Fluid Mechanics of Soil Gas Entry

As Applicable to Measurement and Mitigation of Indoor Soil Gas Concentrations

Provided by Gary Hodgden
With acknowledgement to *The AARST Consortium on National Radon Standards*

The 2016 International Radon Symposium™

Foreword

The work I do does not often include presentation of formal technical papers........ I usually prefer to watch, listen and read.

This year I felt compelled to begin documenting information on topics that we face every day..... but seldom discuss in detail.

These particular topics come up at virtually every ANSI/AARST Standards committee.

4-5 old salty dogs will chime in on the discussion.
6-7 committee members will be completely lost.

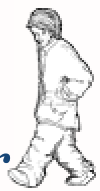
That being true, I tender this information into AARST archives.

Foreword

We have so may folks that come from so many different technological backgrounds.

Radon and soil gas hazards require all of us to bridge over to add new or different disciplines to our life experience.

The vantage point I provide comes from:



- *Typing in nearly 1,000 CRM test graphs each year for 20+ years plus post-mitigation CRM tests;*
- *15+ years of standards discussions where other folks made me realize I was not alone in my observations;*
- *And, time this last few years to contemplate what it adds up to.*

Witnessed concern

A wide diversity of challenges are witnessed when folks attempt to interpret indoor measurements and install mitigation systems.

Mistakes in understanding fluid mechanics are witnessed to result in consequences for both misapplied expense and continued risk to occupants.

So….. Different from limited case studies, this paper addresses the <u>cause</u> of fluctuating conditions that must be accounted for in order to temper any assumptions of test data meaning and usefulness.

Part 1: INDOOR MEASUREMENT

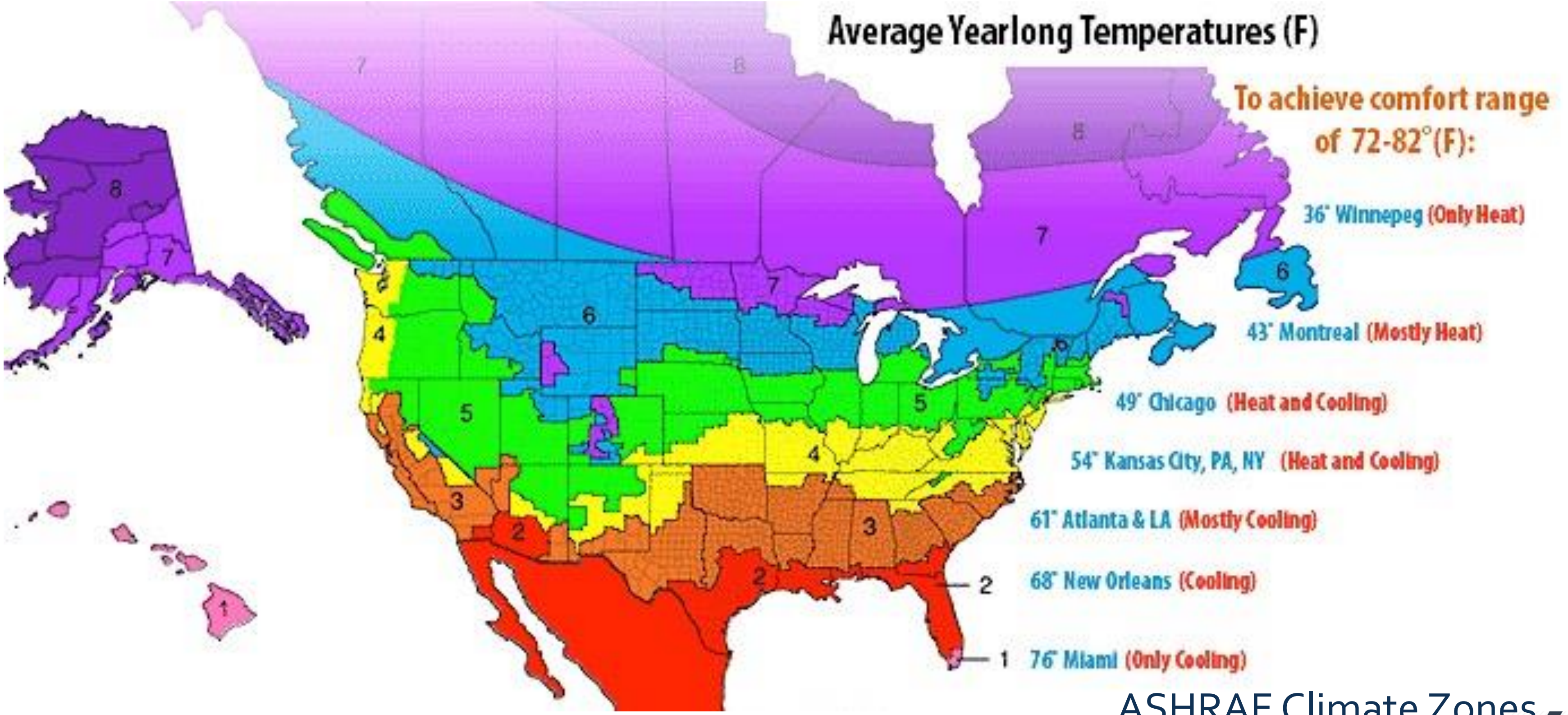
Introduction

- Regardless of test duration (2 days …or … 6 months): **All test regimens make accommodations for the fact that health protection demands timeliness.**
- Longer test durations (e.g., 30-180 days) serve to reduce the influence of brief fluctuations.
- Still: Measurements **less than** 365 days **cannot be exacting** on long-term exposures;
  or …. long-term pressure relationships within buildings.

Interpreting usefulness of test data

- To be useful, **test conditions must be compared to average yearlong conditions.**

Applicable worldwide.



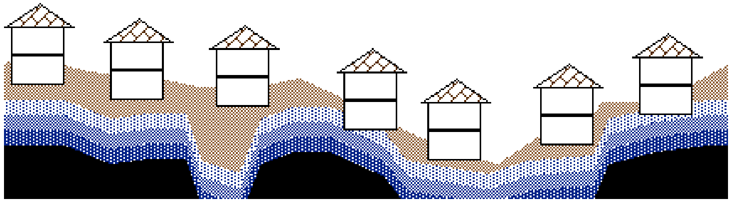
ASHRAE Climate Zones

Interpreting usefulness of test data

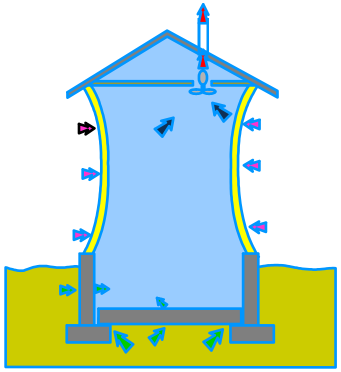
One needs to account for:

1) influences caused by the needs of human comfort in occupied spaces; and

2) influences caused by varying conditions within the vadose zone.



- These two factors trigger a finite set of building responses to outdoor conditions that modulate when air movement occurs and the direction, magnitude, and mixing qualities of diverse air sources



FLUID MECHANICS OF SOIL GAS ENTRY

Constants - Average Condition

Human Comfort: The quest for comfort is the fundamental constant that overwhelmingly dictates variability of soil gas entry and the fate of soil gas once in a building.

Comfort requires a constant condition throughout the year.

- Temperature nominally around **74° F (23°C)**

Relative humidity (RH) **optimally** at ~ **40-60 RH**.
For most humans:

- < 20% RH in cold conditions causes dryness;
- > 80% RH in warm conditions causes perspiration.

> 60% RH allows biological growth (allergen triggers).

FLUID MECHANICS OF SOIL GAS ENTRY

Constants - Average Condition

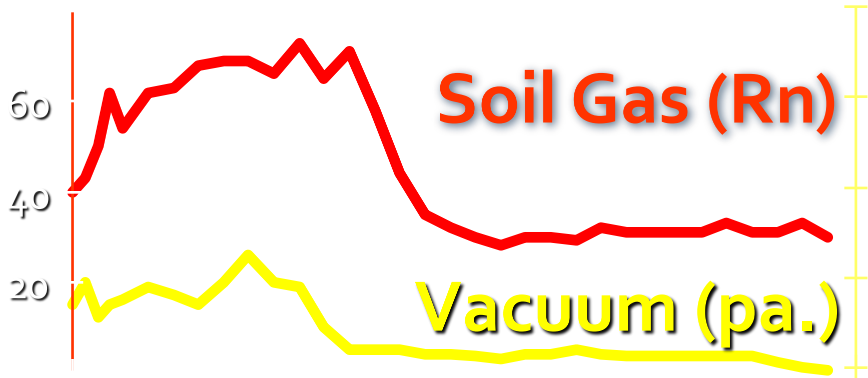
+ **Propensity of Closed Buildings:** Comfort control results in closed-building conditions more than:
  - 70% of the year (e.g., ~ 8.4 months), and
  - > 75% to 85% (e.g., 9 -10 months) in most climate zones.

+ **Building Design Similarities Within Each Climate Zone:** Buildings are more tightly sealed in cold climates compared to mild climates. **Immediate action** if too cold, hot, dry or humid.

24 Hour Temp Averages ZONE		Annual Avg	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
1 Very Hot	Miami, FL	76	82	79	74	69	68	69	72	75	79	82	83	83
2 Hot	New Orleans, LA	69	79	70	61	55	52	55	62	69	76	81	82	82
3 Warm	Atlanta, GA	62	73	63	53	45	43	46	53	62	70	77	79	79
4 Mixed	Phillidelpia, PA	55	68	57	47	36	32	34	42	53	63	72	77	76
5 Cool	Chicago, IL	49	65	53	40	27	22	26	37	49	59	69	74	72
6 Cold	Minneapolis, MN	45	61	50	33	19	13	18	31	46	59	68	73	71
7-Very cold	Minot, ND	39	56	45	26	14	6	11	21	41	53	61	68	67
8 SubArctic	Fairbanks, AK	27	45	25	4	-6	-8	-2	11	31	49	60	62	57
8 SubArctic	Cambridge Bay	6	32	11	-9	-21	-27	-27	-22	-7	15	36	47	44

Natural Air Pressures Within Buildings

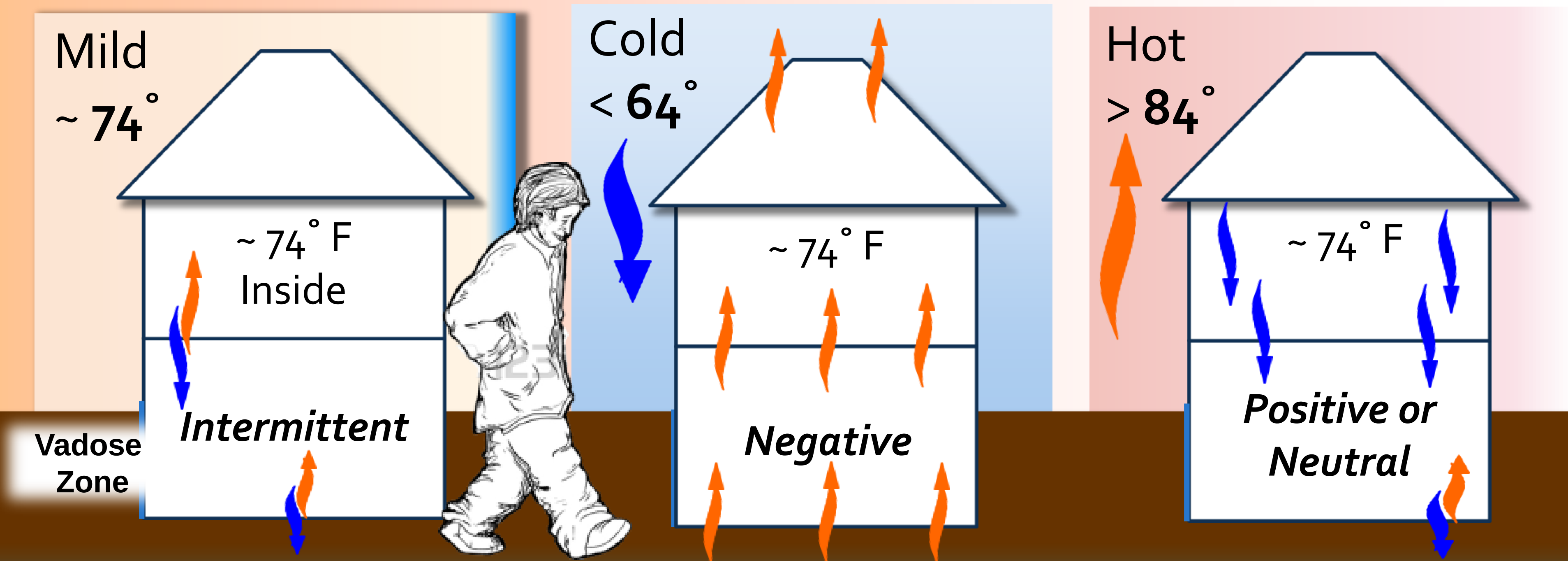
- **The Dominant Cause of Soil Gas Entry:** At any moment outdoor air grows colder than indoor air during closed-building conditions, lighter weight indoor <u>air rises up to escape the top of the building</u>.



