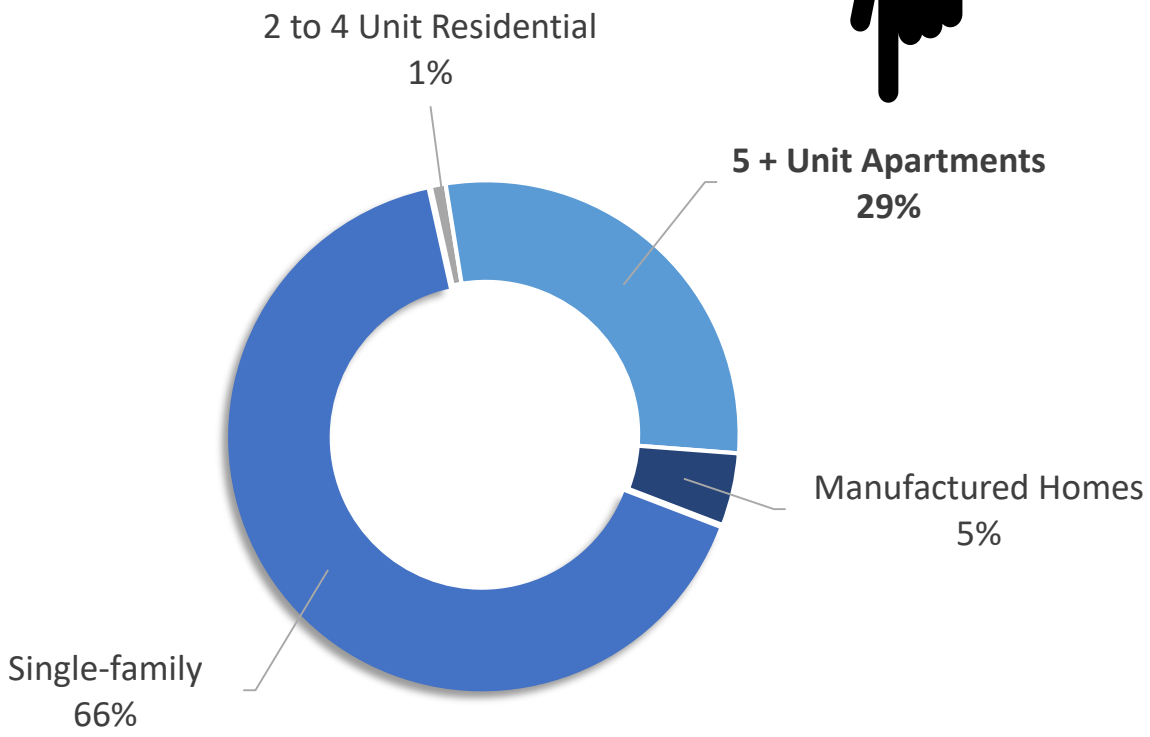


Market Research

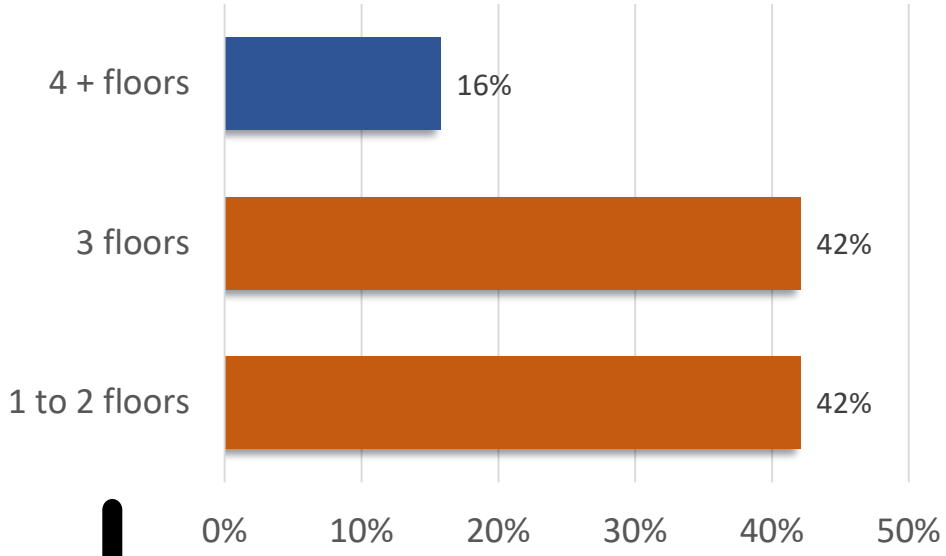
- Gain better understanding of firms in LRMF construction market
  - Design/build practices
  - Energy code education/training



Why Low-Rise Multifamily?



Almost 30% of new residential units are in MF buildings



Nearly 85% of new MF buildings are low-rise

Target Population

Includes

- New construction (~3 years)
- 1-3 stories, 5 + units
- Mixed occupancy buildings

Excludes

- Single-family
- Townhouses/rowhouses
- Duplexes, triplexes, fourplexes
- Dorms, assisted living, nursing homes, hotels, etc.
- High rise MF (4 stories and up)

Building Types

Garden Style

Exterior corridors

Exterior unit entry

Common Entry

Interior corridors

Interior unit entry

Sample Design

Target Population

- Main source: Dodge Data and Analytics (via PNNL)
- Total new LRMF projects over three-year time frame: 2014-2016

25 buildings per state

3-4 units per building

Sample Frame

- Obtain building lists from jurisdictions
- Develop randomized recruiting lists

Sampling Unit

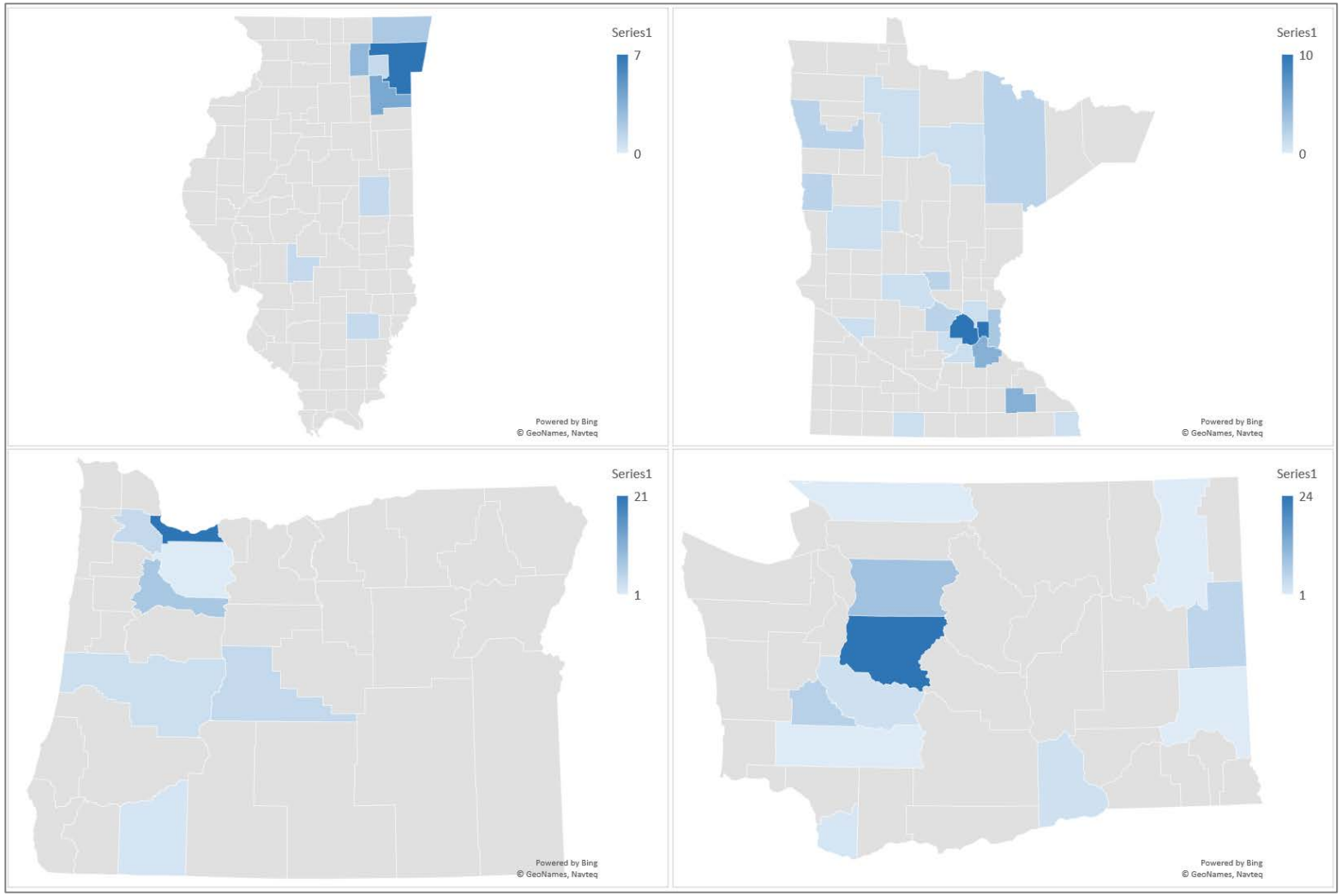
- Primary: Building
- Secondary: Dwelling Unit

Statistical Criteria

- 90/10 confidence/precision (building level)
- 0.66 coefficient of variation (CV) for key variables

Geography

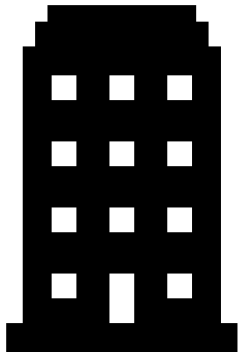
- State-level sample
- LRMF concentrated around large and small cities
- In some cases, the sampling approach resulted in surveying a near-census of all eligible buildings



Two-Stage Sample Design

Primary Sampling Unit

- Building
- Simple random sample



Secondary Sampling Unit

- Living unit (most of the ft^2 at each site)
- Simple random sample within building
  - Assume number of units per building are similar across population
  - Visit fixed number of units per building

Key Compliance Items

Component	Data Collected	Code Reference†
Building		
Exterior wall insulation	R-value	Tables R402.1.2, R402.1.4
Ceiling insulation	R-value	Tables R402.1.2, R402.1.4
Foundation insulation	R-value	Tables R402.1.2, R402.1.4
Window	U-factor and SHGC	Tables R402.1.2, R402.1.4
Exterior lighting	Wattage	Section C405.5
Central HVAC*	Efficiency rating	Section C403, (IECC section R403.8)
Pipe insulation*	R-value	Section C403.2.10
Central DHW*	Efficiency rating	Section C403
Circulating system*	Pump controls	Section C404.6
Envelope tightness	Air changes per hour (ACH)	Section R404.4.1.2
Common Areas		
Lighting	Lighting power density	Section C405.4.2
Corridor ventilation*	Air flow (CFM/ft2)	Table 403.3 (IMC)
Units		
Lighting	Percent high efficacy	Section R404.1
Ventilation	Flow rating	Section M1507 (IRC), (IECC section R403.6)
Envelope tightness	Air changes per hour (ACH)	Section R404.4.1.2

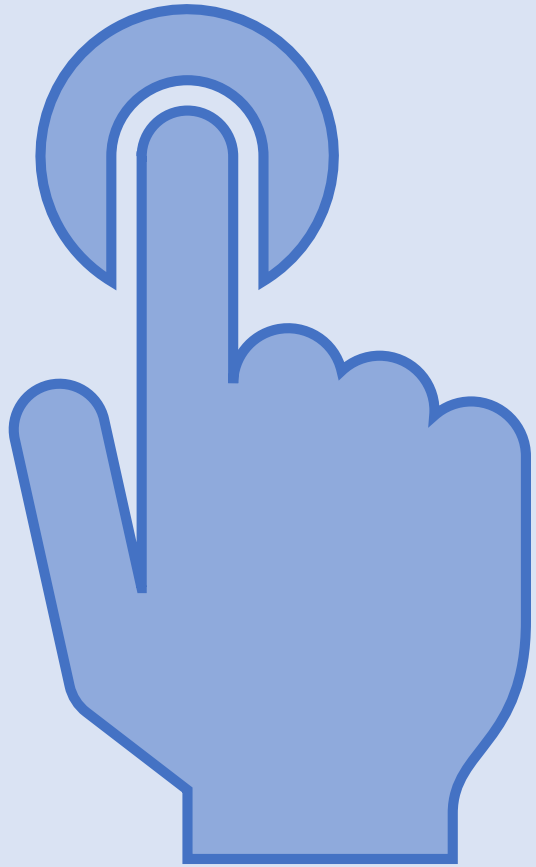
† - IECC reference. Individual state energy code references vary.
** Additional items added for low-rise multifamily study not included in single-family study*

