Airtightness and Energy Use of Single-Family Insulated Concrete Form Houses

Hannah Durschlag, MIT

Les Norford, MIT

Agenda

Motivation

Air leakage of different construction types

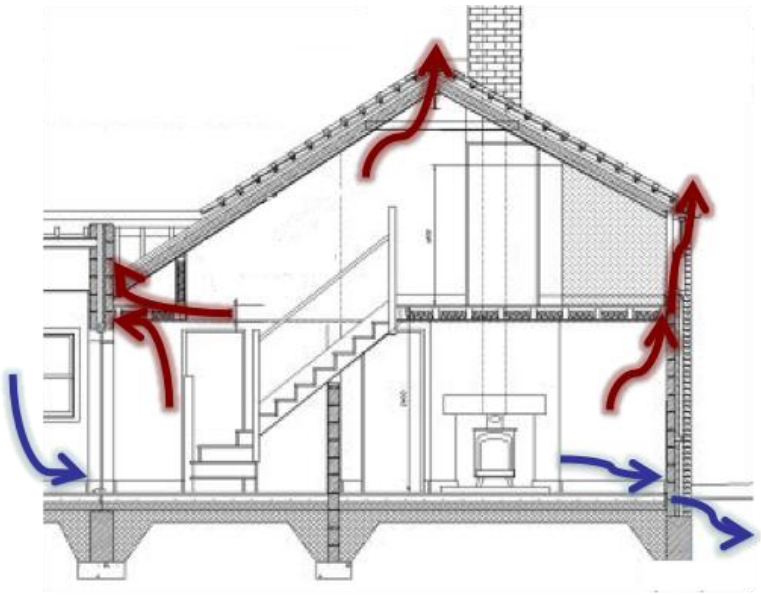
- Air Changes Per Hour
- Normalized Leakage

Modeling air leakage in EnergyPlus

Motivation

Infiltration can create a wide range of energy demand

16 - 33% of energy consumption has been attributed to infiltration

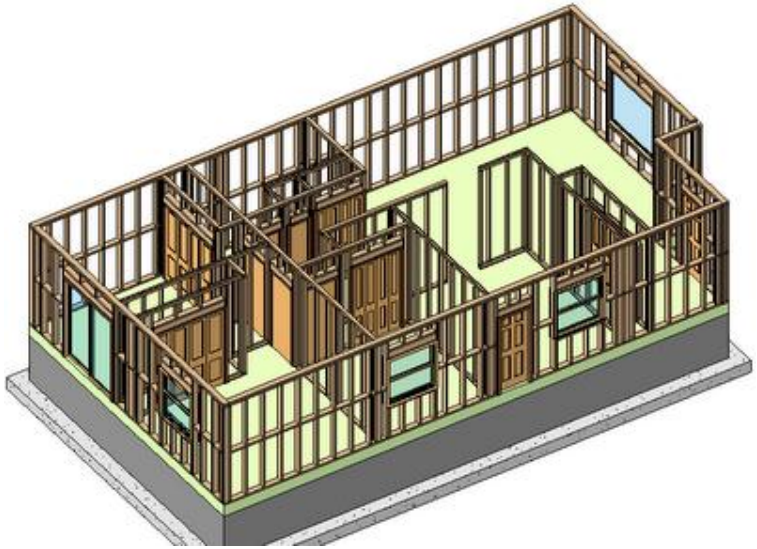


Understanding of wall system air leakage is limited in some construction types

Goals: understand the leakage area of ICF construction and compare it to conventional home leakage and code values. Determine how this difference affects energy usage.

Single-Family Construction

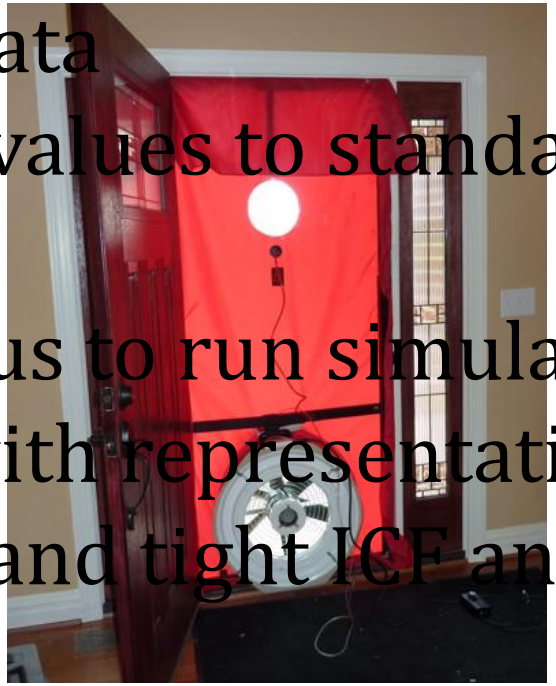
Light-framed Wood (Conventional)