- This results hydraulically in **negative pressure** within lower regions of a building to <u>replace that air from locations that present the least path of resistance</u>. The major portion of available soil gas under the foundation is immediately pressure-driven into the building. <u>5-15% comes from soil</u>.

Propensity of Negative Pressure:

(Temperature Hydraulics - **Stack Effect**)



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2 Hot	New Orleans, LA	69	79	70	61	55	52	55	62	69	76	81	82	82
3 Warm	Atlanta, GA	62	73	63	53	45	43	46	53	62	70	77	79	79
4 Mixed	Phillidelpia, PA	55	68	57	47	36	32	34	42	53	63	72	77	76
5 Cool	Chicago, IL	49	65	53	40	27	22	26	37	49	59	69	74	72
6 Cold	Minneapolis, MN	45	61	50	33	19	13	18	31	46	59	68	73	71
7-Very cold	Minot, ND	39	56	45	26	14	6	11	21	41	53	61	68	67
8 SubArctic	Fairbanks, AK	27	45	25	4	-6	-8	-2	11	31	49	60	62	57
8 SubArctic	Cambridge Bay	6	32	11	-9	-21	-27	-27	-22	-7	15	36	47	44

Propensity of Negative Pressure:

Whenever outdoor air is ~ 10° F (5°C) colder than indoor air.

+ Reflects Day to Night Temperatures

ZONE		Averages in °F Annual		Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
# 1			Hi	88	85	80	77	76	77	80	83	86	88	89	90
Very Hot	Miami, FL	76	Avg	82	79	74	69	68	69	72	75	79	82	83	83
	Similar: Hawaii		Lo	76	72	66	61	60	61	64	68	72	75	76	76
# 2			Hi	87	80	71	64	62	65	71	78	85	89	91	90
Hot	New Orleans, LA	69	Avg	79	70	61	55	52	55	62	69	76	81	82	82
	Similar: Florida, Houston		Lo	71	61	52	45	43	46	52	59	66	72	74	74
# 3			Hi	82	73	63	54	52	56	64	73	80	86	89	88
Warm	Atlanta, GA	62	Avg	73	63	53	45	43	46	53	62	70	77	79	79
	Southern California to S.Carolina		Lo	64	53	42	36	33	36	43	51	59	67	70	69
# 4			Hi	78	67	55	44	39	42	51	63	73	82	87	85
Mixed	Phillidelpia, PA	55	Avg	68	57	47	36	32	34	42	53	63	72	77	76
	NYC, PA, NJ, VA, KT, TN, KS, MO, OR, WA		Lo	59	47	38	29	24	26	33	43	53	62	68	66
# 5			Hi	75	63	48	35	29	34	45	58	70	80	84	82
Cool	Chicago, IL	49	Avg	65	53	40	27	22	26	37	49	59	69	74	72
	MA, NY, OH, MI, IN, IL, IA, NE, UT, NV		Lo	54	42	31	20	43	18	28	39	48	57	63	62
# 6			Hi	71	59	40	26	21	27	29	56	69	78	83	81
Cold	Minneapolis, MN	45	Avg	61	50	33	19	13	18	31	46	59	68	73	71
	ME, NH, VT, WI, MN, ND, WY, SD, ND		Lo	50	40	25	11	4	9	22	36	48	58	63	61
# 7			Hi	69	57	35	23	16	21	30	52	65	72	81	80
Very cold	Minot, ND	39	Avg	56	45	26	14	6	11	21	41	53	61	68	67
	Similar: Anchorage, Winnipeg		Lo	43	34	17	6	-3	2	12	30	41	50	56	54

Bottom up-blue most of year; day / nite (20˚ flux); Spring cheated or not; Jim McNeese - two different animals

For fun

the West Coast

+MAMF and MALB

Economizers save a lot of energy

City		Avg'g School		Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
San Diego	Hi	70	68	76	73	69	65	65	65	66	68	69	71	75	76
	Avg	64	62	71	68	61	56	57	58	59	62	64	66	70	72
	Lo	58	55	65	61	54	48	49	51	53	56	59	62	65	67
Los Angeles	Hi	74	72	82	78	73	67	66	67	69	71	73	77	82	83
	Avg	65	63	72	68	63	58	57	59	60	62	65	68	73	74
	Lo	56	54	63	59	53	49	48	50	51	53	57	60	63	64
San Francisco	Hi	64	63	70	69	64	57	57	60	62	63	64	66	66	67
	Avg	57	56	63	62	57	52	51	54	55	56	58	60	60	61
	Lo	51	50	56	54	51	47	46	48	49	50	51	53	54	55
Portland	Hi	63	59	76	64	63	46	47	51	57	61	68	74	81	81
	Avg	55	50	65	55	47	40	41	44	48	52	58	64	69	70
	Lo	46	42	53	46	40	35	36	36	40	43	49	54	58	58
Seattle	Hi	60	57	71	70	51	46	47	50	54	59	65	70	76	76
	Avg	53	49	61	53	45	41	42	43	47	50	56	61	66	66
	Lo	45	42	52	46	40	36	37	37	39	42	47	52	56	56

Can't have radon here !

Ooops

+ **Houses and when Economizer is off**

City		Avg School		Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
San Diego	Hi	70	68	76	73	69	65	65	65	66	68	69	71	75	76
	Avg	64	62	71	68	61	56	57	58	59	62	64	66	70	72
	Lo	58	55	65	61	54	48	49	51	53	56	59	62	65	67
Los Angeles	Hi	74	72	82	78	73	67	66	67	69	71	73	77	82	83
	Avg	65	63	72	68	63	58	57	59	60	62	65	68	73	74
	Lo	56	54	63	59	53	49	48	50	51	53	57	60	63	64
San Francisco	Hi	64	63	70	69	64	57	57	60	62	63	64	66	66	67
	Avg	57	56	63	62	57	52	51	54	55	56	58	60	60	61
	Lo	51	50	56	54	51	47	46	48	49	50	51	53	54	55
Portland	Hi	63	59	76	64	63	46	47	51	57	61	68	74	81	81
	Avg	55	50	65	55	47	40	41	44	48	52	58	64	69	70
	Lo	46	42	53	46	40	35	36	36	40	43	49	54	58	58
Seattle	Hi	60	57	71	70	51	46	47	50	54	59	65	70	76	76
	Avg	53	49	61	53	45	41	42	43	47	50	56	61	66	66
	Lo	45	42	52	46	40	36	37	37	39	42	47	52	56	56

Understanding Limited Force due to Limits of Air Volume Movement

This table is based only on the weight of 30,000 cu ft of air inside a moderate size home. Weights double for larger two story homes above a basement and far more for taller bldgs.

75˚ F Indoor air is				Outdoor Temperature		
61 kg	**135**	pounds heavier than outside air	@	**110** ˚F	43 ˚C	
41 kg	**90**	pounds heavier than outside air	@	**95** ˚F	35 ˚C	
20 kg	**45**	pounds heavier than outside air	@	**85** ˚F	29 ˚C	
7 kg	**15**	virtually equal weight	@	**80** ˚F	27 ˚C	
0 kg	**0**	virtually equal weight	@	**75** ˚F	24 ˚C	*Annual Avg Temp for:* Miami
7 kg	**15**	virtually equal weight	@	**70** ˚F	21 ˚C	*Annual Avg Temp for:* New Orleans
20 kg	**30**	pounds lighter than outside air	@	**60** ˚F	16 ˚C	*Annual Avg Temp for:* Atlanta
34 kg	**75**	pounds lighter than outside air	@	**55** ˚F	13 ˚C	*Annual Avg Temp for:* Philidelpia
48 kg	**105**	pounds lighter than outside air	@	**50** ˚F	10 ˚C	*Annual Avg Temp for:* Chicago
61 kg	**135**	pounds lighter than outside air	@	**45** ˚F	7 ˚C	*Annual Avg Temp for:* Minneapolis
75 kg	**165**	pounds lighter than outside air	@	**40** ˚F	4 ˚C	*Annual Avg Temp for:* Minot ND
88 kg	**195**	pounds lighter than outside air	@	**30** ˚F	-1 ˚C	*Annual Avg Temp for:* Fairbanks AK

+ However, the actual energy and force that drives soil gas into a building is kinetic

Understanding Limited Force due to Limits of Air Volume Movement

- The **actual energy and force** that drives soil gas into a building is limited by the smaller volume of either:
  - a) air entering a building; or
  - b) air exiting a building.

The fluid mechanics in simple terms:

Gravitational force is asserted when water is released to drive turbines for generating electricity. **The actual energy asserted is kinetic and limited to the volume (i.e., weight) of the water that is allowed to be in motion.**

Understanding Limited Force of Air Volume Movement

I cover this in detail because it also affects mitigation considerations

Another example:

With bottom vents open, the degree of negative pressure within the cooker reciprocally changes in force to the extent you vary the volume of air escaping at the top.

For an inverse example:

If a water valve is throttled to allow only 1/2 capacity for the water volume that could travel to an open faucet, the force of water exiting the faucet is reciprocally reduced by about half.

Understanding Limit
of Air Volume Mover

KC BBQ & Royals

Internal dynamic equilibriums and half-lifes…..

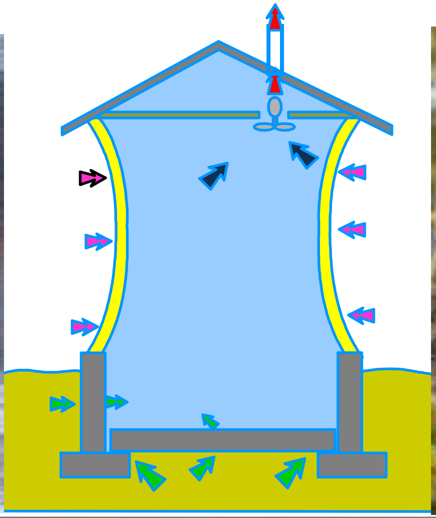
Understanding Limited Force due to Limits of Air Volume Movement

- **Driving force and fixed volume limits.**
  - **Each building has a unique cap** on capacity for infiltrating and exfiltrating air. The small gaps and openings in the building shell, under closed building conditions, are **fixed-size openings**.
  - Shifts in outdoor temperature vary the force and therefore volume of air that enters or exits each small opening. But **as indoor pressures increase** in force, gaps in the building shell and at the soil become **stressed towards their maximum capacity** limits for allowing air to enter or exit each small opening.
- At some juncture, **a virtual cap for the building's driving force has been reached**.

Understanding Limited Force due to Limits of Air Volume Movement

+ Driving force variance and fixed volume limits.

The fluid mechanics in simple terms: Varying the force of a powerful pump that propels water through a 3" fire truck hose serves to vary the volume and force of water expelled. However regardless how much force is applied, a much smaller, fixed diameter garden hose is **severely limited by comparison in terms of capacity to deliver both water volume and force**.



