The Carbon Impact of Sealing the Passive House Building Envelope

Gord Cooke & Bill Shadid

11.9.23

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HOUSTON 2023

Agenda

- Speaker introductions & review what we'll cover
- Air sealing the envelope & carbon
- Carbon impact of housing
- Embodied carbon
- Reported air tightness levels comparison
- Operational carbon & air tightness – modeling the impact
- Carbon impact of other energy efficiency measures
- Carbon impact used in your marketing
- Key learnings & insights
- Q & A with discussion
- Appendix

Who We Are

Gord Cooke

Construction Instruction

- Partner, Construction Instruction
- 35+ years as an Energy Rater and building scientist
- Professional Engineer – University of Toronto

Bill Shadid

Aeroseal Envelope (AeroBarrier)

- Strategic Marketing Leader, Aeroseal Envelope
- Over 25 years in the building industry
- 16+ years in sustainable building technologies
- 9+ years as a sustainable architect
- Judge, Cleantech Division, Minnesota Cup

Air Sealing the Envelope & Carbon

Specific Air Sealing has been a code requirement since at least 2009

2009 IECC has 17 clauses detailing elements to air seal

To limit the potential for condensation in insulated attic and wall cavities

TABLE R402.4.1.1
AIR BARRIER AND INSULATION INSTALLATION

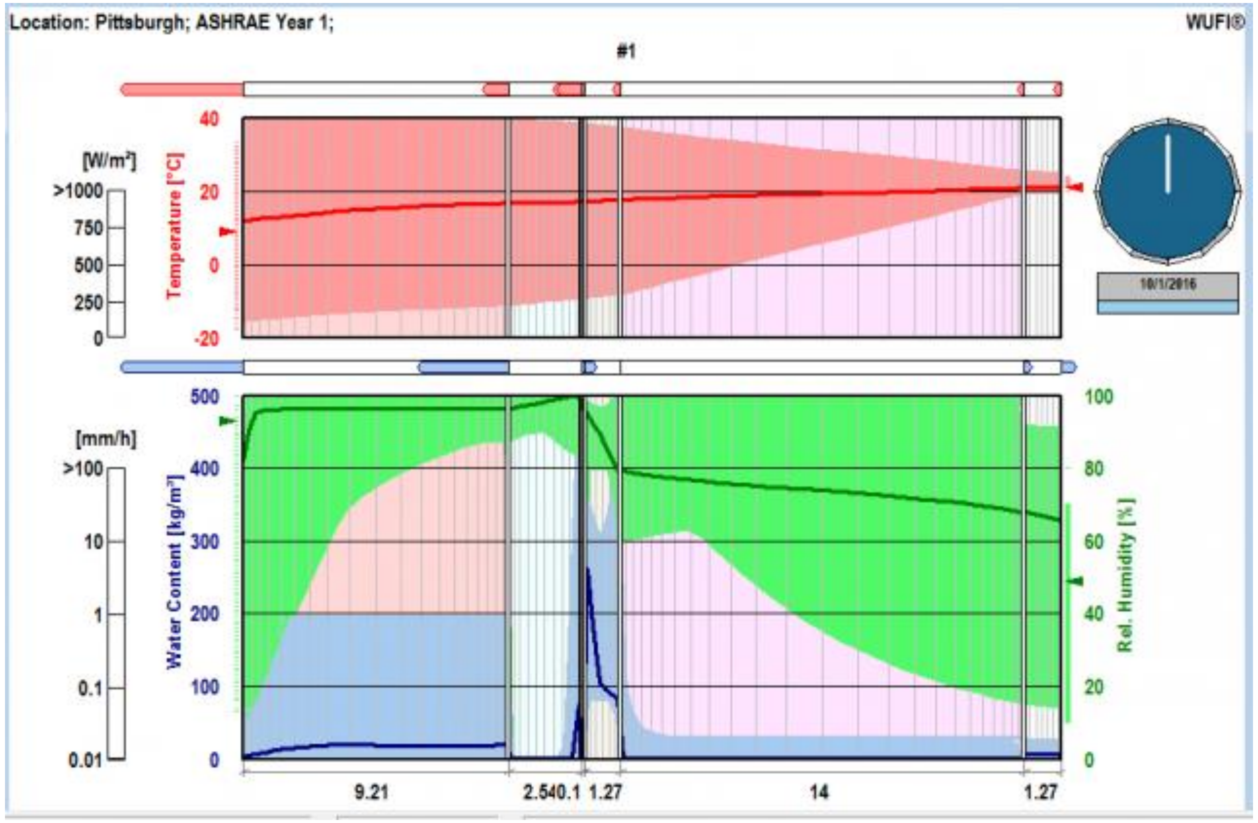
COMPONENT	CRITERIA[a]
Air barrier and thermal barrier	A continuous air barrier shall be installed in the building envelope. Exterior thermal envelope contains a continuous air barrier. Breaks or joints in the air barrier shall be sealed. Air-permeable insulation shall not be used as a sealing material.
Ceiling/attic	The air barrier in any dropped ceiling/soffit shall be aligned with the insulation and any gaps in the air barrier sealed. Access openings, drop down stair, or knee wall doors to unconditioned attic spaces shall be sealed.
Walls	Corners and headers shall be insulated and the junction of the foundation and sill plate shall be sealed.

Air Sealing is Even More Important in Highly Insulated Assemblies

The more insulation in an assembly,

The less the drying potential

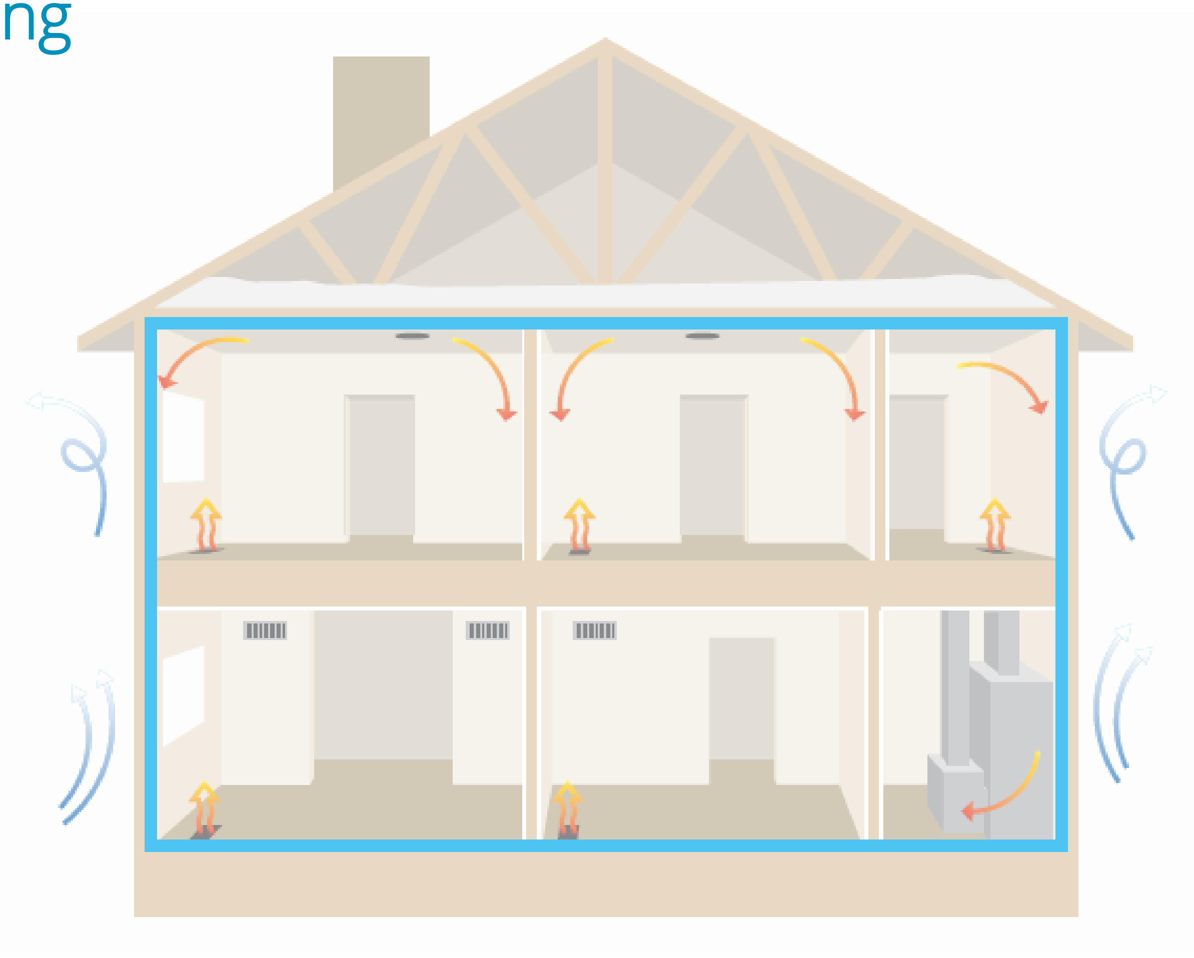
The more air tight the assembly should be.



WUFI output courtesy of Green Building Advisor

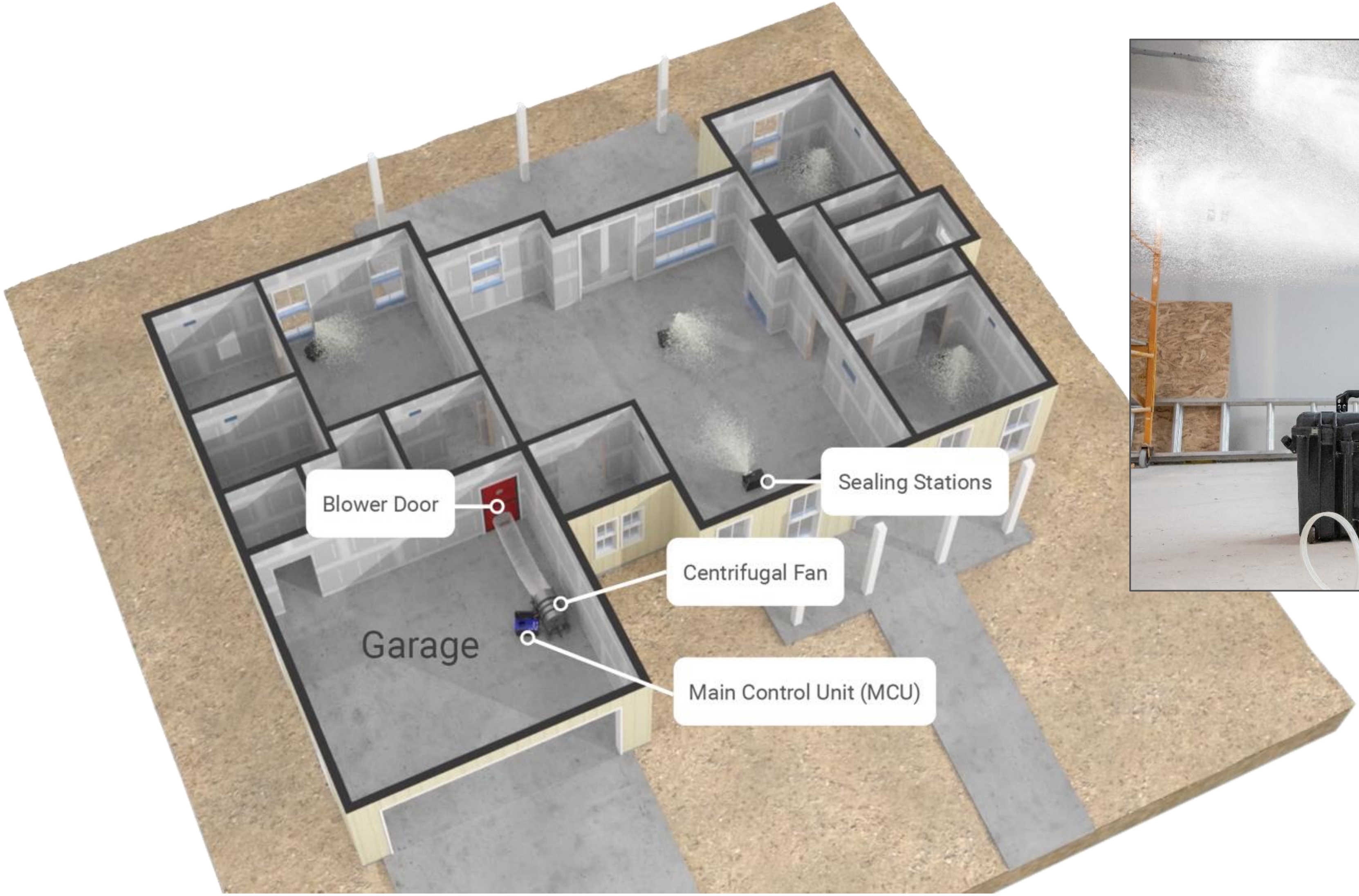
Additional Benefits of Sealing the Envelope