Insulated Concrete Form (ICF)

Procedure

1. Collected the results of blower door tests on 31 ICF single family homes and calculated Leakage Area (A_L) using ASTM 779 Methodology
2. Analyzed the data
3. Compared the values to standards and the US housing stock
4. Used EnergyPlus to run simulations of a single-family house with representative values of loose, average and tight ICF and wood houses



The Single-Family House

Two stories

2,400 ft^2 (233m^2)

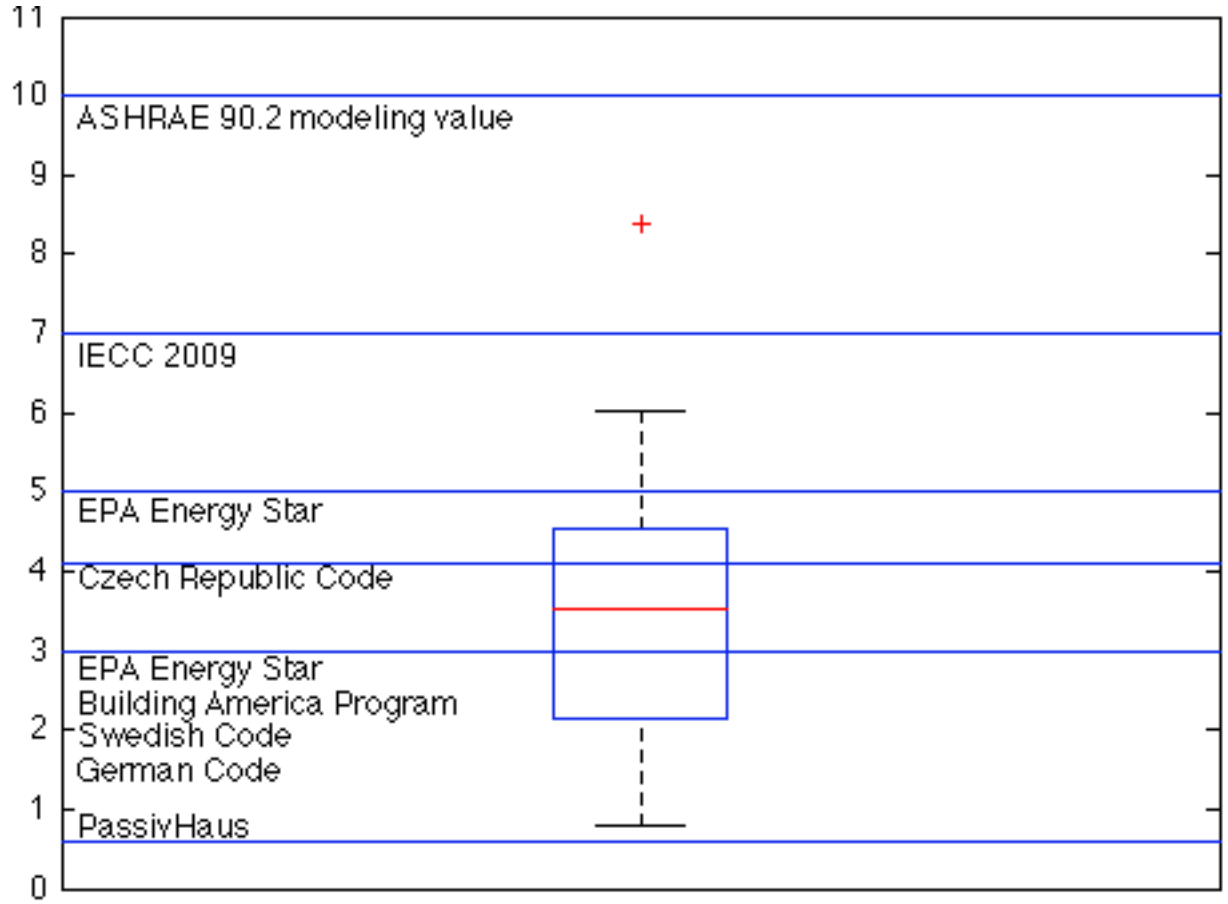
Air Changes Per Hour

$$ACH = \frac{Airflow\ \ at\ \ 50Pa}{House\ Volume}$$

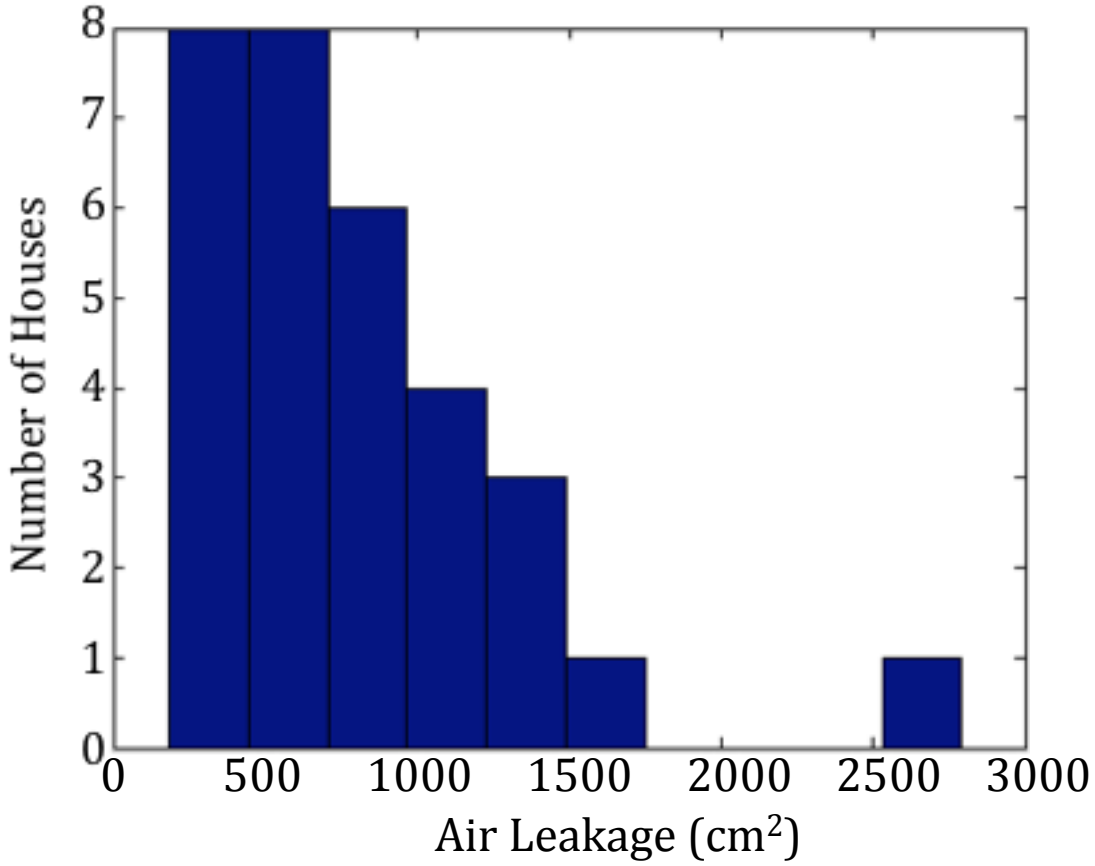
Taken directly from the test

$$h^{-1} = \frac{m^3/s}{m^3} \times 3600\ s/h$$

Air Changes Per Hour



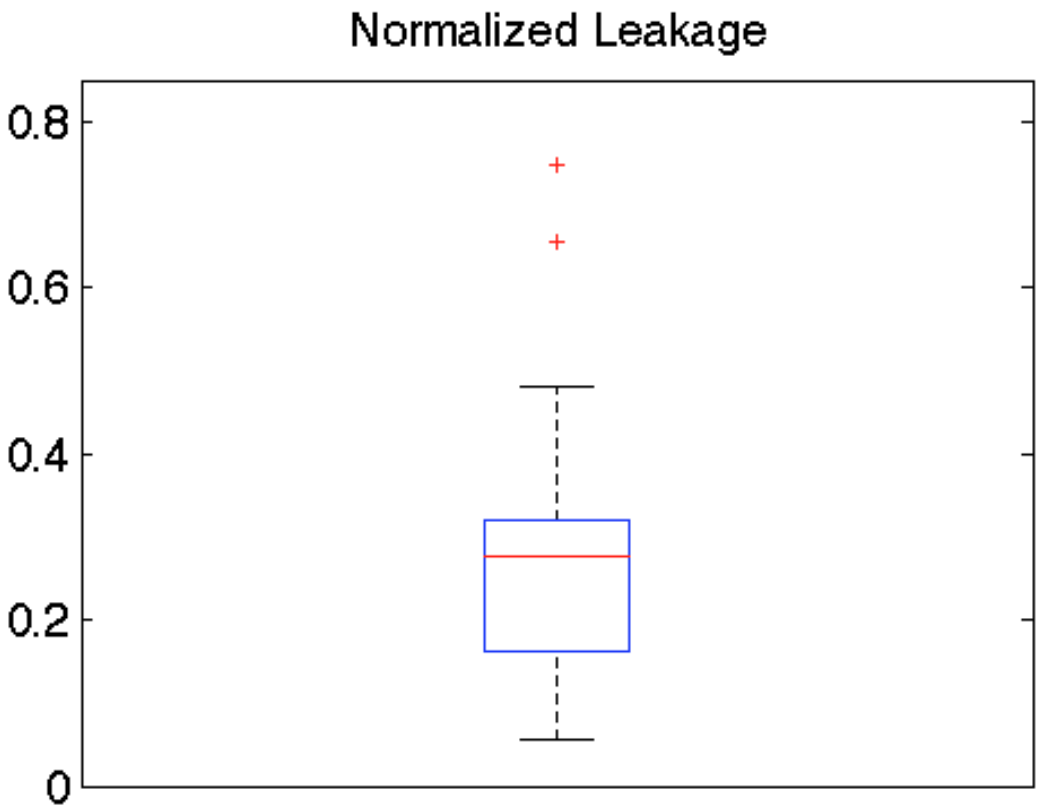
Range of leakage area at 4 Pa
calculated from blower door tests



Leakage Area Normalized by Floor Area and Height

Normalized Leakage =