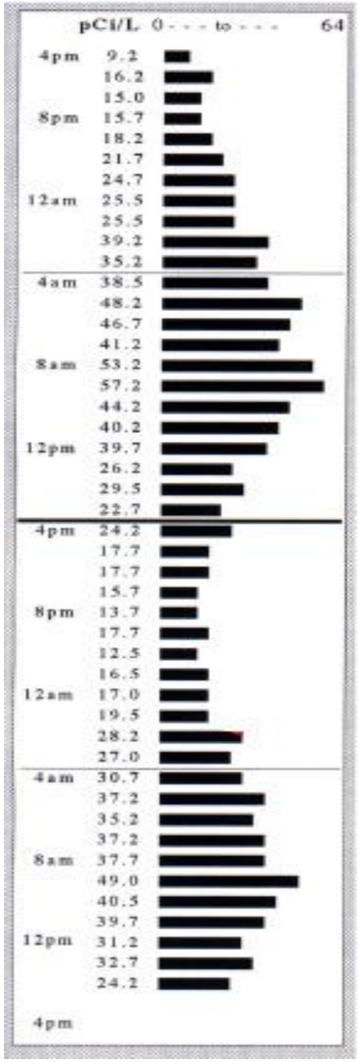
Understanding Limited Force due to Limits of Air Volume Movement

- **<u>All of this</u> dramatically throttles down the range of pressure fluctuations**

Field observations and dozens of case studies published in the last three decades overwhelmingly reveal hourly indoor radon fluctuations that agree with temperature effects.

But they also reveal the boundaries imposed on the magnitude of fluctuation due to limits of air that can enter or escape a building.

Fluctuation 1.5 standard deviation? Sometimes.
But not ~10-20 times different, as per weight of outside air.

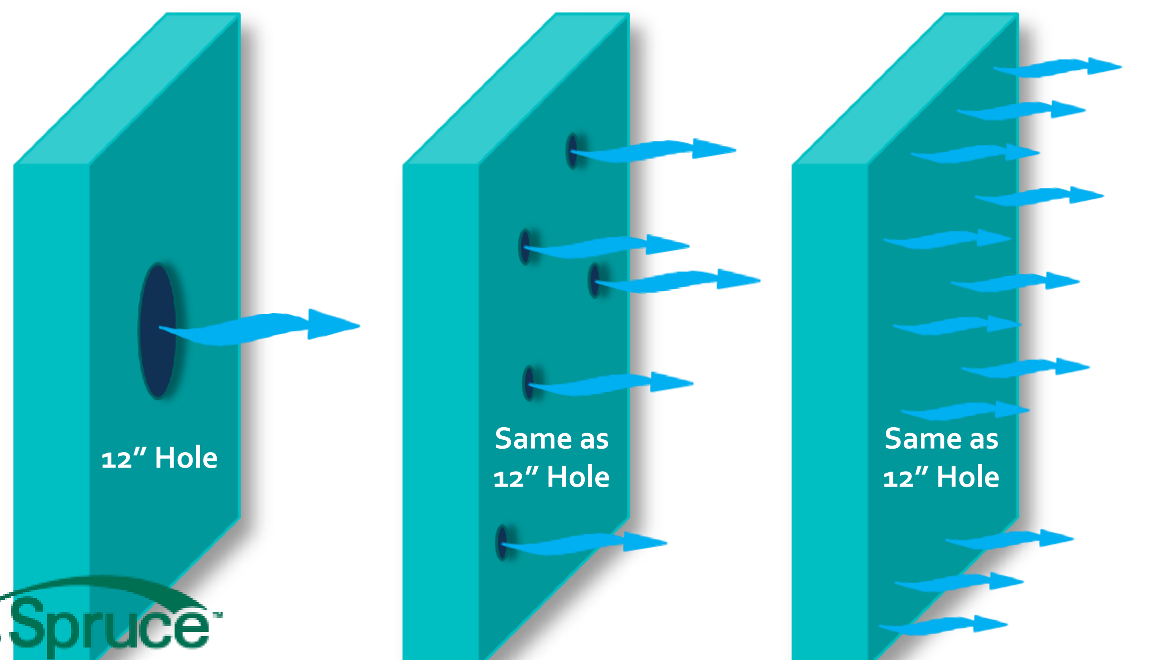


Mechanics of Air Entry

Pressure Driven Air (both soil gas and outside air)

The size of an individual opening is generally inconsequential because the volume of air entering each airspace is dictated by **the combined openings** into that airspace.

Easily Seen (Large Holes) | Still Seen (Cracks or Gaps) | Too Small to See (irregularities in material, nails, etc.)



The same amount of air can enter regardless of gap size. The location of entry is merely the **"path of least resistance"**.

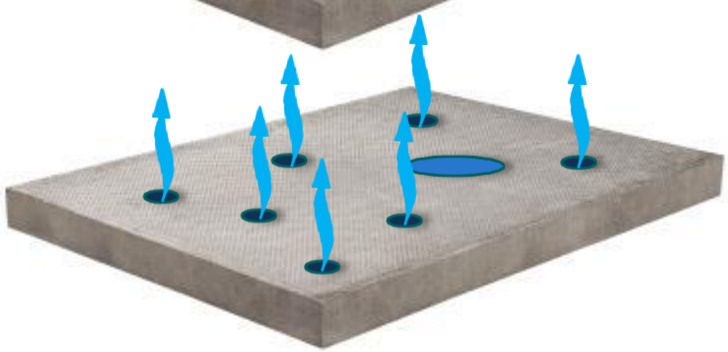
Some artwork is courtesy Spruce

Mechanics of Air Entry

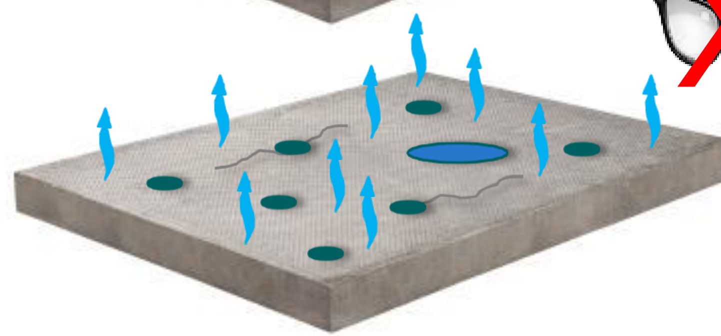
Pressure Driven Air – Soil Gas

12″ Hole – Path of Least Resistance

12″ Hole Closed – Common Example of One Hair-line Crack

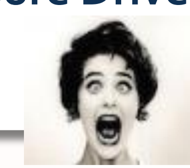


12″ Hole <u>Closed</u> – An almost equal Pathway remains (Cracks, etc.)



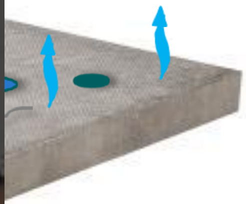
All Readily Visible Holes and Cracks Closed; Pathways still Exist when Pressure Driven

Some artwork is courtesy Spruce



Mechanics of Air Entry

Pressure Driven Air – Soil Gas



…nd Cracks Closed;
… Pressure Driven

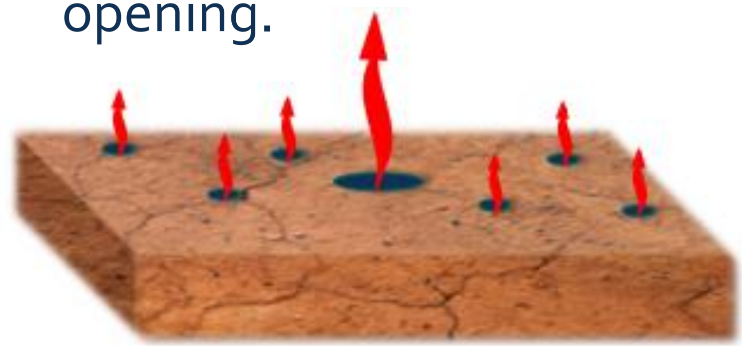
Mechanics of Air Entry

Pressure Driven Air (hydraulic correlation to diffusion)

The **volume of pressure-driven** soil gas and outside air entering **is enormous compared to gradient diffusion** interaction.

Imagine 5 Million atoms a minute **diffusing** through concrete or a vapor barrier

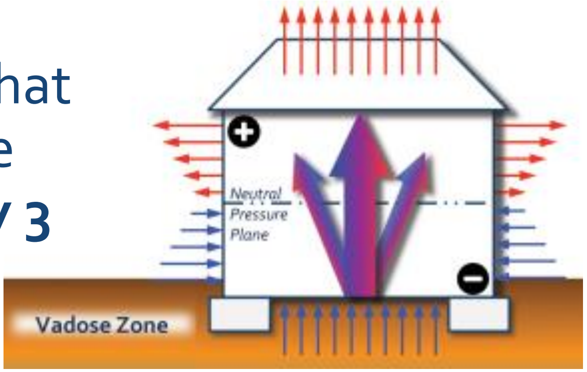
Meanwhile imagine 5 Billion atoms a second pressure driven through a tiny opening.



Mechanics of Air Entry and Mixing

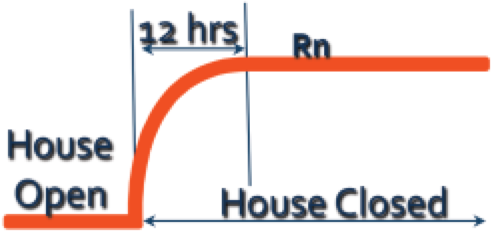
- **Dilution:** Standards recommend **0.35 air changes per hour** for homes. This means that the entire volume of air in a home would be replaced by fresher outside air **about every 3 hours**.

  Homes are **commonly found with even faster ACH** 0.5-1.0 air changes per hour.



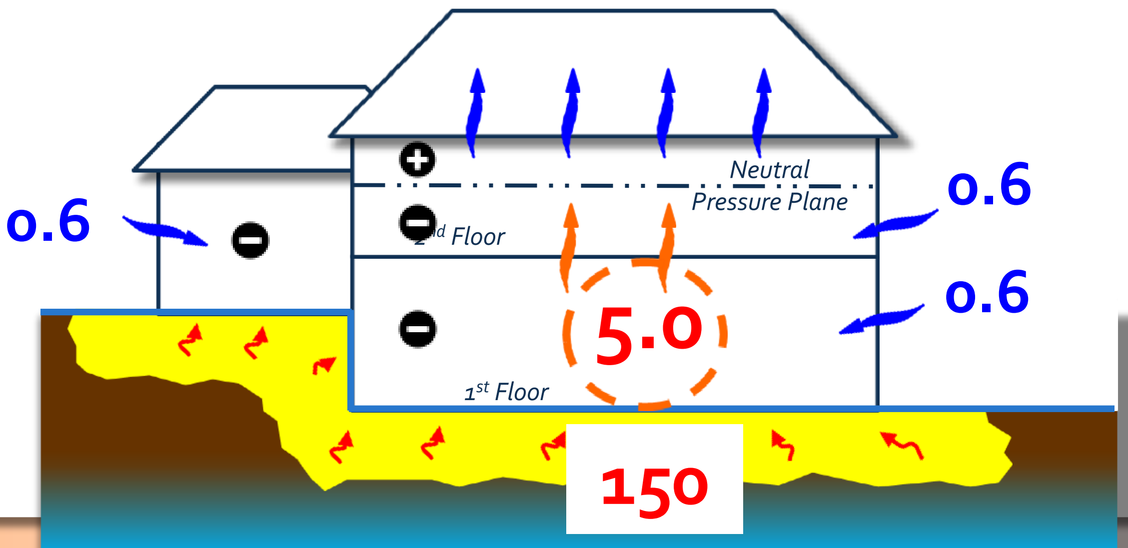
- **Mixture stabilization (dynamic equilibrium).** A period of 12 hours of closed-building conditions prior to initiating tests lasting less than 4 days is normally required to ensure the measurement reflects typical conditions.

  This can take longer (e.g., 24 hours) in mild weather or can occur quickly (e.g., 4 hours) in very cold weather.



Your Test Result

+ **The Concentration You Measure:**
  1. **Soil gas** enters occupiable spaces through **a fixed number of entry points** at concentrations existing in the soil.
  2. **Outdoor air** simultaneously enters through a **fixed number entry points** (e.g., around window and door frames).
  3. The two mix to produce diluted soil gas and **this mixture is the concentration witnessed with indoor measurements**.