- Help prevent moisture from entering the wall and attic systems
- Experience dramatic savings on home heating and cooling
- Enjoy a more comfortable home
- Diminish outside noise
- Improve indoor air quality
- Defend against insects and pests



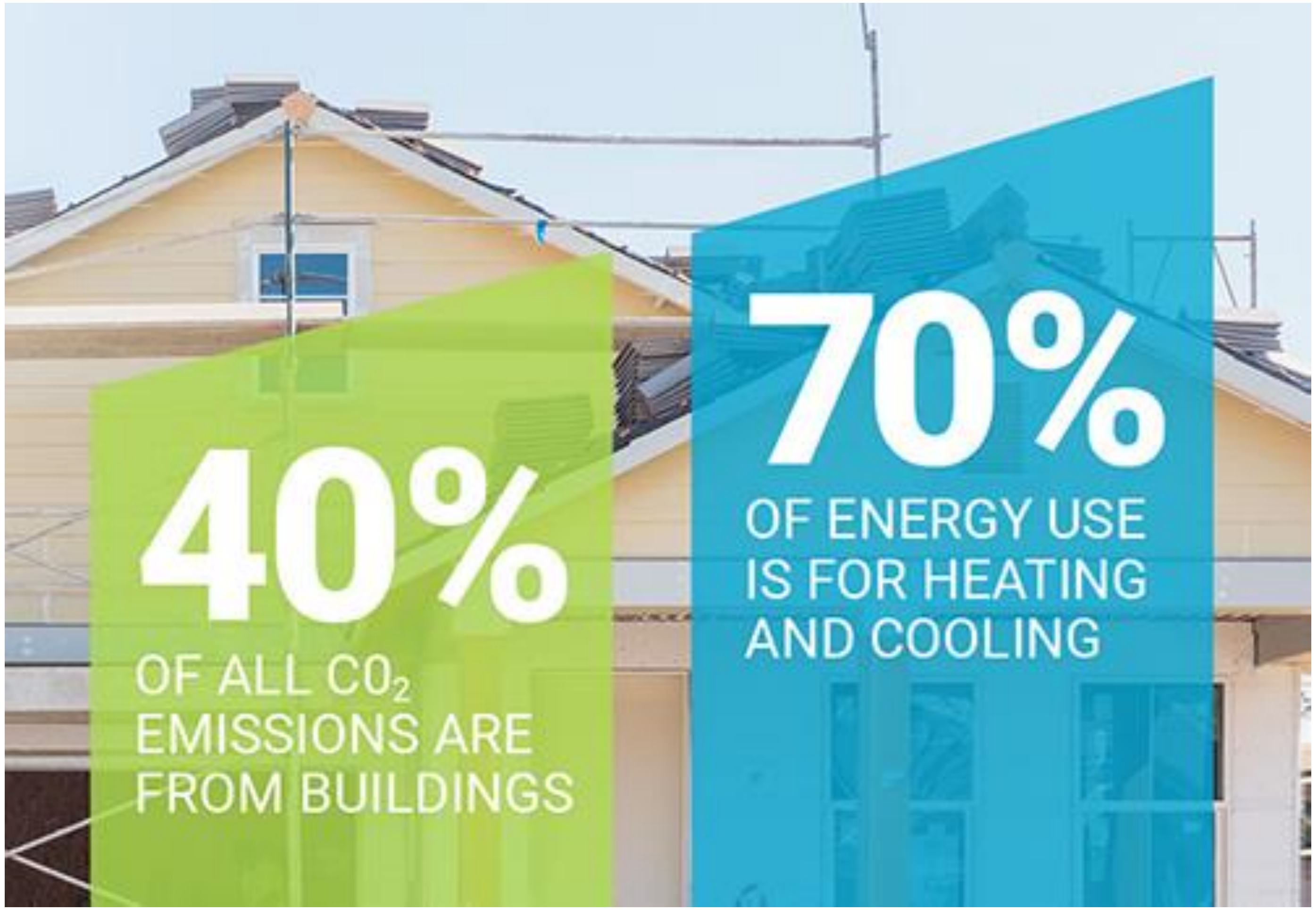
Air Sealing Methods Overview: Manual

Air Sealing Methods Overview: Automated & Blower Door Directed

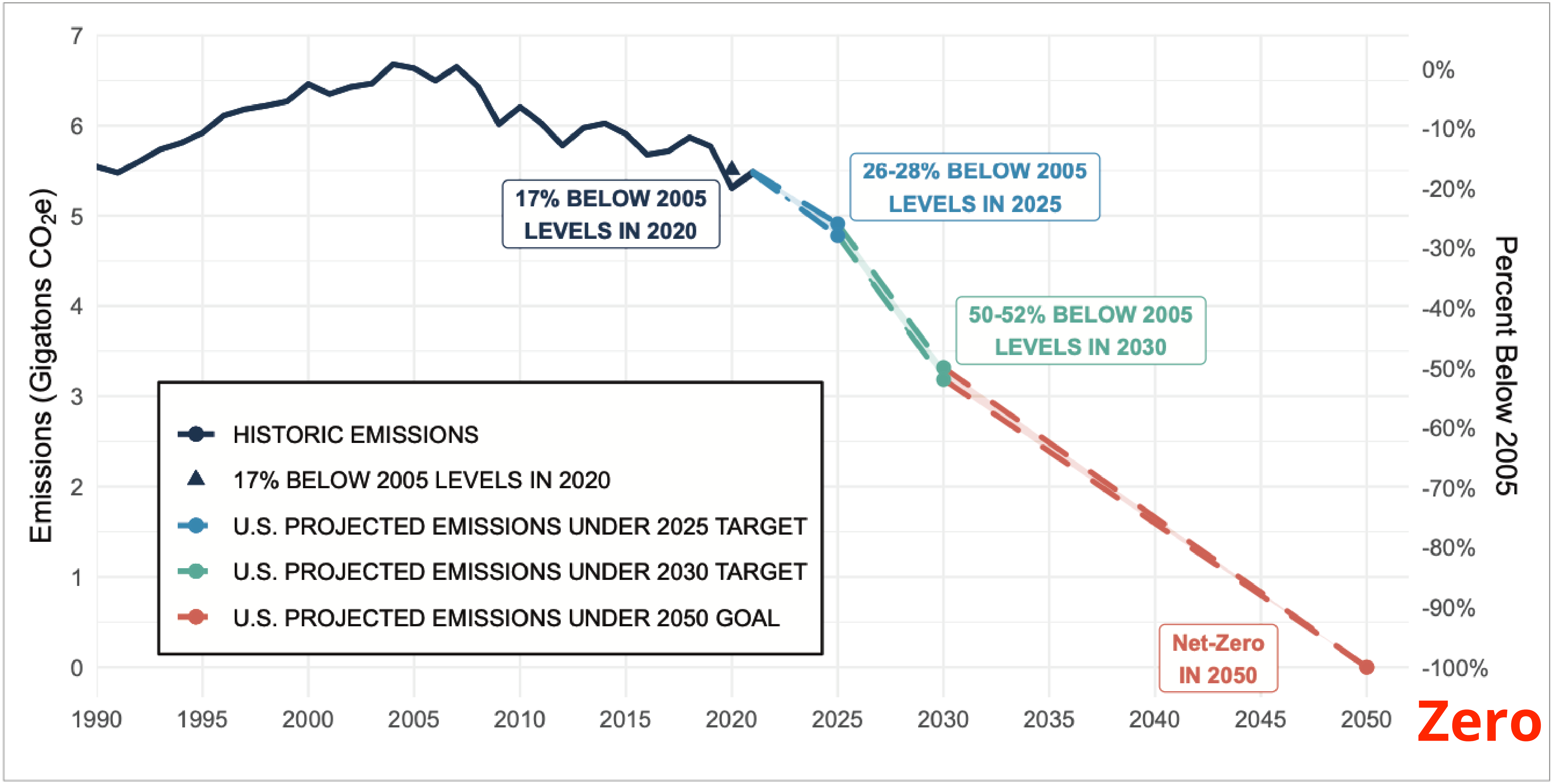


Carbon Impact of Housing

Carbon Impact of Housing



The New Imperative: Greenhouse Gas Emission Reductions



Zero by 2050

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Types of Carbon Impact

'Upfront' Embodied Carbon

Manufacturing, transportation, and installation of construction materials

Operational Carbon

Building energy consumption

Operational Carbon Reduction Options: Reduce the Home’s Energy Use

Less Energy Reduction ⟵⟶ More Energy Reduction

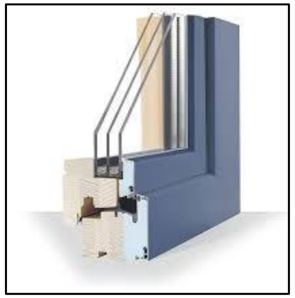
High Efficiency Appliances

Attic Insulation

Wall Insulation

Air Sealing

HVAC



Windows & Doors

Basement Insulation

Exterior Insulation

Embodied Carbon Impacts of Envelope Improvements to Reduce Operational Carbon

Adds More Embodied Carbon | Adds Less Embodied Carbon


Rigid Foam Insulation


Insul. Sheathing


Windows & Doors


Natural Material Insulation


Spray Foam Insulation


Fiberglass Insulation


Air Sealing

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Envelope Air Sealing – Most Carbon Reduction Bang For The Buck

- Biggest impact on operational carbon

- With the lowest cost

- And the lowest embodied carbon impact

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Carbon Assessment Tools Available

Embodied Carbon

- Building modelling software
- Inputs from product manufacturers
- Examples:

BUILDERS FOR CLIMATE ACTION BEAM

EC3

Operational Carbon

- Energy modelling software
- Fuel source emission factors
- Examples:

ekotrope

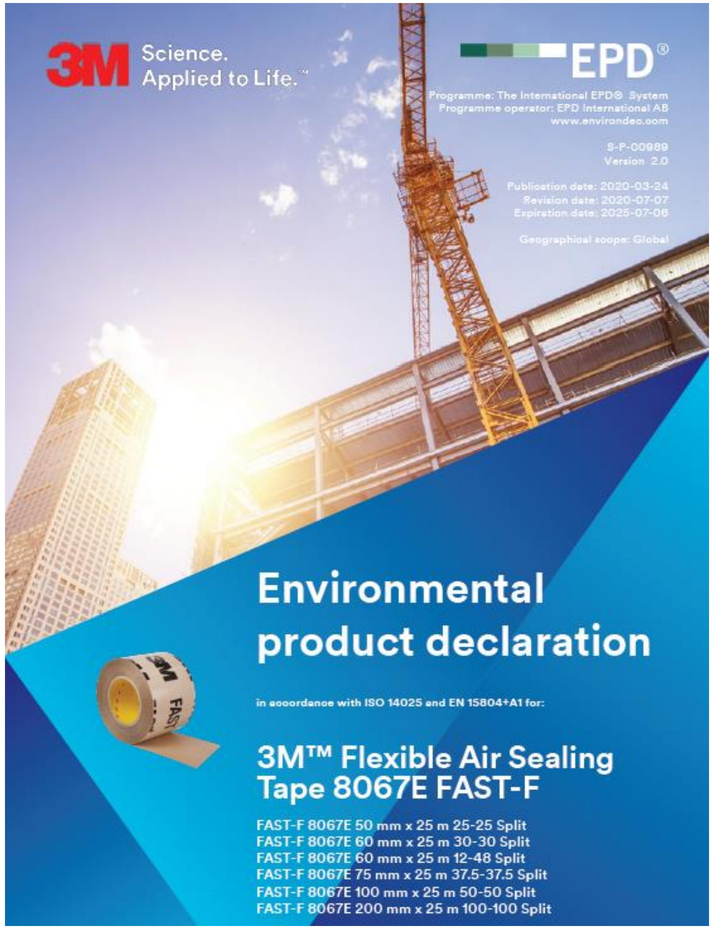
REM/Rate™

PHribbon

Embodied Carbon

How is Embodied Carbon Reported for Building Products?