$$0.1\left(\frac{A_L}{Af}\right)\left(\frac{H}{2.5m}\right)^{0.3}$$



A DOE National Lab Database of Blower Door Data

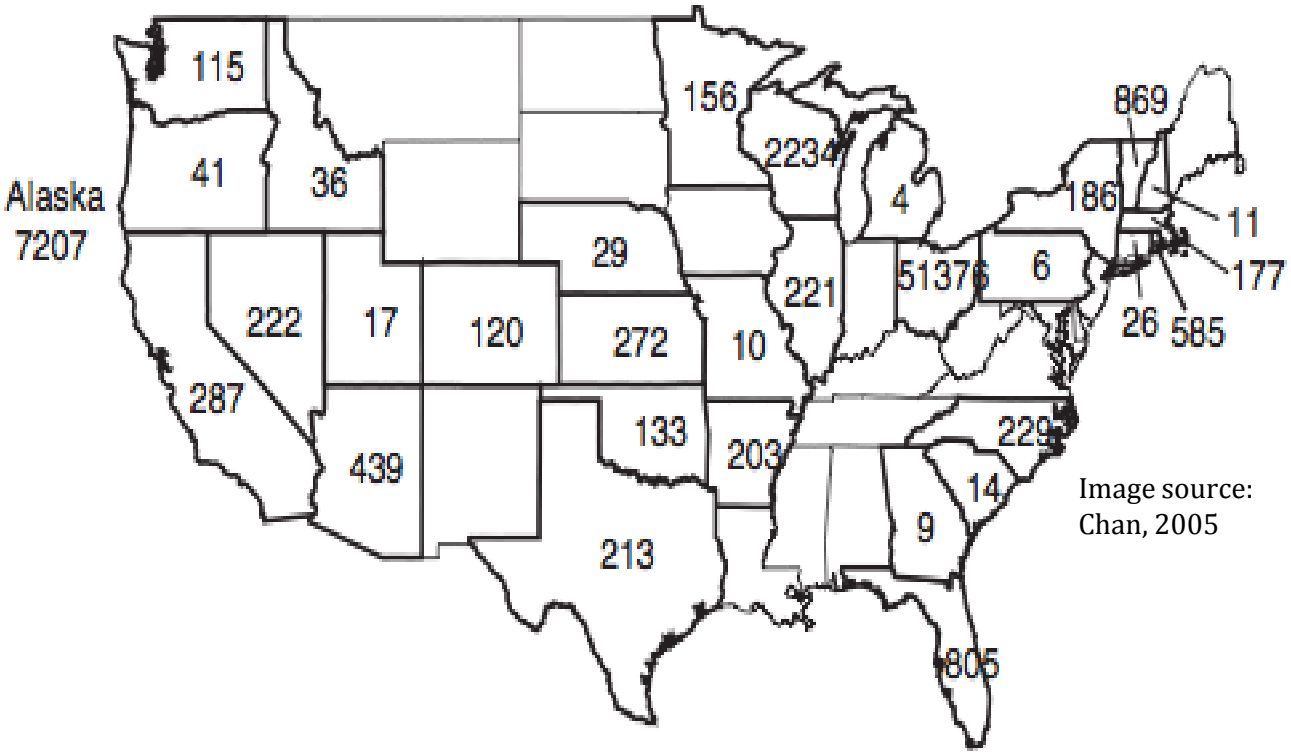


Image source:
Chan, 2005

66500 measurements available in 2003 analysis
3500 were chosen to represent conventional homes

Chan W.R., Price P.N., Sohn M.D., Gadgil A.J. "Analysis of U.S. Residential Air Leakage Database." LBNL 53367. Lawrence Berkeley National Laboratory, 2003.

