Simulating Air Leakage in Walls and Roofs Using Indoor and Outdoor Boundary Conditions

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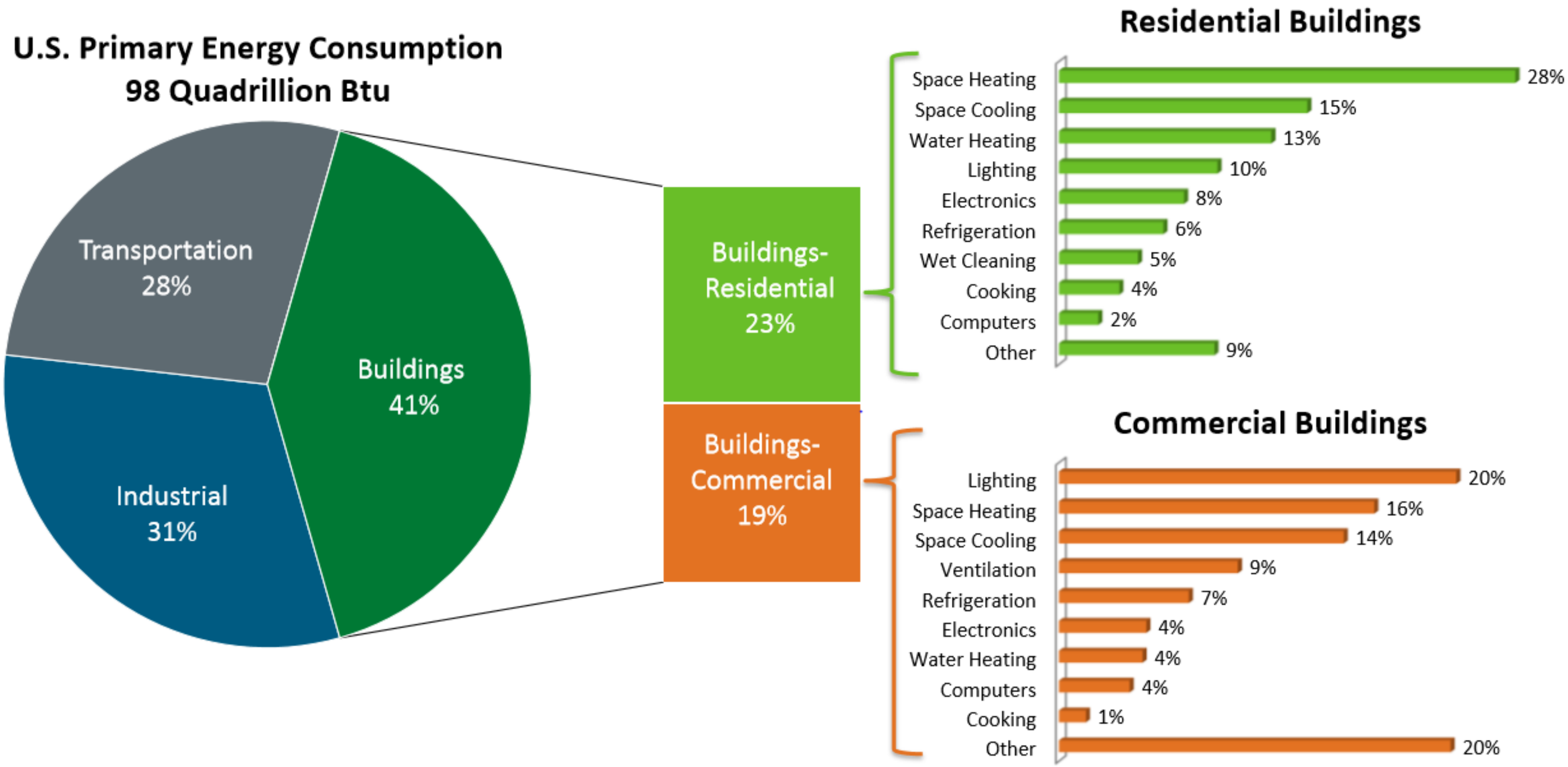
OAK RIDGE National Laboratory
BUILDING TECHNOLOGIES RESEARCH AND INTEGRATION CENTER

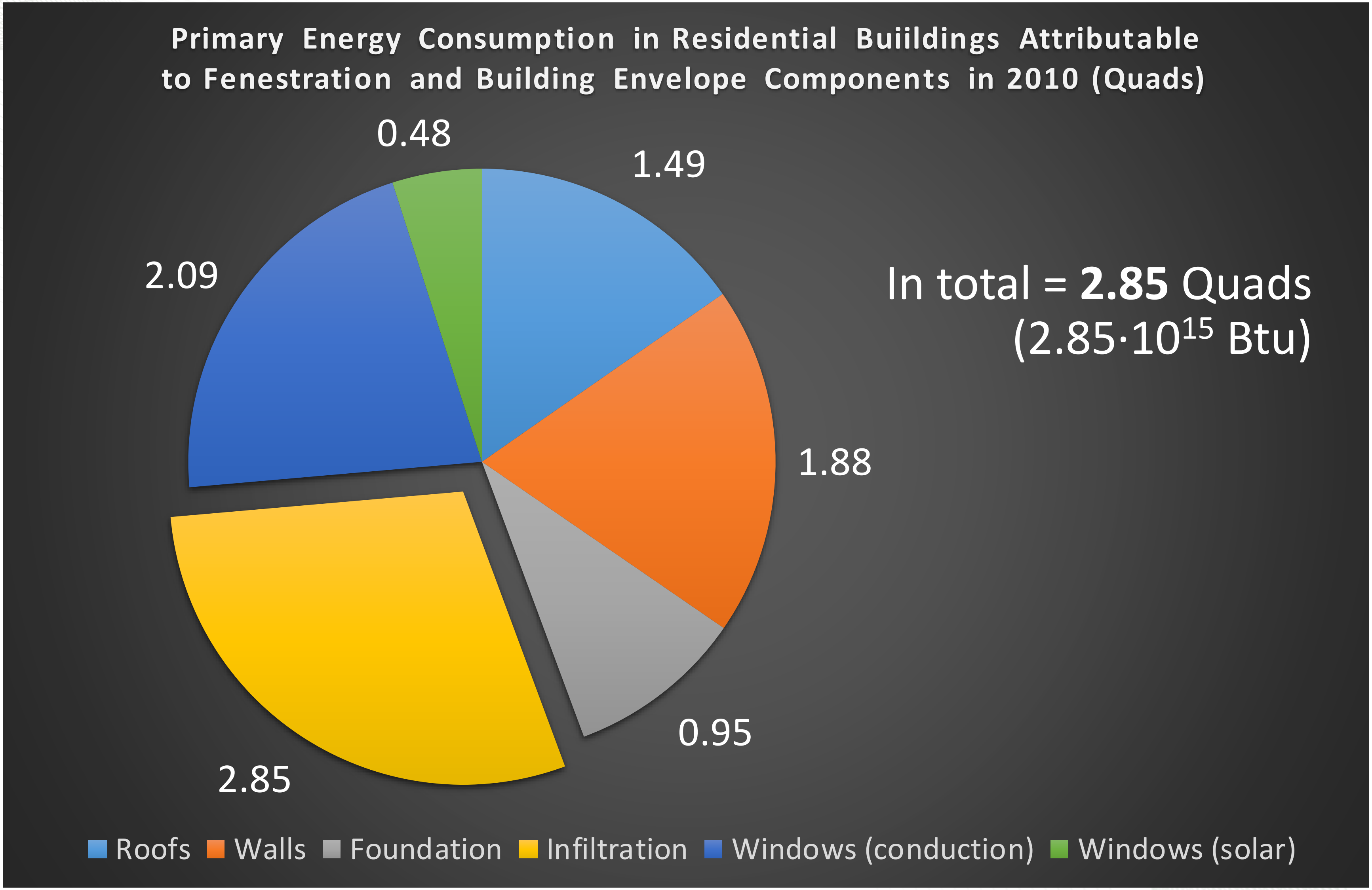
Outline

- Why Reducing Air Leakage Through the Building Envelope?
  - Market Potential
- So What, and Why is Moisture Durability Complicated?
  - Moisture Accumulation
- How Can We Predict the Impact of Air Leakage?
  - Modelling Limitations
  - Simulation Approach
  - Assumptions
- So How Can We Account for Moisture Accumulation?
  - Empirical Formula
  - Example of Usage

Building Envelope Market Potential



Building Envelope Market Potential



Building Envelope Market Potential

Primary Energy Consumption Attributable to Fenestration and Building Envelope Components for Commercial Buildings in 2010 (Quads)

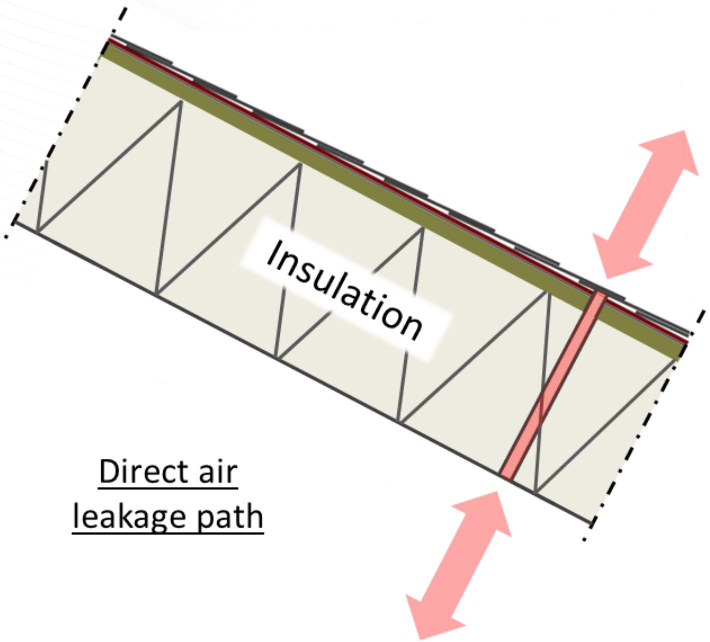
103 million tons of coal

~ 490 million barrels of oil

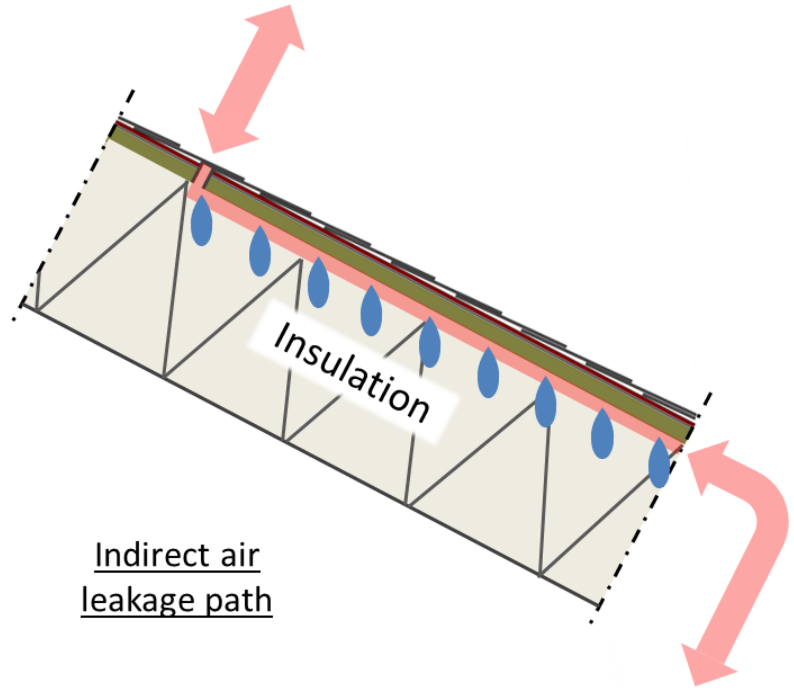
- Roofs
- Walls
- Foundation
- Infiltration
- Windows (conduction)
- Windows (solar)