- Building product embodied carbon is reported in an EPD (Environmental Product Declaration)
- EPDs are still early in adoption by building product manufacturers
- EPDs are more common among building products with higher levels of embodied carbon



EPDs are Not Common Among Air Sealing Products

Air sealing products represent a very small percentage of total embodied carbon

HIGHEST CARBON MATERIAL APPLICATIONS		
SECTION	kg CO_2e	MATERIAL
Footings & Slabs	2,193	XPS foam board / R 5.0/inch [BEAM Avg | US & C
Roof	1,959	Fiberglass loose fill / Owens Corning / AttiCat, P
Footings & Slabs	1,822	Concrete - 0-2500 psi, 20-29% Fly Ash / NRMCA |
Footings & Slabs	1,655	Concrete - 0-2500 psi, 20-29% Fly Ash / NRMCA |
Windows	1,600	Window - triple pane / Vinyl frame / BfCA Study [
Garage	1,397	Concrete - 2501-3000 psi, 20-29% Fly Ash / NRM
Party Walls	1,336	Gypsum panels - glass mat / 1/2" / Gypsum Ass
Exterior Walls	782	XPS foam board / R 5.0/inch [BEAM Avg | US & C
Interior Walls	734	Drywall 1/2" [BEAM Avg | US & CA]
Floors	628	Carpet / EC3 database / 150 sample conservativ

Where to Look for EPDs?

- EPDs are found on program operator online databases and manufacturer's websites
- USA based EPD program operators include:

SPOT® | UL

ASTM INTERNATIONAL

NSF™

Certified Environmental Product Declaration

www.nsf.org

Qualitative Comparison of Embodied Carbon Impact of Air Sealing Products

More Material ⟷ Less Material

Membranes & Fluid Applied	Tapes & Gaskets	Caulking & Foam	Spot Applied

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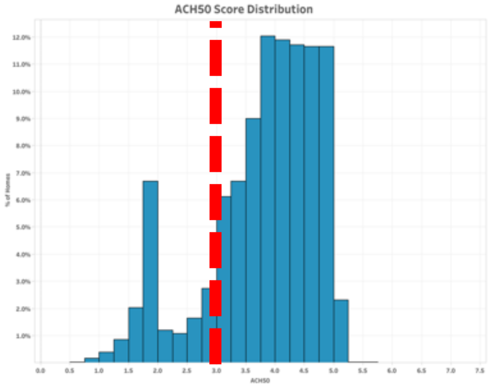
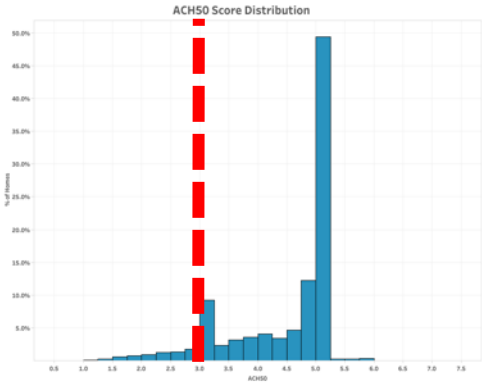
Reported Air Tightness Levels Comparison

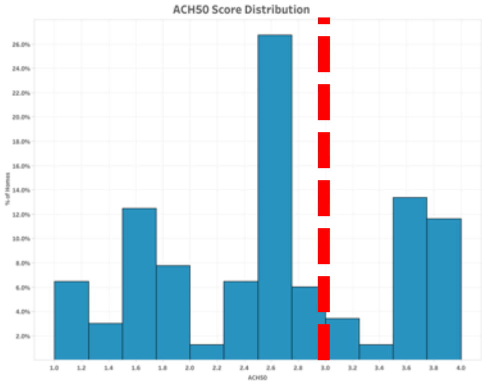
Envelope Air Tightness Data Provided by Ekotrope: Comparison Across Markets



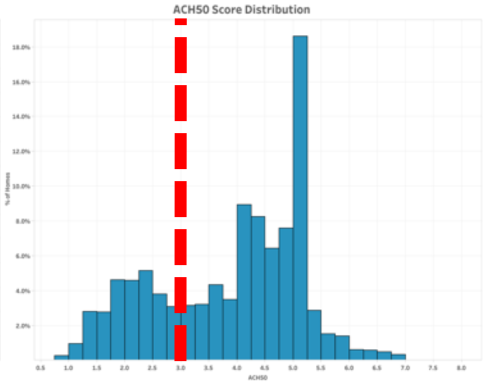
Houston



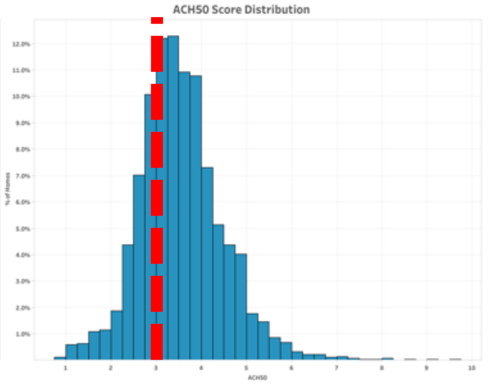
Phoenix



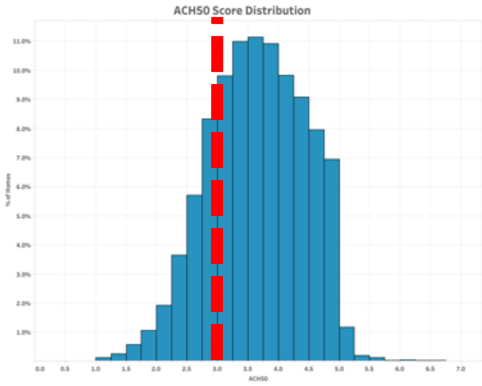
San Diego



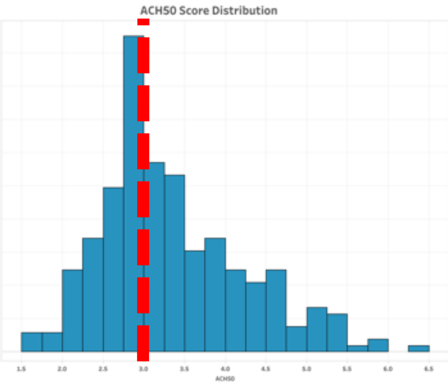
Atlanta



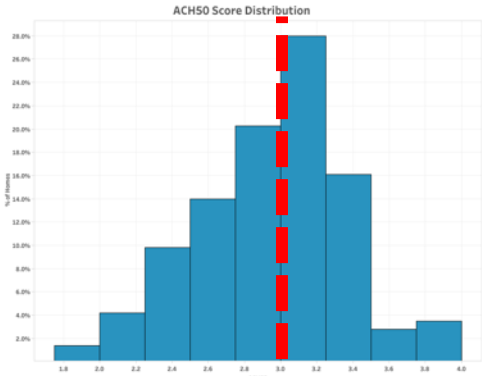
Raleigh



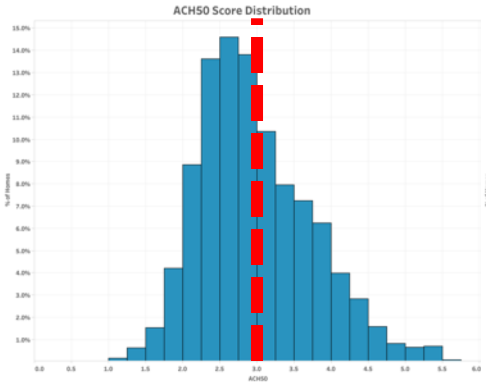
Indianapolis



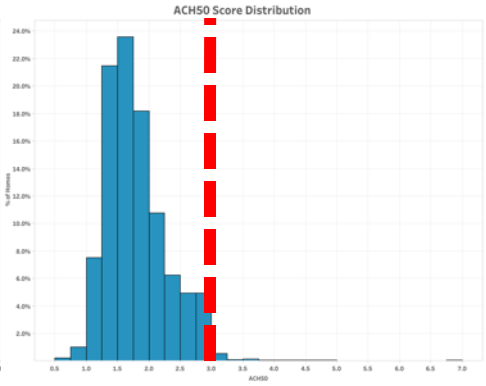
Seattle



Salt Lake City



Chicago



Minneapolis

= 3 ACH50

Single family detached homes
9.10.22 – 9.9.23
Data provided by Ekotrope

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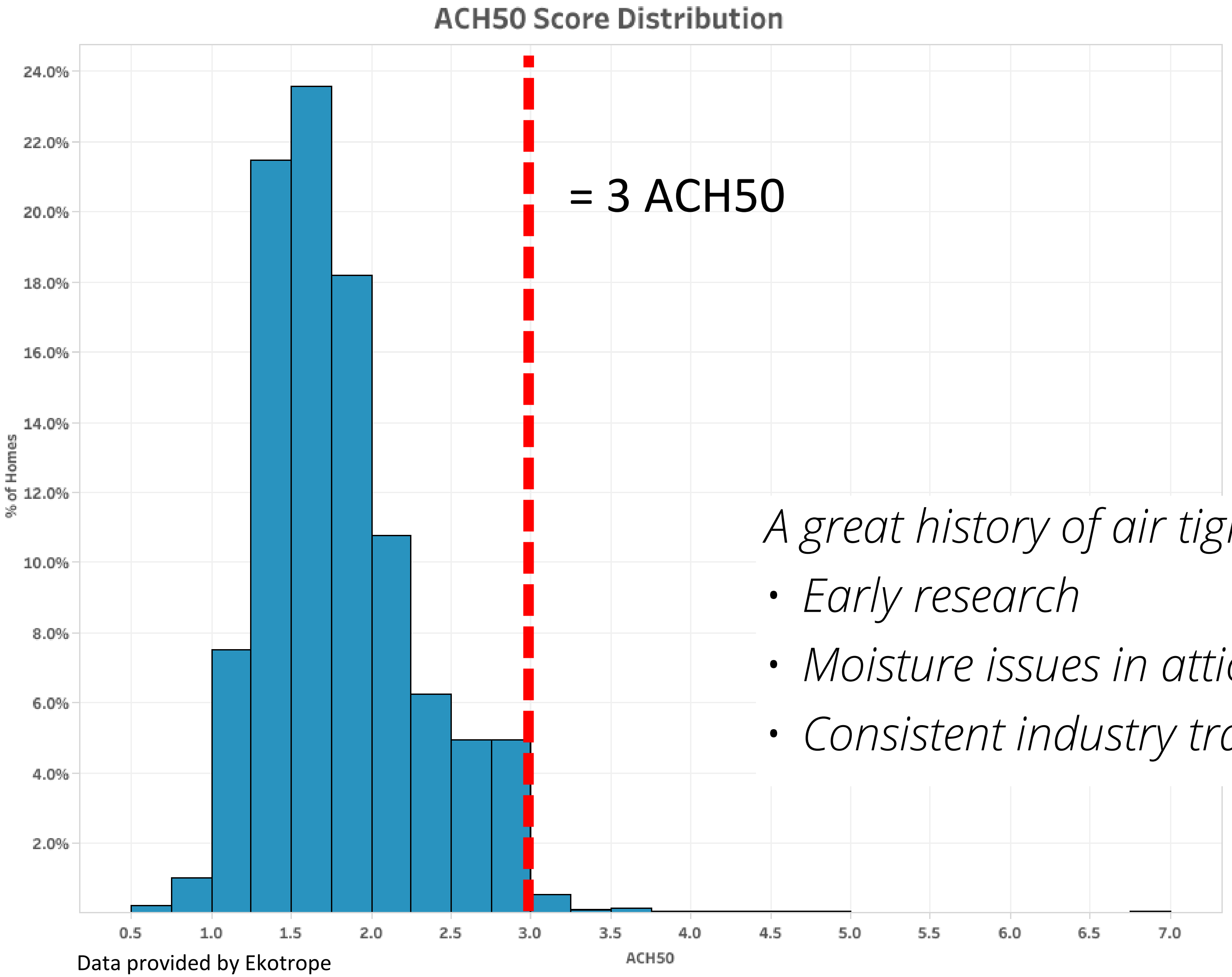
Envelope Air Tightness – Minneapolis