Analysis at NIST

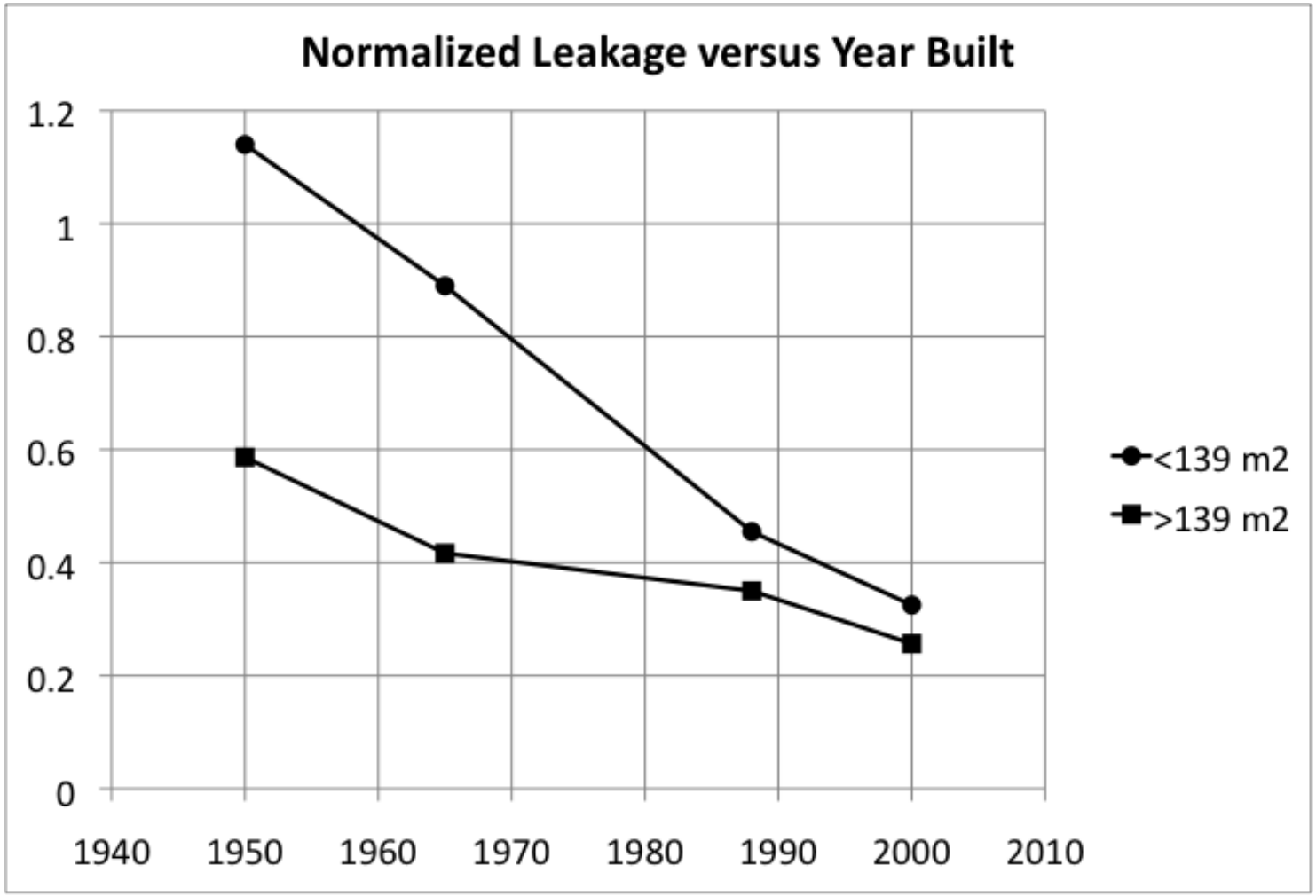
Statistics of normalized leakage of conventional houses