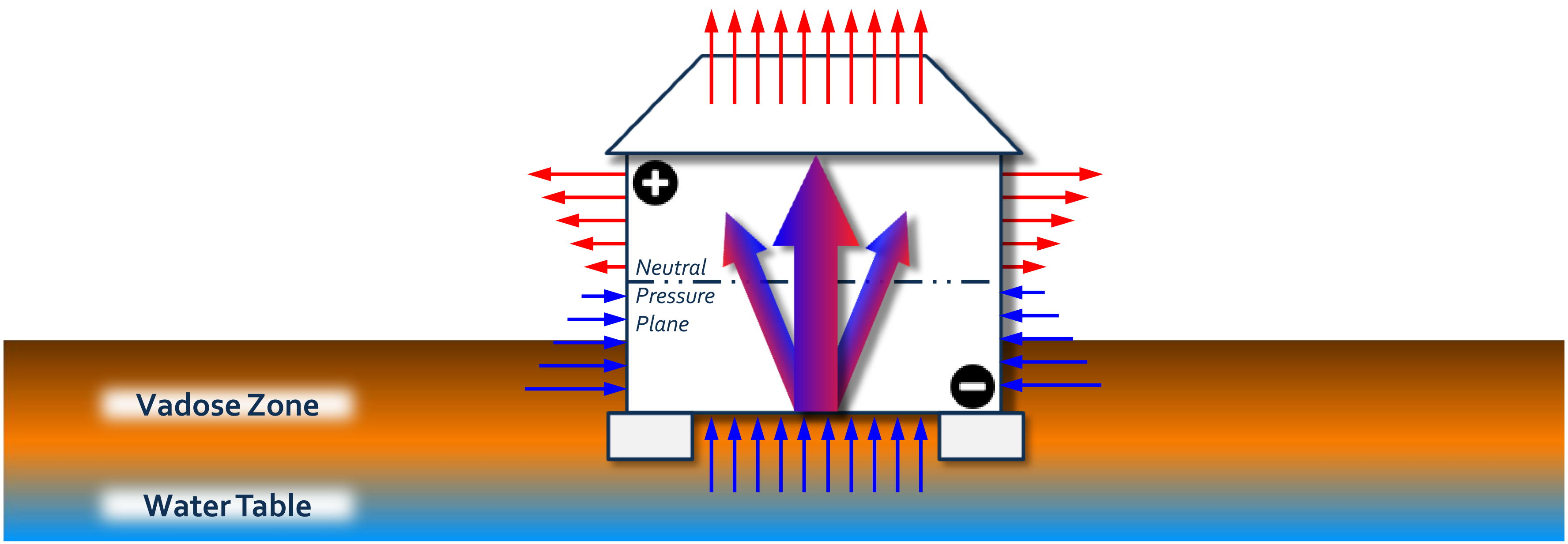


About ~95% of air entering the building is from outside, even with windows closed.

Mechanics of Air Entry and Dilution

- **The Fate of Soil Gas (General):** Soil gas entering a building will normally **dilute to outside ambient concentrations in less than 24 hours** within a closed-building…… due to the rate of air changes per hour.

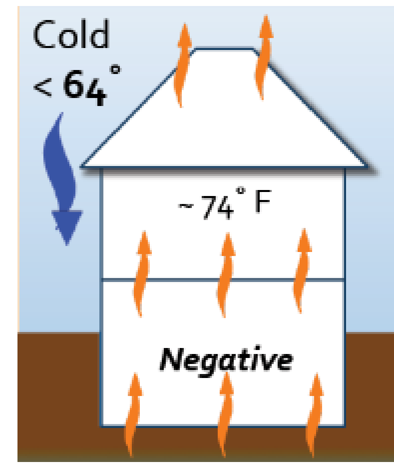
For an opened building, this can occur within minutes.



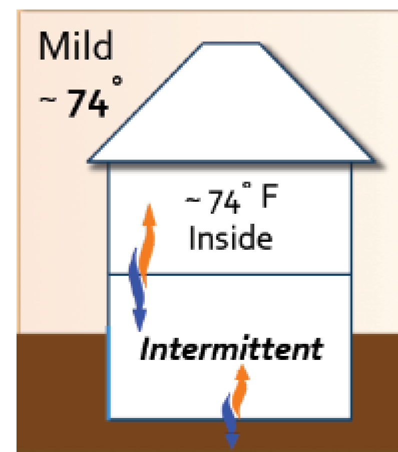
FINITE SET OF BUILDING RESPONSES TO OUTDOOR CONDITIONS

Varying Magnitudes of Pressure

1. *√observable:* **Constancy and Force:** When highest outdoor temperatures are less than indoors, soil gas entry is generally constant. The force **grows somewhat stronger as outside air grows colder**.



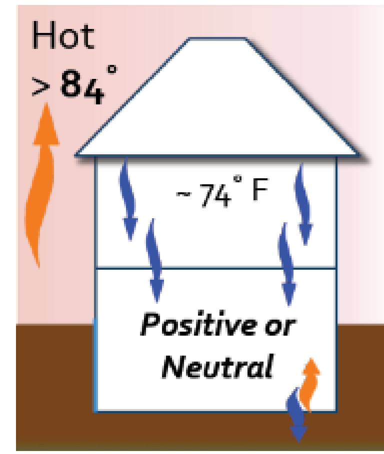
2. *√observable:* **Neutral Pressure:** When daytime outdoor and indoor temperatures virtually the same, the building **tilts back and forth** between negative and positive pressure. However, the **total volume** of soil gas entry across a two-day period is **often similar**.



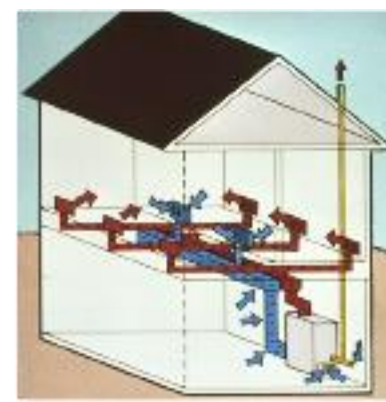
FINITE SET OF BUILDING RESPONSES TO OUTDOOR CONDITIONS

Varying Magnitudes of Pressure

3. *√observable:* **Positive Pressure: Usefulness** of test data when outdoor temperature never went below 65˚ F is **limited**. **Soil gas can temporarily cease to enter. The floodgate can close.**



4. *√observable:* **Blower driven pressure:** A more of **a predominant concern for larger buildings**. Significantly imbalanced return or supply ducting can sometimes have significant impact.

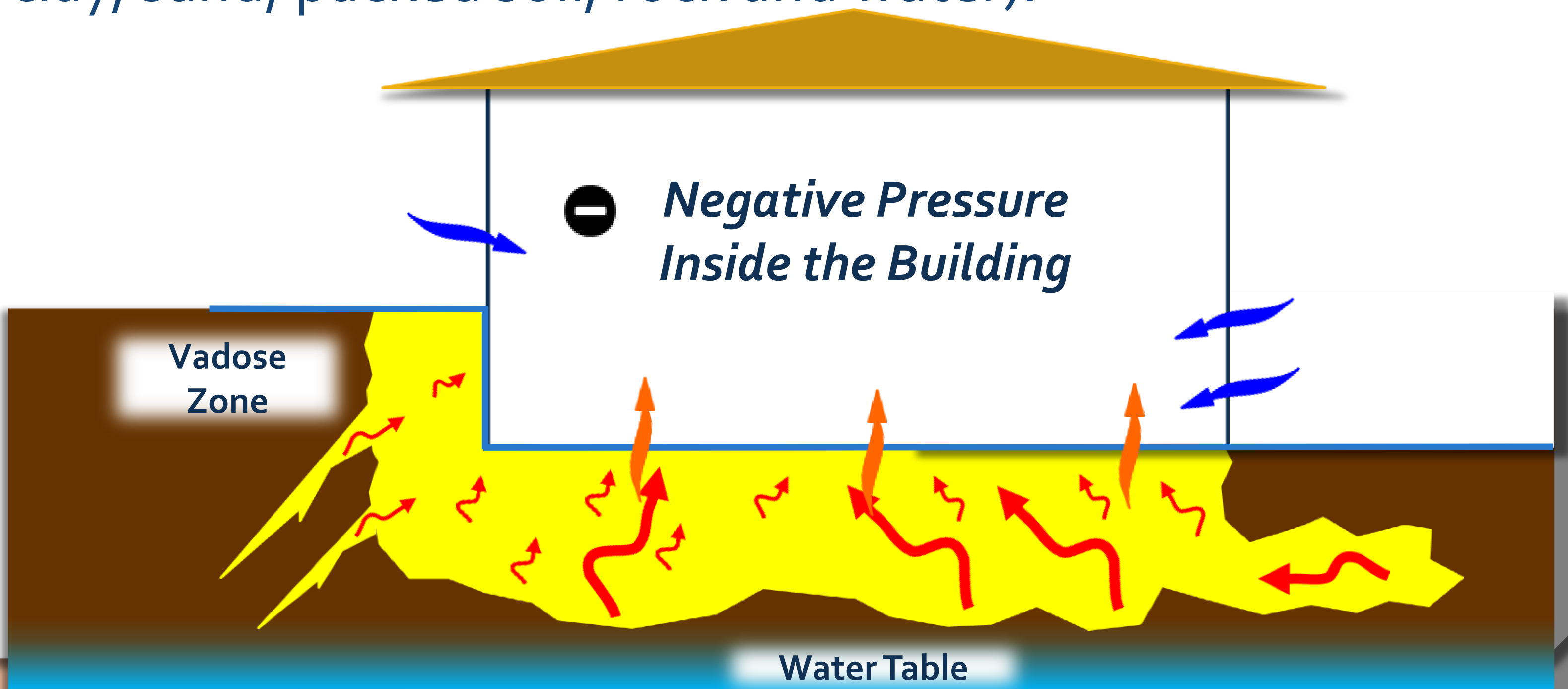


FINITE SET OF BUILDING RESPONSES TO OUTDOOR CONDITIONS

Availability of Soil Gas Volumes

5. *NOT observable:* **The Vadose Zone**

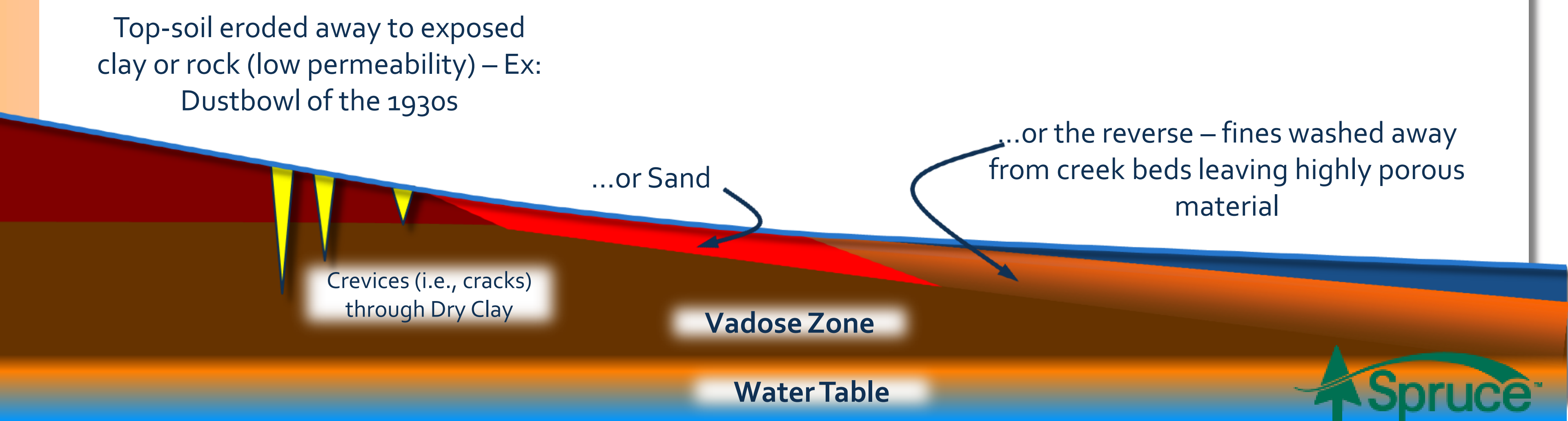
The volume, distance and the path of soil air movement is **limited by impermeable materials** (e.g., clay, sand, packed soil, rock and water).