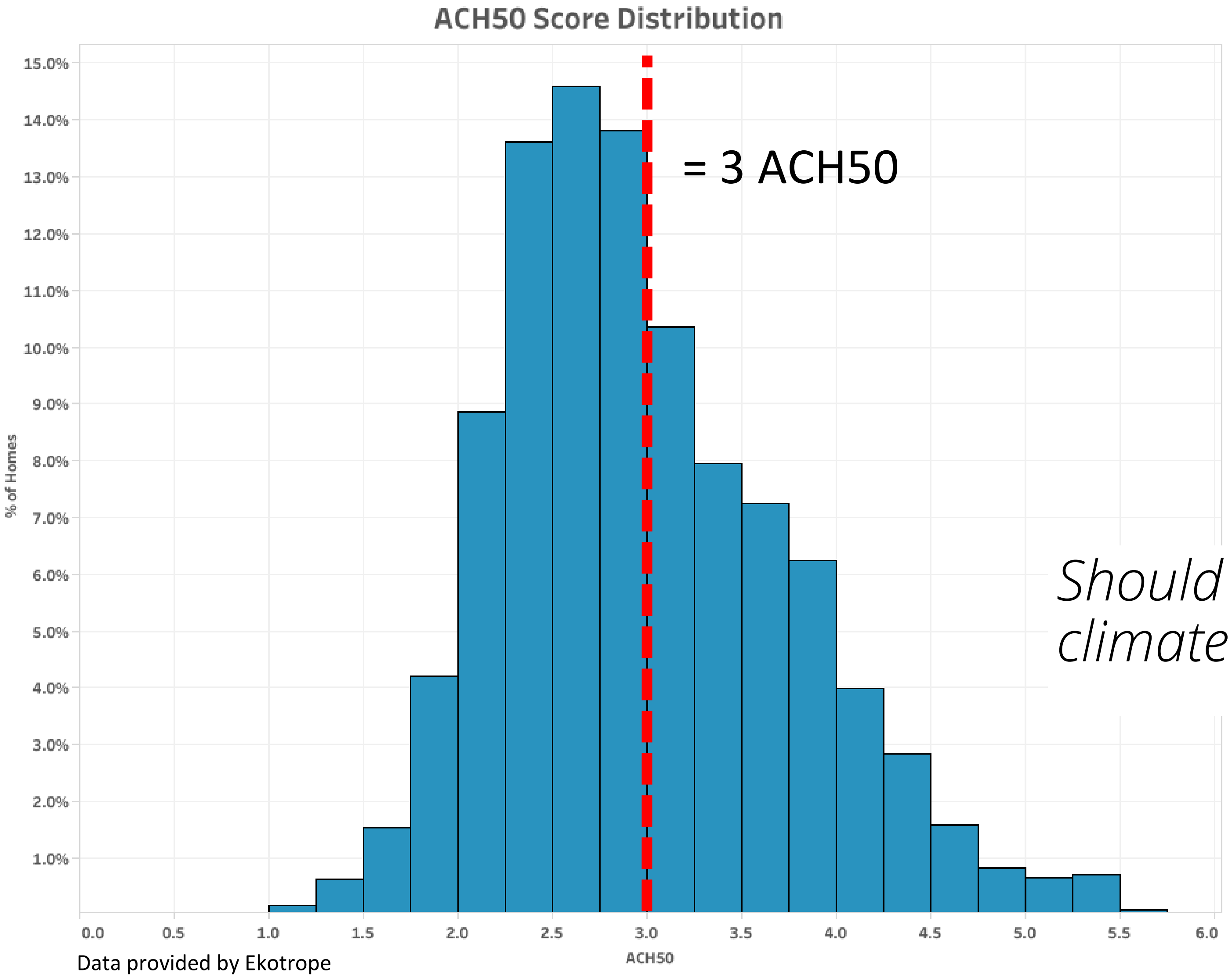
Data provided by Ekotrope

- Minneapolis-St. Paul-Bloomington, MN-WI
- Residence type = Single family detached
- Time period = 9.10.22 – 9.9.23
- Number of homes = 4,792
- Climate zone = 6A
- Average ACH50 = 1.8

A great history of air tightness

- *Early research*
- *Moisture issues in attics and walls*
- *Consistent industry training*

Envelope Air Tightness – Chicago



Data provided by Ekotrope

- Chicago-Naperville-Elgin, IL-IN-WI
- Residence type = Single family detached
- Time period = 9.10.22 – 9.9.23
- Number of homes = 2,404
- Climate zone = 5A
- Average ACH50 = 3.0

Should air tightness be a goal in this climate zone?

Operational Carbon & Air Tightness

Modeling the Impact

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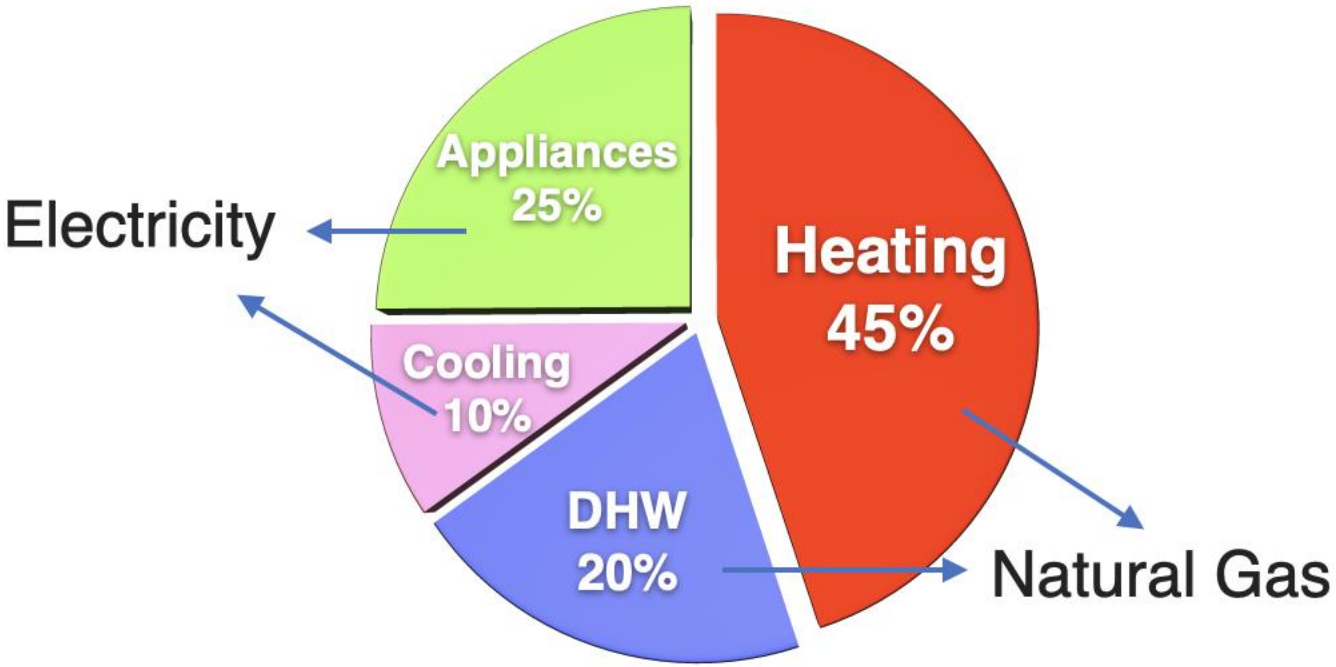
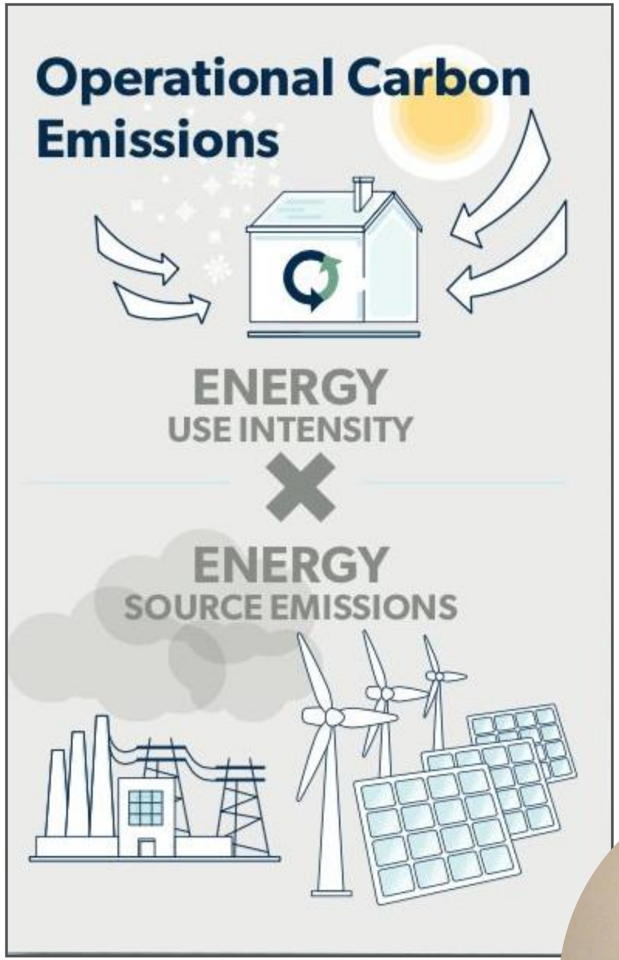
Operational Carbon

A function of energy use:

- Annual energy consumption
- Fuel / energy choice
- Emissions in generating the energy





Methodology

- Chose a typical single family house
- Chose 10 cities, representing Climate Zone 2 through Climate Zone 6
- Modeled 6 different air tightness levels using Ekotrope energy modeling software
  - 7, 5, 3, 2, 1.5, 0.6 ACH50Pa
- Captured **total annual energy consumption** from the energy modeling
  - Converted energy use to total operational carbon, gas and electric, using **national average grid emission factors** - Tonnes of equivalent CO_2
- Captured space heating and space cooling loads kBTU/hr at design conditions

The House We Modelled

- 2 story, slab on grade, approximately 2350 ft^2
- Heated with natural gas, 96% efficient furnace
- Insulated to IECC 2009 levels for CZ 4
  - The same insulation levels were used in every city
- We reported the **total annual energy consumption** in each case, including:
  - Space heating and cooling consumption
  - Domestic hot water
  - Lights and appliances

The Cities We Modelled the House in

City	Climate Zone
Houston	2A
Phoenix	2B
San Diego	3B
Atlanta	3A
Raleigh	3A
Seattle	4C
Indianapolis	4A
Salt Lake	5B
Chicago	5A
Minneapolis	6A

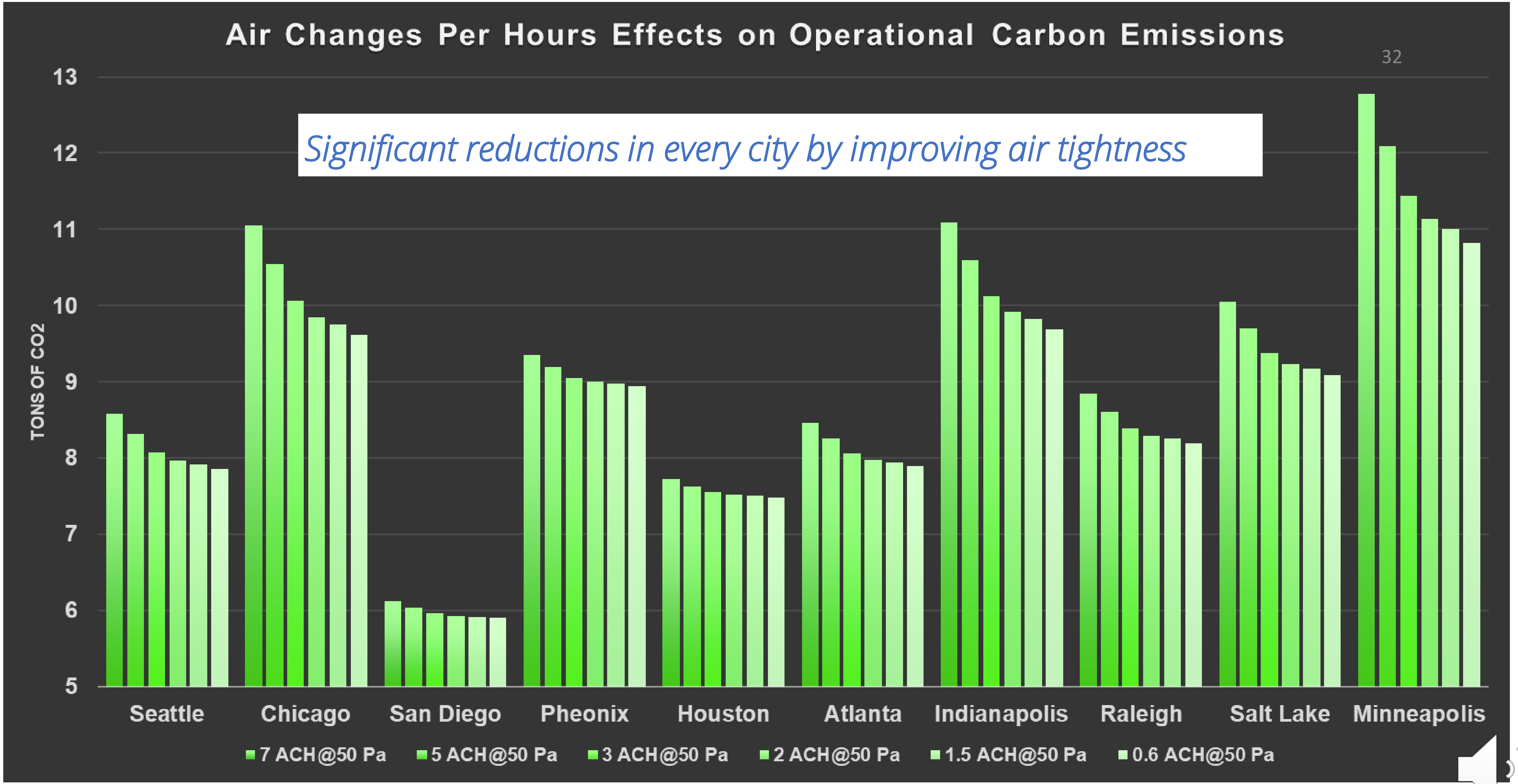
We modelled operational carbon based on National average grid emission factors:

Natural Gas: 0.0053 CO_2eTonnes / Therm

Electricity: 0.0007007 CO_2eTonnes / kWh

In practice the electrical grid factors vary significantly across the country based on how the electricity is generated in each region

Air Sealing Effect on Operational Carbon Emissions



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Operational Carbon Changes - Minneapolis

	Design Loads		Operational Carbon
ACH@50 Pa	**HEATING DESIGN LOAD [kBtu/h]**	**COOLING DESIGN LOAD [kBtu/h]**	**Tonnes CO2e**
7	59	16	12.77
5	54	15	12.09
3	49	14	11.44
2	46	14	11.14
1.5	45	14	11.01
0.6	42	13	10.82

A 15.3% improvement from 7 down to 0.6 ACH 50

A 5% improvement from 3 down to 0.6 ACH50

Operational Carbon Changes - Chicago

	Design Loads		Operational Carbon
ACH@50 Pa	HEATING DESIGN LOAD [kBtu/h]	COOLING DESIGN LOAD [kBtu/h]	Tonnes CO2e
7	47	17	11.05
5	43	16	10.54
3	40	15	10.06
2	38	15	9.85
1.5	37	14	9.75
0.6	35	14	9.61

A 13% improvement from 7 down to 0.6 ACH 50

A 4.5% improvement from 3 down to 0.6 ACH50

Operational Carbon Changes - Atlanta

	Design Loads		Operational Carbon
ACH@50 Pa	**HEATING DESIGN LOAD [kBtu/h]**	**COOLING DESIGN LOAD [kBtu/h]**	**Tonnes CO2e**
7	30	17	8.46
5	28	16	8.25
3	26	16	8.06
2	25	15	7.98
1.5	24	15	7.94
0.6	23	15	7.89

A 6.7% improvement from 7 down to 0.6 ACH 50

A 2% improvement from 3 down to 0.6 ACH50

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Operational Carbon Changes - Houston

	Design Loads		Operational Carbon
ACH@50 Pa	HEATING DESIGN LOAD [kBtu/h]	COOLING DESIGN LOAD [kBtu/h]	Tonnes CO2e
7	24	19	7.73
5	22	18	7.63
3	20	17	7.55
2	19	16	7.52
1.5	19	16	7.50
0.6	18	16	7.49

A 3.1% improvement from 7 down to 0.6 ACH 50

A 1.0% improvement from 3 down to 0.6 ACH50

Summary of Air Sealing Improvements - From 5 ACH50 to 0.6 ACH50

City	Operational Carbon Improvement from 5 ACH to 0.6 ACH	Heating Load Reductions (kBTUS/hr)	Cooling Load Reduction (kBTUS/hr)
Houston	0.14 Tonnes/yr	4	2
Phoenix	0.26	3	4
San Diego	0.14	3	1
Atlanta	0.36	5	1
Raleigh	0.42	5	2
Seattle	0.46	5	1
Indianapolis	0.90	8	1
Salt Lake	0.62	6	2
Chicago	0.93	8	2
Minneapolis	1.27	12	2

Significant carbon emission reductions in every city

2% to 11%

Greater percentage reductions in colder climates

Helpful reductions in heating capacity requirements in colder climates

Recall that this is the reduction in total overall operational carbon for the house

Summary of Air Sealing Improvements
- From 5 ACH50 to 0.6 ACH50 over the next 30 years

In hot climates a reduction of 4 to 12 tonnes over the next 30 years for every house sealed

- That's the equivalent of the carbon sequestered by 150 to 500 mature trees
- Or the equivalent of carbon emitted by burning over 350 propane BBQ tanks
- In hot climates, reducing air leakage is one of the only improvements that can be made to the envelope that is cost effective

In cold climates a reduction of 20 to 40 tonnes over the next 30 years for every house sealed

- That's the equivalent of the carbon sequestered by 700 to 1200 mature trees
- Or the equivalent of carbon emitted by burning over 1200 propane BBQ tanks
- In cold climates, reducing air leakage has always been the most cost effective strategy for improving the building envelope

Total Operational Carbon Change from HERs 75 to Passive House Levels of Performance (HERs 35)

Operational Carbon / yr

City	HERs 75 Home	HERs 35 Home	% Reduction
Houston	7.71 Tonnes	6.38 Tonnes	17%
Chicago	14.02 Tonnes	7.63 Tonnes	46%

Recall that the air tightness alone reduced carbon by 0.93 Tonnes in Chicago and 0.14 Tonnes in Houston

This includes all energy use - lights, appliances, hot water, heating and cooling

Embodied Carbon Change from HERs 75 to Passive House Levels of Performance (HERs 35)

Total Embodied Carbon Change

City	HERs 75 Home	HERs 35 Home	% Increase
Chicago	23.82 Tonnes	31.37 Tonnes	32%

Calculated using the BEAM Carbon Analysis Tool

Carbon Impact of Other Energy Efficiency Measures

For Comparison

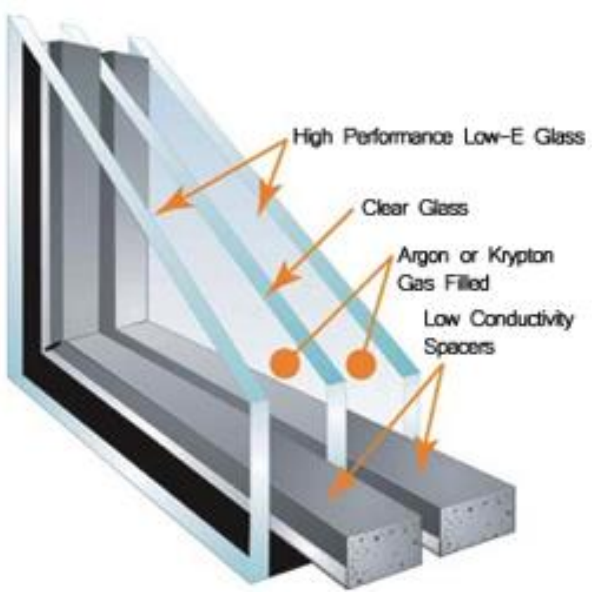
Air Tightness - Chicago House

Tightness ACH50	**Operational CO_2e Tonnes/yr**	**Embodied CO_2e Tonnes**
3.0	10.06	18.15
0.6	9.61	Negligible
Change	-0.45 Tonnes/yr	Negligible

Less than one year "return" on carbon investment

What other advantages does airtightness offer?

Compare to Window Changes - Chicago House



Glazing	Operational CO_2e Tonnes/yr	Embodied CO_2e Tonnes
Double, Low E, Argon	10.06	18.15
Triple, 2 Coats Low E, Argon	9.79	18.65
Change	- 0.27 Tonnes/yr	+0.5 Tonnes

A 2 year "return" on carbon investment

What other advantages do triple glazed windows offer?

Compare to Wall Changes - Chicago House

Insulated Sheathing	**Operational CO_2e Tonnes/yr**	**Embodied CO_2e Tonnes**
None	10.06	23.82
R20	9.04	27.49
Change	-1.2 Tonnes /yr	+3.67 Tonnes

A 3 year "return" on carbon investment

What other process changes are required

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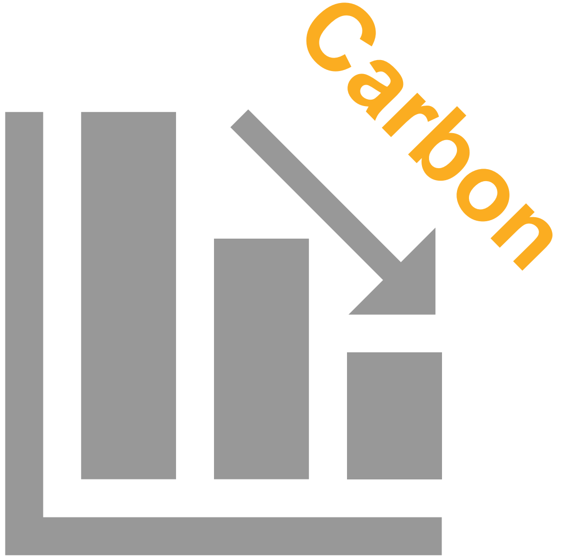
Carbon Impact Used in Your Marketing

Carbon Reduction Should Be Part of Your Marketing

Overall positioning:

- Not only will you get a more comfortable, healthy, and energy efficient home – you'll also be substantially reducing your home's carbon emissions

Passive House =



Operational Carbon Reduction is Likely Your Leading Carbon Message

- Passive House yields substantial operational carbon reduction benefits due to energy use reduction

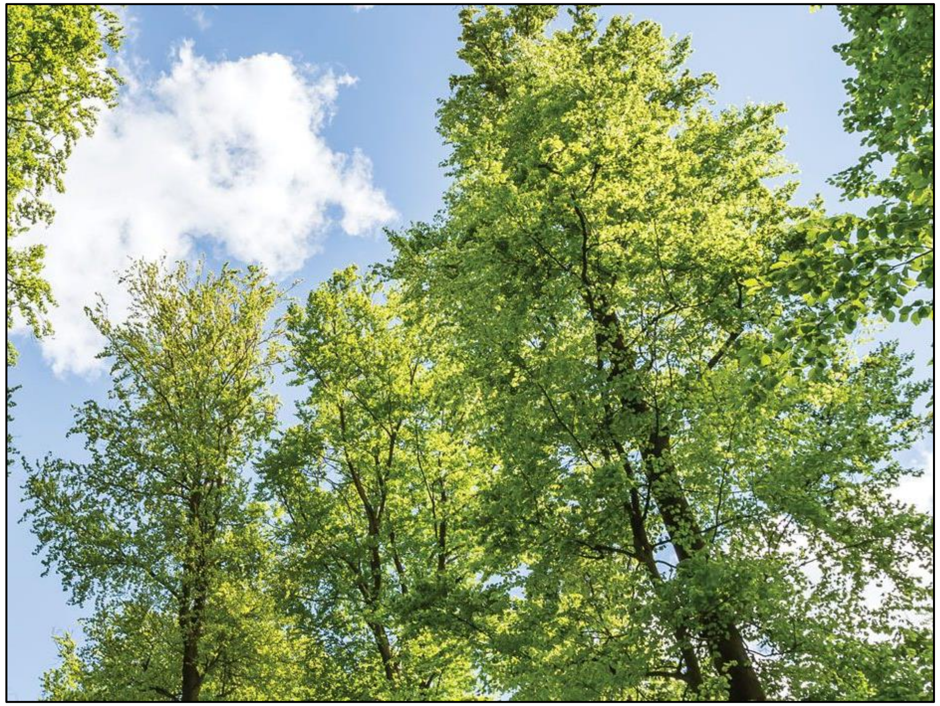
- BUT….increased thermal insulation can lead to higher levels of embodied carbon

- Air sealing the building envelope provides the most carbon reduction bang for the buck in Passive House homes and buildings

Messaging: Use %’s and People Friendly Analogies

Northern climate example: Chicago, Climate Zone 5A

- Your home will emit 13% less carbon into the atmosphere
- That’s equivalent to the carbon sequestered by 700 to 1200 mature trees over the next 30 years



Key Learnings & Insights

Key Learnings & Insights

- We have known for over 30 years the value of reducing unwanted air leakage
  - Avoiding condensation in insulated cavities
  - Controlling indoor humidity, specifically in hot, humid climates
  - Improving comfort - sound, dust, drafts, bugs
  - Cost effective energy savings
  - Reducing the heating and cooling equipment capacities needed

Now we recognize air sealing is one of the most effective measures for reducing operational carbon emissions,

With little added embodied carbon

Questions/Discussion

Thank You!