Moisture Accumulation

Moisture Accumulation

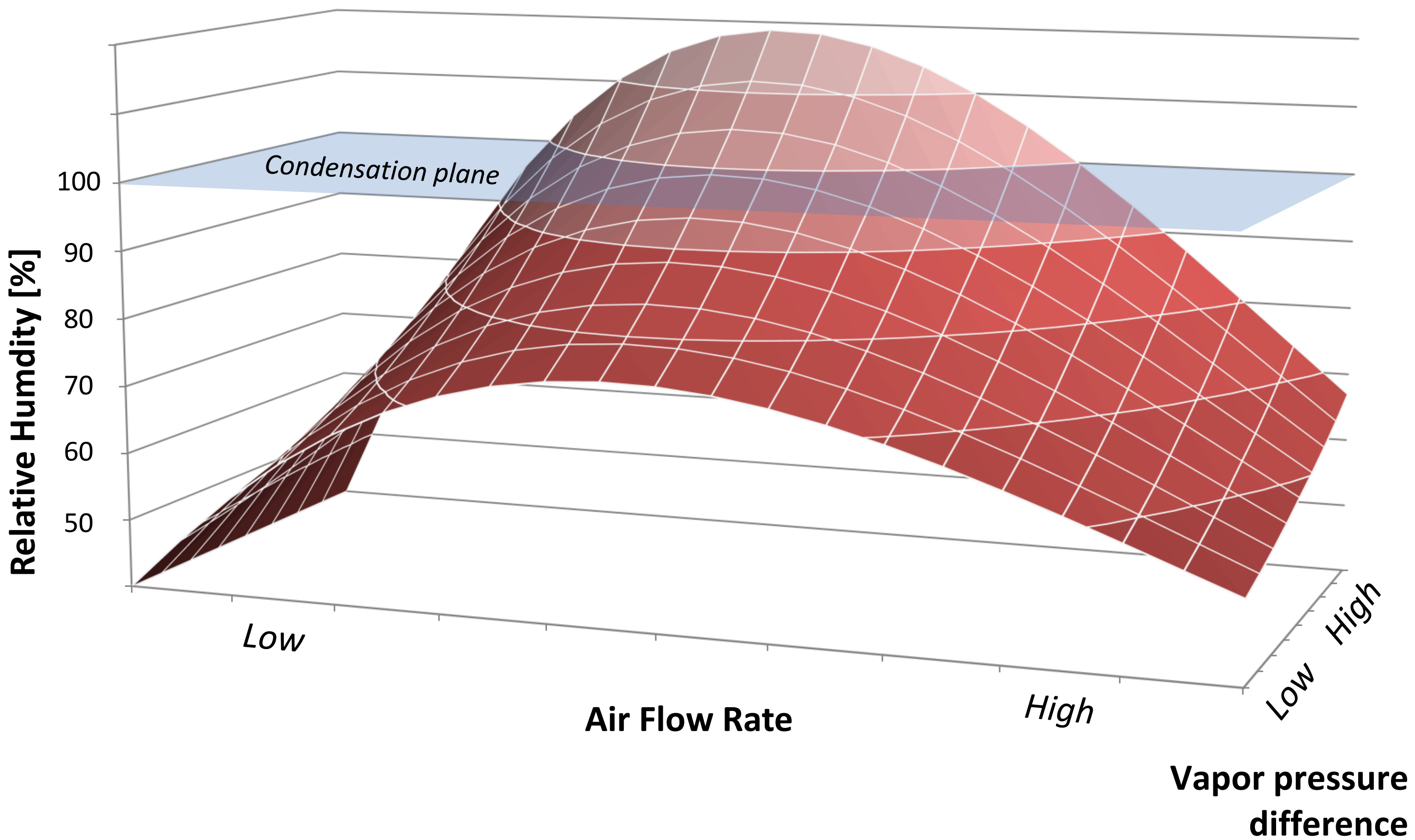


“Energy Leak”

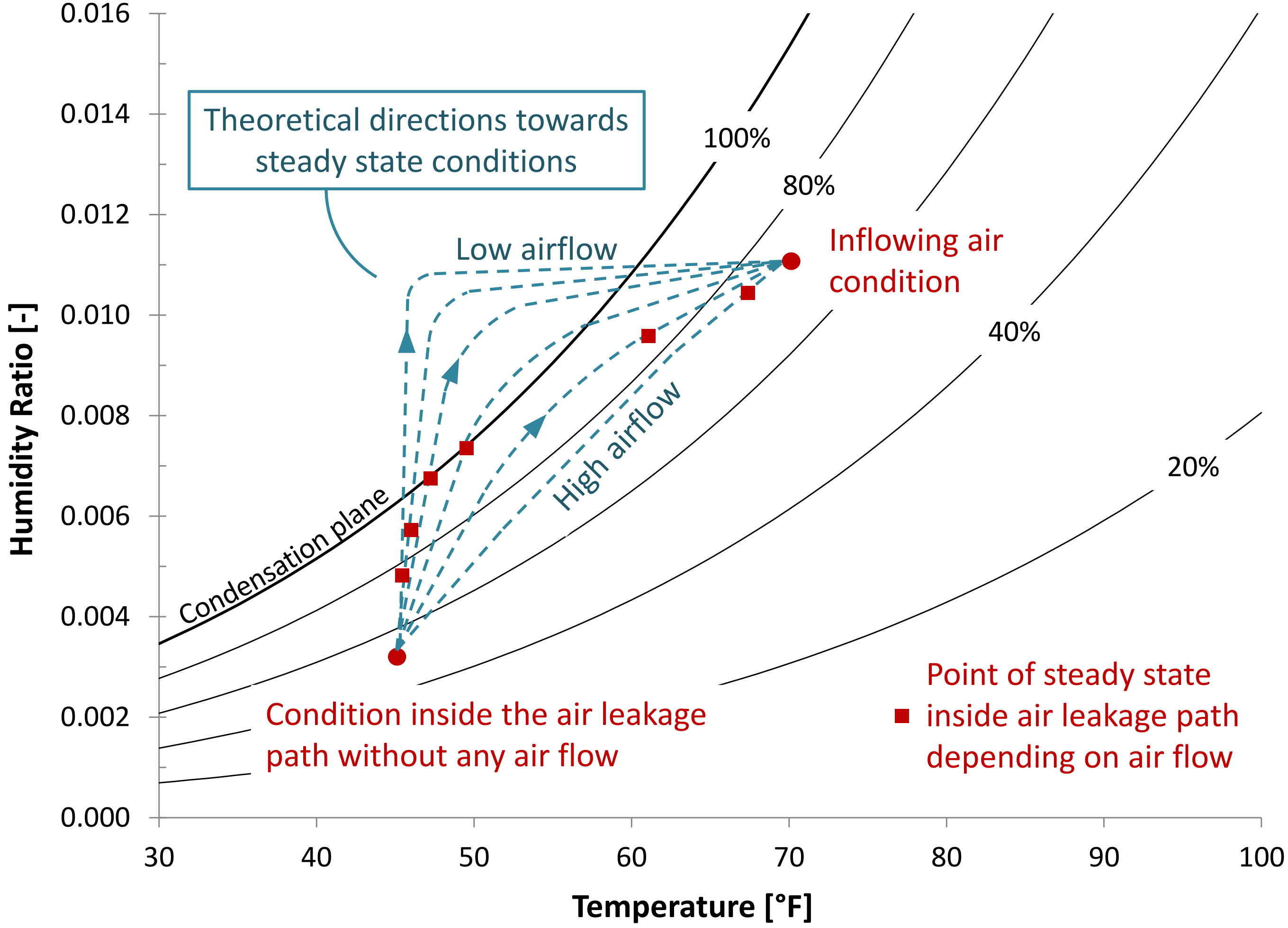


“Moisture Leak”