Parameter Summaries

Variable	Sampling Parameter
Source: RECS National Summary, 2000–2009 Buildings	
DHW in-unit	86.4%
DHW electricity	71.3%
Lighting high-efficacy	1.12 CV
Lighting total lamps turned on at least one hour per day	1.01 CV
Number of major appliances per unit	0.33 CV
Unit floor area	0.58 CV
Units in building	1.55 CV
Unit EUI (kBtu/sqft)	0.88 CV
Has warm air furnace (not including heat pump)	77.1%
Has heat pump	14.9%
Source: RLW Northwest Summary, 2003–2006 Buildings	
Hardwired LPD	0.66 CV
Overall LPD	0.67 CV
Number of Fixtures	1.06 CV
Number of Lamps	0.86 CV
Source: Single-Family DOE Residential Energy Code Field Study	
SF LPD? SF high efficacy?	
Selected Parameters for DOE LRMF Study	
Buildings (Future Studies)	**0.40 CV and 80%**
Buildings (Pilot Study)	**0.30 CV and 90%**
Units	**0.66 CV**

POLLING

“Location”



Data Collection Approach

Buildings

- Single site visit in completed buildings
- Pre-entry of data from plans, verified on site
  - Includes data source tracking
- Recruiting from Dodge and building departments

Units

- Random selection by field technician
- No manager units
- Ideally unoccupied, but not required

Building Distribution Geography and Codes

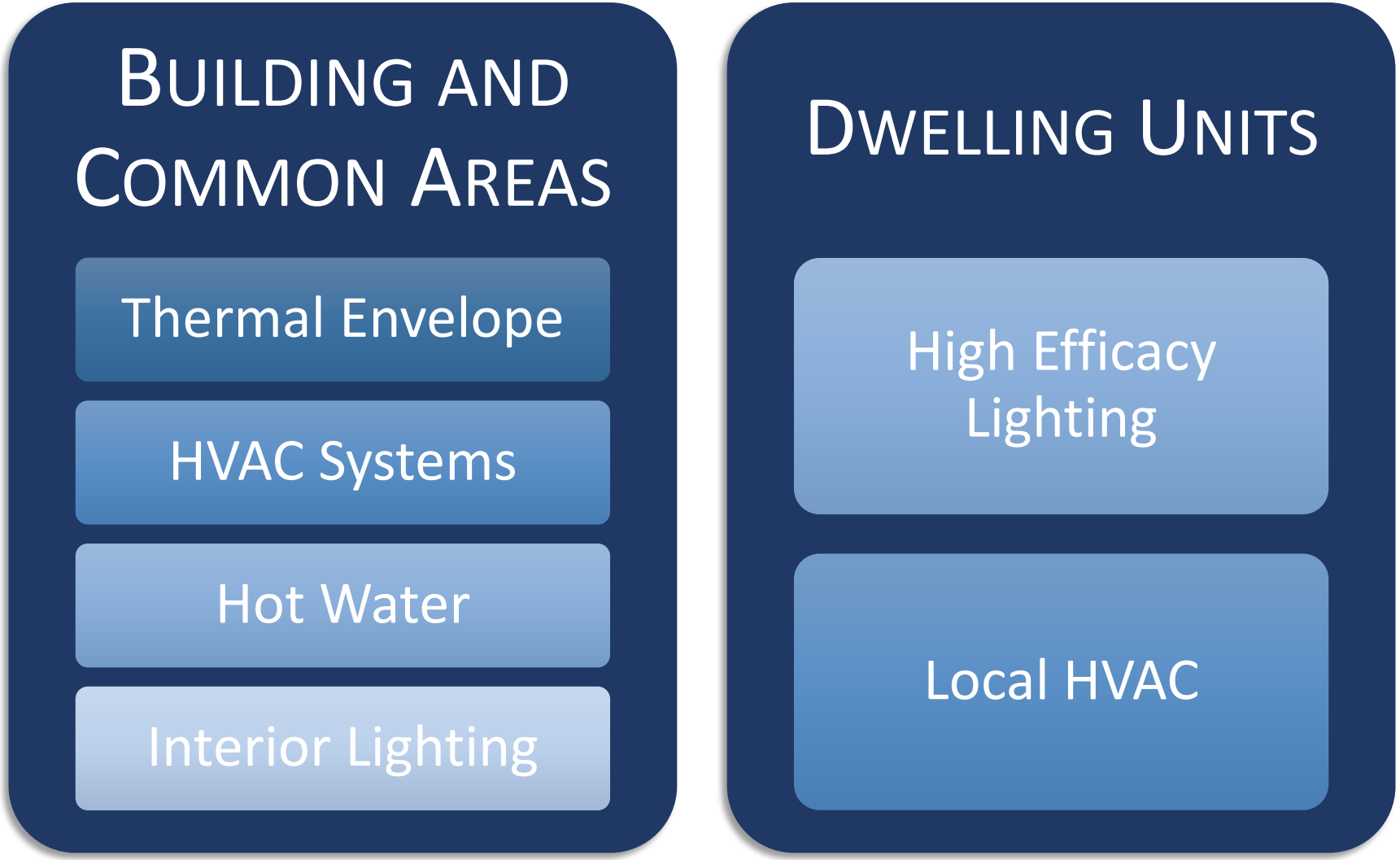
State	Sample Frame Size	Target Sample	Agreed to Participate	Success Rate
IL	105	25	21	20%
MN	250	25	25	10%
OR	249	25	24	10%
WA	463	25	25	5%

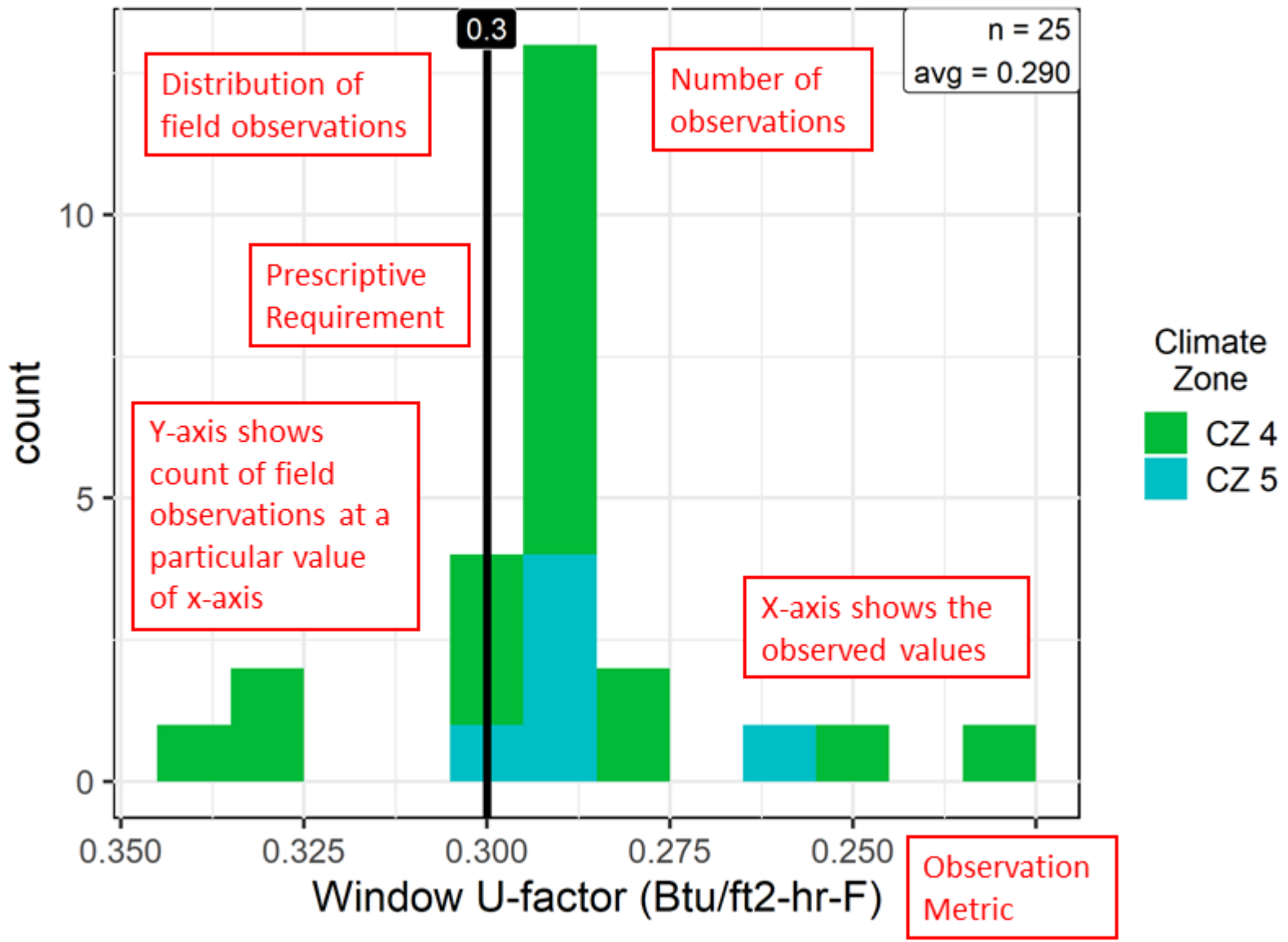
- Applicable code either 2012 or 2015 IECC, with state amendments
- Mixture of residential and commercial code elements (mostly residential)
- Surveyed sites in PacNW mostly in Climate Zone 4 (marine); a few in Climate Zone 5
- Surveyed sites in Midwest mix of Climate Zones 5 (most of IL), 6, and 7 (northern MN)

Building Characteristics Summaries

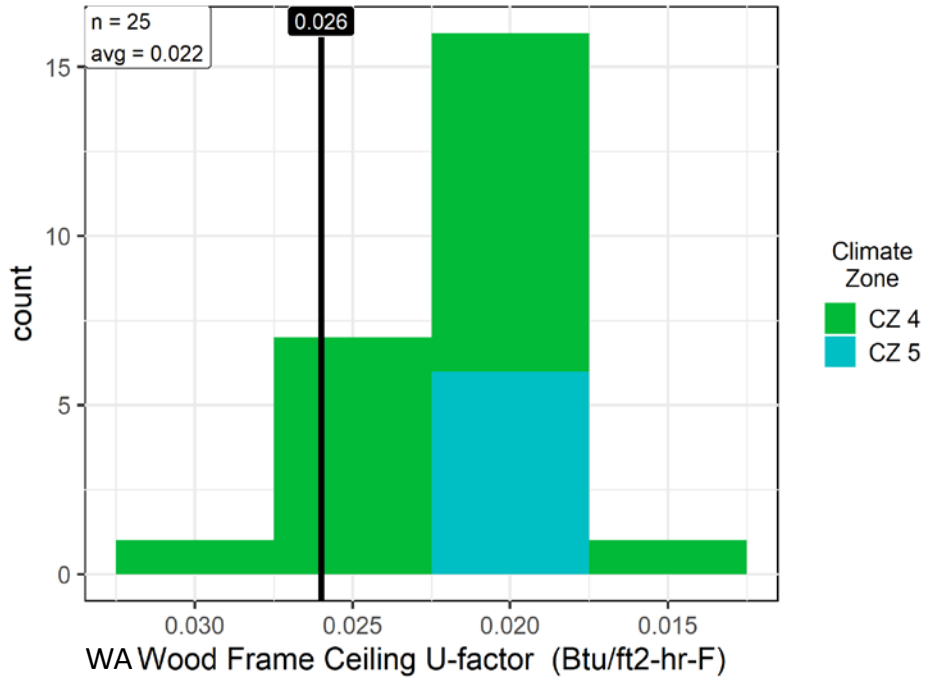
Adria Banks, Research Analyst
Ecotope

Key Energy Characteristics



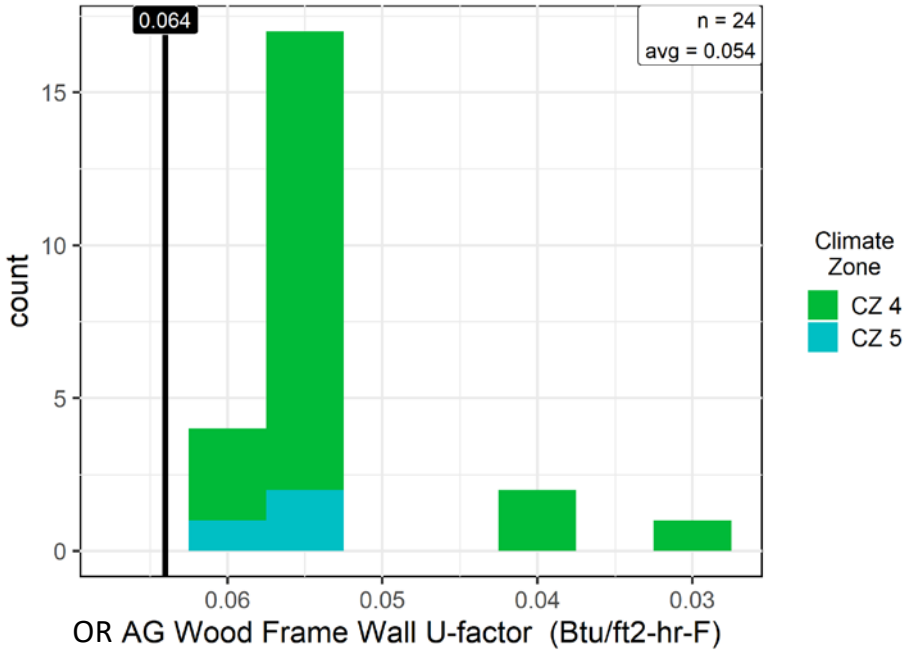

0.3
n = 25
avg = 0.290
Distribution of field observations
Number of observations
Prescriptive Requirement
Y-axis shows count of field observations at a particular value of x-axis
X-axis shows the observed values
Observation Metric
count
10
5
0
0.350
0.325
0.300
0.275
0.250
Window U-factor (Btu/ft2-hr-F)
Climate Zone
CZ 4
CZ 5