Gord Cooke

Construction Instruction

gord@constructioninstruction.com

Bill Shadid

Aeroseal Envelope (AeroBarrier)

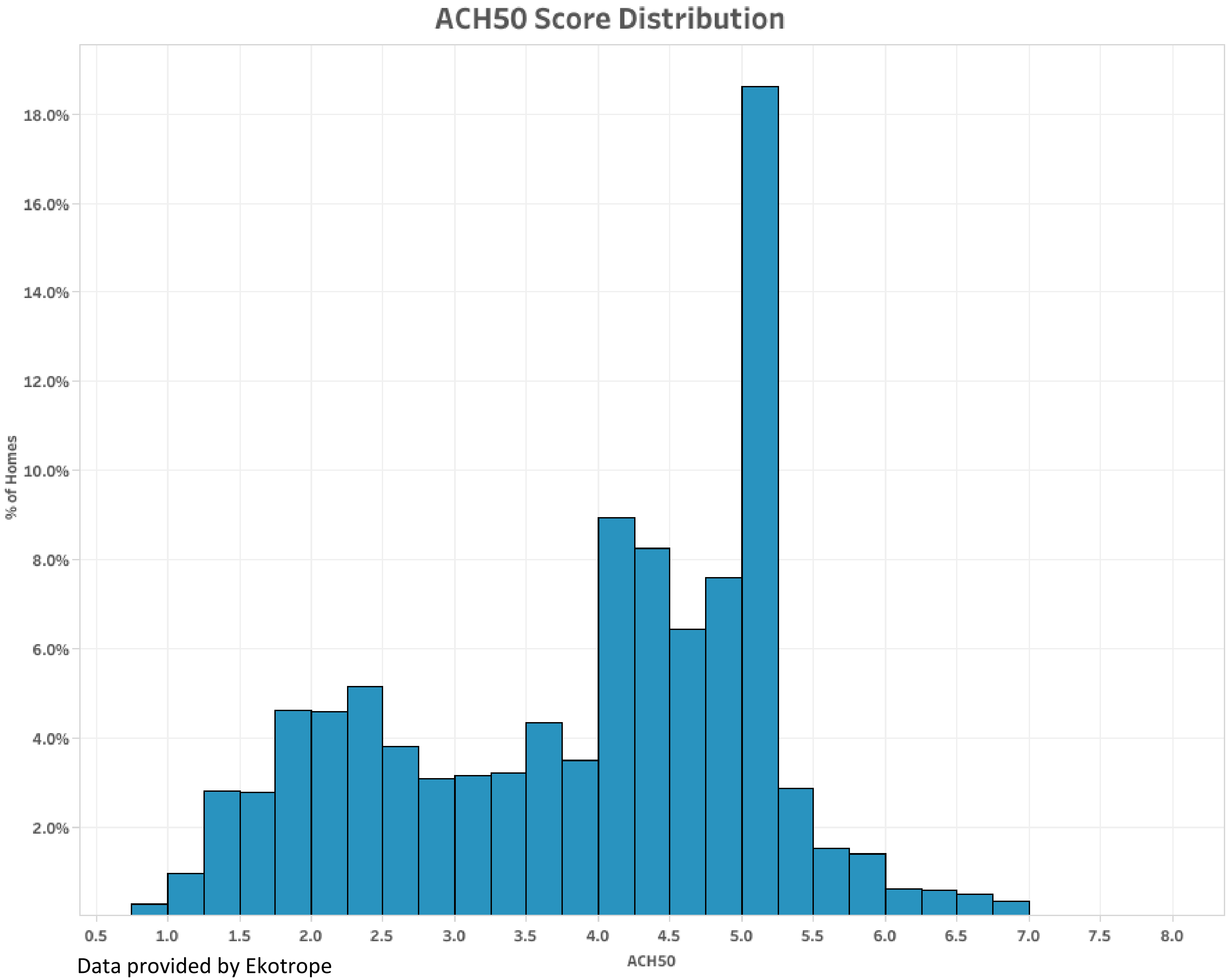
Bill.Shadid@aeroseal.com

The future of Housing isn't fully defined, and we have the green light to shape it to be high performance and low carbon

Appendix

- Envelope Air Tightness for Other Cities
- Operational Carbon Changes for Other Cities

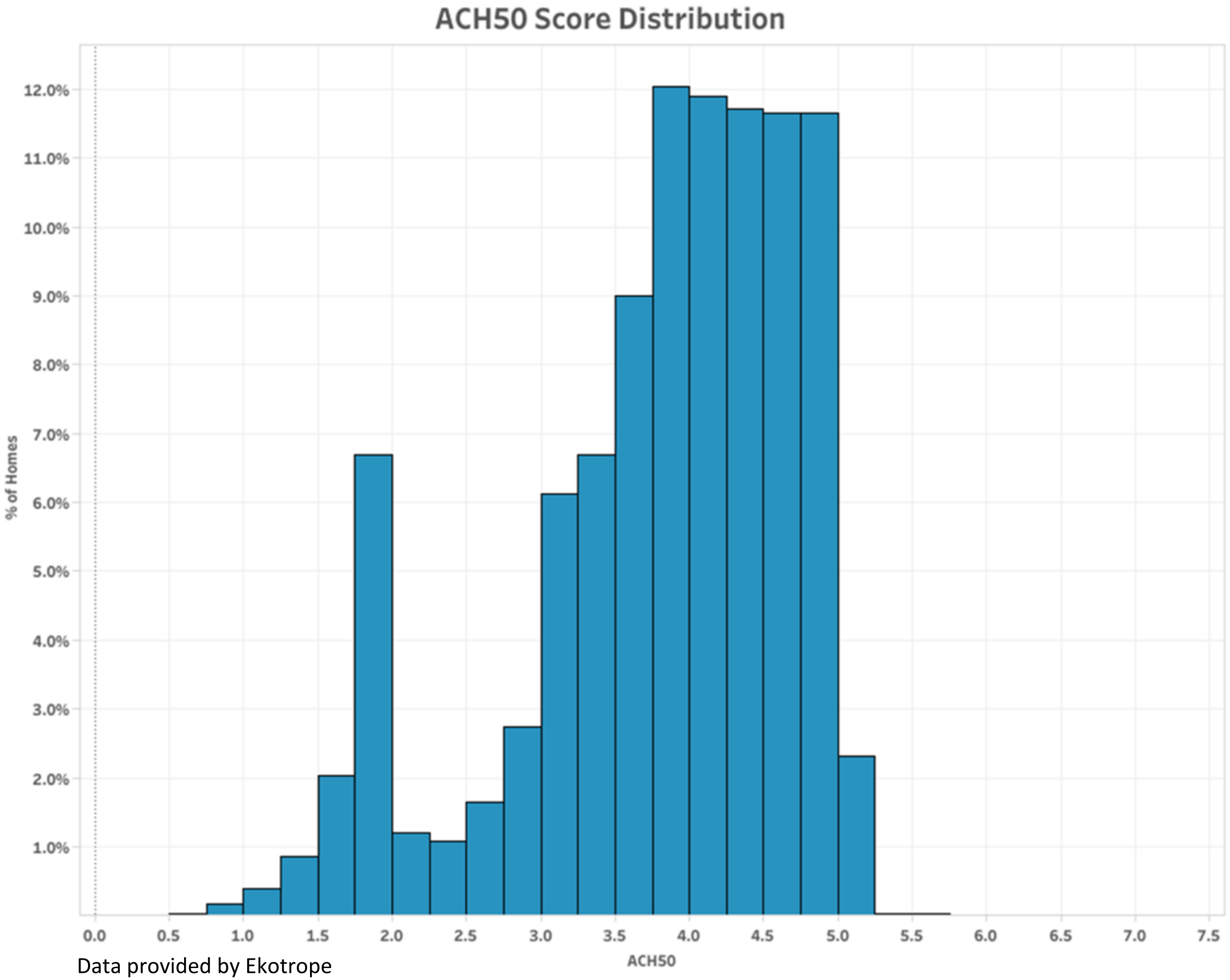
Envelope Air Tightness – Atlanta



Data provided by Ekotrope

- Atlanta-Sandy Springs-Roswell, GA
- Residence type = Single family detached
- Time period = 9.10.22 – 9.9.23
- Number of homes = 4,683
- Climate zone = 3A
- Average ACH50 = 3.9
- Average HERS Index = 62.99

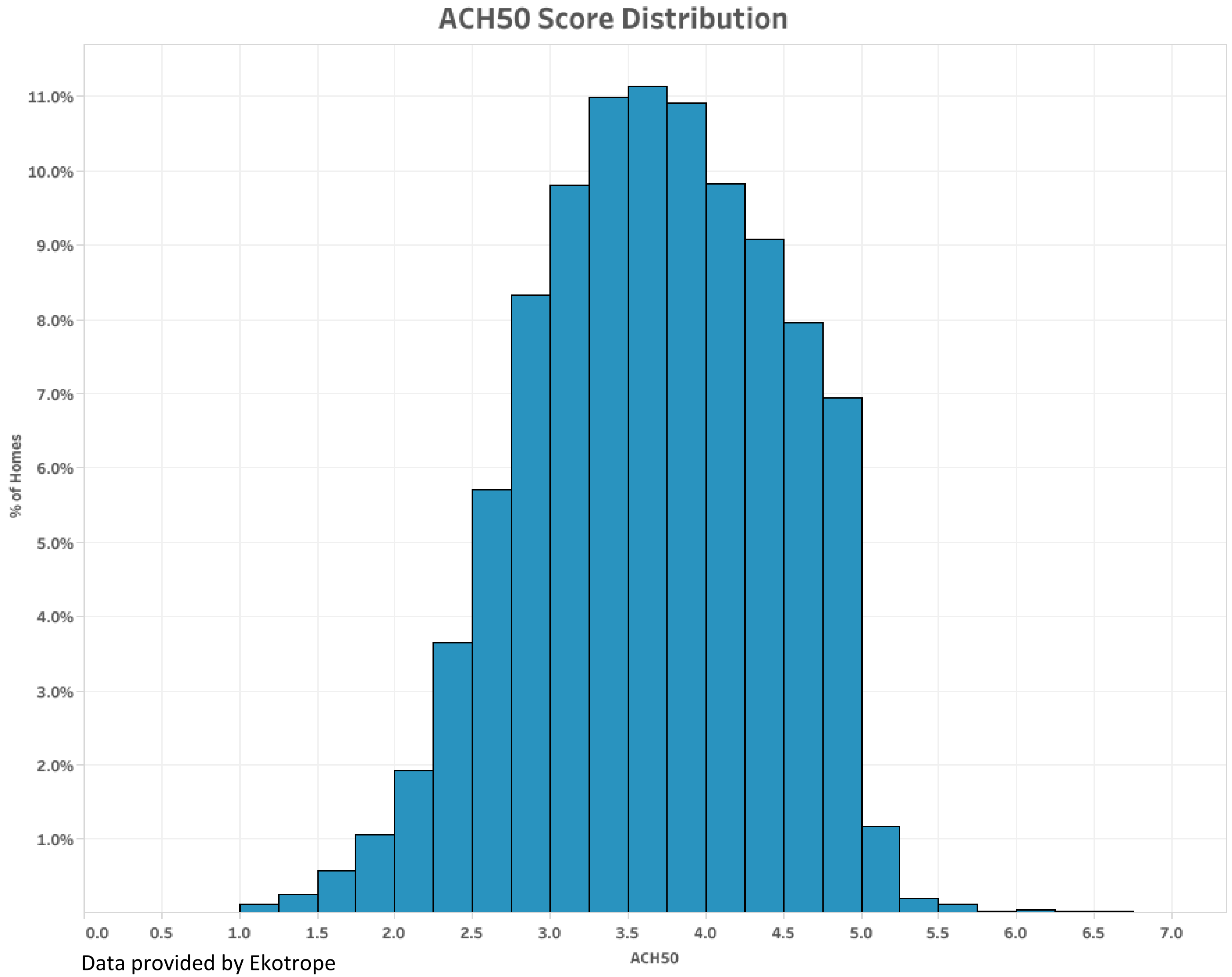
Envelope Air Tightness – Houston



Data provided by Ekotrope

- Houston-The Woodlands-Sugar Land, TX
- Residence type = Single family detached
- Time period = 9.10.22 – 9.9.23
- Number of homes = 18,366
- Climate zone = 2A
- Average ACH50 = 3.8
- Average HERS Index = 58.98