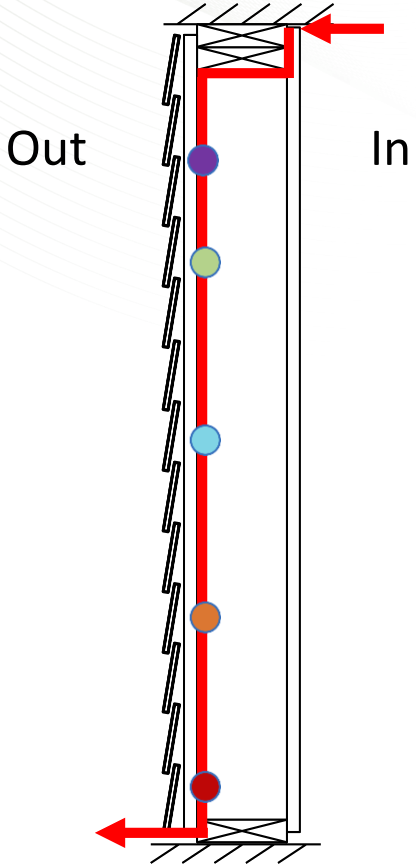
Moisture Accumulation

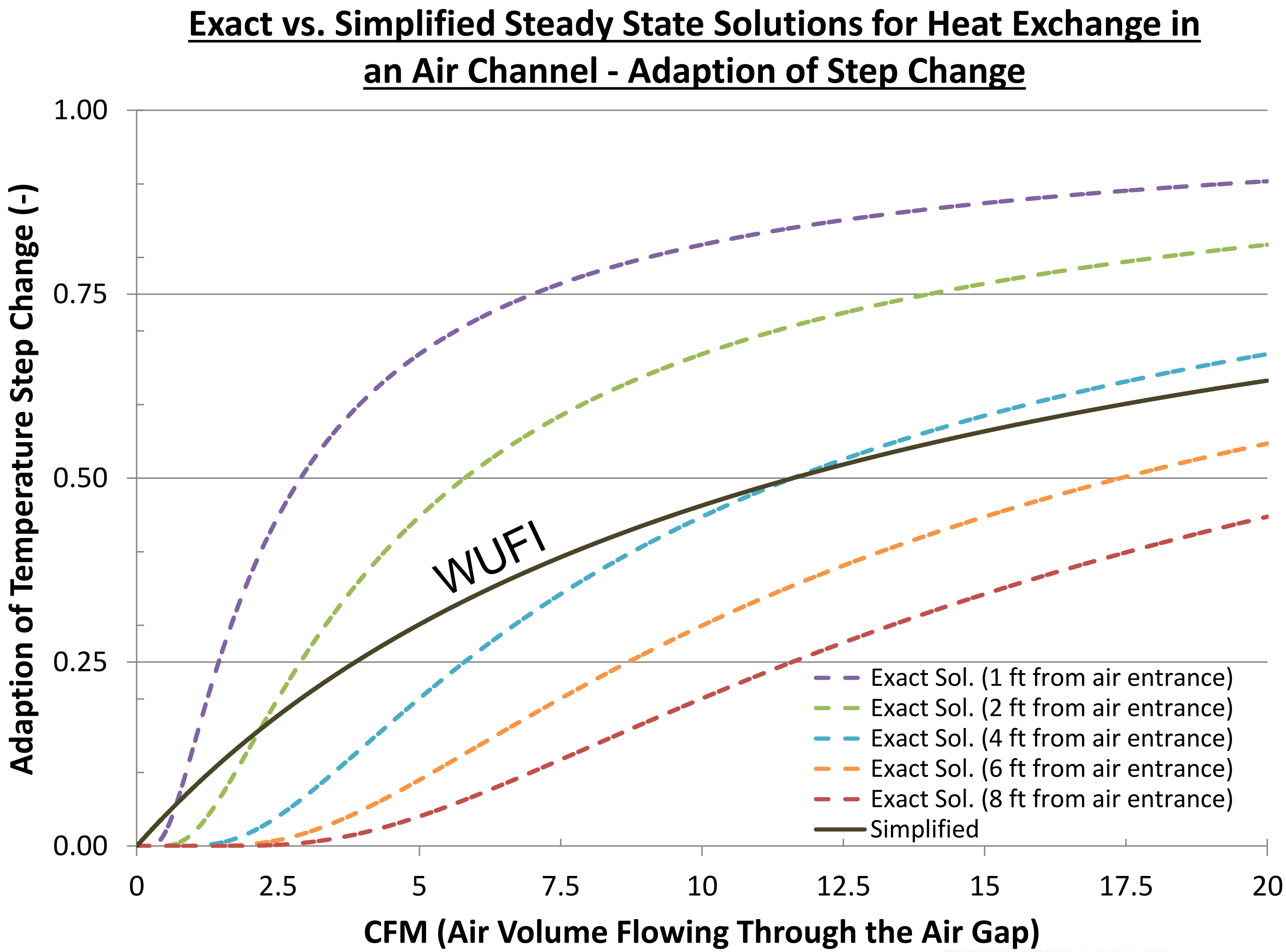


Moisture Accumulation



Modelling Limitations



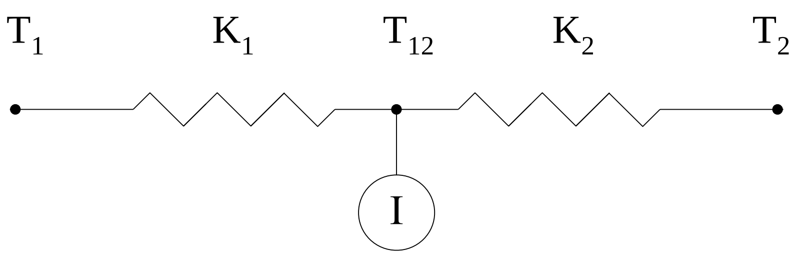


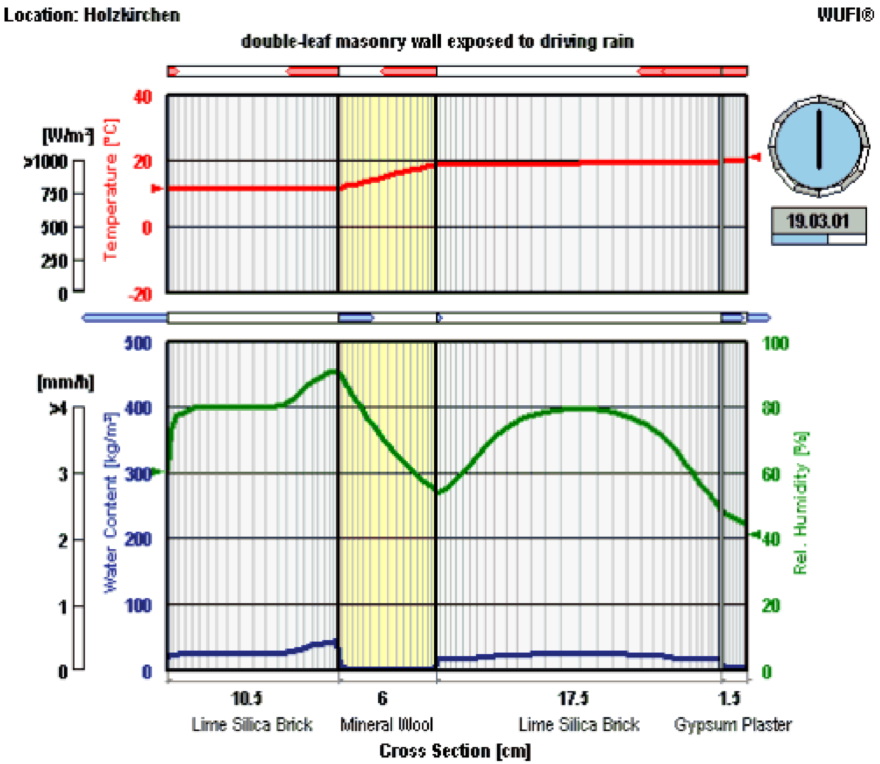
Simulation Approach

1D Solution

$$T_{12}(I) = \frac{\left(T_1 + \frac{I}{K_1}\right) \cdot K_1 + T_2 \cdot K_2}{K_1 + K_2}$$

$$I = \rho_{air} \cdot c_{air} \cdot (T_2 - T_{12}(I)) \cdot \dot{Q}$$





2D Solution

$$T(x) = T_1 + (T_2 - T_1) \cdot e^{\left(\frac{-x}{l_c}\right)}$$

$$l_c = \frac{\rho_{air} \cdot c_{air} \cdot \dot{Q}}{L_{surf} \cdot K}$$

Simulation Approach

1D Solution

$$T_{12}(I) = \frac{\left(T_1 + \frac{I}{K_1}\right) \cdot K_1 + T_2 \cdot K_2}{K_1 + K_2}$$

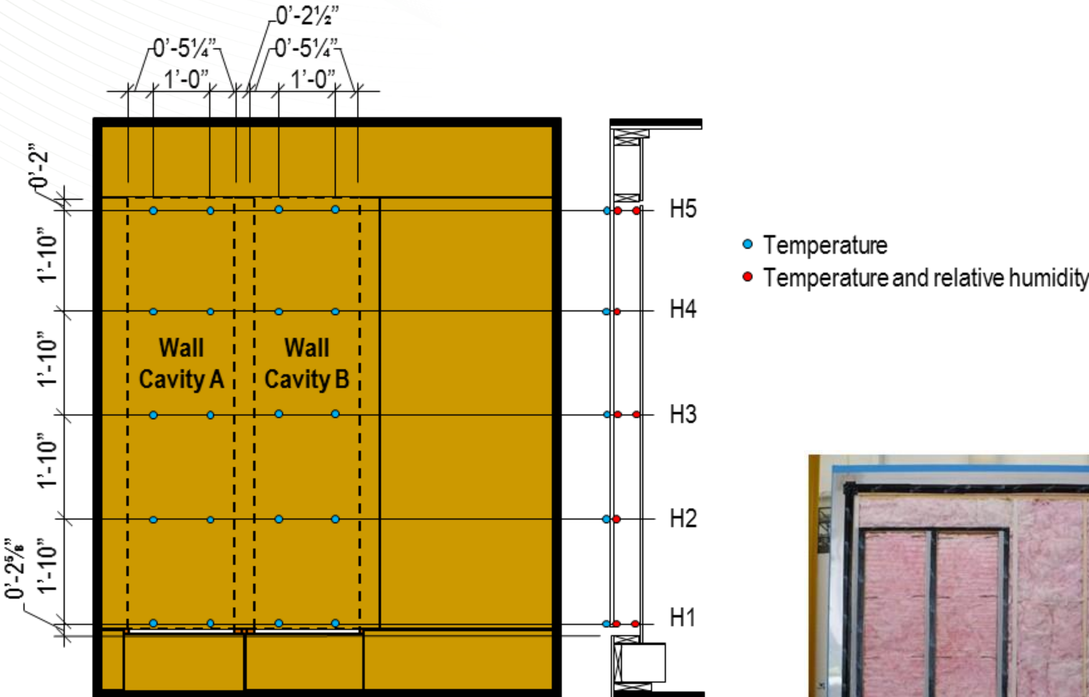
2D Solution

$$T(x) = T_1 + (T_2 - T_1) \cdot e^{\left(\frac{-x}{l_c}\right)}$$

$$\eta = \frac{\left(\frac{T(x) \cdot K - T_2.K_2}{K_1} - T_1\right) \cdot K_1}{\rho_{air} \cdot c_{air} \cdot (T_2 - T_{12}(I)) \cdot \dot{Q}}$$

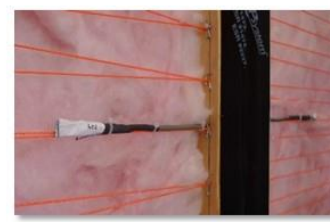
$$ACH_\eta = \eta\left(x, \dot{Q}\right) \cdot ACH$$

Simulation Approach

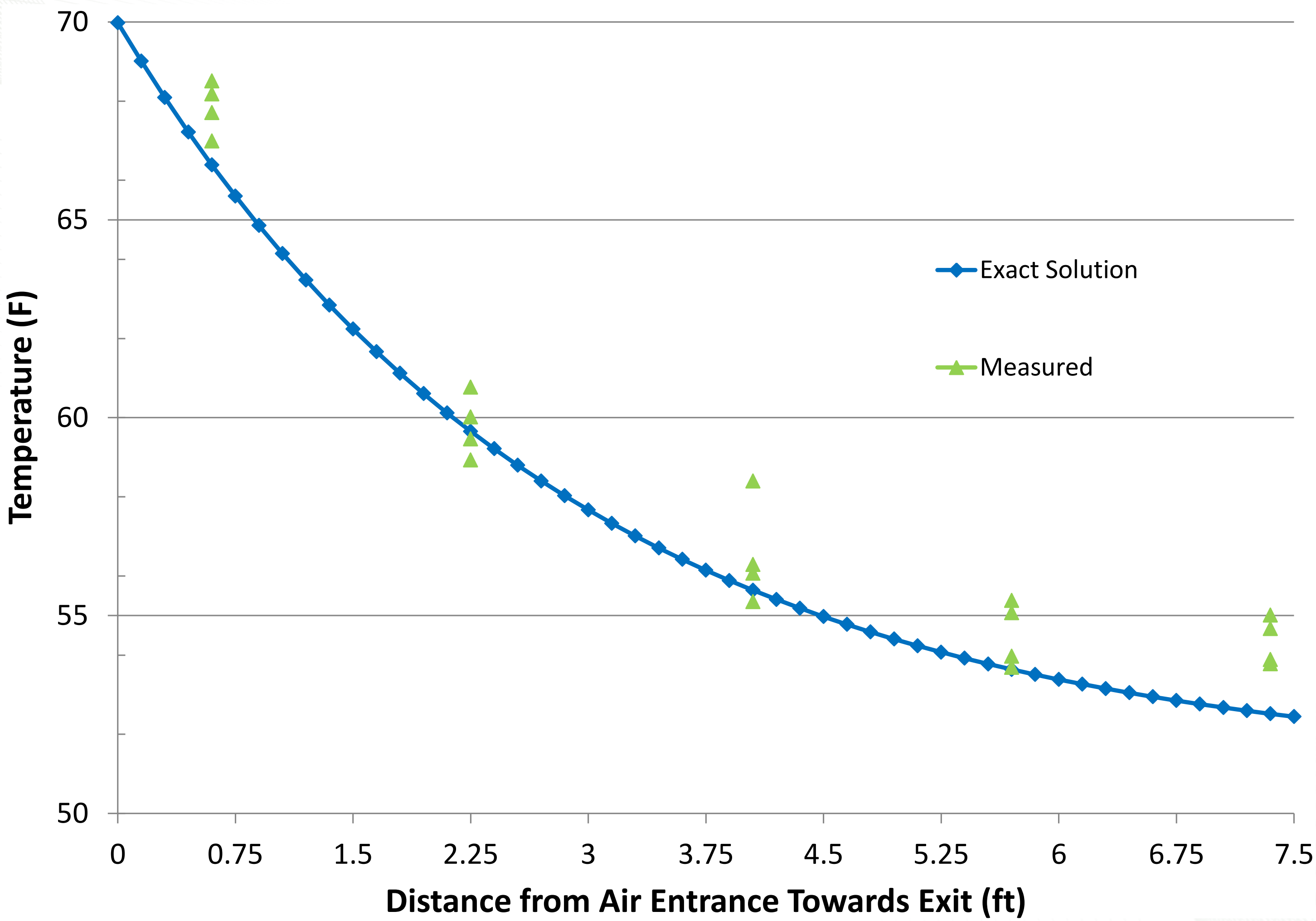


Elevation of test wall

Cross-section



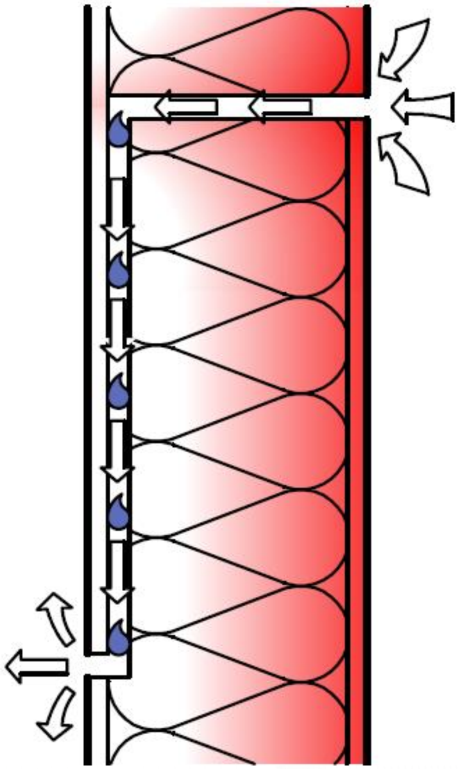
Simulation Approach



Calculated vs. measured steady-state temperatures at a leakage rate of 5.8 cfm (2.7 l/s).