Wood Frame Ceiling/Roof U-Factor



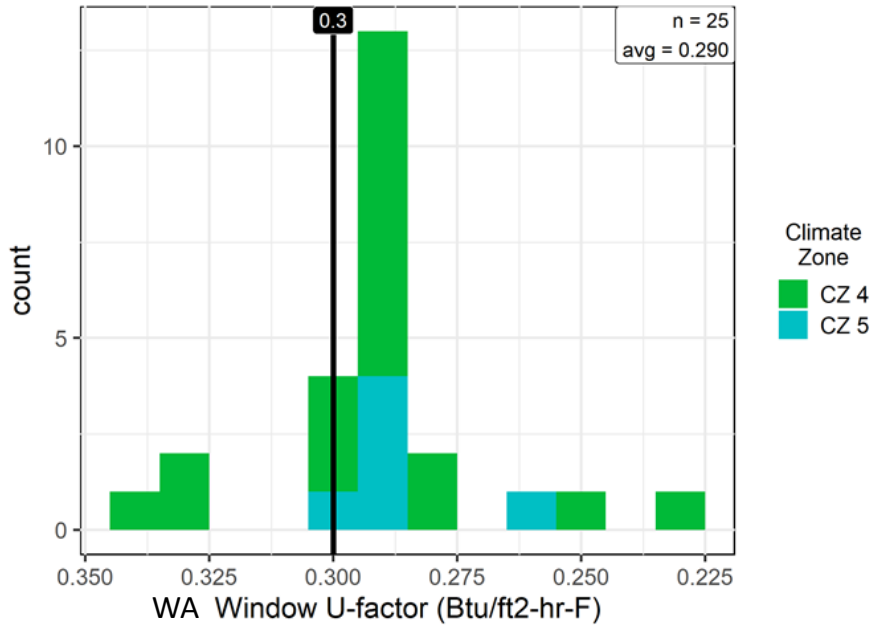
State	IL	MN	OR	WA	Overall
Climate Zone	CZ5	CZ6/CZ7	CZ4/CZ5	CZ4/CZ5	--
Requirement	0.026	0.026	0.027	0.026	**0.026/0.027**
Average	0.023	0.023	0.023	0.022	--
Compliance Rate	14 of 18 (78%)	22 of 24 (92%)	24 of 24 (100%)	24 of 25 (96%)	**84 of 91 (92%)**

Exterior Above-Grade Wood-Frame Wall U-Factor



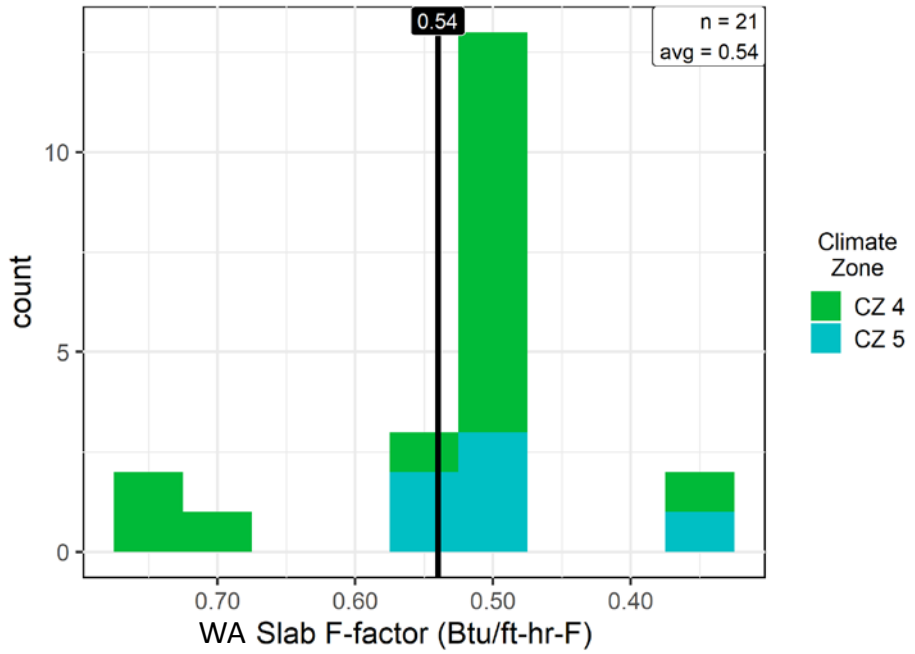
State	IL	MN	OR	WA	Overall
Climate Zone	CZ5	CZ6/CZ7	CZ4/CZ5	CZ4/CZ5	--
Requirement	0.057	0.057 / 0.056	0.064	0.056	**0.056/0.057/0.064**
Average	0.051	0.054	0.054	0.054	--
Compliance Rate	10 of 11 (91%)	18 of 22 (82%)	24 of 24 (100%)	24 of 24 (96%)	**76 of 82 (93%)**

Window U-Factor



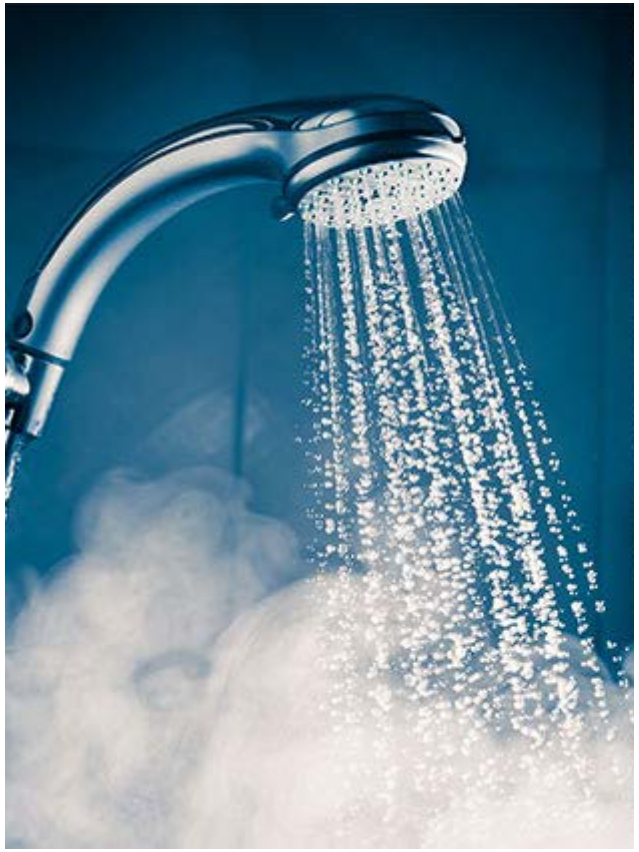
State	IL	MN	OR	WA	Overall
Climate Zone	CZ5	CZ6/CZ7	CZ4/CZ5	CZ4/CZ5	--
Requirement	0.32	0.32	0.35	0.30	**0.30/0.32/0.35**
Average	0.302	0.304	0.317	0.290	--
Compliance Rate	15 of 21 (71%)	20 of 25 (80%)	21 of 24 (88%)	22 of 25 (88%)	**78 of 95 (82%)**

Slab F-Factor



State	IL	MN	OR	WA	Overall
Climate Zone	CZ5	CZ6/CZ7	CZ4/CZ5	CZ4/CZ5	--
Requirement	0.54	0.52 / 0.4	0.54	0.54	**0.4/0.52/0.54**
Average	0.49	0.45	0.57	0.54	--
Compliance Rate	11 of 14 (79%)	10 of 12 (83%)	7 of 16 (44%)	16 of 21 (76%)	**44 of 63 (70%)**

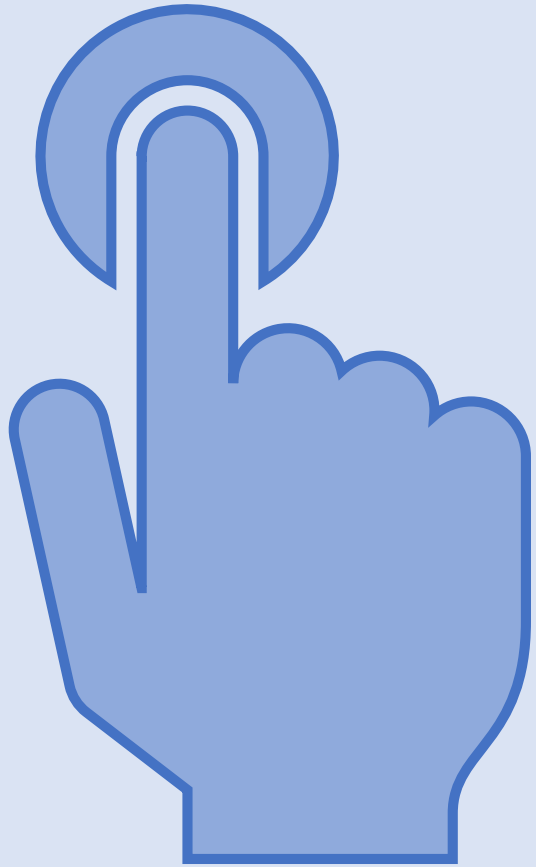
Service Hot Water



			IL	MN	OR	WA
Central	Electricity	HP			4%	4%
		Boiler/Storage				
	Gas	Boiler/Storage	64%	92%	21%	20%
In-unit	Electricity	Storage	24%		75%	76%
	Gas	Storage	14%	8%		

POLLING

“Profession”



Common Area Heating/Cooling Systems

Heating

	IL	MN	OR	WA
	CZ5	CZ6/CZ7	CZ4/CZ5	CZ4/CZ5
Electric resistance	25%	17%	25%	70%
Split system HP	5%	--	58%	10%
Gas Boiler	5%	22%	--	--
Gas Furnace	60%	52%	8%	10%
None	5%	9%	8%	10%

Cooling

	IL	MN	OR	WA
	CZ5	CZ6/CZ7	CZ4/CZ5	CZ4/CZ5
Split system AC	--	4%	--	--
Split system HP	20%	30%	58%	30%
PTAC	45%	35%	8%	--
Water source HP	--	13%	--	--
None	35%	9%	33%	70%

Interior Lighting

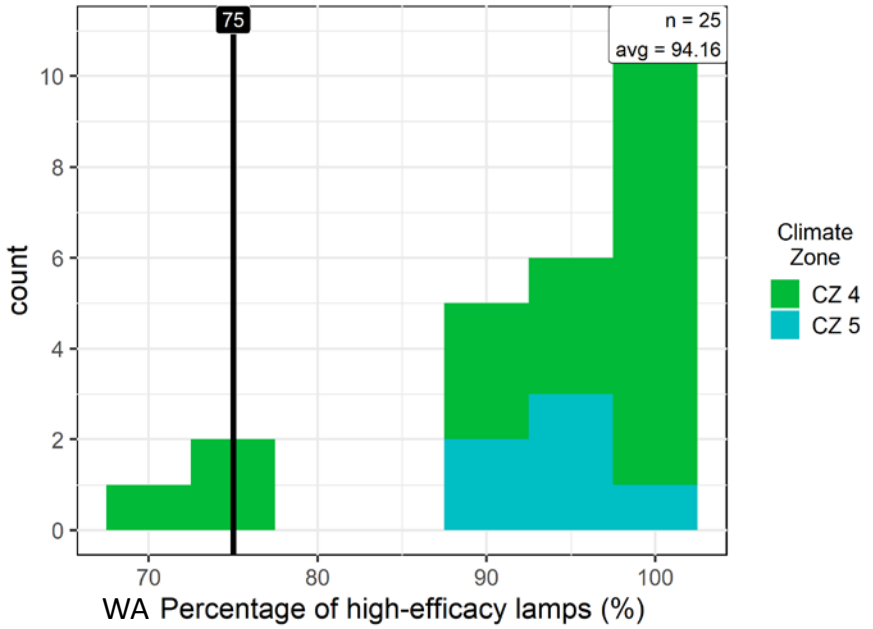
Corridors

State	IL	MN	OR	WA	Overall
Code Year	2012/2015	2015	2011/2014	2012/2014	--
Requirement	0.7/0.66	0.7	0.41	0.66/0.53	--
Average	0.98	0.40	0.32	0.28	--
Compliance Rate	12 of 16 (75%)	22 of 23 (96%)	7 of 10 (70%)	9 of 9 (100%)	**50 of 58 (86%)**