Envelope Air Tightness – Indianapolis



Data provided by Ekotrope

- Indianapolis-Carmel-Anderson, IN
- Residence type = Single family detached
- Time period = 9.10.22 – 9.9.23
- Number of homes = 6,730
- Climate zone = 4A, 5A
- Average ACH50 = 3.7
- Average HERS Index = 65.04

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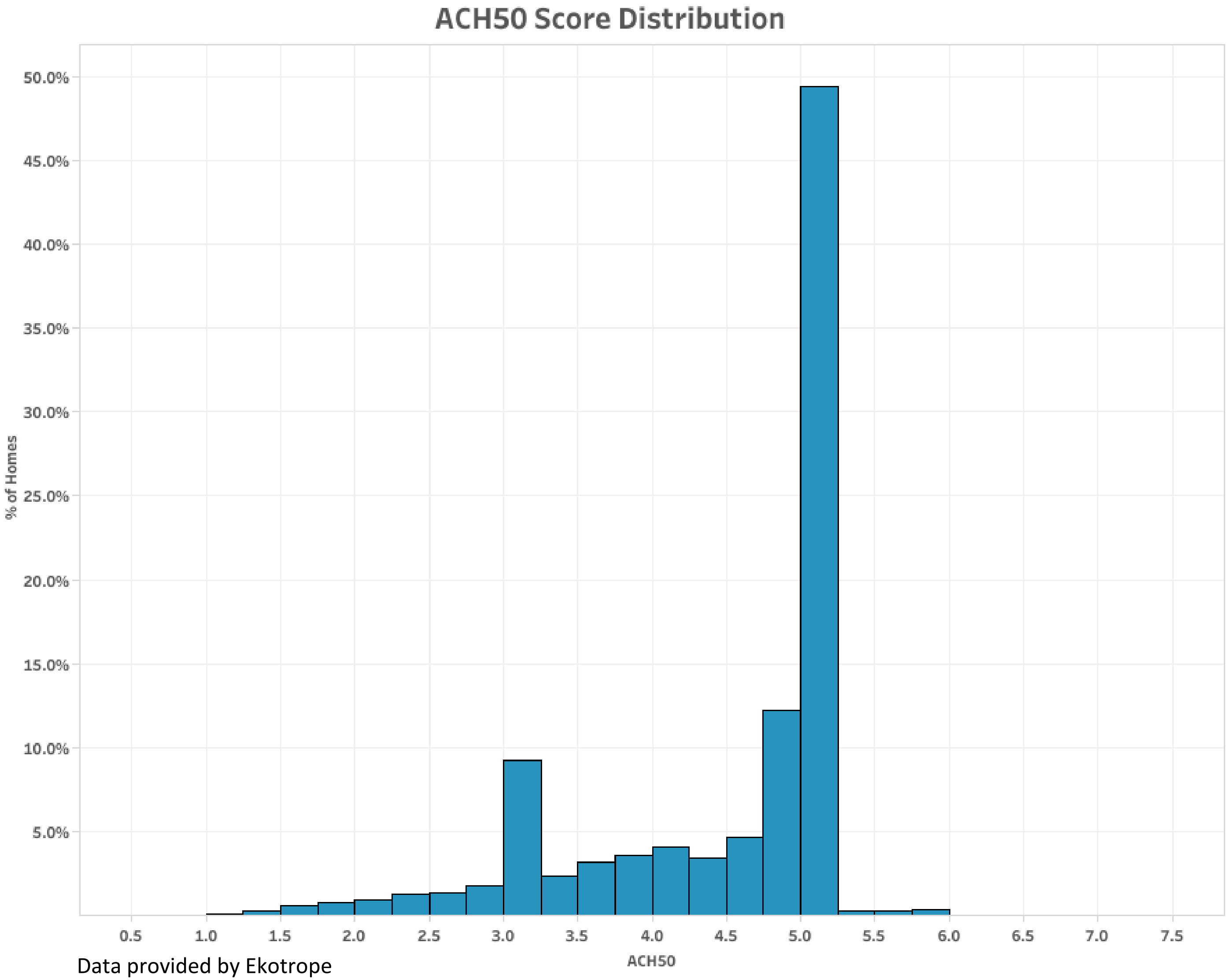
Envelope Air Tightness – Phoenix



Data provided by Ekotrope

- Phoenix-Mesa-Scottsdale, AZ
- Residence type = Single family detached
- Time period = 9.10.22 – 9.9.23
- Number of homes = 18,272
- Climate zone = 2B, 3B
- Average ACH50 = 4.4
- Average HERS Index = 53.95

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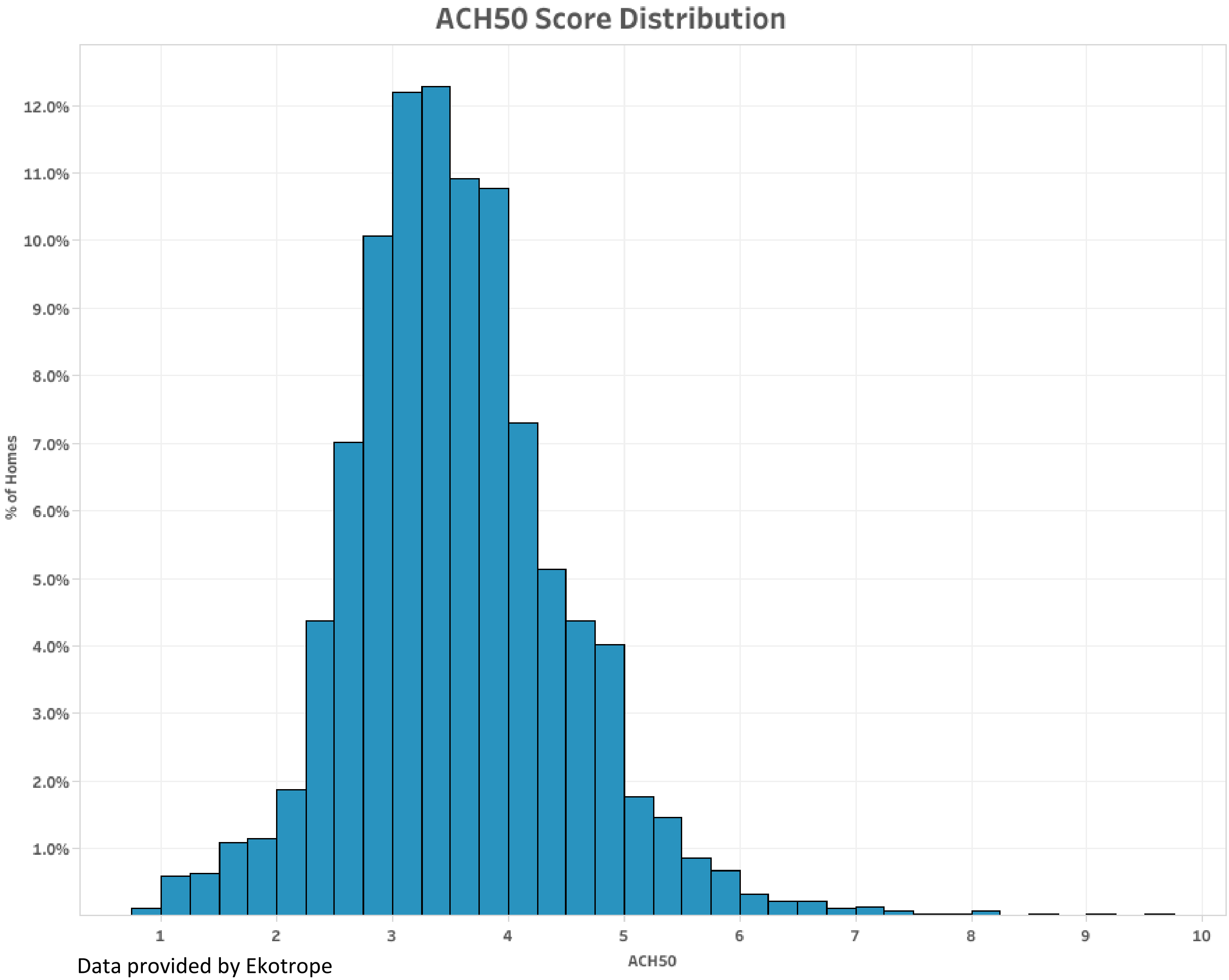
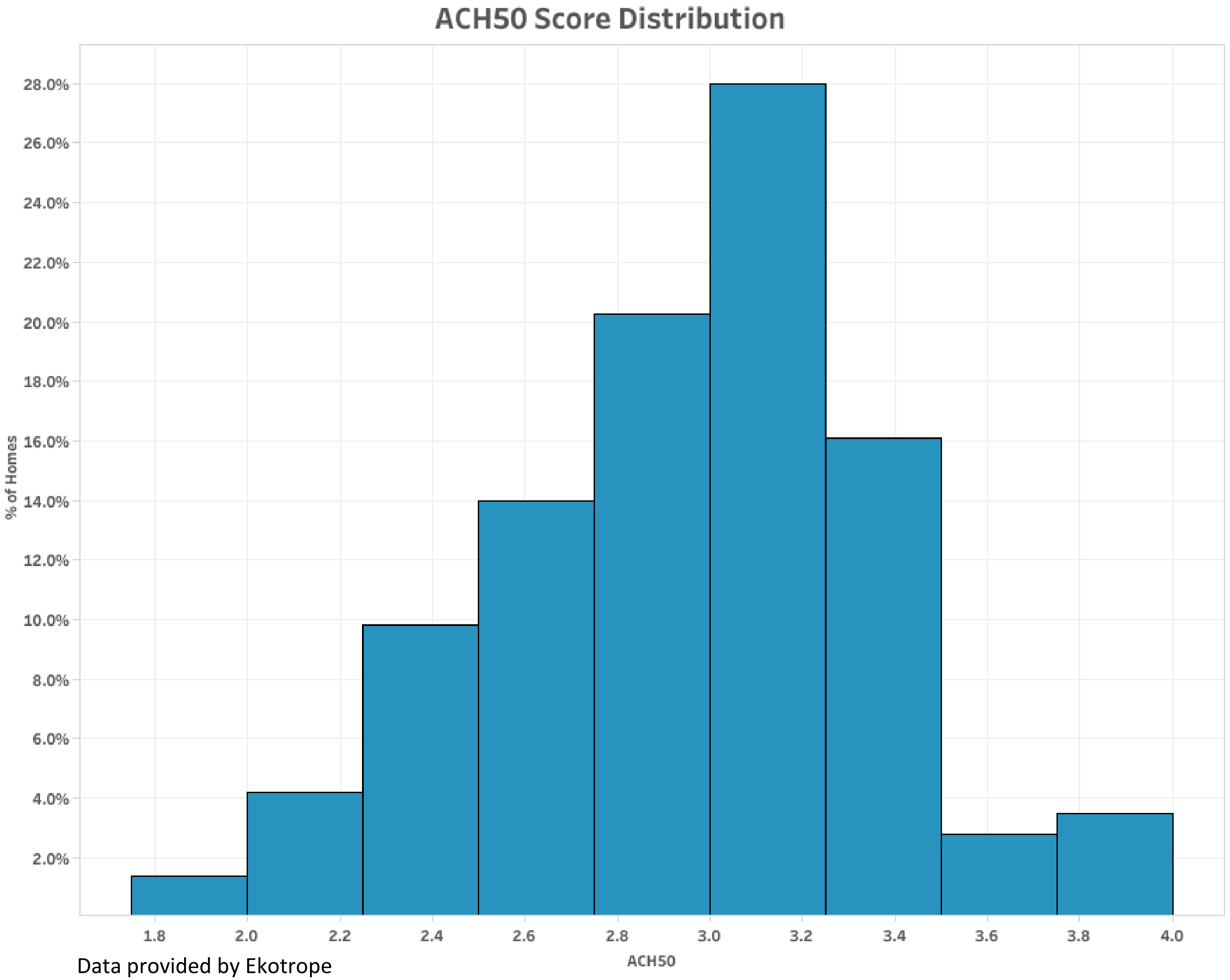
Envelope Air Tightness – Raleigh