Floor Area	Year Built	# Data	GM	GSD	p05	p25	p50	p75	p95
<93 m^2	before 1950	63	1.09	1.84	0.47	0.61	1.09	1.57	3.20
	1950-1979	71	0.98	1.92	0.37	0.60	0.96	1.55	2.88
	1980-1995	29	0.49	1.62	0.17	0.34	0.48	0.74	0.85
	after 1995	17	0.33	1.36		0.28	0.32	0.34	0.48
93-139 m^2	before 1950	166	1.14	1.78	0.37	0.79	1.19	1.53	2.93
	1950-1979	149	0.82	1.73	0.35	0.54	0.82	1.26	2.21
	1980-1995	191	0.44	1.74	0.22	0.30	0.43	0.55	1.11
	after 1995	85	0.34	1.45	0.20	0.28	0.33	0.41	0.61
140-185 m^2	before 1950	149	0.74	1.76	0.33	0.48	0.67	0.95	2.24
	1950-1979	186	0.51	1.68	0.23	0.37	0.49	0.66	1.78
	1980-1995	163	0.41	1.79	0.16	0.27	0.38	0.64	1.05
	after 1995	75	0.28	1.57	0.11	0.23	0.31	0.36	0.47
186-232 m^2	before 1950	200	0.55	1.49	0.31	0.44	0.54	0.69	1.09
	1950-1979	275	0.40	1.49	0.21	0.31	0.39	0.50	0.75
	1980-1995	129	0.35	1.59	0.15	0.27	0.37	0.50	0.74
	after 1995	67	0.25	1.64	0.06	0.21	0.27	0.35	0.43
>232 m^2	before 1950	328	0.53	1.41	0.29	0.44	0.55	0.67	0.89
	1950-1979	543	0.37	1.40	0.21	0.30	0.37	0.46	0.61
	1980-1995	159	0.29	1.67	0.13	0.20	0.30	0.44	0.58
	after 1995	403	0.18	1.68	0.07	0.14	0.19	0.25	0.39

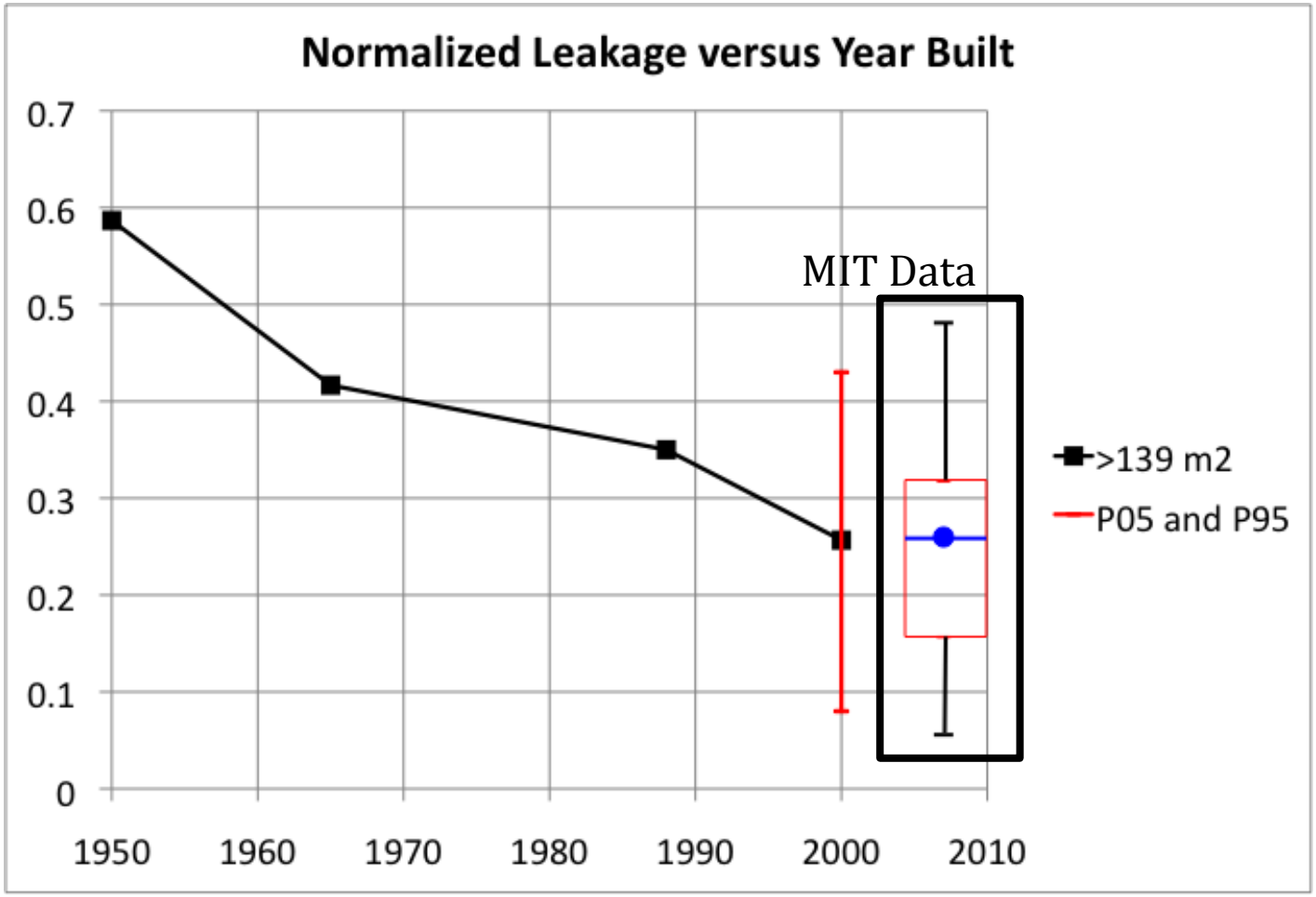
Persily averaged normalized leakage by year for the floor areas below and above 1500 ft^2 (139 m^2)