Stairwells

State	IL	MN	OR	WA	Overall
Code Year	2012/2015	2015	2011/2014	2012/2015	--
Requirement	0.7/0.69	0.7	0.49	0.69/0.55	--
Average	0.5	0.42	0.34	0.32	--
Compliance Rate	12 of 16 (75%)	17 of 19 (89%)	11 of 13 (85%)	10 of 10 (100%)	**50 of 58 (86%)**

Dwelling Unit Lighting



State	IL	MN	OR	WA	Overall
Code Year	2012/2015	2015	2011/2014	2012/2014	--
Requirement	75%	75%	N/A	75%	75%
Average	97%	99.5%	95%	94%	--
Compliance Rate	19 of 19 (100%)	25 of 25 (100%)	N/A	24 of 25 (96%)	**68 of 69 (99%)**

Dwelling Unit Heating Systems

	IL	MN	OR	WA
	CZ5	CZ6/CZ7	CZ4/CZ5	CZ4/CZ5
Electric resistance	10%	4%	42%	80%
Split system HP	14%	--	29%	8%
PTHP	5%	--	25%	8%
Gas Furnace	67%	68%	4%	4%
Hydronic (gas boiler)	5%	12%	--	--
Water source HP (gas boiler)	--	16%	--	--

Dwelling Unit Cooling Systems

	IL	MN	OR	WA
	CZ5	CZ6/CZ7	CZ4/CZ5	CZ4/CZ5
Split system AC	62%	8%	8%	4%
Split system HP	14%	--	25%	8%
PTAC	19%	64%	4%	8%
PTHP	5%	--	29%	8%
Water source HP	--	16%	--	--
Window AC	--	12%		8%
None	--	--	33%	64%

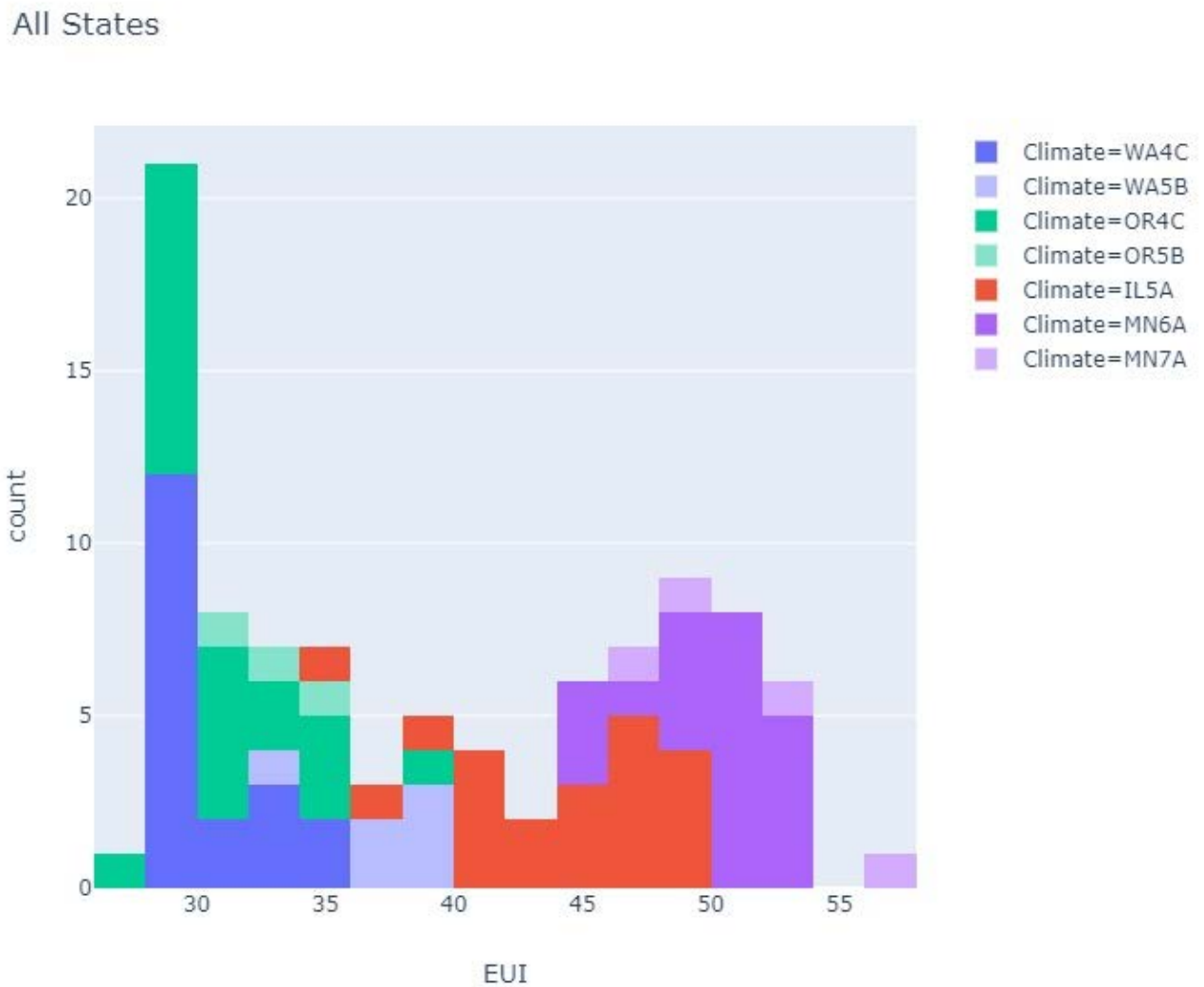
Energy Use Analysis

Scott Spielman, Research Engineer
Ecotope

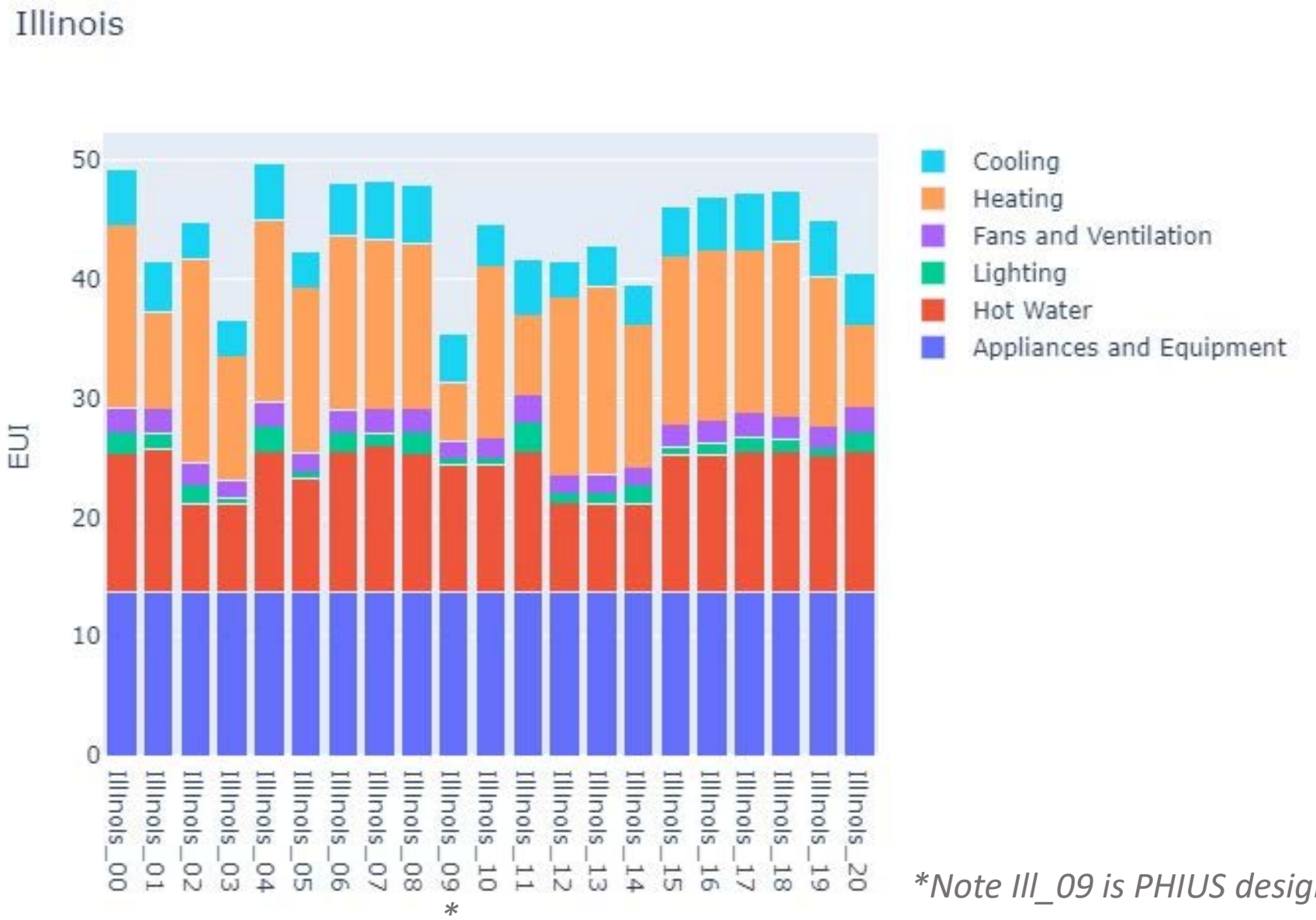
Energy Use Analysis

- Prototype approach, both common entry and garden style. Used PNNL ‘buildings’
- EnergyPlus simulations were run on each of the 95 buildings surveyed by altering key inputs (envelope performance, mechanical system, hot water system, and lighting power) on 4 different seed models.
- Results expressed in EUI (energy use intensity); dimensions are kBtu/ft^2-yr.
- Simulation results were used to generate an expected EUI range for buildings in each state and understand end-use breakdown.
- Histogram and End-Use EUI plots were generated from results.

EUI Histograms



State-Wide EUI Distribution (IL)



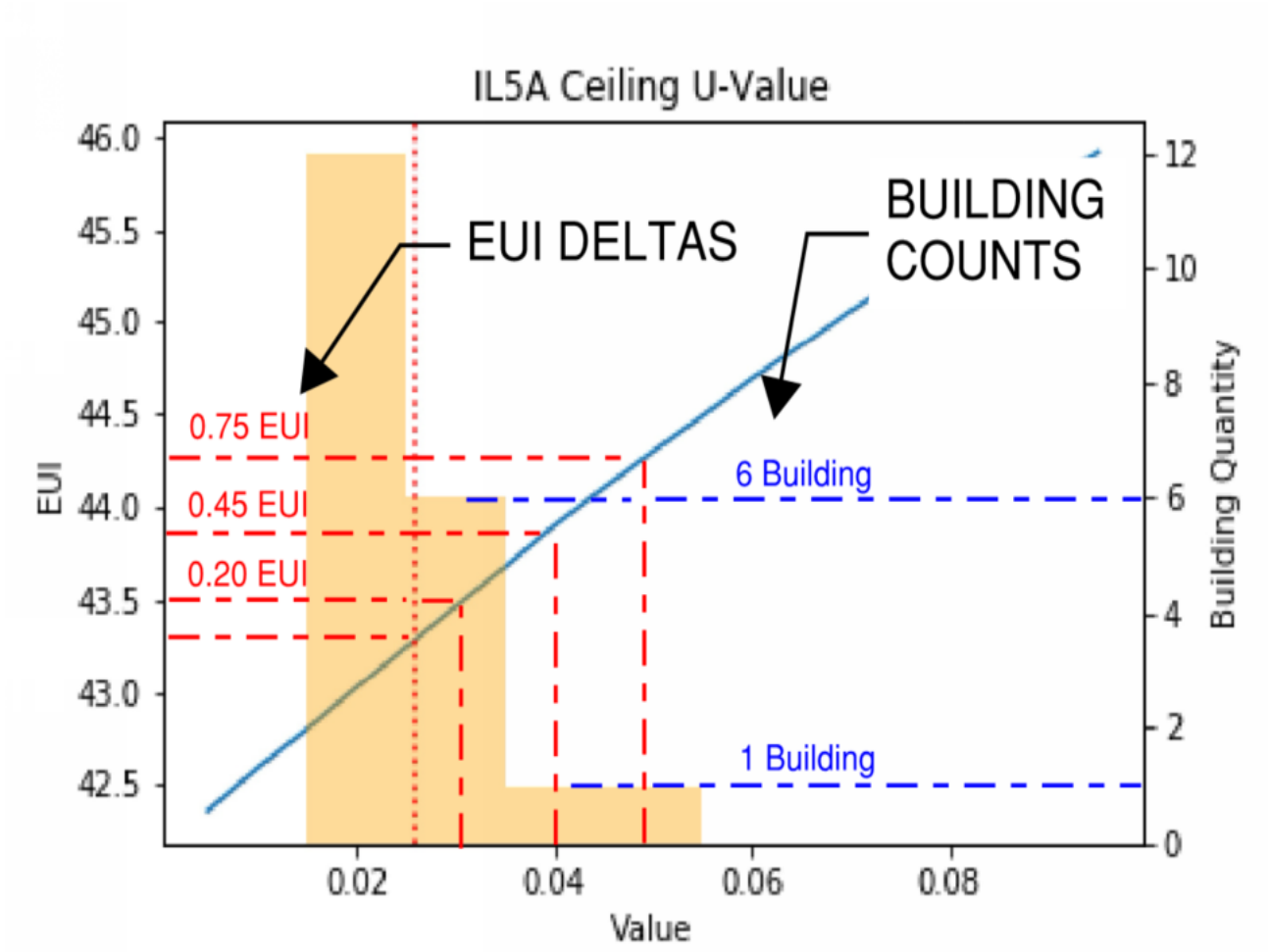
**Note Ill_09 is PHIUS design*

Measure Analysis

- The goal of measure analysis simulation is to quantify the energy and cost savings for bringing each building component up to code.
- EnergyPlus was used to create performance maps for each building component, which were used to determine savings.
- Only envelope and lighting components are included. It was assumed that all the HVAC equipment used in the buildings surveyed was code-minimum compliant*.
- Results are then extrapolated to the building stock, treating surveyed buildings as a representative sample.