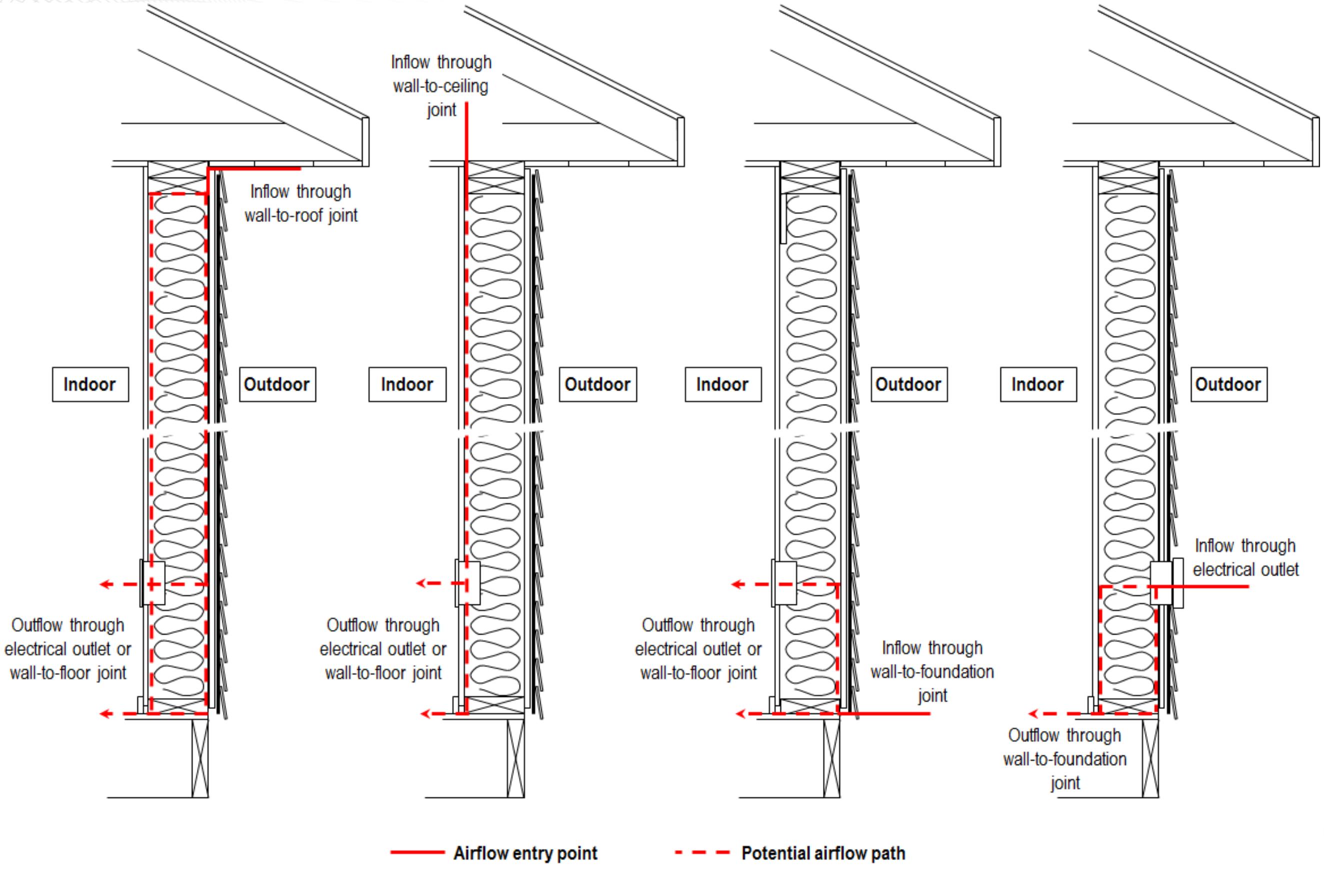
Simulation Approach

- Where are these moisture leaks?
- Flow pattern?