Data provided by Ekotrope

- Raleigh, NC
- Residence type = Single family detached
- Time period = 9.10.22 – 9.9.23
- Number of homes = 7,324
- Climate zone = 3A
- Average ACH50 = 3.6
- Average HERS Index = 66.29

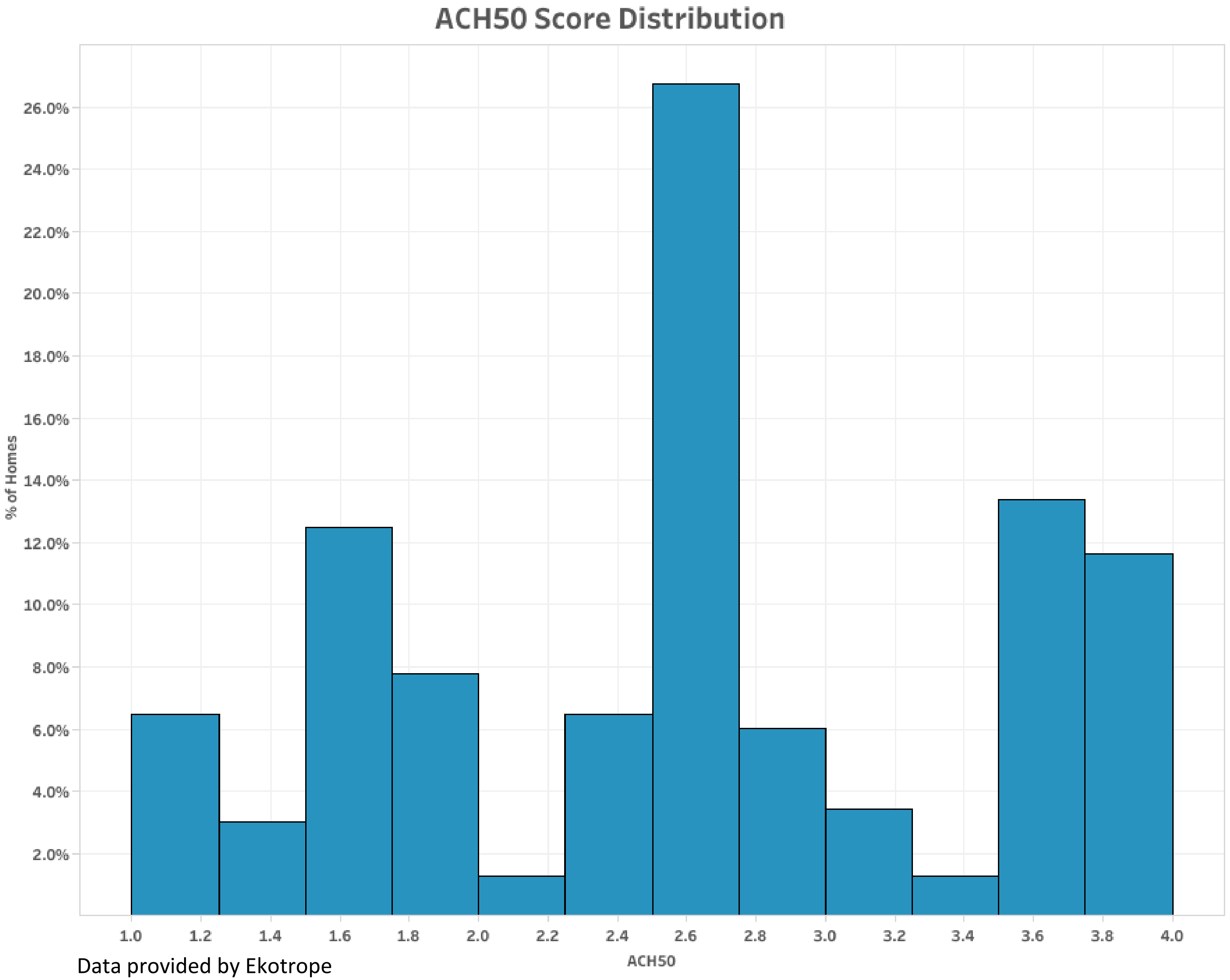
Envelope Air Tightness – Salt Lake City



Data provided by Ekotrope

- Salt Lake City, UT
- Residence type = Single family detached
- Time period = 9.10.22 – 9.9.23
- Number of homes = 143
- Climate zone = 5B
- Average ACH50 = 3.0
- Average HERS Index = 58.23

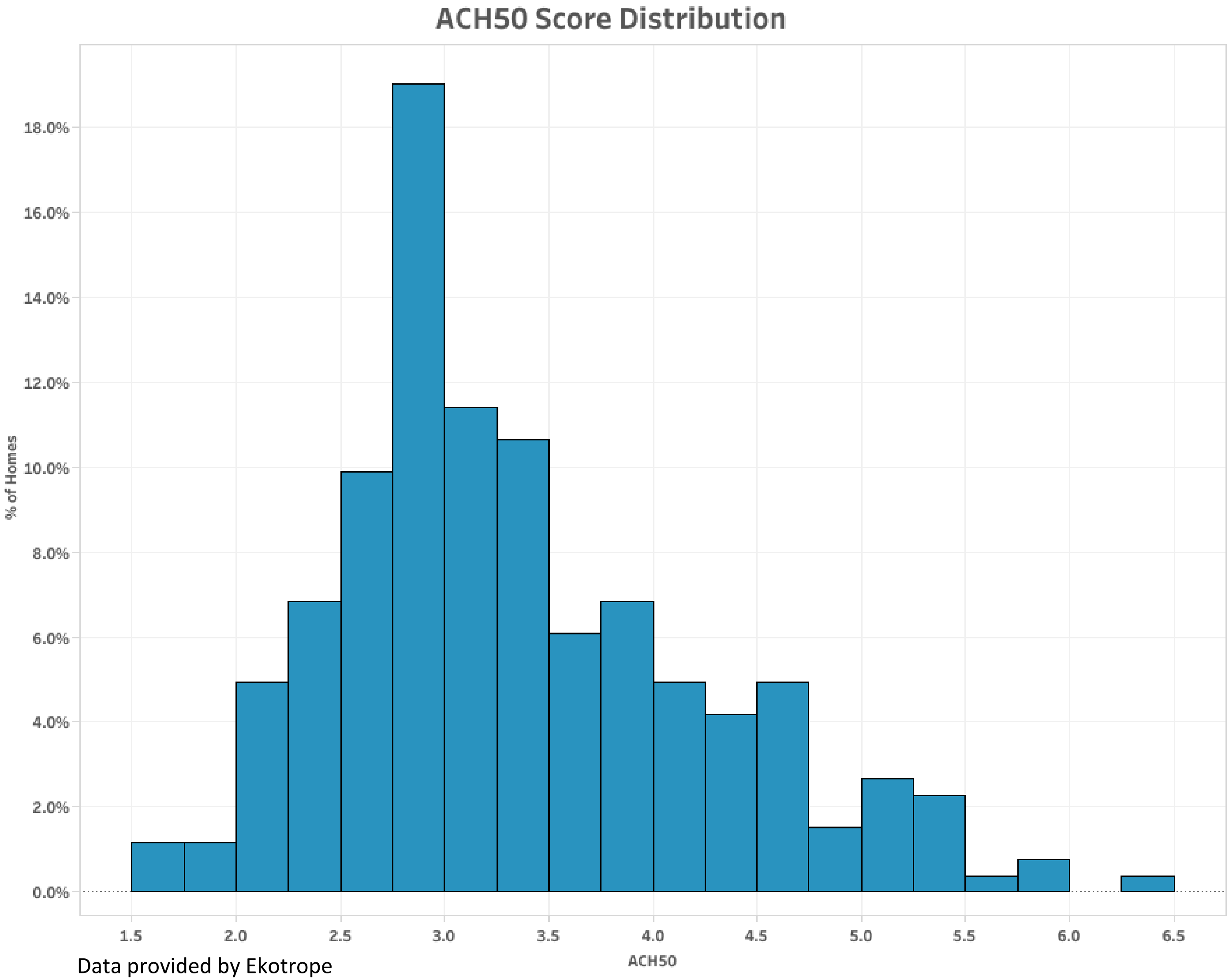
Envelope Air Tightness – San Diego



Data provided by Ekotrope

- San Diego-Carlsbad, CA
- Residence type = Single family detached
- Time period = 9.10.22 – 9.9.23
- Number of homes = 241
- Climate zone = 3B
- Average ACH50 = 2.6
- Average HERS Index = 9.107

Envelope Air Tightness – Seattle



Data provided by Ekotrope

- Seattle-Tacoma-Bellevue, WA
- Residence type = Single family detached
- Time period = 9.10.22 – 9.9.23
- Number of homes = 266
- Climate zone = 4C
- Average ACH50 = 3.4
- Average HERS Index = 57.55

Operational Carbon Changes - San Diego

	Design Loads		Operational Carbon
ACH@50 Pa	HEATING DESIGN LOAD [kBtu/h]	COOLING DESIGN LOAD [kBtu/h]	Tonnes CO2e
7	18	12	6.13
5	17	12	6.04
3	16	11	5.96
2	15	11	5.93
1.5	15	11	5.92
0.6	14	11	5.90

A 3.7% improvement from 7 down to 0.6 ACH 50

A 1.0% improvement from 3 down to 0.6 ACH50

Operational Carbon Changes - Phoenix

	Design Loads		Operational Carbon
ACH@50 Pa	**HEATING DESIGN LOAD [kBtu/h]**	**COOLING DESIGN LOAD [kBtu/h]**	**Tonnes CO2e**
7	19	30	9.36
5	18	28	9.20
3	17	26	9.06
2	16	25	9.00
1.5	16	25	8.97
0.6	15	24	8.94

A 4.4% improvement from 7 down to 0.6 ACH 50

A 1.3% improvement from 3 down to 0.6 ACH50

Operational Carbon Changes - Raleigh

	Design Loads		Operational Carbon
ACH@50 Pa	HEATING DESIGN LOAD [kBtu/h]	COOLING DESIGN LOAD [kBtu/h]	Tonnes CO2e
7	32	17	8.85
5	30	17	8.60
3	27	16	8.39
2	26	16	8.29
1.5	26	15	8.25
0.6	25	15	8.20

A 7.4% improvement from 7 down to 0.6 ACH 50

A 2.3% improvement from 3 down to 0.6 ACH50

Operational Carbon Changes - Seattle

	Design Loads		Operational Carbon
ACH@50 Pa	**HEATING DESIGN LOAD [kBtu/h]**	**COOLING DESIGN LOAD [kBtu/h]**	**Tonnes CO2e**
7	29	11	8.59
5	27	11	8.32
3	24	11	8.07
2	23	10	7.97
1.5	23	10	7.92
0.6	22	10	7.86

A 8.5% improvement from 7 down to 0.6 ACH 50

A 2.6% improvement from 3 down to 0.6 ACH50

Operational Carbon Changes - Indianapolis

	Design Loads		Operational Carbon
ACH@50 Pa	HEATING DESIGN LOAD [kBtu/h]	COOLING DESIGN LOAD [kBtu/h]	Tonnes CO2e
7	45	16	11.09
5	42	15	10.59
3	38	14	10.13
2	36	14	9.92
1.5	36	14	9.82
0.6	34	14	9.69

A 12.7% improvement from 7 down to 0.6 ACH 50

A 4.3% improvement from 3 down to 0.6 ACH50

Operational Carbon Changes - Salt Lake City

	Design Loads		Operational Carbon
ACH@50 Pa	**HEATING DESIGN LOAD [kBtu/h]**	**COOLING DESIGN LOAD [kBtu/h]**	**Tonnes CO2e**
7	38	20	10.06
5	36	19	9.70
3	33	18	9.37
2	32	18	9.23
1.5	31	18	9.17
0.6	30	17	9.08

A 9.7% improvement from 7 down to 0.6 ACH 50

A 3.1% improvement from 3 down to 0.6 ACH50