FINITE SET OF BUILDING RESPONSES TO OUTDOOR CONDITIONS

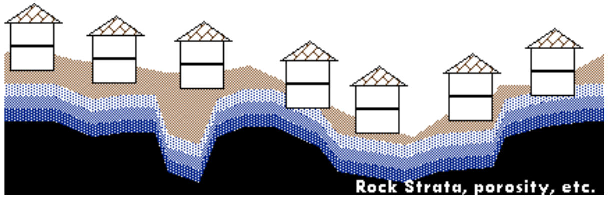
Availability of Soil Gas Volumes

The **Vadose Zone is not naturally homogenous** in terms of permeability and pollutant concentrations, especially after building construction. Permeable areas subject to the influence of building pressures can unknowingly range from inches to hundreds of feet away.



FINITE SET OF BUILDING RESPONSES TO OUTDOOR CONDITIONS

Availability of Soil Gas Volumes



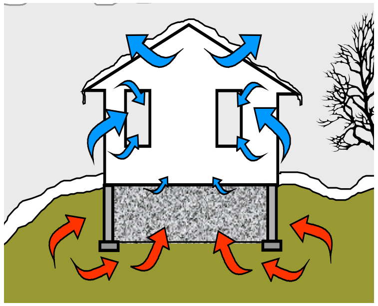
6. *√observable:* **Water Table:**

Flood conditions can produce a binary effect for cessation of soil gas entry.

Drought conditions can render a far larger volume of soil gas available for migration into the building.

7. *√observable:* **Capped Soil:** Above-grade air is part of the air influenced to travel into a building.

- Regions with large permeability expanses below the building report enhanced soil gas entry.
- Inversely, regions with smaller permeable areas witness cessation of hydraulic flow of soil gas into the building.



Test Locations

√*Controllable:* **Ground contact rooms.** These areas are least affected by fluctuations in air distribution and ventilation systems.

Mixtures in upper floors: Test data usefulness is limited.

Soil gas is distributed throughout the building.

However, accounting for variability of test conditions is far more complicated.

Air pressures and movement, room sizes and openings to outside air are very different in upper regions of the building compared to the area where soil gas initially entered and mixed.

Test Locations

Greatly **complicating test reproducibility in upper floors is the changing vigor and constancy of air distribution systems**.

Forced Air HVAC: 75% of U.S. homes

HVAC with no fans or WHEN fans are inactive : Most HVAC blowers only activate for **short durations**.

Heat pump more continuous air distribution.

For older buildings- like a single airspace for mixing.

DATABASE CORRELATIONS:
POOLED DATA

Properties of Pooled Data Compared to Individual Tests

- **It must be understood that unique conditions exist for any short-term period regardless if that period ranges from days to multiple months.**
- One **should never assume** that an individual test is immune to unusual magnitudes of influence not seen in pooled data.
    - **<u>What you don't know from each test is just as important as what you do know</u>**
- Only additional testing conducted under varied conditions can qualify the magnitude of any specific influence on test results.

POOLED DATA

Data location: Kansas City but similar to most studies

Pooled Average in Ground Contact Areas: Data suggests the average measurement under closed-building conditions will result within one order of magnitude from the yearlong average.

8 year averages for 4,400 different tests. Radon n and Rain n

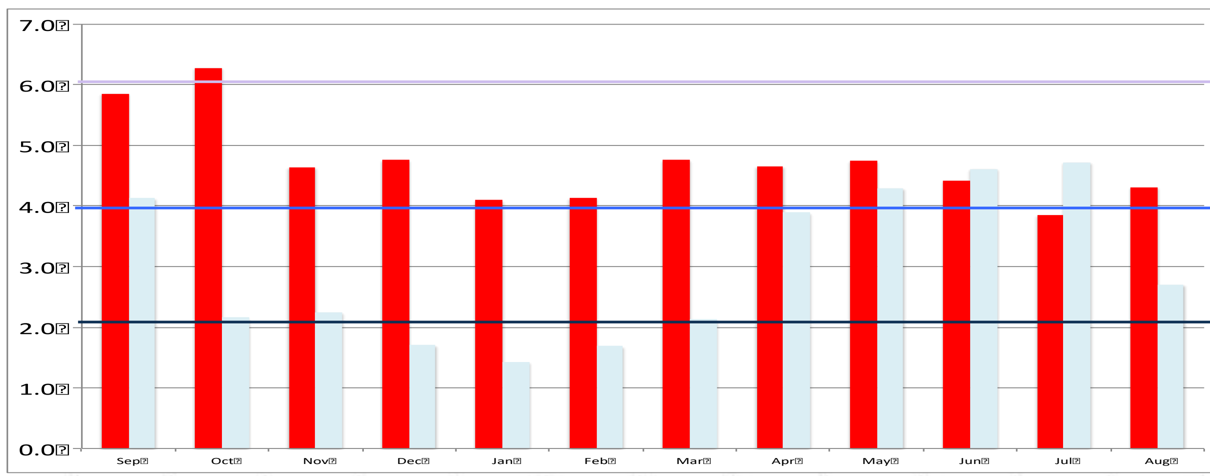
Note: Dry soil & furnace (Sept-Oct); Frozen soil (Jan-Feb); and A/C (July)

6

Action Level

4

Concern Level 2



ZONE		Averages in °F Annual		Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
# 4			Hi	78	67	55	44	39	42	51	63	73	82	87	85
Mixed	Phillidelpia, PA	55	Avg	68	57	47	36	32	34	42	53	63	72	77	76
NYC, PA, NJ, VA, KT, TN, KS, MO, OR, WA			Lo	59	47	38	29	24	26	33	43	53	62	68	66

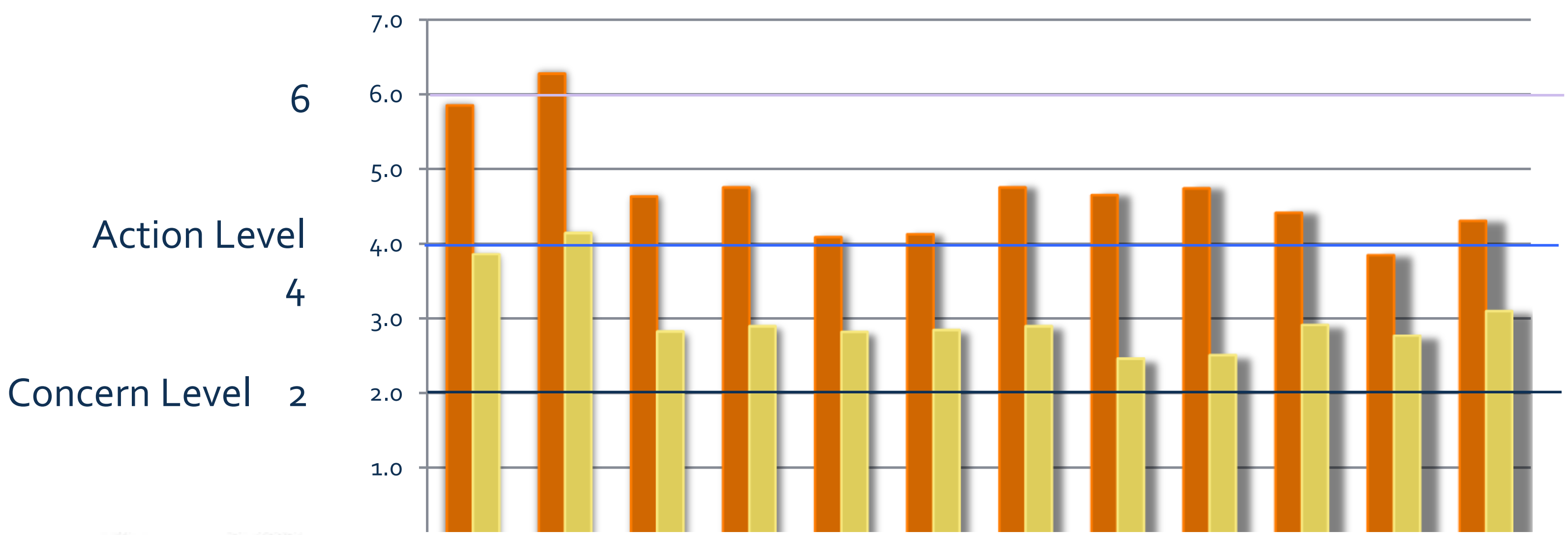
POOLED DATA

Data location: Kansas City but similar to most studies

Basement Compared to Upper Areas:

When HVAC is active, distribution mixes basement air into a larger upper airspace (**30-40% dilution**)

1,100 different homes. Basement n and Upstairs n



ZONE		Averages in °F Annual		Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
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NYC, PA, NJ, VA, KT, TN, KS, MO, OR, WA			Lo	59	47	38	29	24	26	33	43	53	62	68	66

POOLED DATA

Wind (Kansas City)

- Our pooled data indicated little difference.

Avg. wind speed	10 mph	
Tests conducted:	<10 mph-->	**+1%** diff. from all Rn
Tests conducted:	>10 mph -->	**- 1%**
At max wind speeds		
Tests conducted:	<25 mph-->	**0%**
Tests conducted:	>25 mph -->	**0%**
Tests conducted:	<20 mph -->	**+1%**
Tests conducted:	**>30 mph -->**	**-3%**

POOLED DATA

Barometric Pressure

- Due to **stack-effect dominance in two-story basement homes**, we seldom saw barometric pressure correlate with radon fluctuations in individual home tests.

All Barometric Avg.	28.92	
+ Below the average	< 28.92	**0%** difference
+ Above the average	> 28.92	**0%**
+ At more extremes:		
+ Lower Extremes	< 28.77	**-2%**
+ Higher Extremes	**> 29.01**	**-12%**