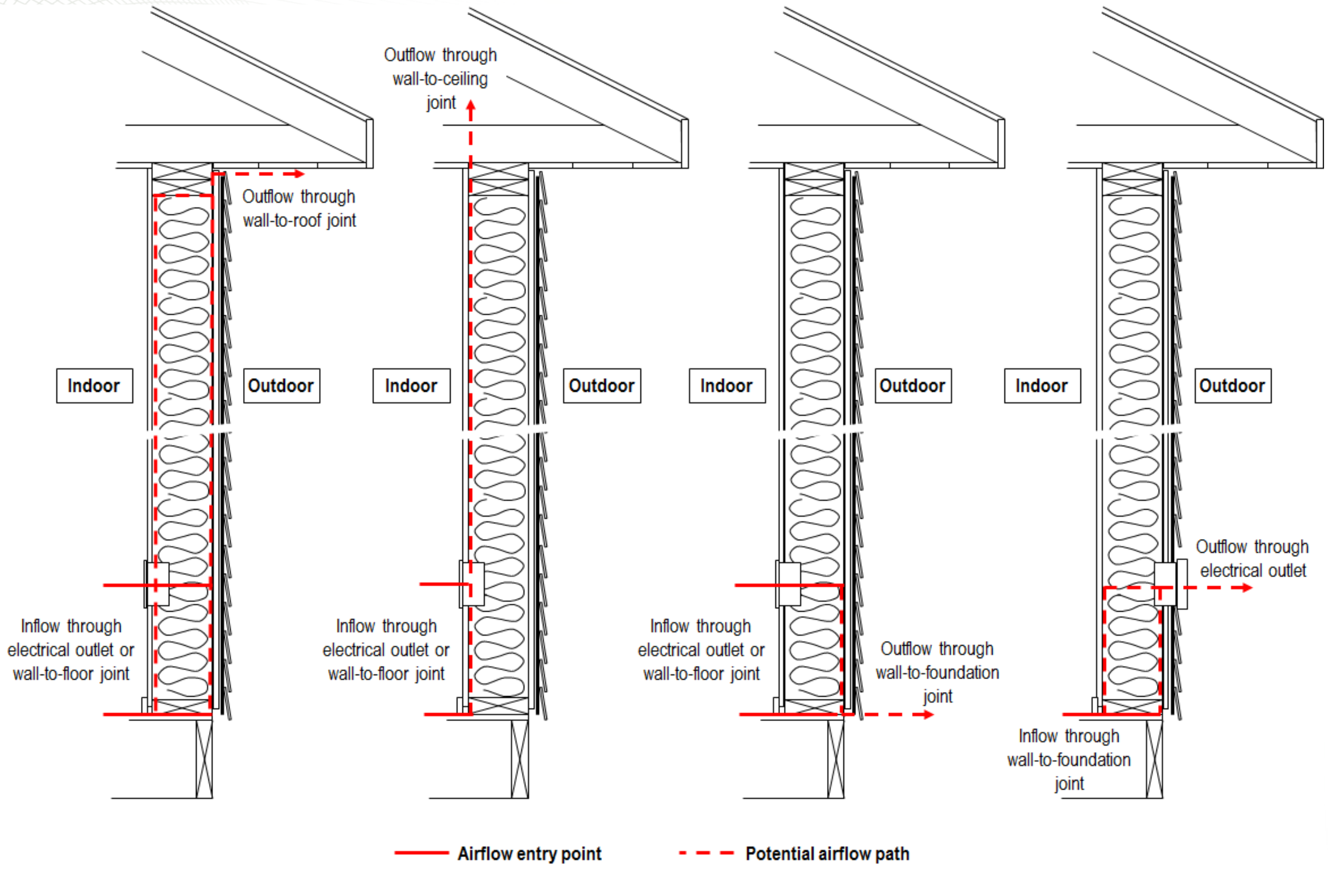


Fraunhofer IBP

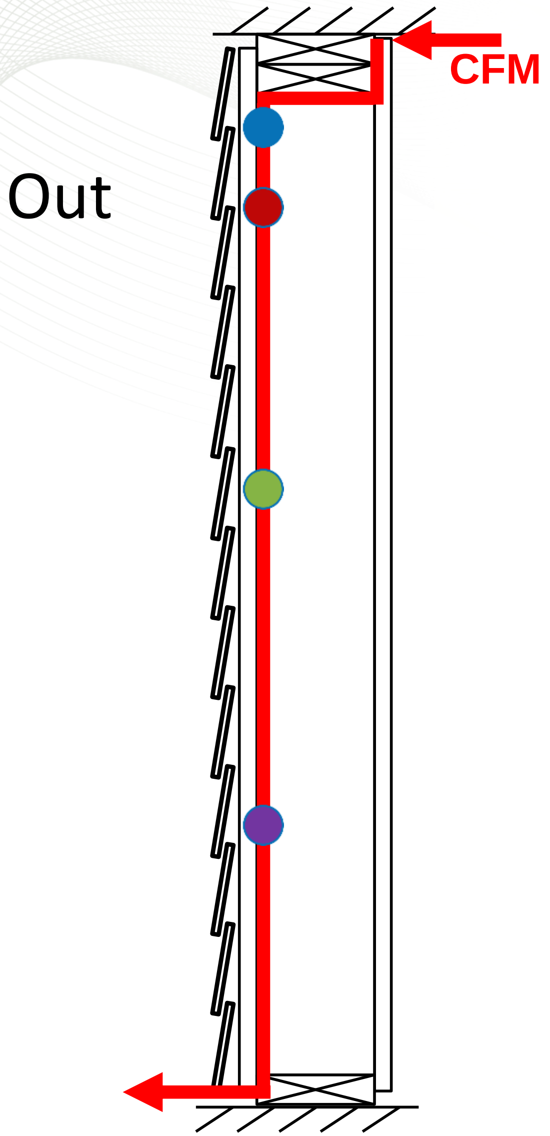
Simulation Approach – Inward Flow

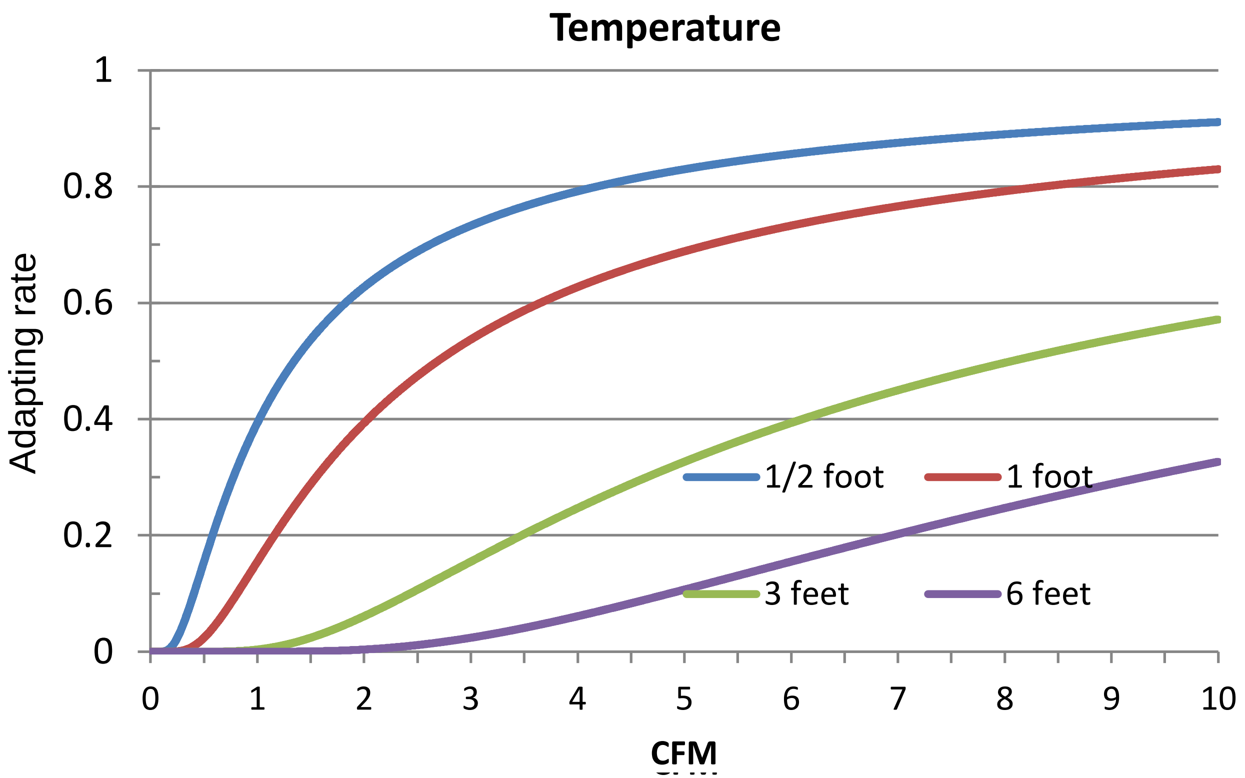


Simulation Approach – Outward Flow

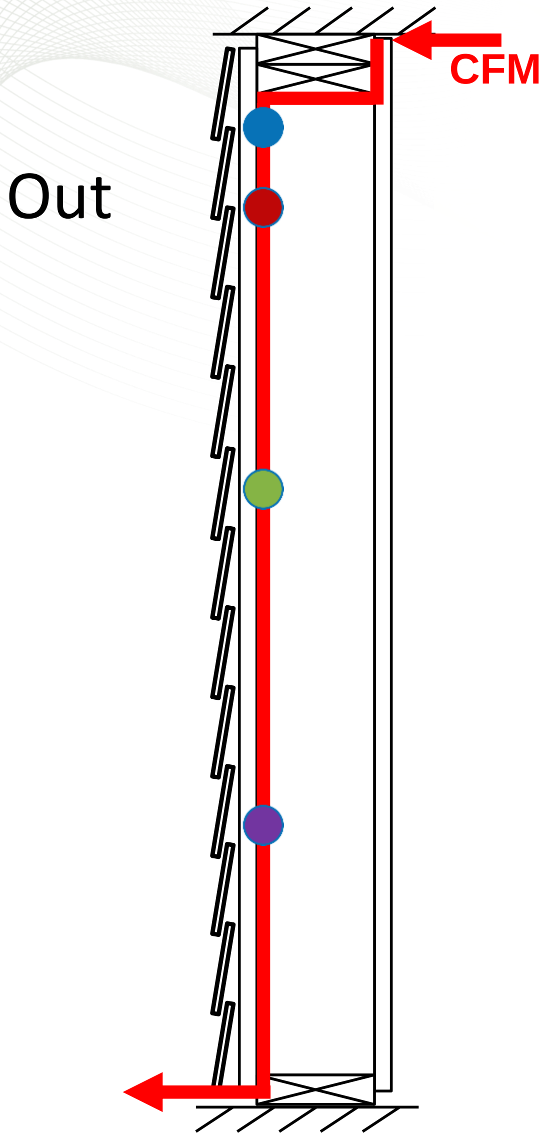


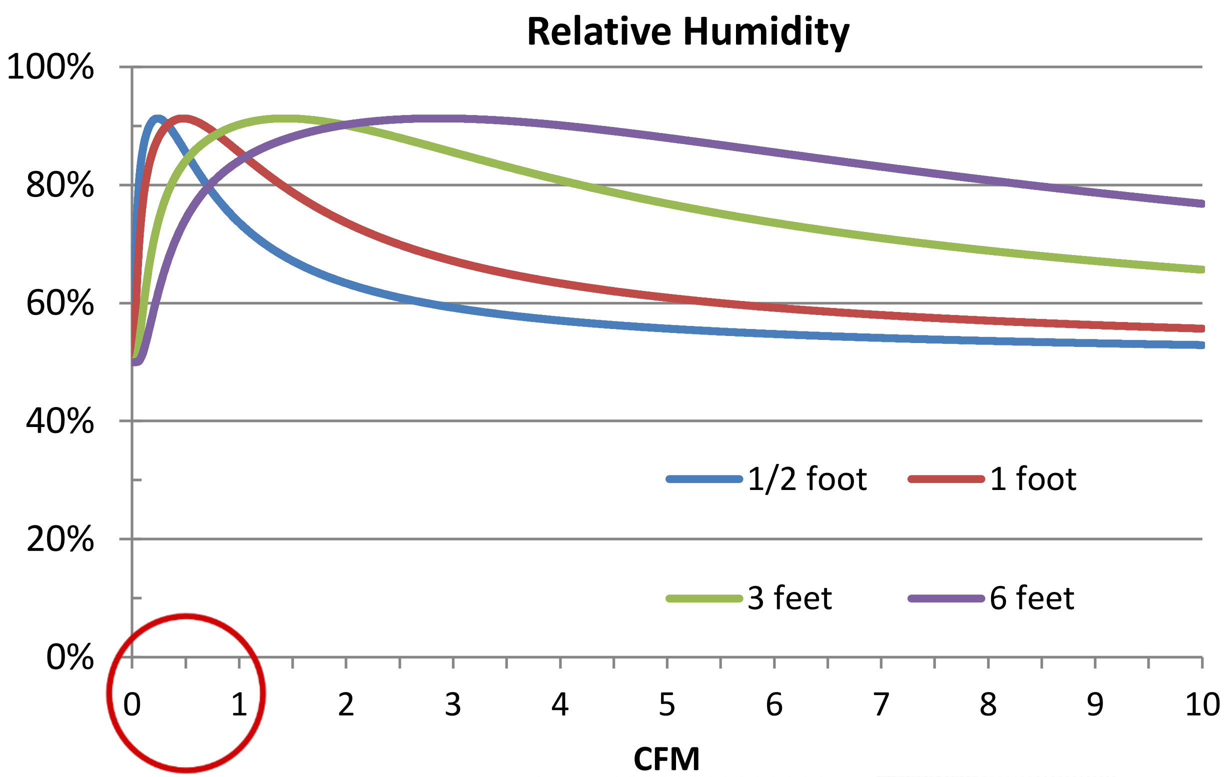
Simulation Approach - Assumption





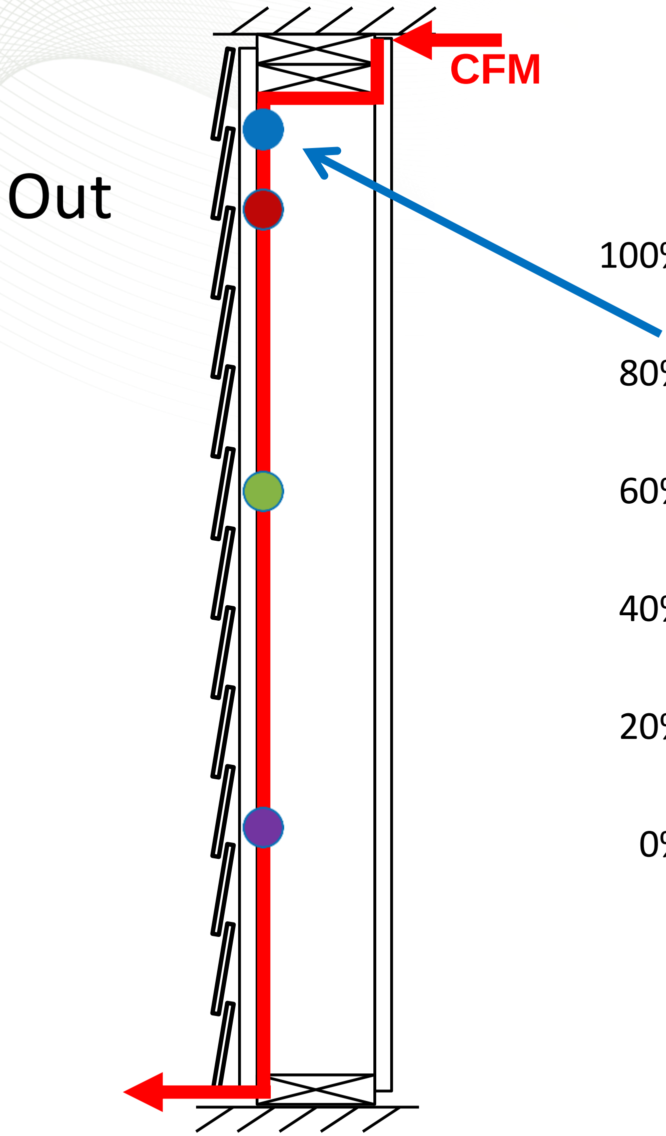
Simulation Approach - Assumption

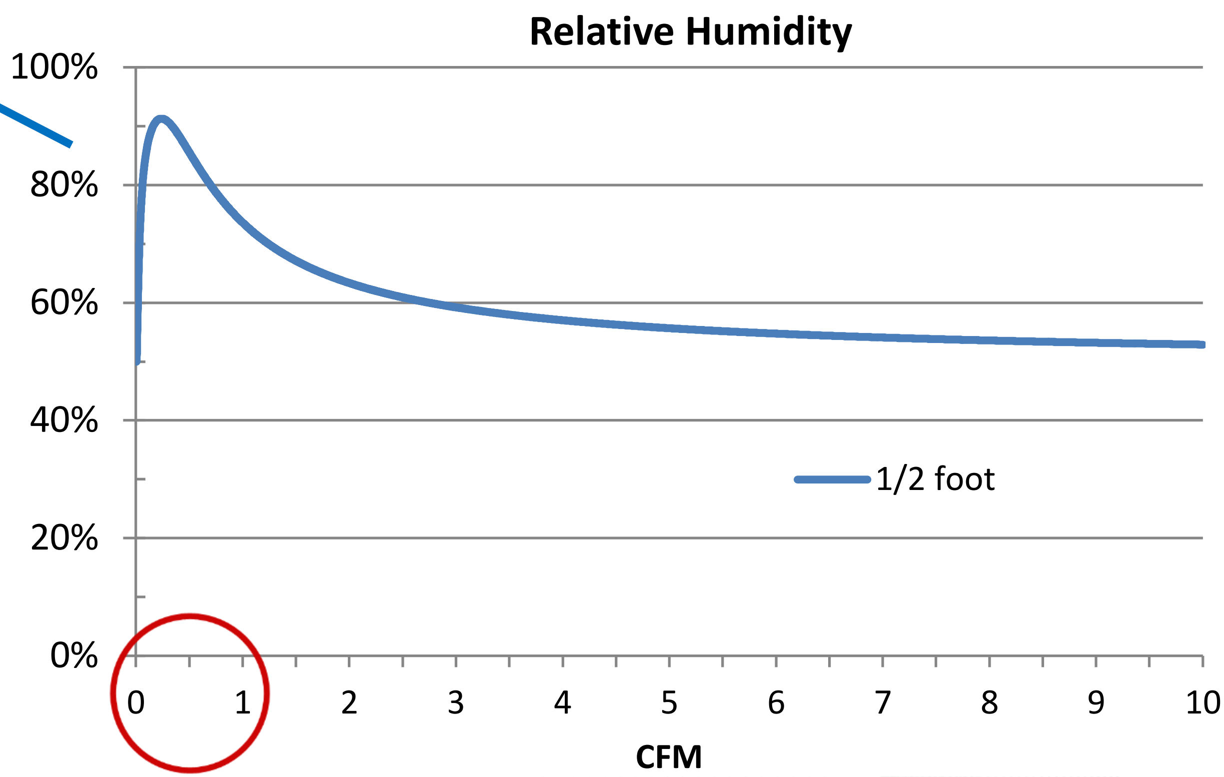




Air flow rates rarely exceed 1 cfm

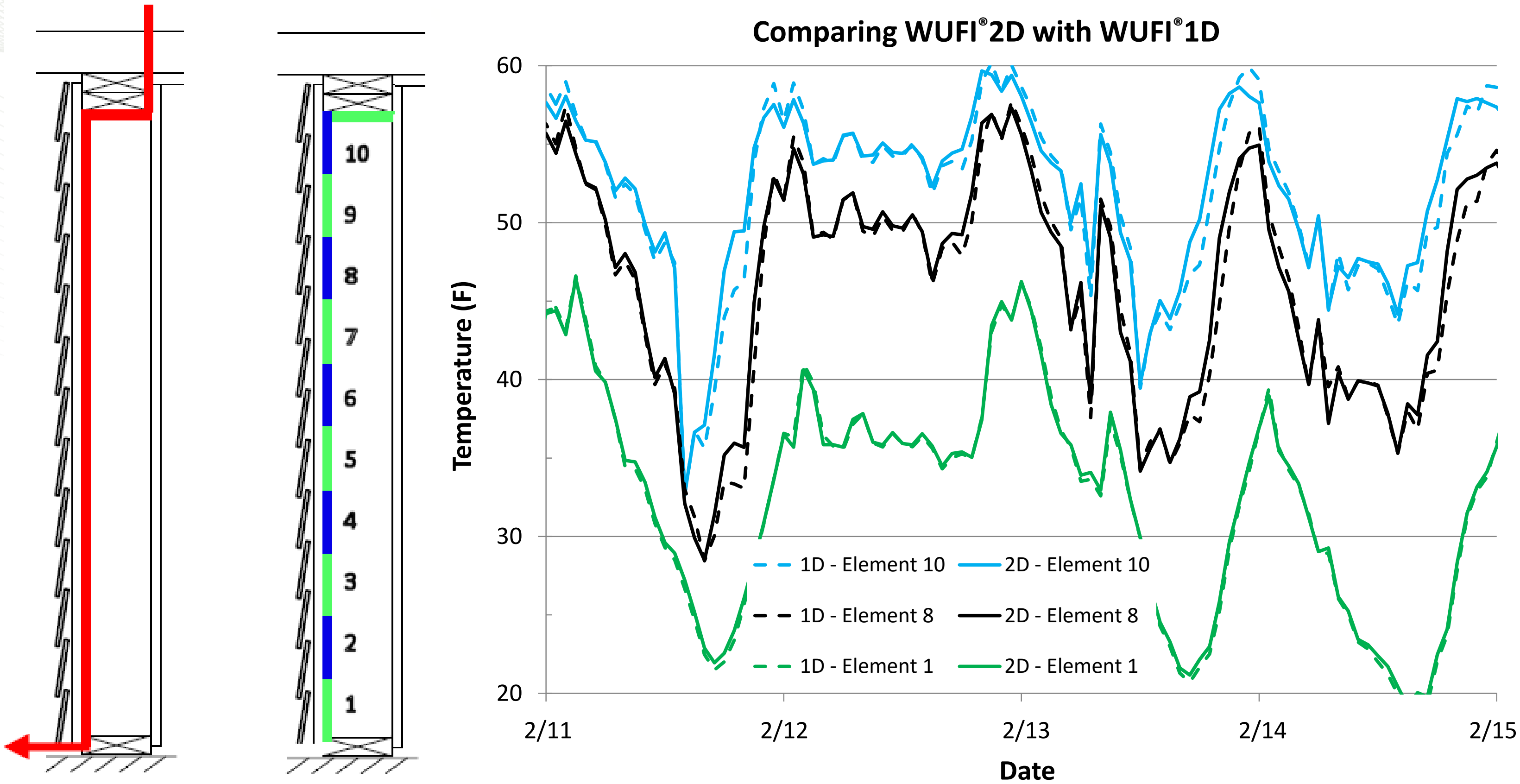
Simulation Approach - Assumption