Persily, A., Musser, A., and Leber, D. "A Collection of Homes to Represent The US Housing Stock" NISTIR 7330, NIST, 2006.

Comparison of National Database and MIT Data



Comparison of National Database and MIT Data



Methodology for E+ input

$$NL = \frac{ELA}{A_f}\left(\frac{H}{2.5}\right)^{.3}$$

(definition)

$$Q = ELA * \sqrt{\frac{2 * P_r}{\rho}}$$

(from Bernoulli)

$$Q = C\Delta P^n$$

(power law – Sherman and Grimsrud 1980)

EnergyManagementSystem:Program

E+ input

		C
ICF	max	0.0967
	median	0.0522
	min	0.0112
Wood	max	0.0864
	median	0.0516
	min	0.0161

E+ Method: EnergyManagementSystem

Input coefficients $\longrightarrow$

$$Q_S = cC_S\Delta t^n$$

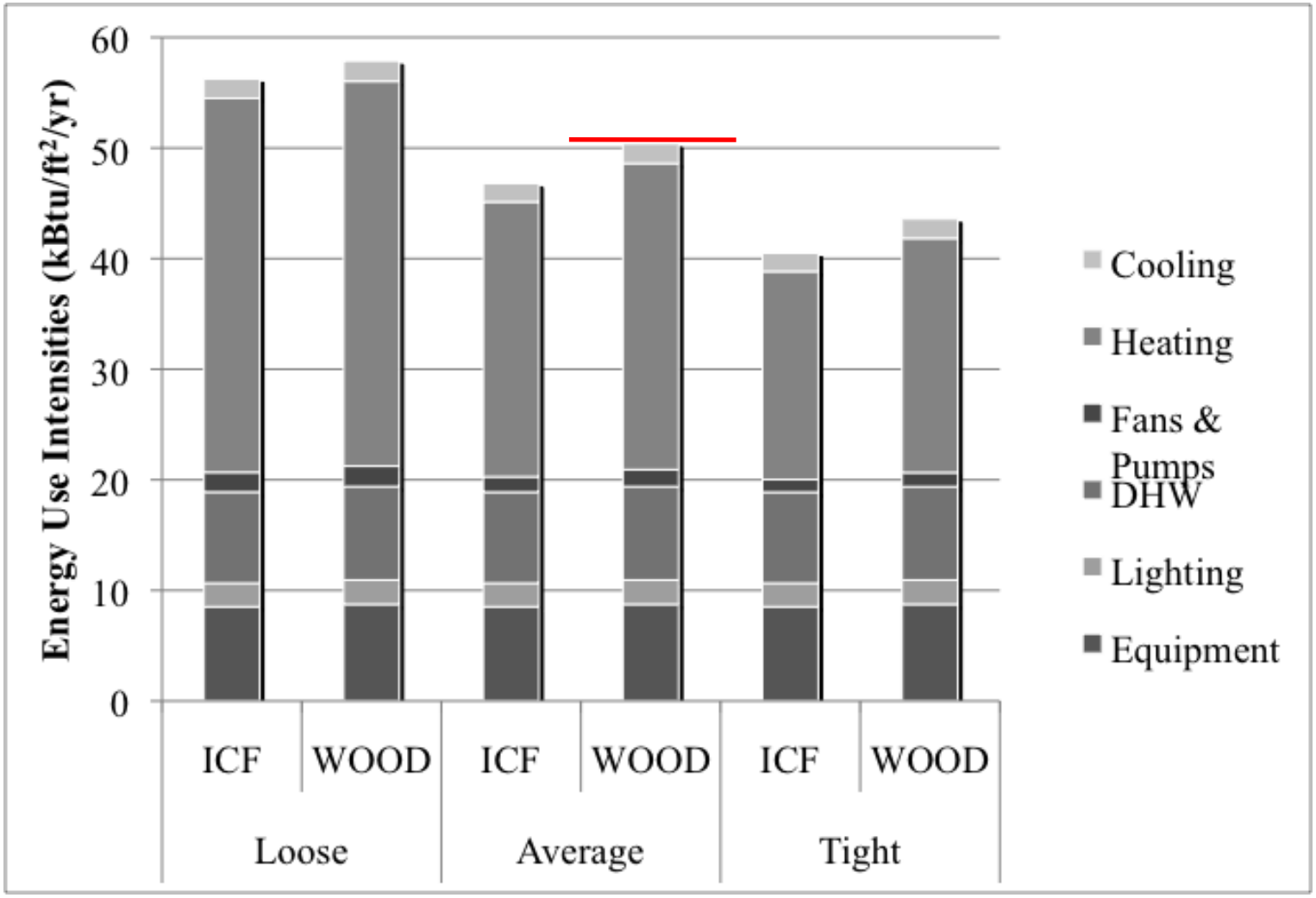
$$Q_W = cC_W(sU)^{2n}$$

$$Q_{\inf} = \sqrt{Q_S{}^2 + Q_W{}^2}$$

$\longrightarrow$ Calculate air flow from other sources

$$\longrightarrow Q_{comb} = Q_{bal} + \sqrt{Q_{unbal}{}^2 + Q_{\inf}{}^2}$$

Annual Energy Use for Single-Family House in Chicago



Conclusions

- We measured infiltration in 31 ICF houses
- ACH data is generally smaller than national standards but somewhat larger than international standards
- ICF air leakage appears to be similar to newer, wood homes
- Energy demands vary widely based on infiltration

Future Work

- Identify reasons for variation in ICF air tightness
- Determine locations of leakage

References

- ASHRAE Standard 90.2-2007. “Energy Efficient Design of Low-Rise Residential Buildings.” American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
- ASHRAE Standard 119-1988. “Air Leakage Performance for Detached Single-Family Residential Buildings.” American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