*The characteristics review found only a tiny number of systems that were non-compliant and other systems that greatly exceeded code minimums

Measure Analysis- EUI-based Adjustment



Each modeled EUI delta is multiplied by the number of corresponding buildings, shown in blue. In the example above a total of 2.4 modeled EUI is calculated for non-compliance.

Statewide Annual Measure Level Savings (IL)

Savings Measure	Electricity Savings (kWh / unit)	Natural Gas Savings (Therms / unit)	Total Savings (kBtu / unit)	Total Number of Units Built in State	Total Energy Savings (MMBtu)	Total Energy Cost Savings ($)	Total State Emissions Reduction (MT CO2)
Ceiling U-Value	4	0.83	98	17,789	1,742	26,545	276
Exterior Wall U-Value	4	1.11	126	17,789	2,238	32,745	356
Corridor LPD	6	0.00	19.06	17,789	339	10,935	45

Energy & Measure Analysis Summary

- Overall, most buildings met or bettered code prescriptive requirements.
- Climate, mechanical system type, and hot water system type had the biggest impacts on modeled EUI; installed systems almost always met (or exceeded) minimum requirements.
- High efficacy lighting was common; there was some improvement possible in exterior/common area lighting (typically regulated by commercial code).

Market Research Study

Scott Pigg, Principal Researcher
Slipstream

Market Research

Gain insights on:

- nature of the firms working in the LRMF market
- knowledge of energy-code requirements for LRMF
- availability of code training
- need for code training

Closed-ended survey sent to more than 800 firms

- Developers
- A&E companies
- Contractors
- Facility managers

Interviews with code officials and others in each state

Survey respondents (n=44)

Company Type	Number of Responses
Developer	19
A&E Firm	14
General Contractor	6
HVAC Contractor	2
Other	3
Geographic Reach of firm	
State	27
Regional	10
National	5
Construction Delivery Method	
Design-Build-Bid	9
Design-Build	8
Spec-Build	7
Construction Manager at Risk	3
Integrated Property Delivery	2

Interview respondents (n=21)

Role	Number Interviewed
State Building/Energy Code Official	2
County Building/Energy Code Official	3
City Building Code/Energy Official	9
Other*	7
Total interviews	21

Other: staff from building associations (2); university energy program (2); air leakage testing company (2); and non-profit energy policy organization (1).

LRMF built by firms that work in a variety of construction types

Reported percent of business by building type, for developers, A&E firms and general contractors (n=34).

Building Type	Mean	Range
Single-family homes	13%	0 to 70%
Multifamily buildings, 2-4 units	20%	0 to 100%
Apartment buildings, 1-3 stories	35%	0 to 100%
Condominiums, 1-3 stories	4%	0 to 15%
Multifamily buildings, 4+ stories	34%	0 to 100%
Mixed-use buildings	22%	2 to 95%
Commercial buildings	21%	0 to 70%
Other (unstated)	2%	0 to 62%
Number of types cited	3.6	1 to 7

2/3rds of firms work on fewer than 10 projects per year

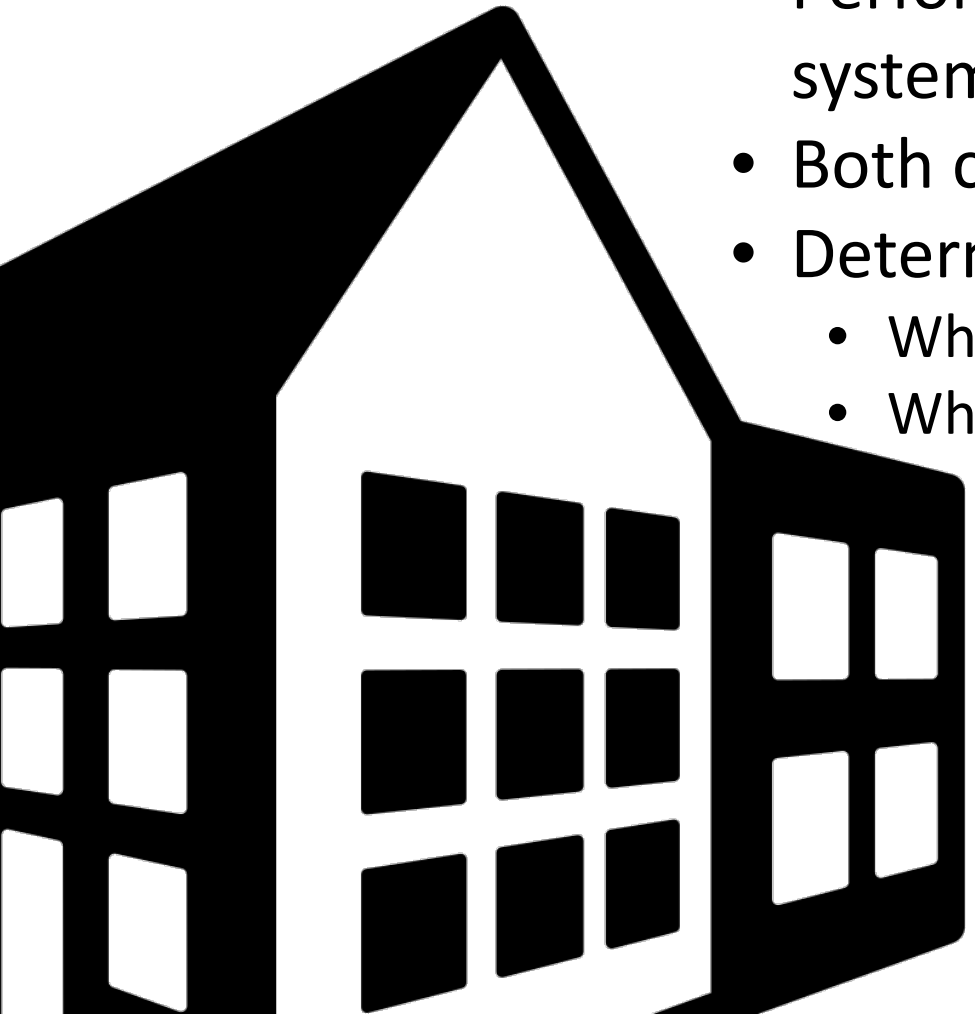
Residential Code Knowledge and Training

- **Confusion about applicable code (residential vs commercial) for LRMF!**
  - particularly in Minnesota and Oregon
- Code officials and online resources are main sources of information about code
- Developers rely on contractors and subcontractors to know the code
- Architects feel they know the code that applies to their work
- Survey respondents identified issues with understanding and complying with the code – but half are uninterested in residential code training.
- Code officials say…
  - …code generally well-followed
  - …issues stem primarily from a skillset gap or lack of knowledge
  - …air- and duct-sealing testing requirements most common compliance issue

Air Tightness Testing Study

Dave Bohac, Director of Research
Center for Energy and Environment

Air Tightness Testing (ATT) Study Objectives

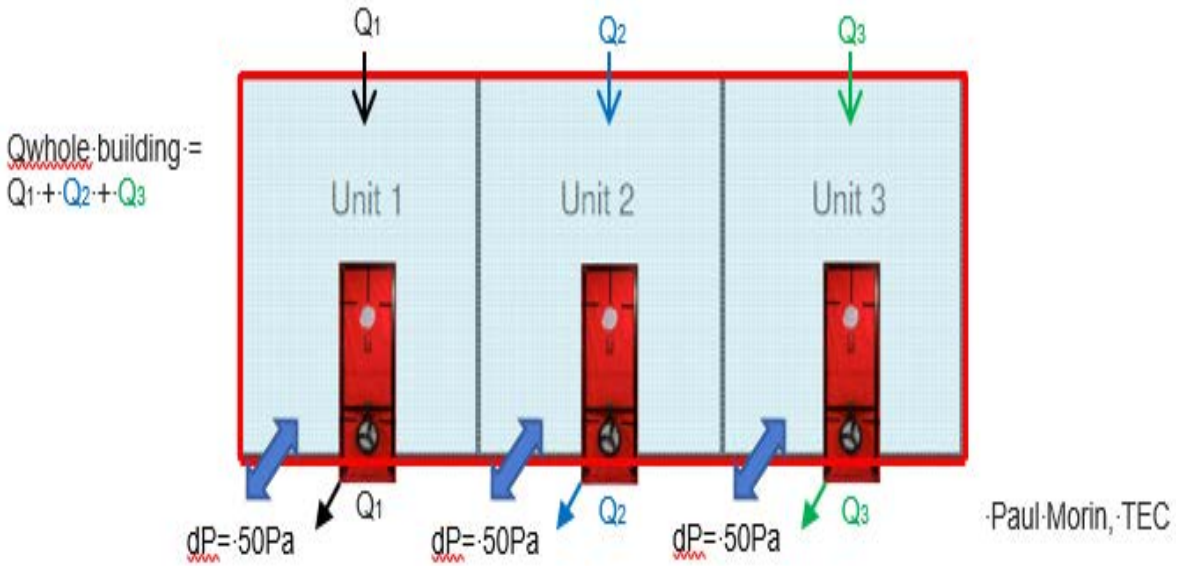


- Perform 25-30 tests with semi-automated blower door system in Midwest and Pacific NW
- Both common entry and garden style (exterior entry)
- Determine whether relationship exists between tests
  - Whole building vs compartmentalization vs unit exterior
  - What variables affect predictive power for energy use?

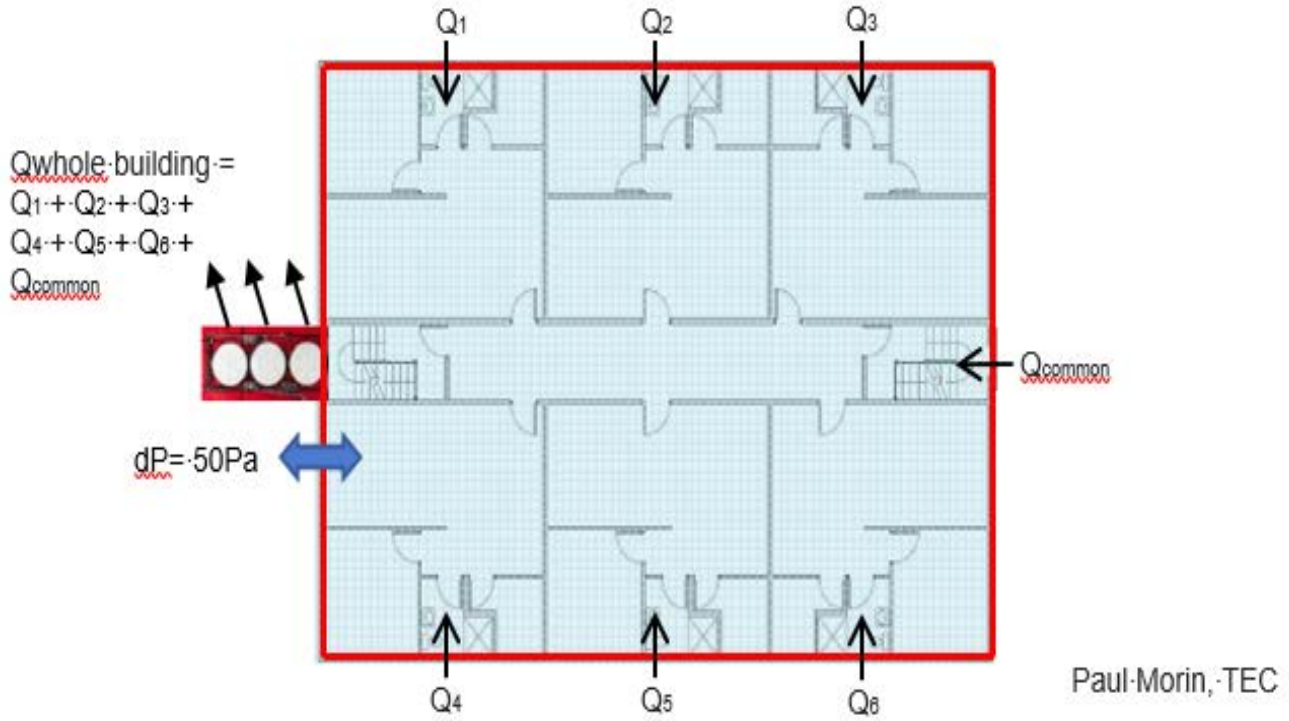
- Provide envelope air leakage protocol
- Provide guidance for code language
- Assess energy impact of ATT using this protocol