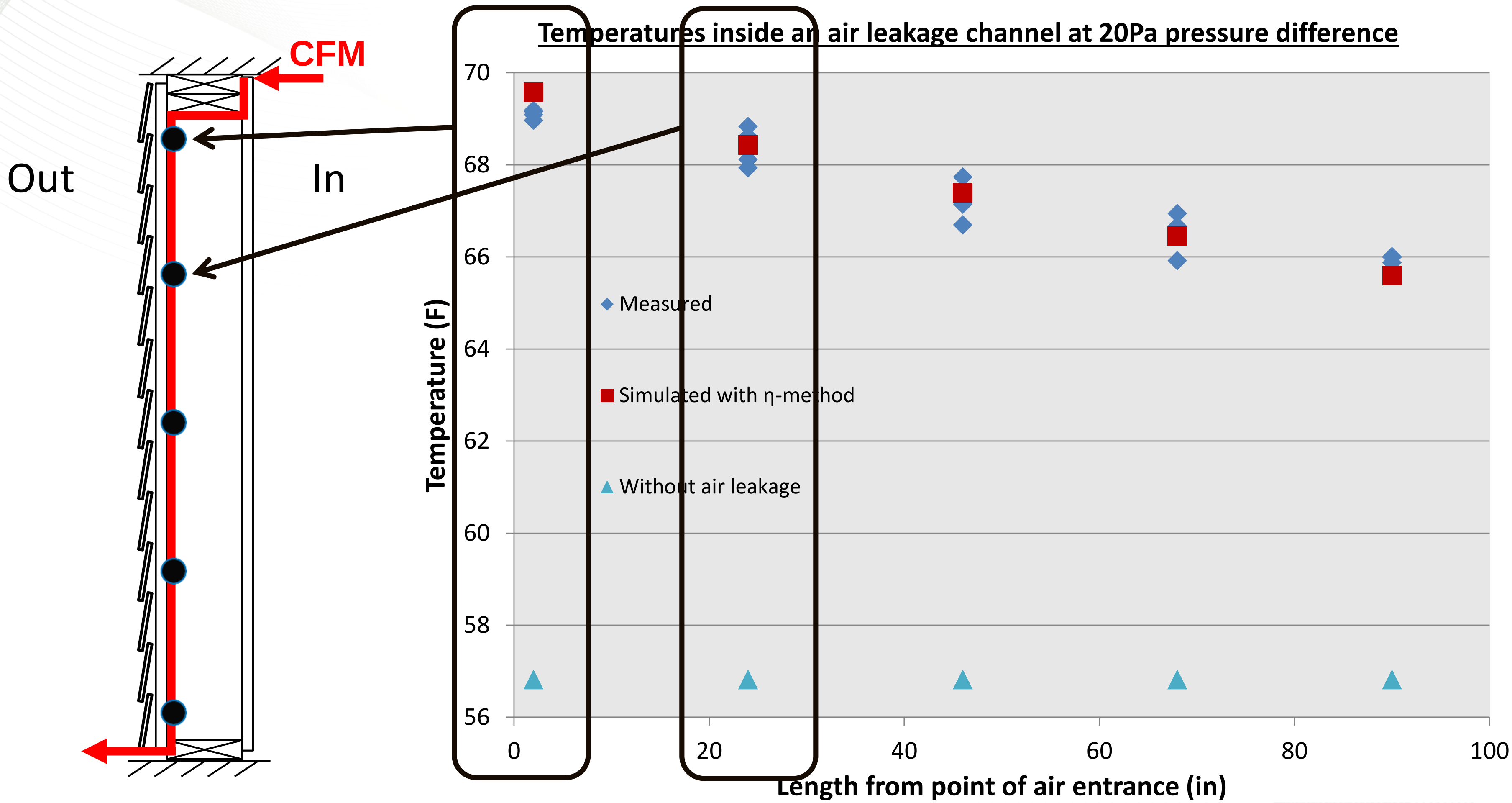
Air flow rates rarely exceed 1 cfm

Simulation Approach - Assumption

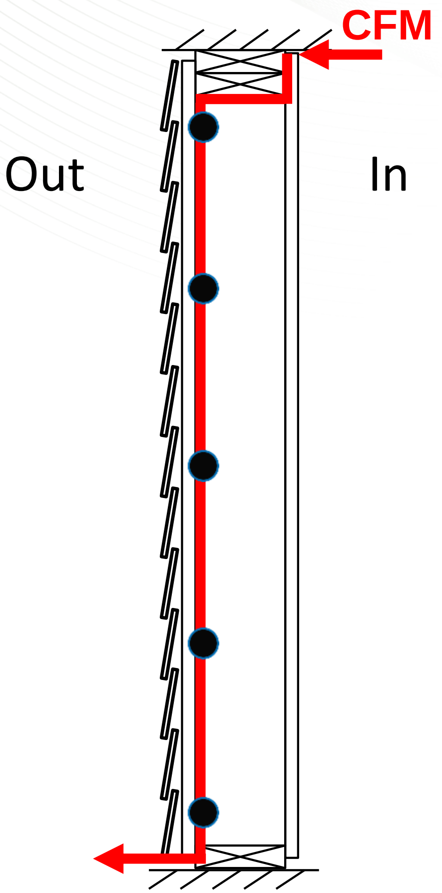


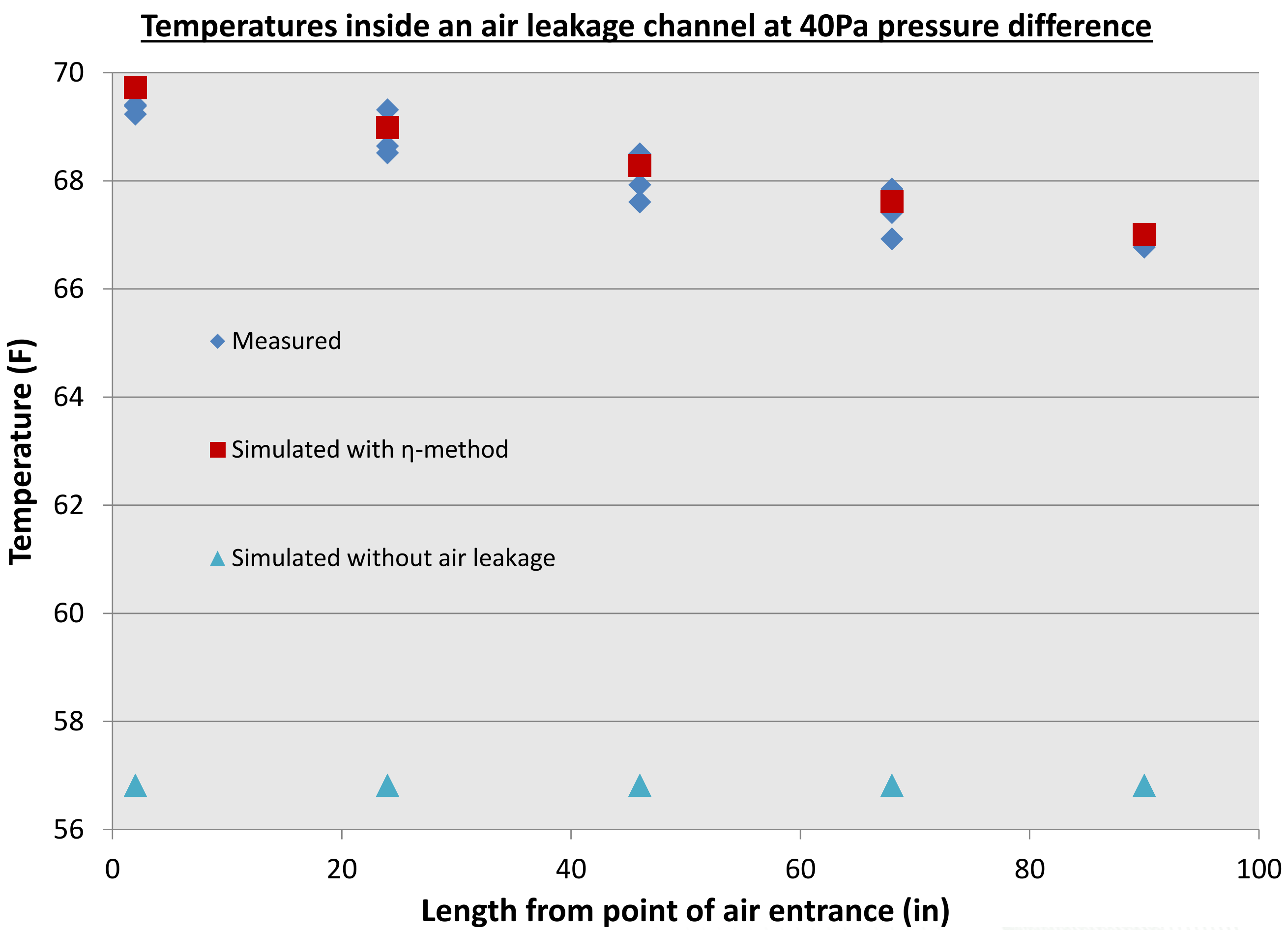
A comparison between WUFI 2D and WUFI 1D reveals that the 1D tool is capable of simulating air leakage at any location inside the air leakage path.

Simulation Approach - Validation



Simulation Approach - Validation

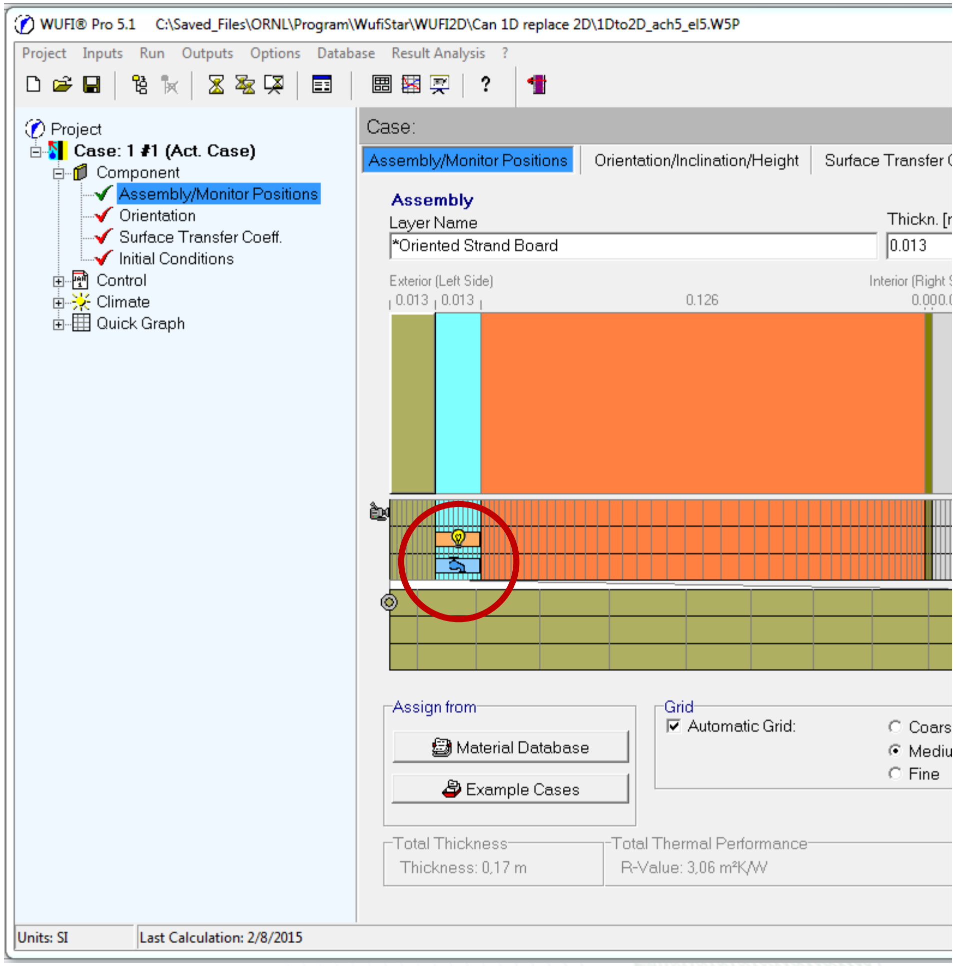




Empirical Formula

Essential Inputs to account for Air leakage in the Assessment:

- Wind forces
- Wall air tightness
- *R*-value



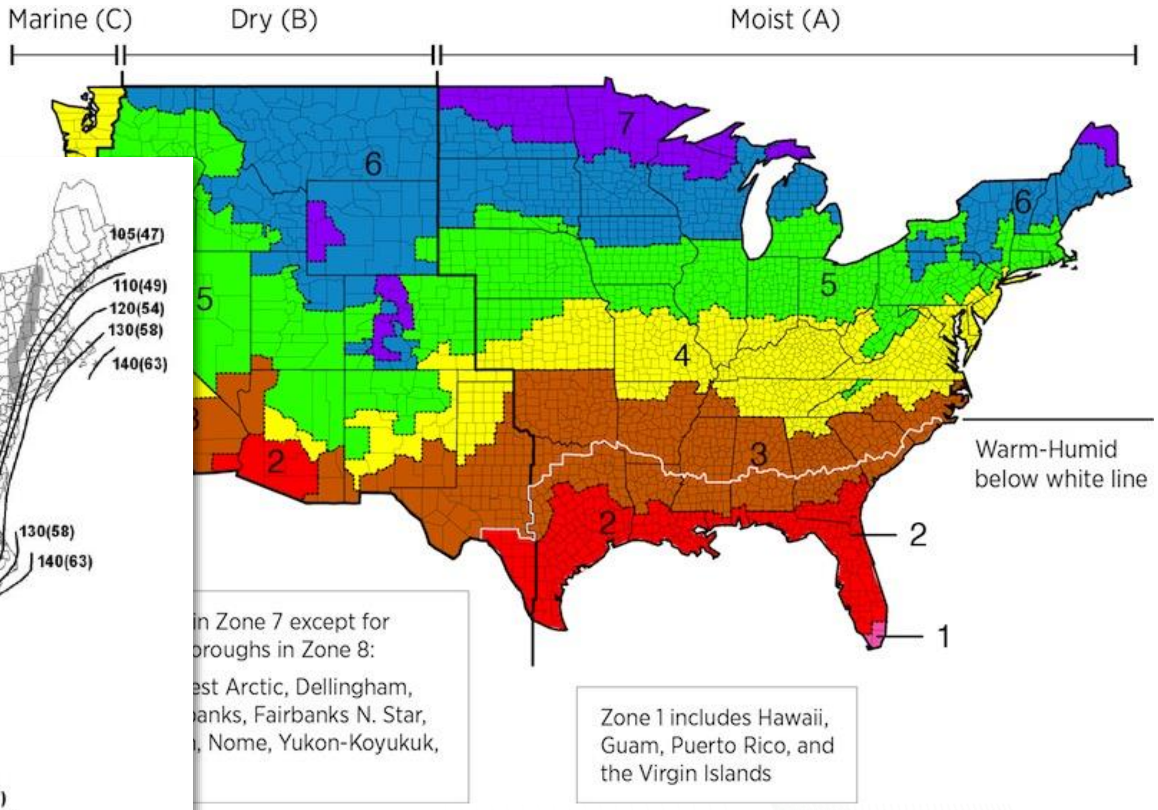
Output:

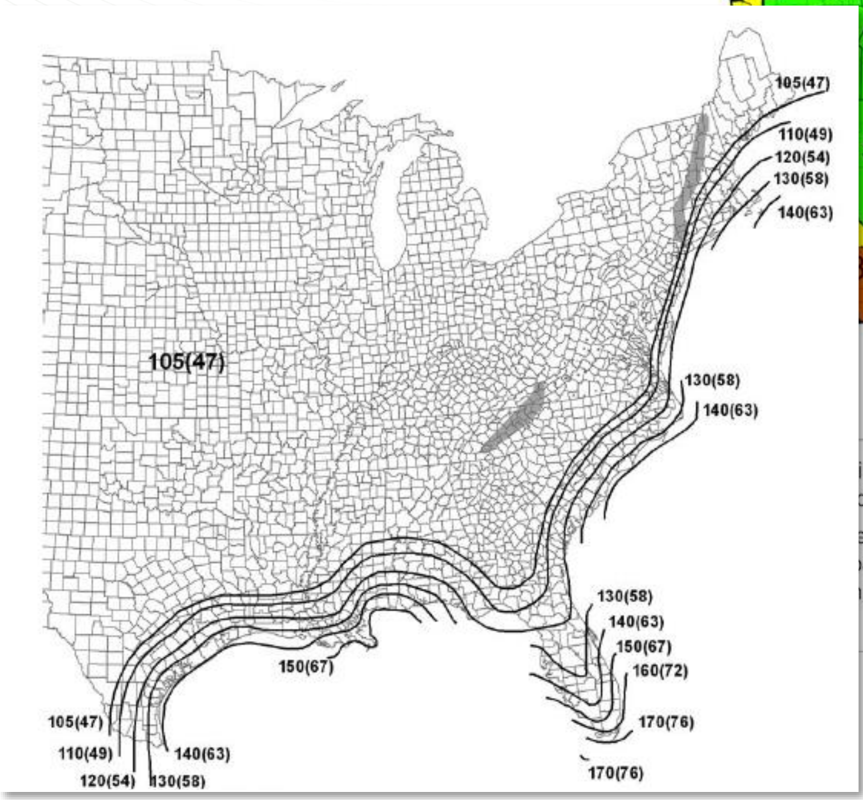
- Air flow rate

Empirical Formula

Essential Inputs to account for Air leakage in the Assessment:

- Wind forces

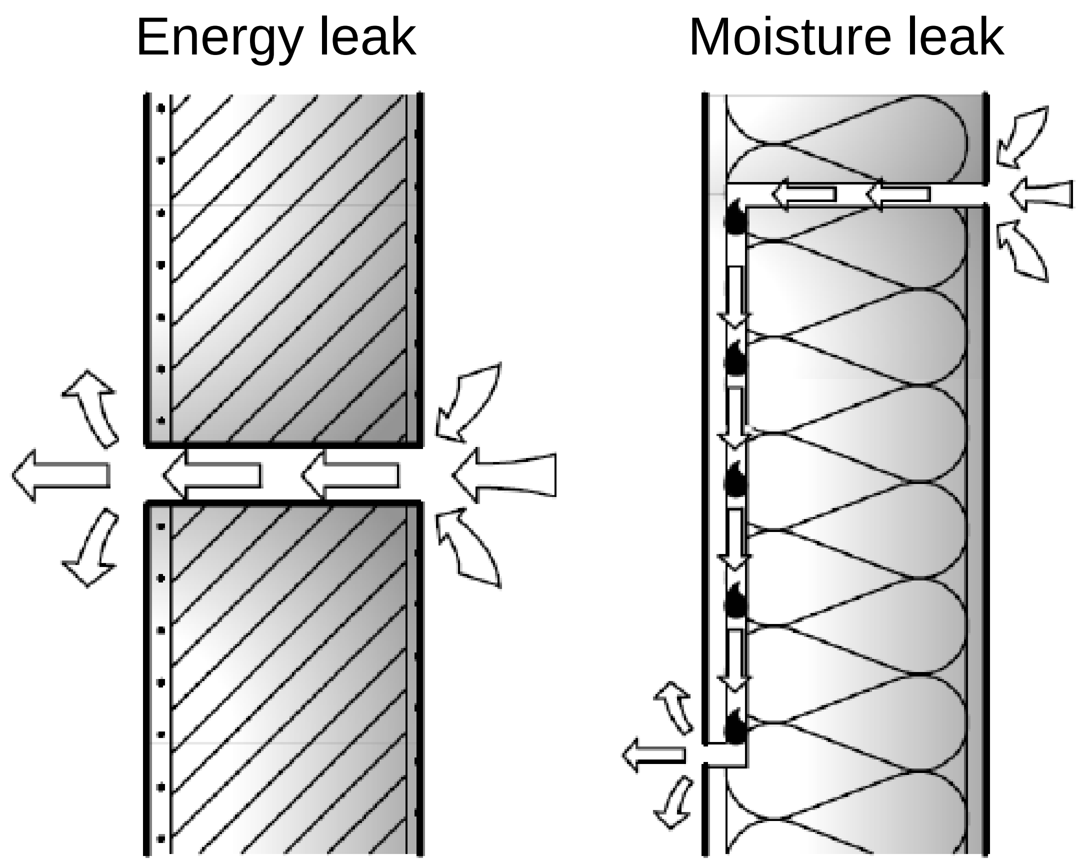




Empirical Formula

Essential Inputs to account for Air leakage in the Assessment:

- Wall air tightness



Künzel, H. et.al. (2011). Vapour control design in wooden structures including moisture sources due air exfiltration.

Empirical Formula

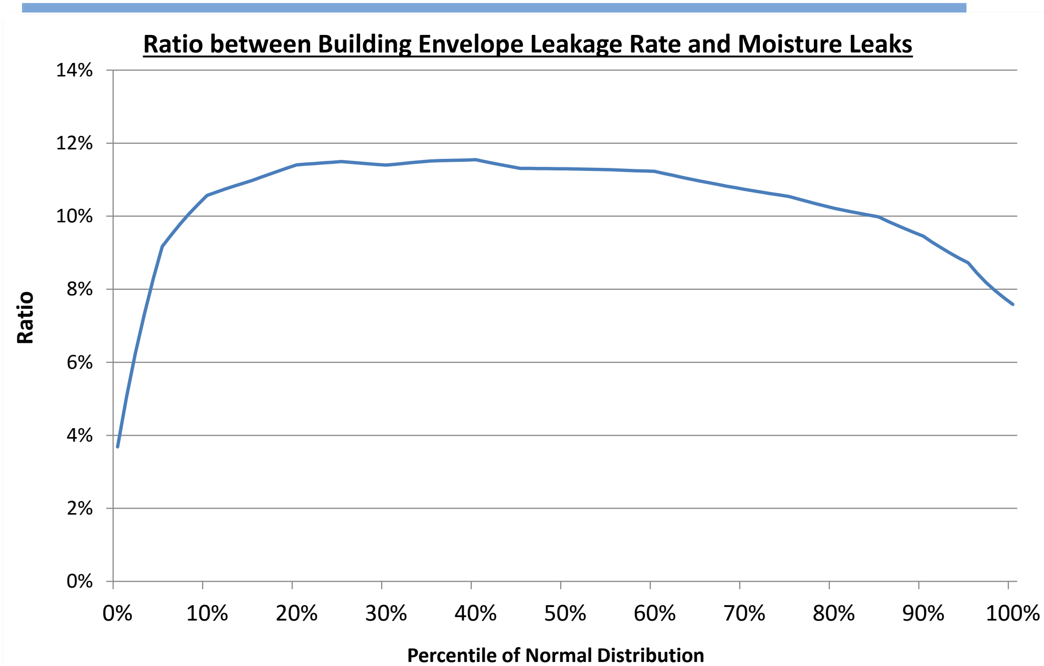
Essential Inputs to account for Air leakage in the Assessment:

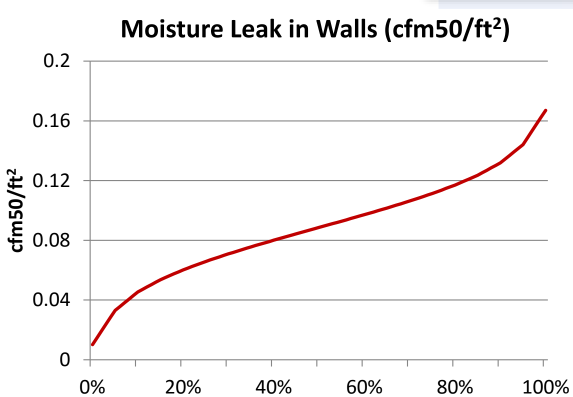
- Wall air tightness

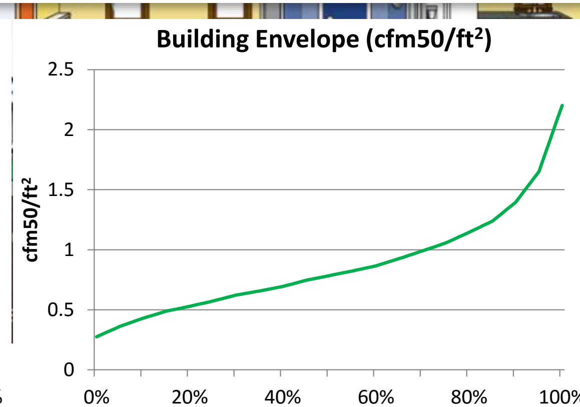
ACH50

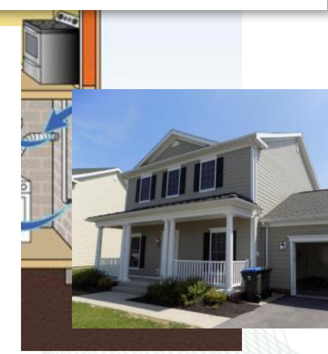
Energy leak 90%

Moisture leak 10%









Empirical Formula

<u>Essential Inputs to account for Air leakage in the Assessment:</u>

- *R*-value

TABLE R402.1.1
INSULATION AND FENESTRATION REQUIREMENTS BY COMPONENT[a]