- ASTM Standard E779, 2010, "Standard Test Method for Determining Air Leakage Rate by Fan Pressurization," ASTM International, West Conshohocken, PA, 2003, DOI: 10.1520/E0779-10, www.astm.org.
- Balaras, C.A., Droutsa, K., Argiriou, A.A., and Asimakopoulos, D.N. “Potential for Energy Conservation in Apartment Buildings.” Energy and Buildings. 31: 143–154, 2000.
- Chan W.R., Price P.N., Sohn M.D., Gadgil A.J. “Analysis of U.S. Residential Air Leakage Database.” LBNL 53367. Lawrence Berkeley National Laboratory, 2003.
- Emmerich, S.J. and Persily, A. “Energy Impacts of Infiltration and Ventilation in US Office Buildings Using Multizone Airflow Simulation.” Proc. of the IAQ and Energy Conference. 98: 191-203. 1998.
- Erhorn-Kluttig, H., Erhorn, H., Lahmidi, H. “Airtightness requirements for high performance buildings.” Information paper # 157. Available on www.buildup.eu. 2009.
- International Energy Conservation Code. 2009.
- Lstiburek, J.W. “Just Right and Airtight.” ASHRAE Journal. Vol 53. no. 5. 58 - 66. May, 2011.
- “Outline Specification.” <passivhuas.org/uk/standard.jsp?id=18>
- Persily, A., Musser, A., and Leber, D. “A Collection of Homes to Represent The US Housing Stock” NISTIR 7330, NIST, 2006.
- Shaw, C.Y., Jones, L. “Air Tightness and Infiltration of School Buildings”. National Research Council of Canada. ASHRAE Transactions 85: 85-95. 1975.
- Sherman, M.H. “Air Infiltration in Buildings.” Proc. of the American Institute of Physics Conference. 135: 655-662. 1985.
- Tamura, G.T. and Shaw, C.Y. “Studies on Exterior Wall Airtightness and Infiltration of Tall Buildings.” ASHRAE Transactions. 82: 122-134. 1977.

Thank you

Questions?

Additional comments or questions can be directed to hrd@mit.edu