High barometric pressure is usually associated with warmer weather

AARST NRPP

RADON PROFESSIONALS SAVING LIVES

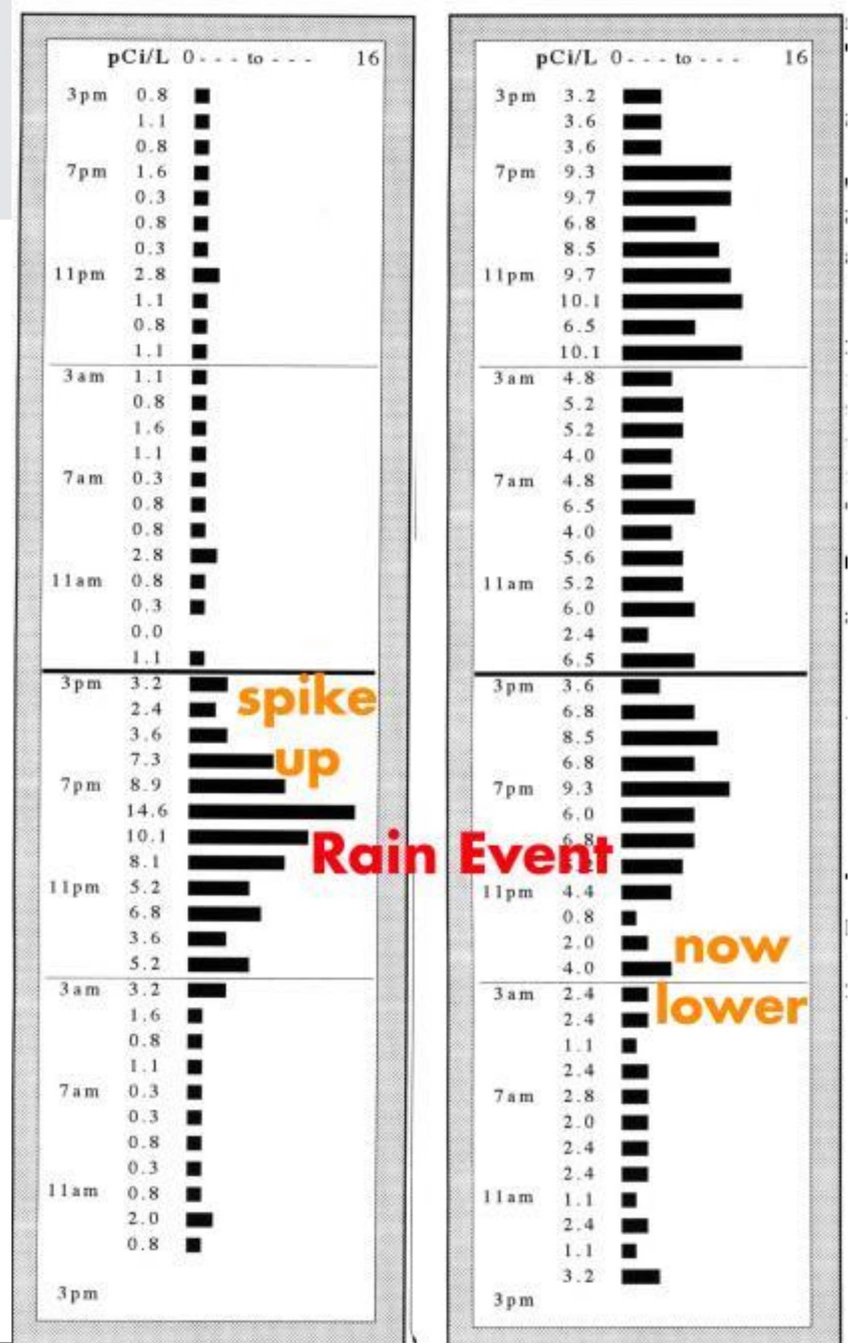
POOLED DATA

Common Rain

Impact on average of all tests

All Weeks with:

<1" rain	-->	**0%**
>1" rain	-->	**-1%**

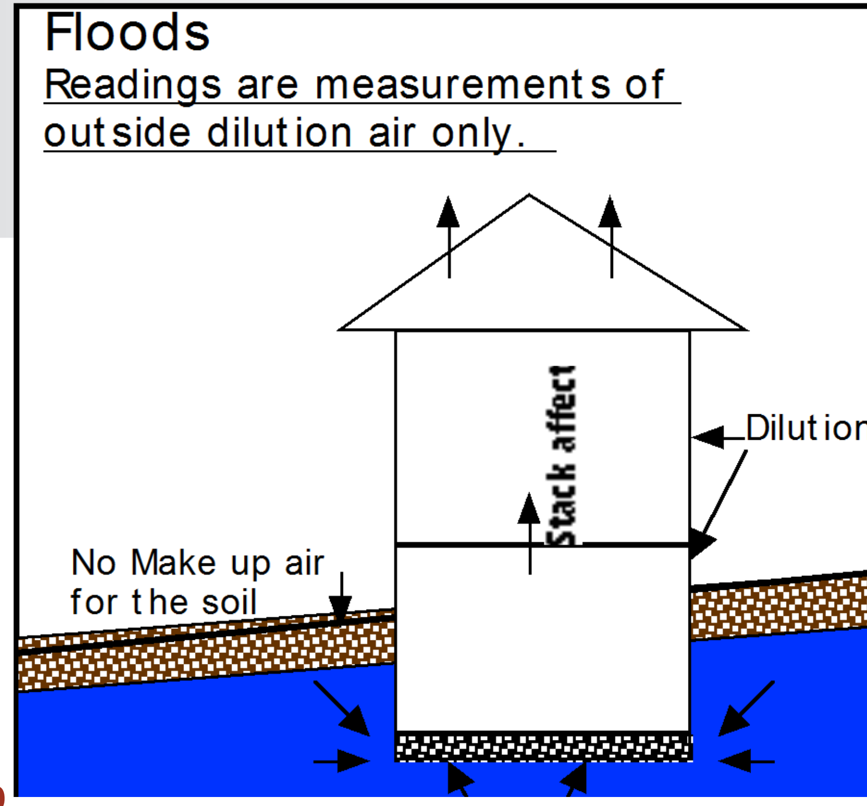


- We often see two different homes tested simultaneously with one home spiking high while the other drops low during a rain event.

POOLED DATA

Vadose Zone

Floods and Droughts

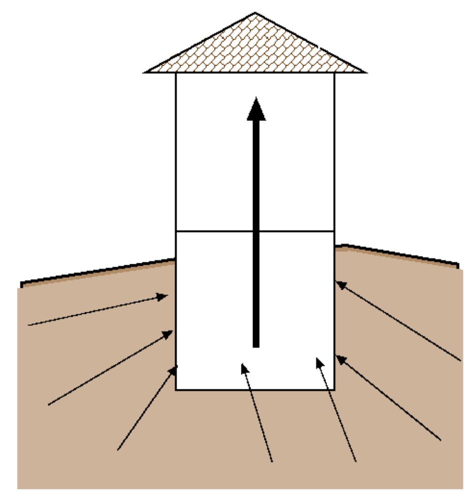


Impact on average of all tests

Normal yearly rainfall:	39" rain	
Floods of 1993	53" rain	**-3%**
Mild drought 2000	31" rain	**+3%**

+ Drought

Pores between soil granules become open and crevices or dried underground waterways may allow soil air movement from far distances.

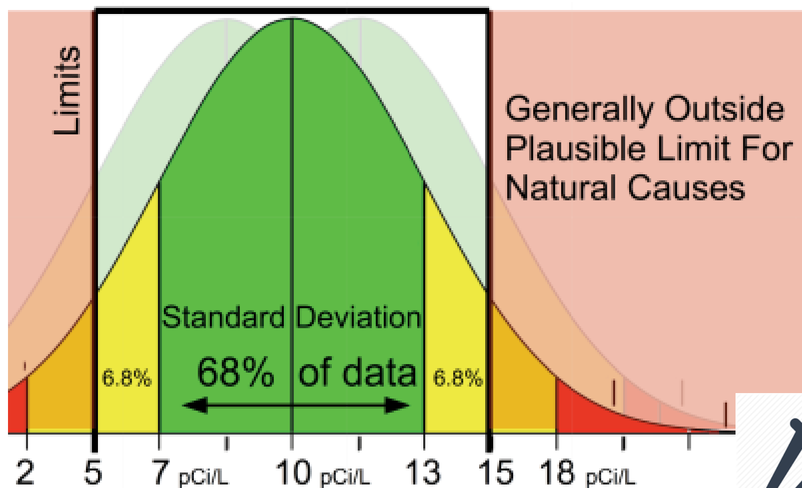


AARST-NRPP

RESULTS AND DISCUSSION

- If you do not control the conditions of the test, the measurements are not reproducible (i.e., meaningless)
- If you control test conditions to simulate the yearlong "average" building operating condition and tests are conducted in ground contact areas:
  - Subsequent tests and hourly fluctuations in indoor soil gas concentrations were prominently witnessed to agree within 1 standard deviation.

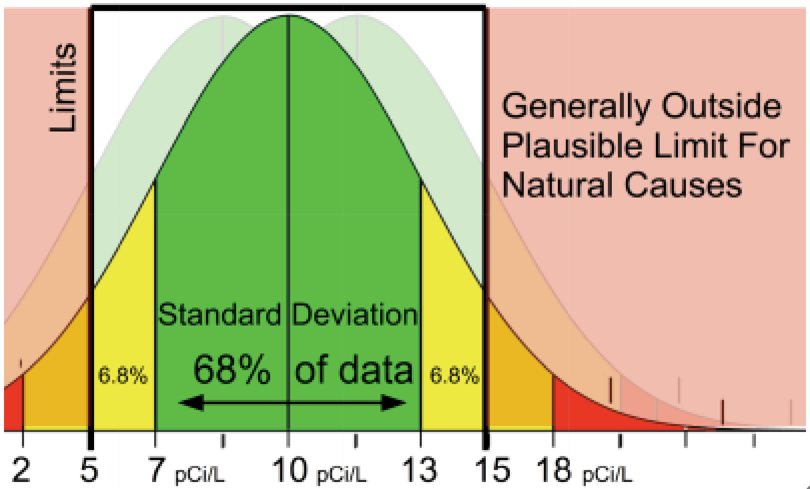
This assumes: closed-building conditions; outdoor temperatures less than 65˚ F (18˚ C) at least each night; and no floods, drought, or hurricanes.



RESULTS AND DISCUSSION

- More than one data point (e.g., hourly data, follow-up tests or duplicate measurements) serves to more than double the statistical confidence in each test result. (EPA 400-R-92-011 1992)
- Fluctuations wider than a 1.5 standard deviation were rarely due to natural causes.
- Conducting tests under two or more different test conditions (e.g., cool versus cold weather) adds much greater confidence.

Additional testing can also be warranted: if unexpected wide fluctuations are witnessed; and if suspected concerns exist regarding temporary conditions.



CONCLUSIONS:

1. **Fluctuations in soil gas entry are not random.** There are known causes for effects that modulate when air movement occurs and the direction, magnitude, and mixing qualities of diverse air sources. This fact applies worldwide.

2. **To be useful**: **Test conditions must be compared to average yearlong conditions**.

3. One must account for:

   a) the building's reaction to needs of **human comfort**; and

   b) conditions within the **vadose zone**.

   These factors trigger a **finite set of building responses** that modulate when air movement occurs and the direction, magnitude, and mixing qualities of diverse air sources.

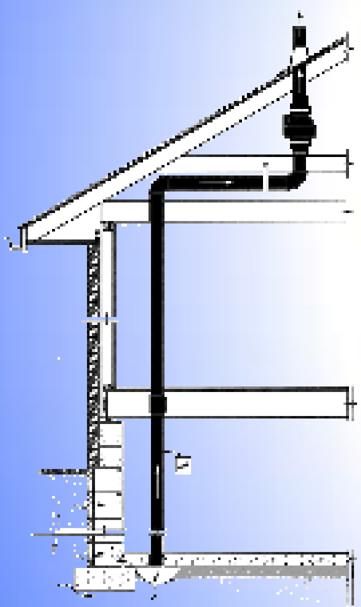
Questions on Part 1 ?

+ Reflects Day to Night Temperatures

ZONE	Location	Averages in °F Annual		Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
# 1			Hi	88	85	80	77	76	77	80	83	86	88	89	90
Very Hot	Miami, FL	76	**Avg**	82	79	74	69	68	69	72	75	79	82	83	83
	Similar: Hawaii		Lo	76	72	66	61	60	61	64	68	72	75	76	76
# 2			Hi	87	80	71	64	62	65	71	78	85	89	91	90
Hot	New Orleans, LA	69	**Avg**	79	70	61	55	52	55	62	69	76	81	82	82
	Similar: Florida, Houston		Lo	71	61	52	45	43	46	52	59	66	72	74	74
# 3			Hi	82	73	63	54	52	56	64	73	80	86	89	88
Warm	Atlanta, GA	62	**Avg**	73	63	53	45	43	46	53	62	70	77	79	79
	Southern California to S.Carolina		Lo	64	53	42	36	33	36	43	51	59	67	70	69
		Annual		**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**
# 4			Hi	78	67	55	44	39	42	51	63	73	82	87	85
Mixed	Phillidelpia, PA	55	**Avg**	68	57	47	36	32	34	42	53	63	72	77	76
	NYC, PA, NJ, VA, KT, TN, KS, MO, OR, WA		Lo	59	47	38	29	24	26	33	43	53	62	68	66
		Annual		**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**
# 5			Hi	75	63	48	35	29	34	45	58	70	80	84	82
Cool	Chicago, IL	49	**Avg**	65	53	40	27	22	26	37	49	59	69	74	72
	MA, NY, OH, MI, IN, IL, IA, NE, UT, NV		Lo	54	42	31	20	43	18	28	39	48	57	63	62
# 6			Hi	71	59	40	26	21	27	29	56	69	78	83	81
Cold	Minneapolis, MN	45	**Avg**	61	50	33	19	13	18	31	46	59	68	73	71
	ME, NH, VT, WI, MN, ND, WY, SD, ND		Lo	50	40	25	11	4	9	22	36	48	58	63	61
# 7			Hi	69	57	35	23	16	21	30	52	65	72	81	80
Very cold	Minot, ND	39	**Avg**	56	45	26	14	6	11	21	41	53	61	68	67
	Similar: Anchorage, Winnipeg		Lo	43	34	17	6	-3	2	12	30	41	50	56	54

Part 2

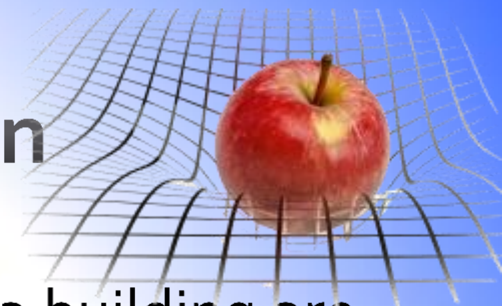
FLUID MECHANICS AND PASSIVE MITIGATION



Clarity for understanding fundamentals with a hope to improve standard practice and possibly provide insight for future innovation

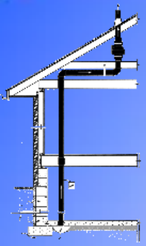
Energy Sources

and the Natural Condition



- Air pressure differences that drive soil gas into a building are due to **gravitational force** that occurs as a result of differences in weight between indoor and outdoor air.