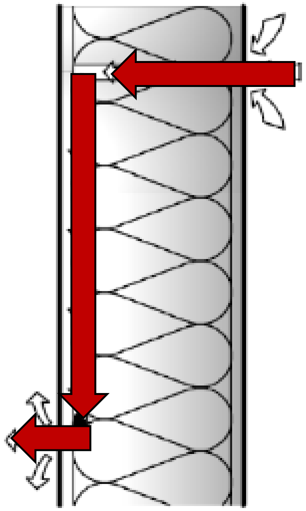
CLIMATE ZONE	FENESTRATION *U*-FACTOR[b]	SKYLIGHT[b] *U*-FACTOR	GLAZED FENESTRATION SHGC[b, e]	CEILING *R*-VALUE	WOOD FRAME WALL *R*-VALUE	MASS WALL *R*-VALUE[i]	FLOOR *R*-VALUE	BASEMENT[c] WALL *R*-VALUE	SLAB[d] *R*-VALUE & DEPTH	CRAWL SPACE[c] WALL *R*-VALUE
1	NR	0.75	0.25	30	13	3/4	13	0	0	0
2	0.40	0.65	0.25	38	13	4/6	13	0	0	0
3	0.35	0.55	0.25	38	20 or 13+5[h]	8/13	19	5/13[f]	0	5/13
4 except Marine	0.35	0.55	0.40	49	20 or 13+5[h]	8/13	19	10 /13	10, 2 ft	10/13
5 and Marine 4	0.32	0.55	NR	49	20 or 13+5[h]	13/17	30[g]	15/19	10, 2 ft	15/19
6	0.32	0.55	NR	49	20+5 or 13+10[h]	15/20	30[g]	15/19	10, 4 ft	15/19
7 and 8	0.32	0.55	NR	49	20+5 or 13+10[h]	19/21	38[g]	15/19	10, 4 ft	15/19

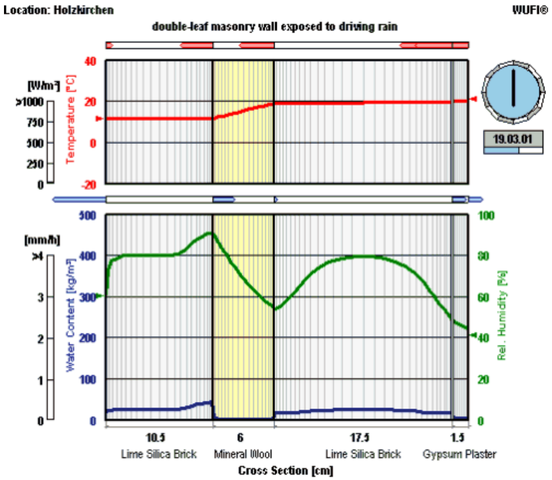
Empirical Formula

Wind, *W* (*mph*)

Wall air tightness, *P* (*cfm/ft²*) → Air Flow, *Q* (*cfm*)

Q(*W*,*P*)





Empirical Formula

$$Q = A + B \cdot W + C \cdot P + D \cdot W^2 + E \cdot W \cdot P + F \cdot P^2 \quad (cfm)$$

Example of Usage

$$Q = A + B \cdot W + C \cdot P + D \cdot W^2 + E \cdot W \cdot P + F \cdot P^2 \quad \textit{(cfm)}$$

Low Range ➔ $W \leq 5$ *mph*

High Range ➔ $W > 5$ *mph*

Example of Usage

$$Q = A + B \cdot W + C \cdot P + D \cdot W^2 + E \cdot W \cdot P + F \cdot P^2 \quad (cfm)$$

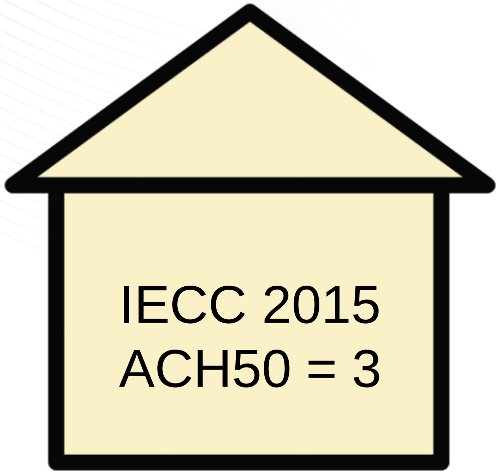
	Empirical Factors – Low Range (for *W* ≤ 5 *mph)*						
	R-20	R-20 + 3.75	R-20 + 7.5	R-20 + 11.25	R-20 + 15	R-13	R-20 + 5
A	0.0709	-0.0598	-0.0876	-0.0976	-0.1018	0.07215	-0.0661
B	-0.1142	0.01123	0.04161	0.05457	0.06122	-0.1153	0.01777
C	-0.2439	0.18237	0.2744	0.30936	0.32504	-0.2478	0.20294
D	0.02163	0.00329	-0.0015	-0.0037	-0.0049	0.02178	0.00227
E	0.44165	0.28122	0.21963	0.1871	0.1671	0.44241	0.26905
F	0.00751	-0.221	-0.2608	-0.2722	-0.2751	0.00983	-0.2306

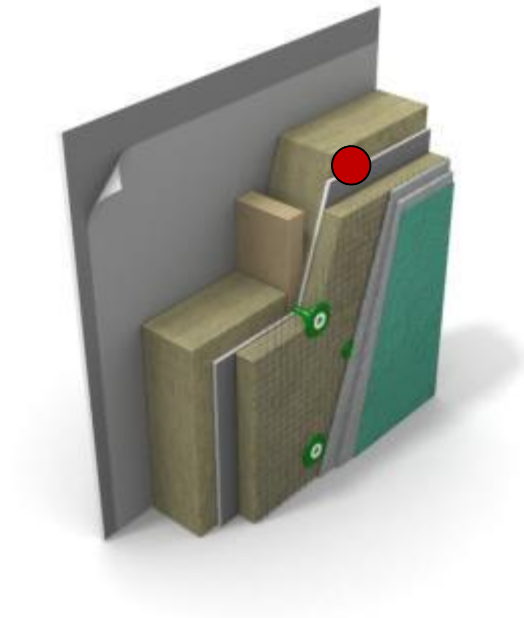
Example of Usage

$$Q = A + B \cdot W + C \cdot P + D \cdot W^2 + E \cdot W \cdot P + F \cdot P^2 \quad (cfm)$$

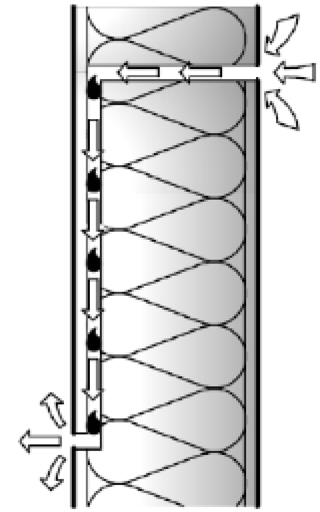
	Empirical Factors – High Range (for *W* > 5 *mph*)						
	R-20	R-20 + 3.75	R-20 + 7.5	R-20 + 11.25	R-20 + 15	R-13	R-20 + 5
A	-0.2599	-0.6423	-0.5036	-0.4064	-0.3419	-0.2534	-0.6214
B	0.01469	0.13171	0.1114	0.09502	0.08371	0.013	0.12917
C	0.17613	1.86783	1.73113	1.55883	1.42492	0.15629	1.86376
D	0.00159	-0.0046	-0.0039	-0.0032	-0.0028	0.00167	-0.0045
E	0.50945	0.14144	0.08522	0.06698	0.05897	0.51235	0.12772
F	-0.6499	-1.2146	-1.0939	-0.9842	-0.9032	-0.6422	-1.201

Example of Usage





R-20+5



ACH50 = 3 ➔ $P \approx 0.2\ cfm/ft^2$

Example of Usage

$$Q = A + B \cdot W + C \cdot 0.2 + D \cdot W^2 + E \cdot W \cdot 0.2 + F \cdot 0.2^2$$

	Empirical Factors – Low Range (for *W* ≤ 5 *mph)*						
	R-20	R-20 + 3.75	R-20 + 7.5	R-20 + 11.25	R-20 + 15	R-13	R-20 + 5
A	0.0709	-0.0598	-0.0876	-0.0976	-0.1018	0.07215	-0.0661
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E	0.44165	0.28122	0.21963	0.1871	0.1671	0.44241	0.26905
F	0.00751	-0.221	-0.2608	-0.2722	-0.2751	0.00983	-0.2306

Example of Usage

$$Q = A + B \cdot W + C \cdot 0.2 + D \cdot W^2 + E \cdot W \cdot 0.2 + F \cdot 0.2^2$$

$$Q = -0.0661 + 0.0177 \cdot W + 0.20294 \cdot 0.2 + 0.0023 \cdot W^2 + 0.2691 \cdot W \cdot 0.2 - 0.2603 \cdot 0.2^2$$

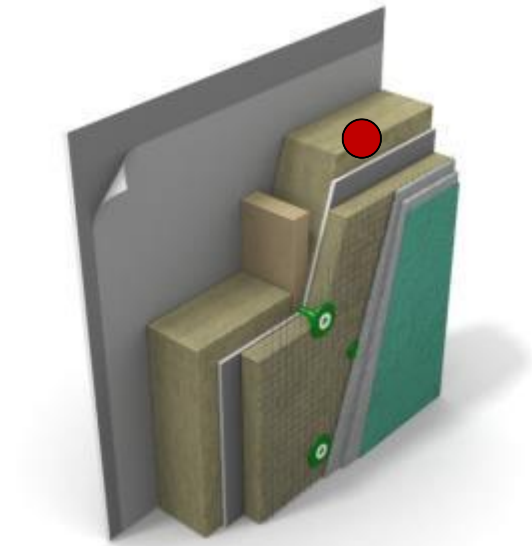
$$Q = -0.0347 + 0.0716 \cdot W + 0.0023 \cdot W^2$$

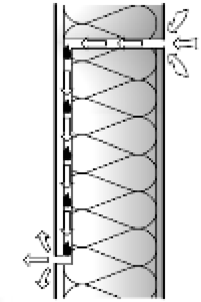
Wind = 5 *mph*

Q = 0.38 *cfm*

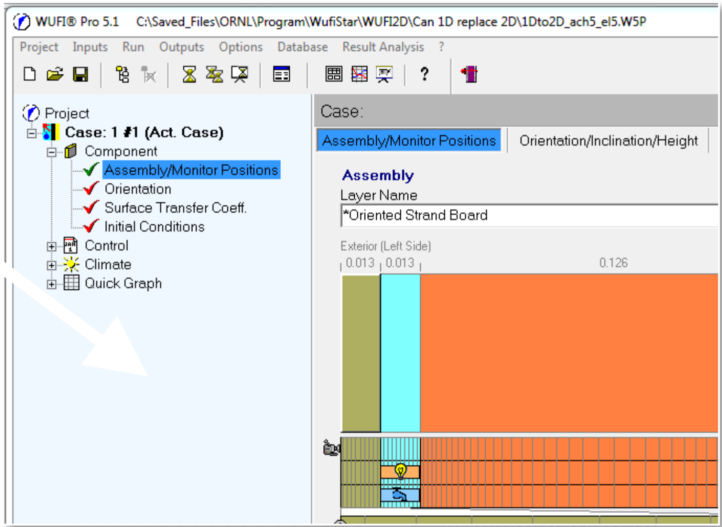
Example of Usage

3 ACH50 & R-20+5	
Wind (mph)	Air Leakage (cfm)
0	0
0.1	4.83564E-08
0.2	0.000173
0.3	0.001587
0.4	0.004482
0.5	0.008417
0.6	0.01307
0.7	0.01826
0.8	0.02387
…	…





$$Q = -0.0347 + 0.0716 \cdot W + 0.0023 \cdot W^2$$



Discussion

Contact information

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