Testing Set Up: whole building tests

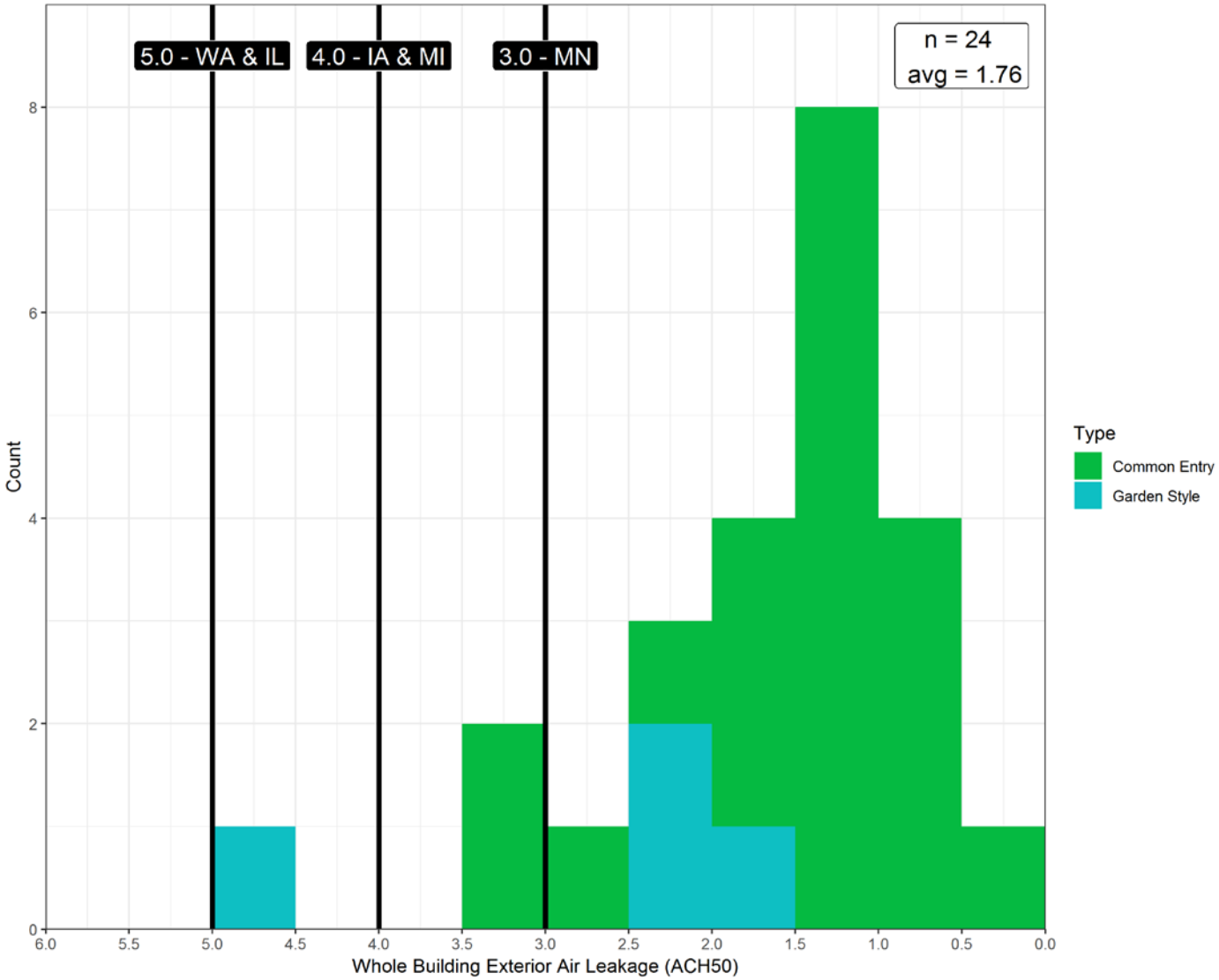
Garden-Style Building



Common-Entry Building

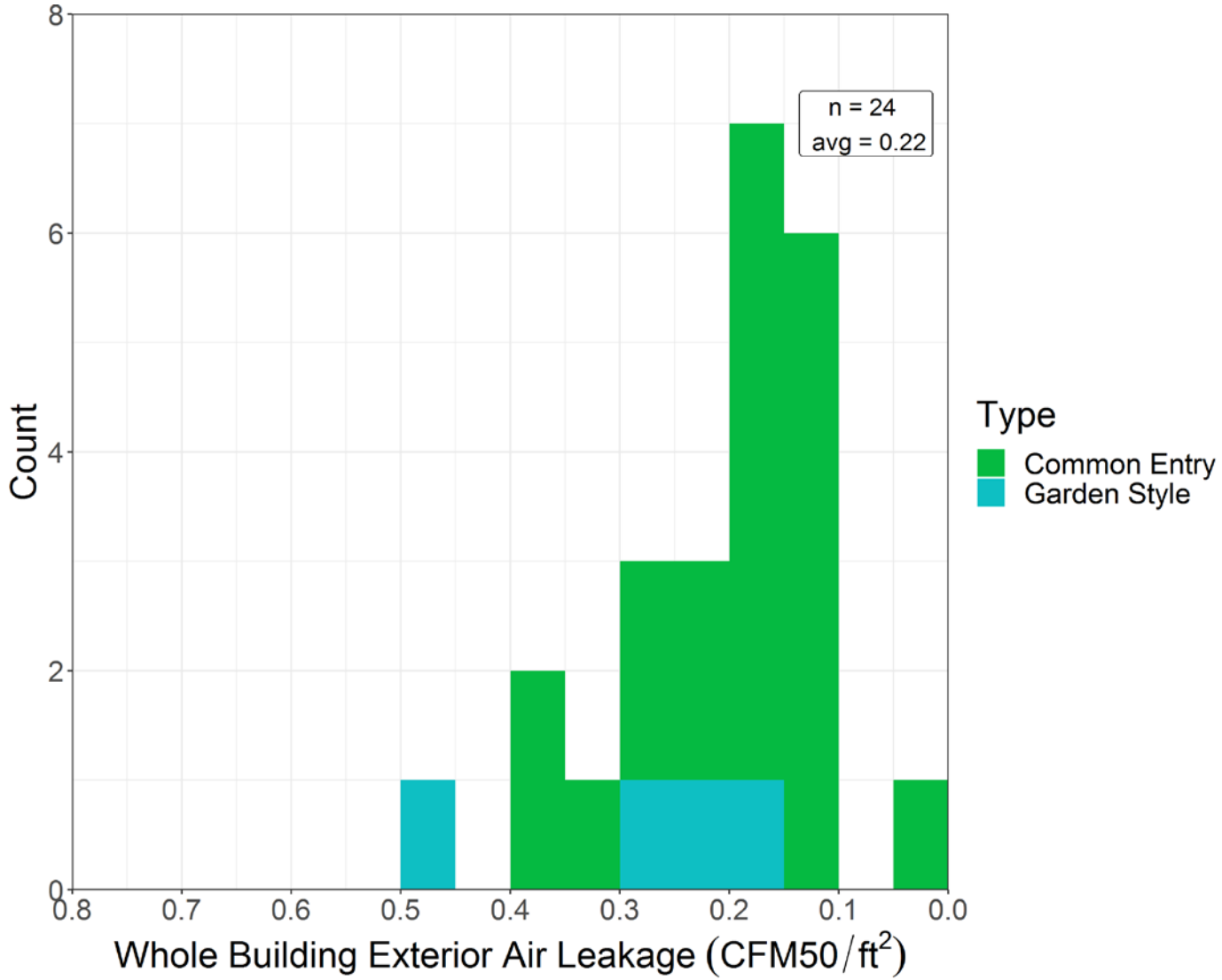


Whole Building Leakage: ACH_{50}



- Summary
  - 100% compliance
  - 3 bldgs > 3 ACH_{50}
  - Average = 1.61
  - Min = 0.41 (IL Passive House)
  - Max = 4.72
- State averages
  - MN= 1.34
  - IL = 1.47 (1.82 w/o PH)
  - IA = 1.63
  - MI = 1.89
  - OR = 2.81
  - WA = 3.89

Whole Building Leakage: CFM_{50}/ft^2



- Summary
  - Average = 0.23
  - Min = 0.05 (IL Passive House)
  - Max = 0.47
  - 58% < 0.20
  - 71% < 0.25
  - 83% < 0.30
- State averages
  - MN= 0.18
  - IL = 0.18
  - IA = 0.24
  - MI = 0.28
  - OR = 0.33
  - WA = 0.37

CFM_{50} x 1.3 = CFM_{75} (n=0.65)
0.25 CFM_{75}/ft^2 = 0.19 CFM_{50}/ft^2

Building & Design Characteristics

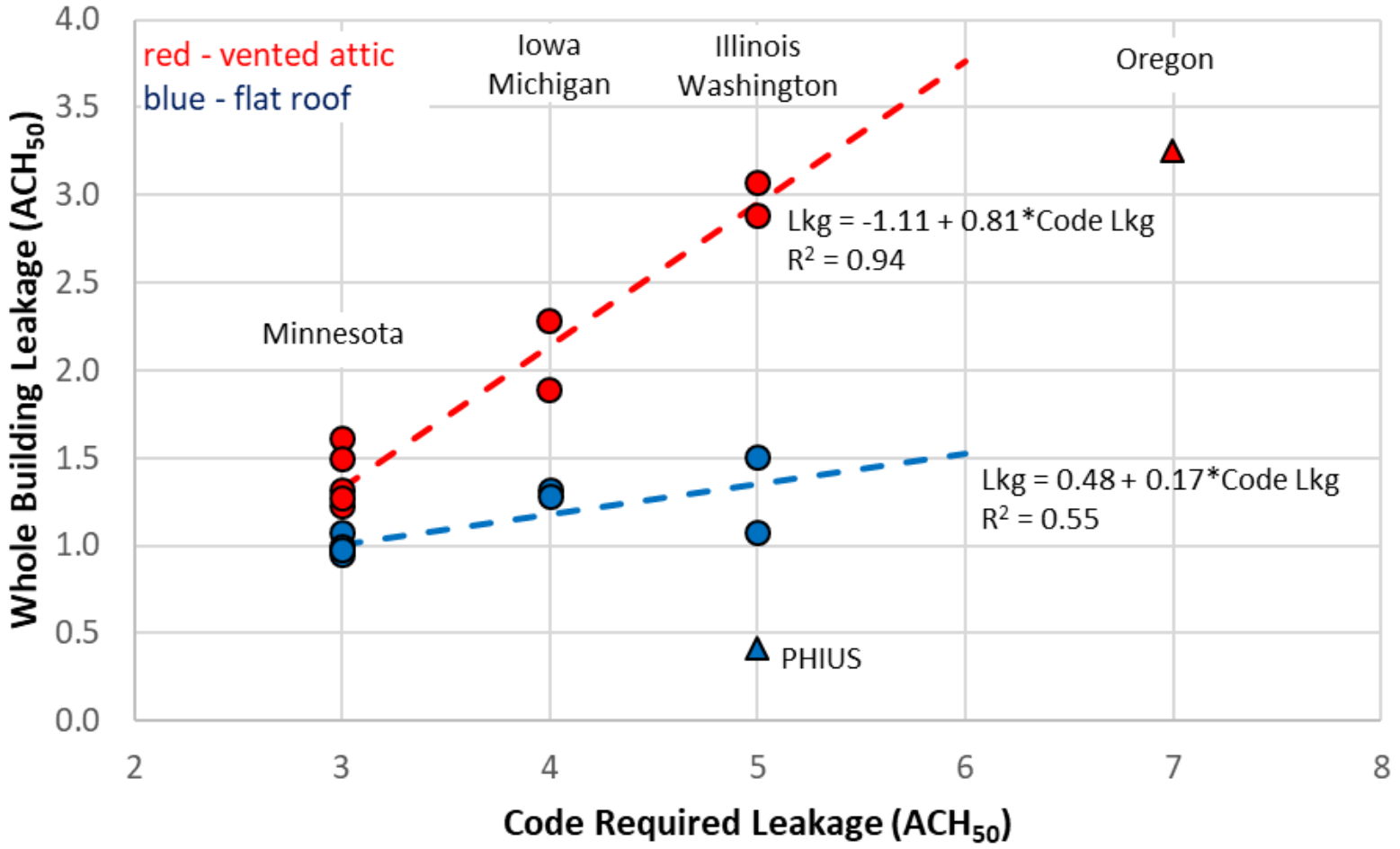
That Could Impact Envelope Leakage

- Municipality air leakage code requirement/enforcement?
  - Test type and max acceptable
- Ceiling-roof (flat or vented attic)
- Program requirement for air leakage test
  - Program, test type, max acceptable (target or requirement)
- Space below lowest level (slab, garage, basement, commercial)
- Air barrier design approach
  - Exterior, above grade walls
  - Demising walls
  - Ceiling-roof
- Common Entry or Garden Style