- This gravitational phenomenon exists by virtue of energy from the **sun (i.e., atomic reaction)** where disparate distribution of heat causes differences in weight across oceans of outside air. The potential of this gravitational force is sufficient to unleash tornadoes.



Energy Sources and the Natural Condition

- **Other sources of energy** that cause air movement within a building include radiant heat from the sun, fans and energies resulting from chemical **combustion** (e.g., needs for achieving **human comfort** that commonly entail combustion systems for natural gas, fuel oil, propane, coal and wood).

- **The result of gravitational energy:**

  Stack effect. The varying degree of temperature (i.e., weight) difference between air within a stack (e.g., building) compared to outside a stack determines the direction of airflow and potential hydraulic force.

Energy Sources

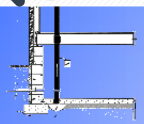
and the Natural Condition

- **Propensity of upward stack effect**

24 Hour Temp Averages ZONE		Annual Avg	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
1 Very Hot	Miami, FL	76	82	79	74	69	68	69	72	75	79	82	83	83
2 Hot	New Orleans, LA	69	79	70	61	55	52	55	62	69	76	81	82	82
3 Warm	Atlanta, GA	62	73	63	53	45	43	46	53	62	70	77	79	79
4 Mixed	Phillidelpia, PA	55	68	57	47	36	32	34	42	53	63	72	77	76
5 Cool	Chicago, IL	49	65	53	40	27	22	26	37	49	59	69	74	72
6 Cold	Minneapolis, MN	45	61	50	33	19	13	18	31	46	59	68	73	71
7-Very cold	Minot, ND	39	56	45	26	14	6	11	21	41	53	61	68	67
8 SubArctic	Fairbanks, AK	27	45	25	4	-6	-8	-2	11	31	49	60	62	57
8 SubArctic	Cambridge Bay	6	32	11	-9	-21	-27	-27	-22	-7	15	36	47	44

- **Kinetic limits.** The actual force depends upon the smaller volume of **either: a.)** air entering a stack or building**, or b.)** air exiting a stack or building.
  Note… The volume of air exiting a building can be no more than the volume available to enter a building.

COUNTERING NATURAL ENERGY with Passive Means (RRNC)



1) Reducing air infiltration and exfiltration

- **Whole Building.** Minimizing the volume of air that enters and exits a building serves to minimize the magnitude of force required to overcome natural forces and thereby energy needed to control soil gas movement.

- **Bottom.** Critical component: A complete closed barrier between soil gas and the air within the building is absolutely essential for any passive design. This both minimizes pathways for soil gas entry and reduces energy needs to counter the persistently present driving force of stack effect.

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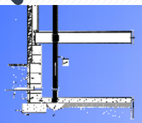

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  pathways for soil gas entry and reduces energy needs to counter the persistently present driving force of stack effect.

Countering Natural Energy with Passive Means (RRNC)

1) Reducing air infiltration and exfiltration

- **Upper Building**. Studies support similar radon reductions as for sealing a slab. Meanwhile, retrofitting such closure after the building is constructed is often considered cost prohibitive.

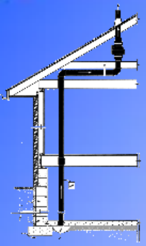
- **Limitations.** The disciple of energy auditing and field experience for radon testing tell us it is appropriate to assume that no barrier, slab or partition is airtight.
  - Gaps smaller than you can see are witnessed to be fully sufficient for allowing large volumes of pressure driven soil gas to enter.

Countering Natural Energy with Passive Means (RRNC)

2) Enhancing hydraulic conductivity

- A complete hollow void under a building would require the least amount of energy for controlling the destiny of soil gas. Inversely, the amount of energy required to move air within solid clay is excessive to the point of impossible.

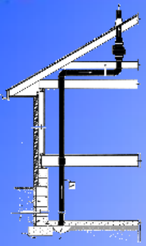
Range of Hydraulic Conductivity of Natural Soils			
USCS class	Soil Type	Hydraulic Conductivity Range gallons per day/ft2	Permeability desciption
GP	Uniform gravel	4,000 to 20,000	High
GW	Well-graded gravel	1,000 to 6,000	Moderate to high
SP	Uniform sand	100 to 4,000	Moderate to high
SW	Well-graded sand	20 to 2,000	Low to moderate
SM	Silty sand	20 to 100	Low
SC	Clayey sand	20 to 20	Low to very low
ML	Silt	1 to 2	Very low
CL	Clay	0.02 to 0.2	Very low to impermeable



Countering Natural Energy with Passive Means (RRNC)

3) Confining the expanse of soil gas

- The size of gas permeable expanses under a building has traditionally been considered a commodity that can't be manipulated.
- Meanwhile, **controlling large volumes of air requires more energy** (fan drive or passively induced).
- Wherever there is **leakage** between a gas permeable layer other **inadvertently connected air spaces**, the soil gas control system will inevitably include air transport from all inadvertently connected air spaces.

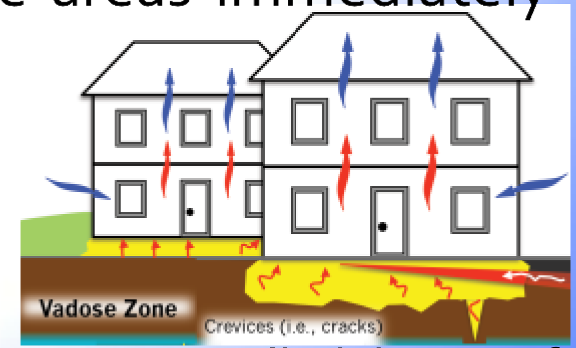


Countering Natural Energy with Passive Means (RRNC)

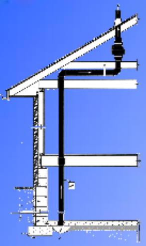
3) Confining the expanse of soil gas

- If seeking to minimize energy needs (even for fan driven systems), **care can be exercised in building design** to establish boundaries for permeable gas expanses when constructing a building.

- The more tightly confined to permeable areas immediately adjoining the building, the better.



Uncontrolled design of permeable expanses.



Countering Natural Energy with Passive Means (RRNC)

3) Confining the expanse of soil gas

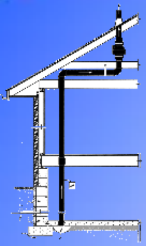
- **For constructing boundaries:** Earthen aggregates cross a line for use in construction standards promulgated by ASTM and ASHTO when the soil aggregate significantly limits hydraulic conductivity for water. The same line that distinguishes poor **hydraulic conductively for water is applicable for soil gas with earthen aggregates that contain more than**:
  - 35% of sand, rock fragment fines, clay and silt; or
  - 10% high plasticity clay or silt (e.g., expansive soil with a liquid limit ≥50%)

Energy Sources and RRNC VENT PIPES

- **The vent pipe is the conduit** pathway of air movement **for applying energy** to control the destination of soil gas. The vent pipe extends from the gas permeable layer at the soil to above the roof.

- RRNC systems often described as "passive soil depressurization" actually function intermittently with periods of soil depressurization, soil pressurization and neutralized pressure.

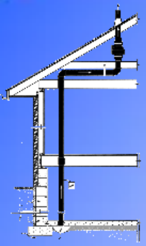
- The degree of reduction demonstrated in most studies is thereby inherently limited compared to constant depressurization with fan driven systems.



Energy Sources and RRNC VENT PIPES

Existing Heat.

- For passive application, the use of heat already existing within a structure is an important energy source to control (depressurize) soil gas. Locating pipe lengths where they naturally remain warm most of the year will serve to aid effectiveness.
- Insulation for pipes in intermittently cold locations and expanded exposure of pipes without insulation in locations that are warm all year can aid effectiveness.



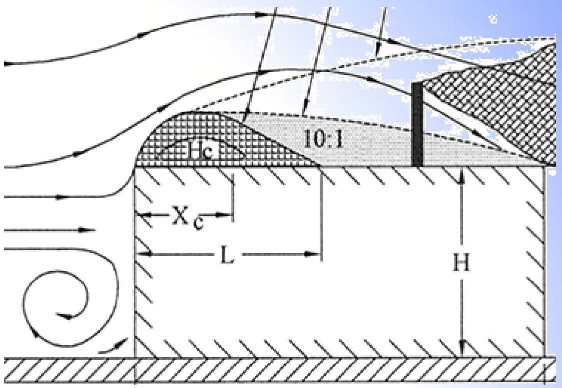
Energy Sources and RRNC VENT PIPES

Existing Heat.

- Extreme heat in the attic during summer is often witnessed to achieve consistent soil depressurization during summer.
- However in winter, long pipes in attics and pipes installed near cold walls will be ineffective during the very season when use of heat within the building is most beneficial.
- Can you optimize for the local climate?
  - Maybe sunny California with 40 ft of pipe in the attic?
  - But no good for Seattle where it rains most of the year.

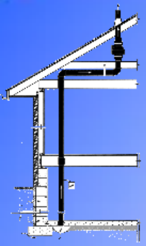
Energy Sources and RRNC VENT PIPES

RRNC and wind effect energy



- While a degree of depressurization can occur when wind crosses the top of vent pipes, it is typically a **random** event and always **intermittent**. This effect is sometimes rightly or wrongly described as Chimney effect, Venturi effect, Bernoulli effect, etc.

- However in winter, long pipes in attics and pipes installed near cold walls will be ineffective during the very season when use of heat within the building is most beneficial.

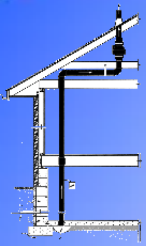


Energy Sources and **RRNC Vent Pipes**

RRNC vent pipe ventilation

- The **breathing** properties of RRNC installations can provide **intermittent** periods when soil gas is expelled and replaced by outside air.
- For many climates, neutralized pressure between soil gas and the vent pipe that is open to outside air is the only hydraulic mechanism for reducing soil gas entry across ± 6 months of the year. ~Neutralized pressure alone is not consistently effective.

AARST-NRPP RADON PROFESSIONALS SAVING LIVES



Discussion of Alternative Methods and Passive Energy Sources

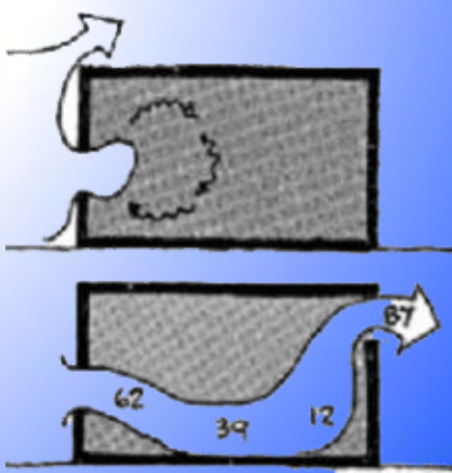
Alternative passive energy.