Building & Design Characteristics

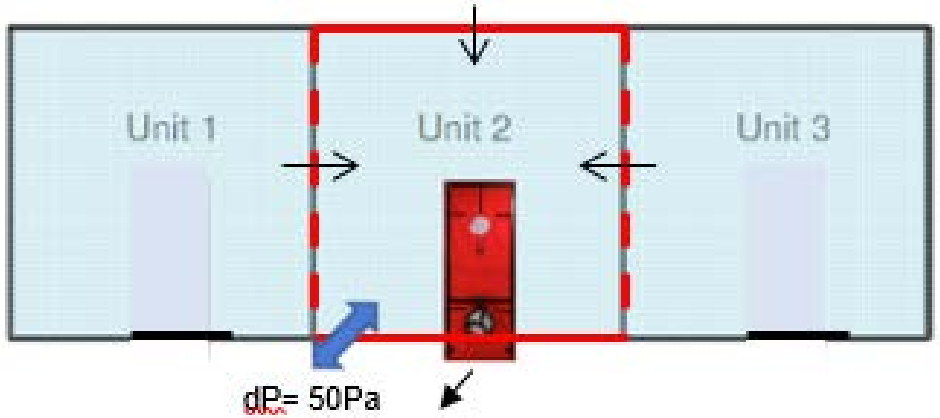
Significant: type of roof and code required leakage

Not Significant: energy program, space below, type of exterior air barrier



Testing Set Up:
unit compartmentalization tests = total leakage

Garden-Style Building



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Common-Entry Building

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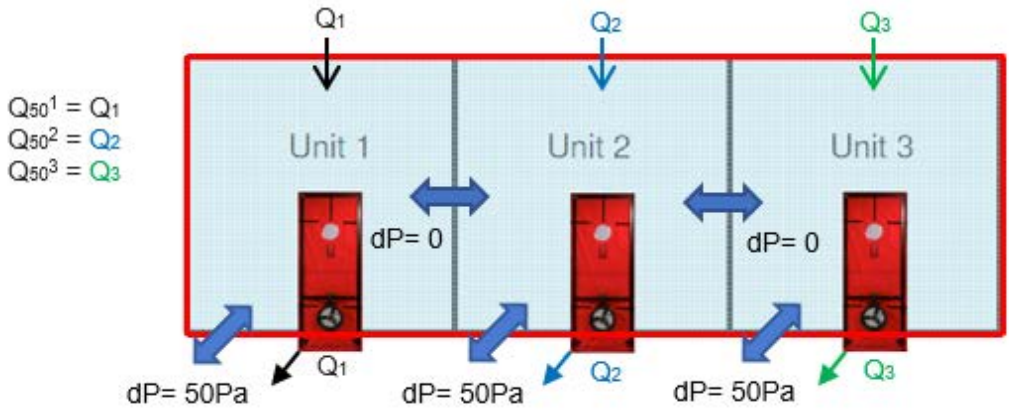
Testing Set Up:
unit guarded tests = exterior leakage

Garden-Style Building



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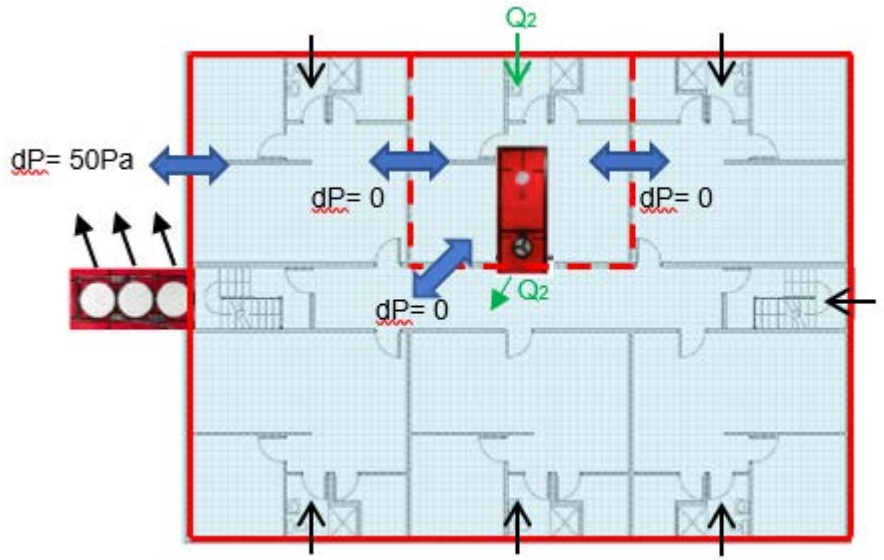
Common-Entry Building



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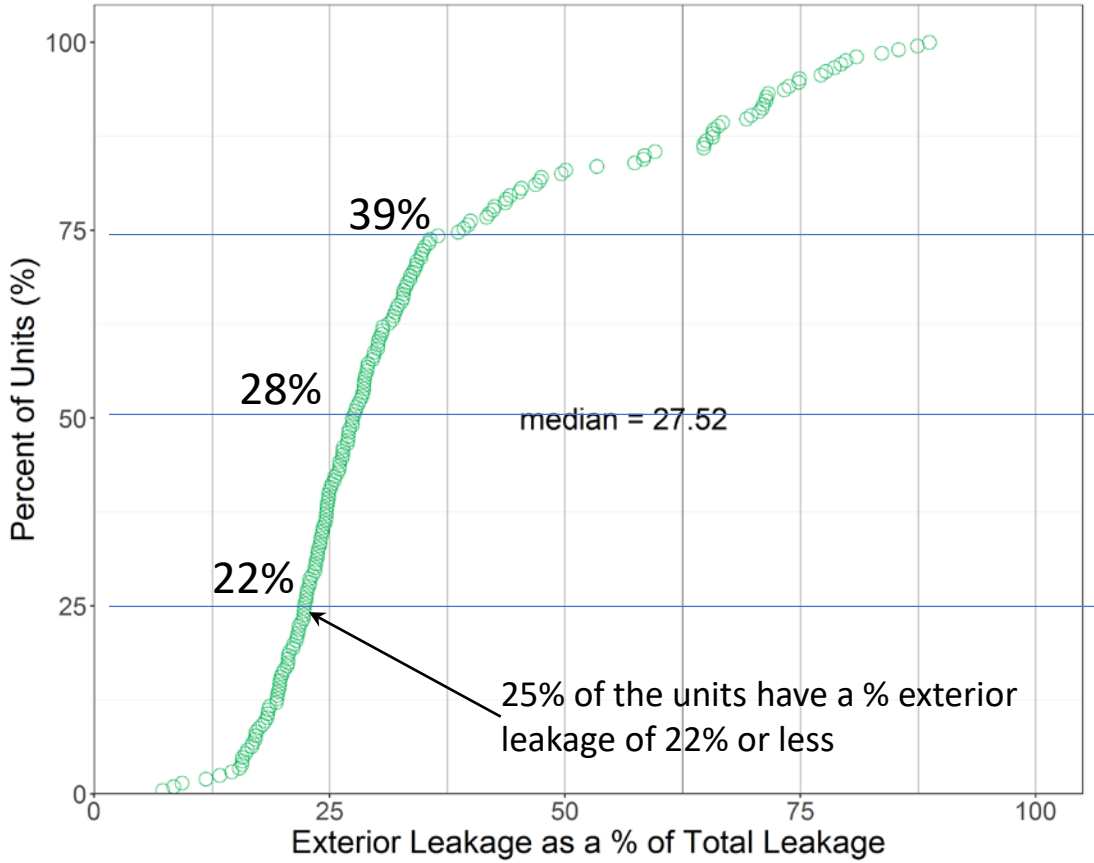
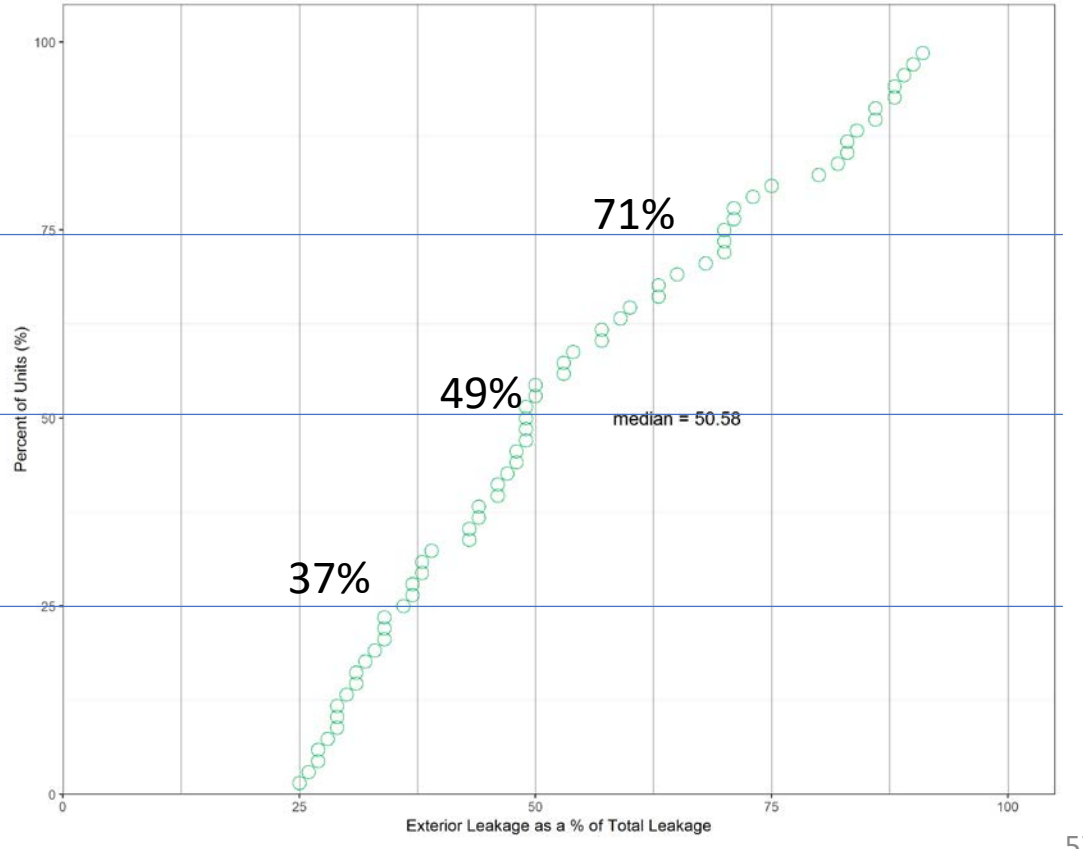
Unit Total and Exterior Leakage

- Common-Entry
  - Total = 2.72 ACH_{50}
  - Exterior = 1.41 ACH_{50}
  - % Exterior = 34%

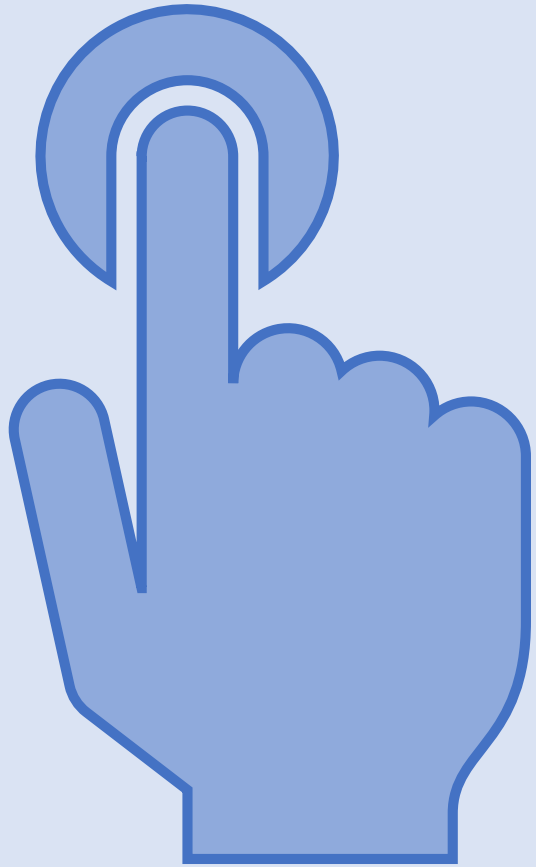


- Garden-Style
  - Total = 5.13 ACH_{50}
  - Exterior = 2.72 ACH_{50}
  - % Exterior = 49.4%



POLLING

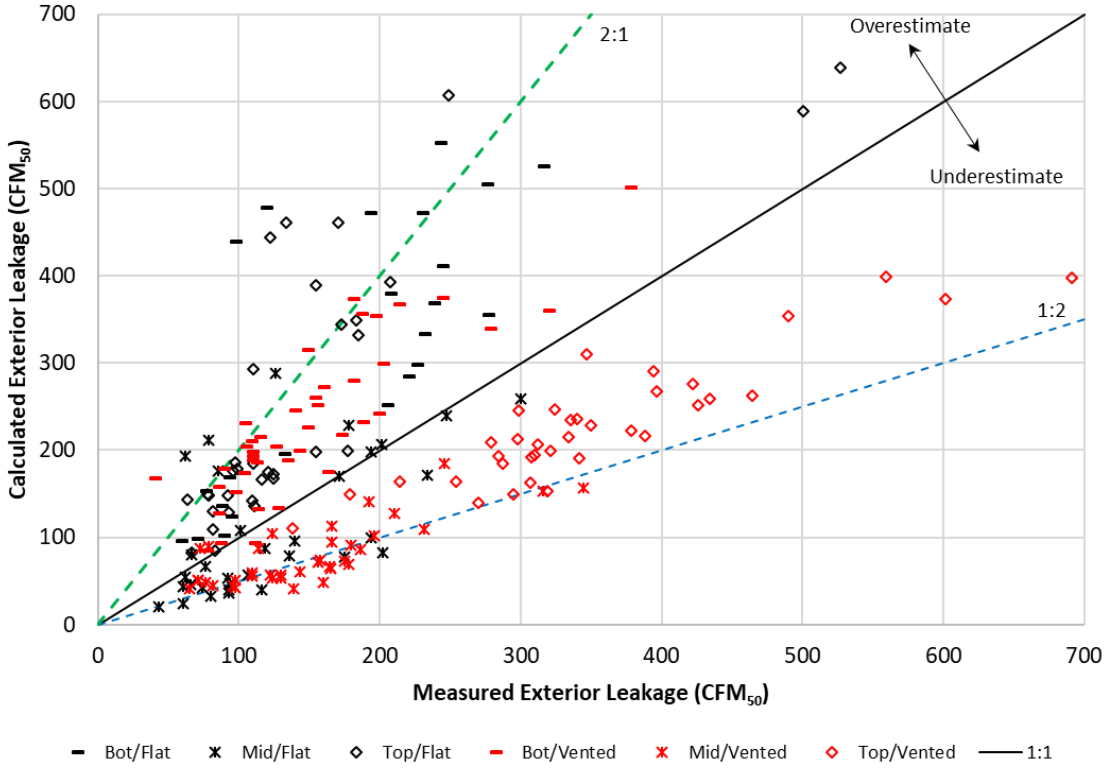
Further Research

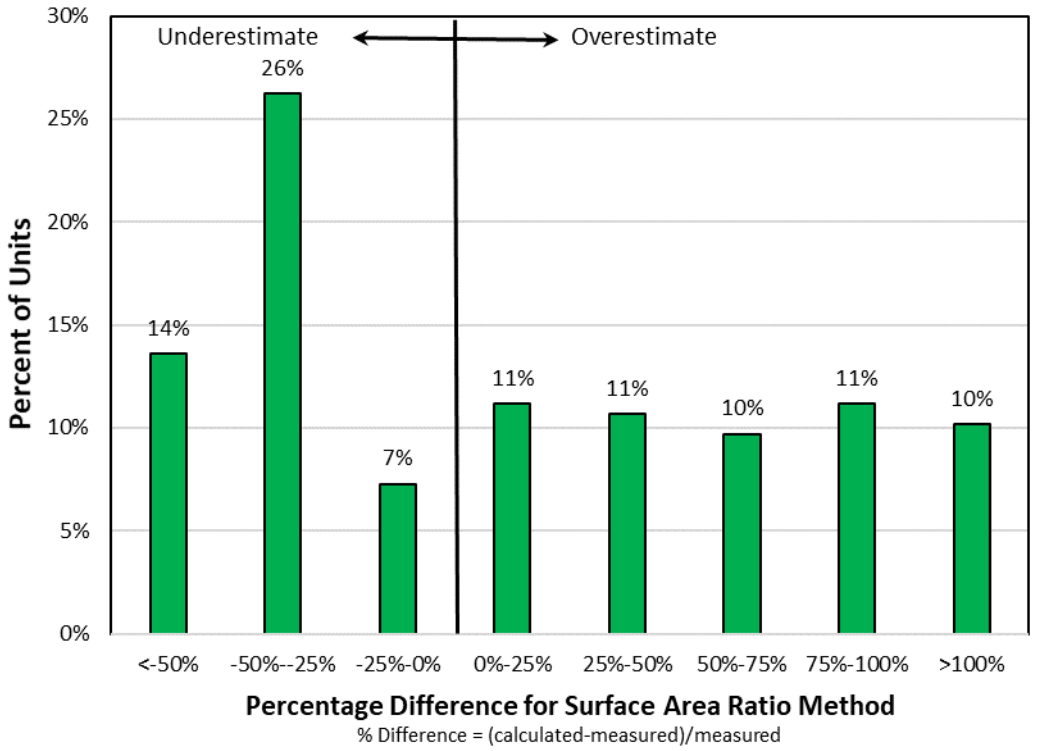


Compute Exterior Leakage from Total Leakage

Exterior Leakage = Total Leakage * (Exterior Surface Area/Total Surface Area)

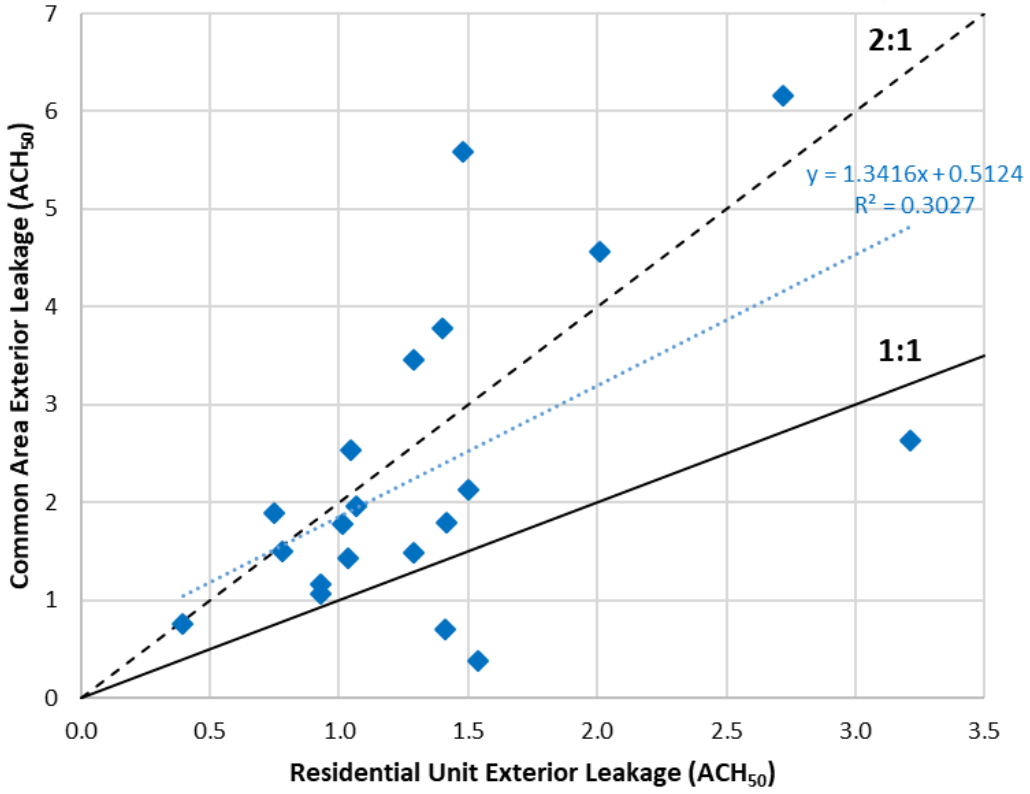
- Computed leakage within 25% of measured value for only 18% of the units
- 50% overestimate for 31% of the units
- 50% underestimate for 14% of the units



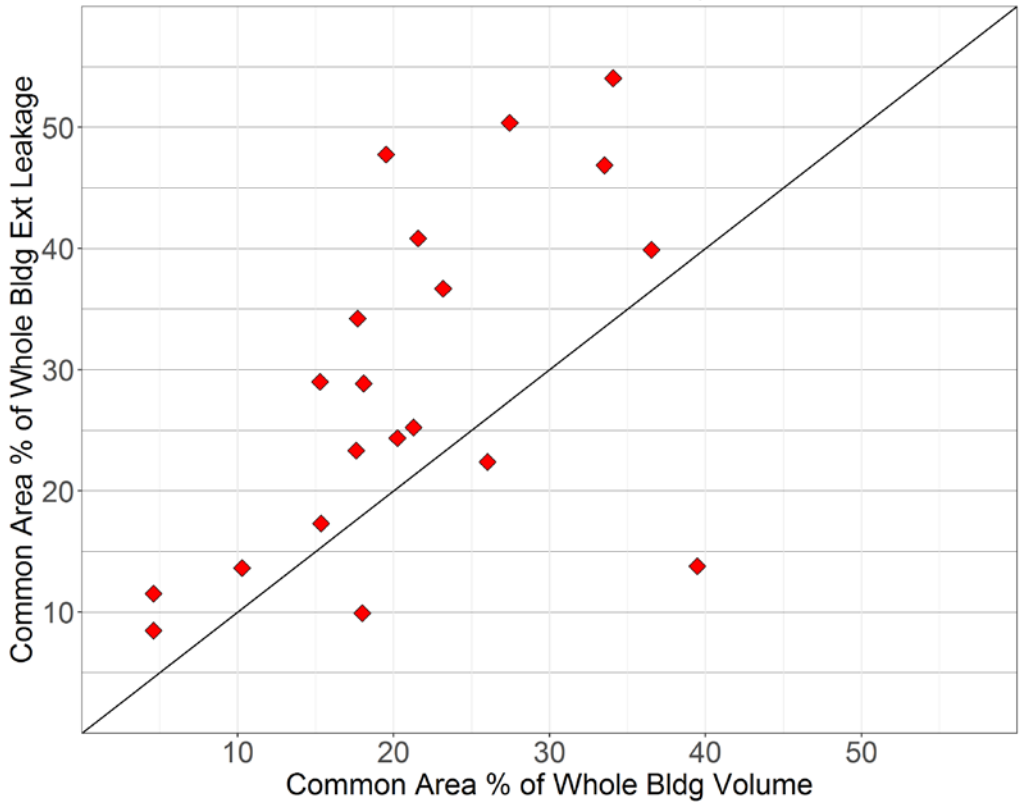


Impact of Common Space

- Exterior Leakage (ACH_{50})
  - Residential Units: 1.36 ACH_{50}
  - Common: 2.34 ACH_{50}
  - Common > Residential for 17 of 20
  - Common > 2x Resid for 7 buildings



- Volume vs Leakage
  - Common averages 21% of volume
  - Common averages 29% of leakage
  - For 30% of bldgs., Common > 40% leakage
  - If Common = Resid, leakage reduced 15%



Notable Air Leakage Results

- Whole building procedure equipment/labor-intensive, especially for garden style
- All buildings met state-required leakage levels for whole-building air leakage
- Type of building, roof type, and code required leakage had significant impact on leakage
- Common areas leakier than residential units & have significant impact on whole building leakage
- Percent exterior leakage: common-entry= 34%, garden-style = 54%
- Surface area ratio method => poor prediction of exterior leakage

Other Air Leakage Report Items

- Accuracy of exterior leakage computed from total based on building type, level in building, and roof type
- Accuracy of exterior leakage computed from total leakage using adjacent unit dP (Garden Style Only)
- Breakdown of interior leakage to common space and adjoining units
- Impact of closed adjoining units for compartmentalization test
- Variability of measured leakage for units in a building and on same floor.
- Number of fans needed for whole building tests
- Modeling of air leakage energy penalty with different levels of (interior and exterior) leakage and ventilation systems

Future Research

- Measured exterior & total leakage for additional units:
  - Are trends consistent with this study
  - Exterior leakage from total for garden-style buildings - use adjacent unit dP?
  - Typical leakage for other parts of U.S.
- Whole building measurements
  - Typical leakage for other parts of U.S.
  - Trend for exterior leakage of common area vs residential units
- Measure leakage and investigate paths – what is needed for tighter buildings/units?
- Modelling
  - Relate unit leakage to air infiltration and inter-unit airflow rates
  - Impact of interior leakage
  - Effectiveness of exhaust, supply and balanced ventilation
  - Impact of common area leakage on building energy use

Q & A

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QUESTIONS

THANK YOU!

- Building Energy Codes Program

www.energycodes.gov/training

- Multifamily Resources are available at

https://www.energycodes.gov/compliance/energy-code-field-studies

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