- At this time, affordable products that generate electricity (e.g., solar, wind, magnetic and even man or animal energy for creation of electricity) have not demonstrated consistent or sufficient energy for relying on as a standalone energy source to power fans.
- The challenge is to provide **electricity at all times** to drive fans that consume in the range of **20-80 watts** for most newly constructed homes.

Discussion of Alternative Methods and Passive Energy Sources

Ventilation of soil gas

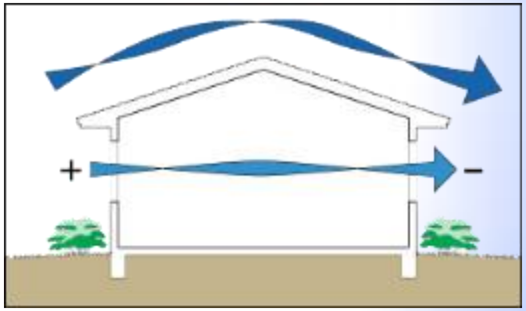
- Effects are witnessed to be **intermittent** due to constant variance in the magnitude of force and direction of wind.
- Soil gas typically represents **only 5-15%** of all air entering a building. **The pollutant mass (e.g., radon atoms or vapor molecules) is not diminished unless first diminished by cross-ventilation with the outside atmosphere.**
- **Single vents do not cross-ventilate,** so elevated concentrations commonly still persist much of the year.



Discussion of Alternative Methods and Passive Energy Sources

Ventilation of soil gas

- **Multiple vents** can intermittently cross-ventilate a gas permeable layer or crawl space to expel a portion of pollutant mass to the outside atmosphere.

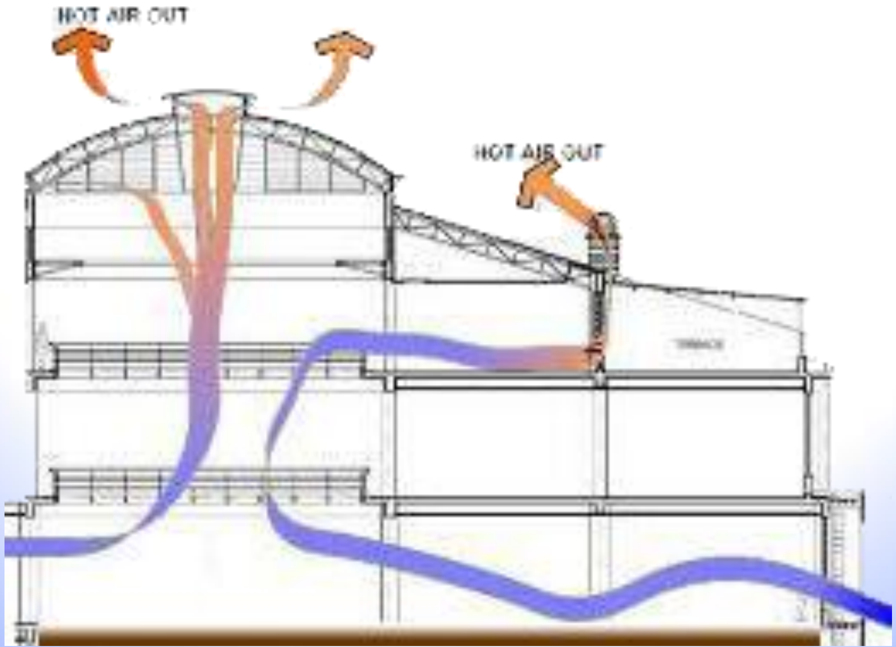


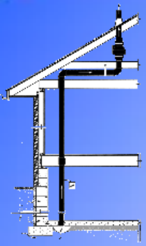
- However, whenever the combination of wind energy force and direction of wind are not sufficient, effectiveness fails. In many climates, **cross-ventilation often comes with significant energy penalties for the rest of the building**.

Discussion of Alternative Methods and Passive Energy Sources

Ventilation of soil gas

- Cross-ventilation is **not occurring when you witness outside air flowing inward at all vents.** This is often witnessed when outdoor temperatures drop lower than about 65˚

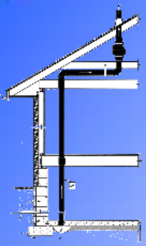




Discussion of Alternative Methods and Passive Energy Sources

Wind Turbine Energy

- Studies in <1988 demonstrated good effectiveness for use of wind turbines but **also recognized** that success is only for **intermittent** periods and the chance for a compromised turbine mechanism is high.
- Wind to drive a turbine is intermittent in duration and force and **high humidity of soil air discharged serves to degrade metal components and form ice** to close the pipe and sometimes damage roofing and mechanical components.



Conclusions and Discussion

1) The degree of reduction in soil gas entry is directly attributable to the degree achieved for both:
   - Breaking the connection between soil air and occupied spaces, and
   - Countering or minimizing air pressures that drive soil gas into a building.

2) RRNC techniques currently employed will not be effective without care to construct:
   - appropriate gas permeable layers;
   - a complete closed barrier between soil gas and indoor air; and
   - vent pipes designed to maximize heat energy that already exists within a structure.

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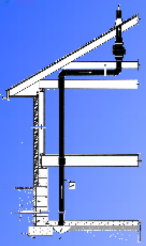
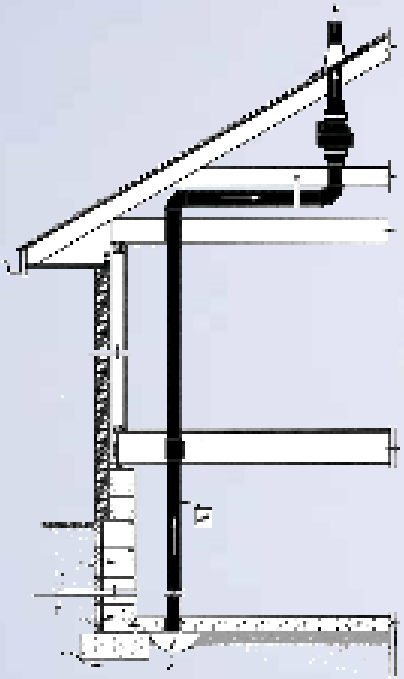


Conclusions and Discussion

3) For **optimizing** innovative designs, energy needs for both passive and active design are minimized if ….

- air infiltration and exfiltration is minimized for both soil gas entry and the entire building;
- a gas permeable layer is provided that provides high hydraulic conductivity for soil air; and
- the gas permeable layer is tightly confined to areas only immediately adjoining the building within impermeable boundaries.

Questions?



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Part 3

Vacuum Strength Needs, Limitations and Whole Building Consideration

When Applying ASD for Mitigating Soil Gas Entry

Provided by Gary Hodgden

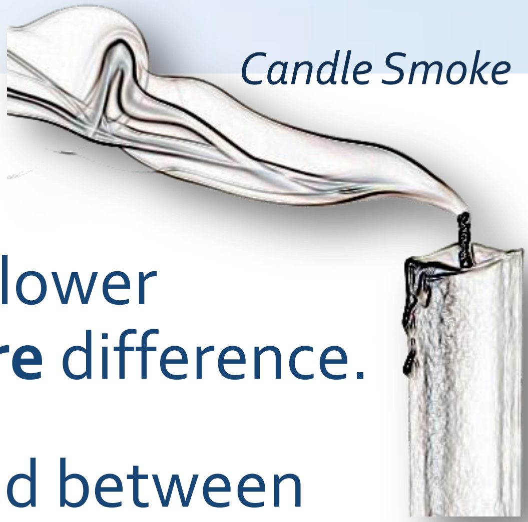
An important misunderstanding witnessed

- **Assumption:** ***the degree of vacuum strength for an ASD system is equal to the degree of system protectiveness or buffer for protectiveness.***

- While this may seem **intuitively** correct........
  It is **technologically incorrect**.

- And, there are **limits regarding required considerations of health, safety, comfort and other interests of building occupants.**

VACUUM STRENGTH - Fundamentals

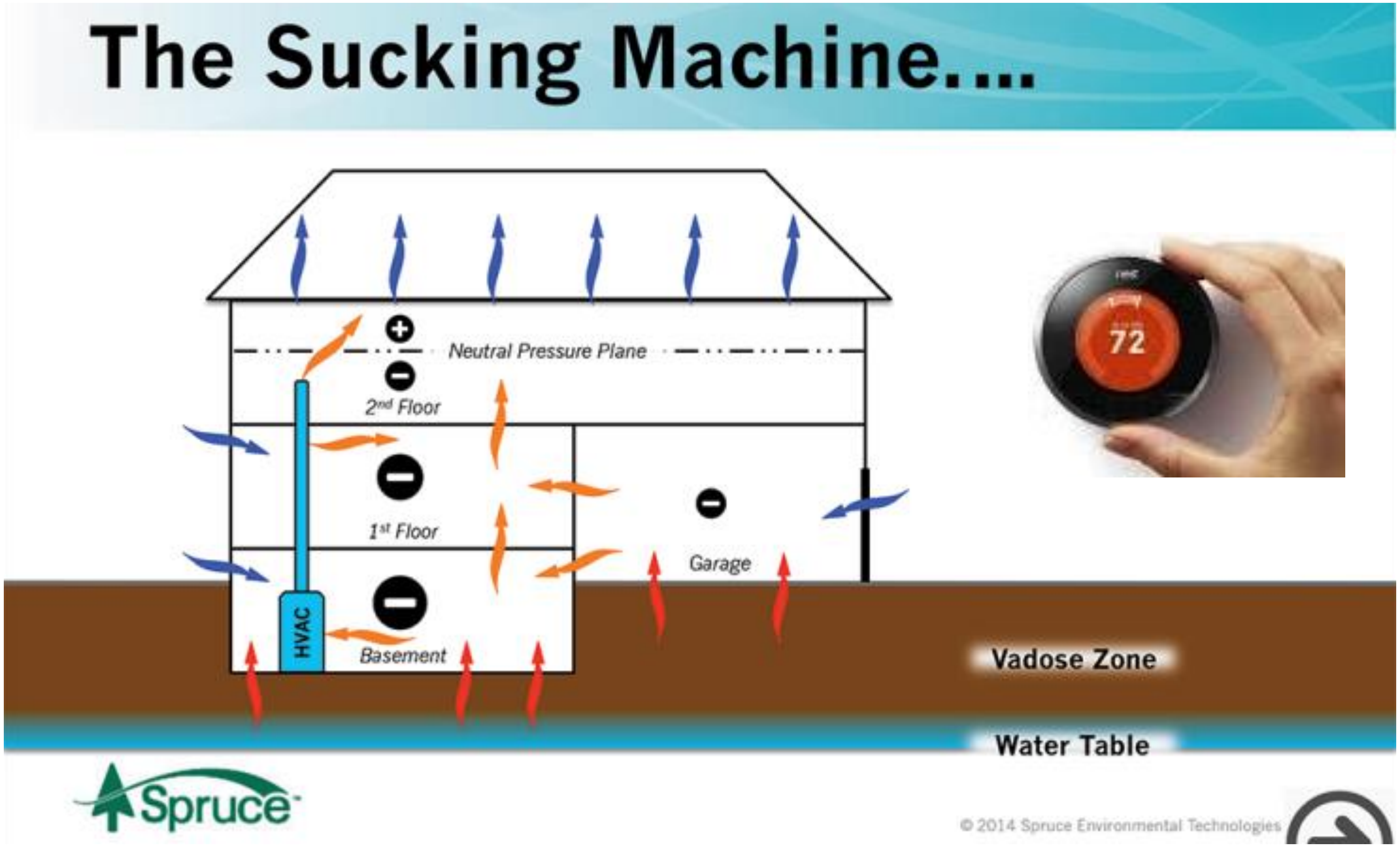


Fundamentals

- Air moves from locations of higher to lower pressure with the **slightest ±0 pressure** difference.
- **If "0" pressure** difference is maintained between two rooms, air does not cross between the two airspaces.
- This principle underpins all considerations for vacuum strength of ASD.
- **ASD success or failure does not hinge on ventilation or diffusion control.**

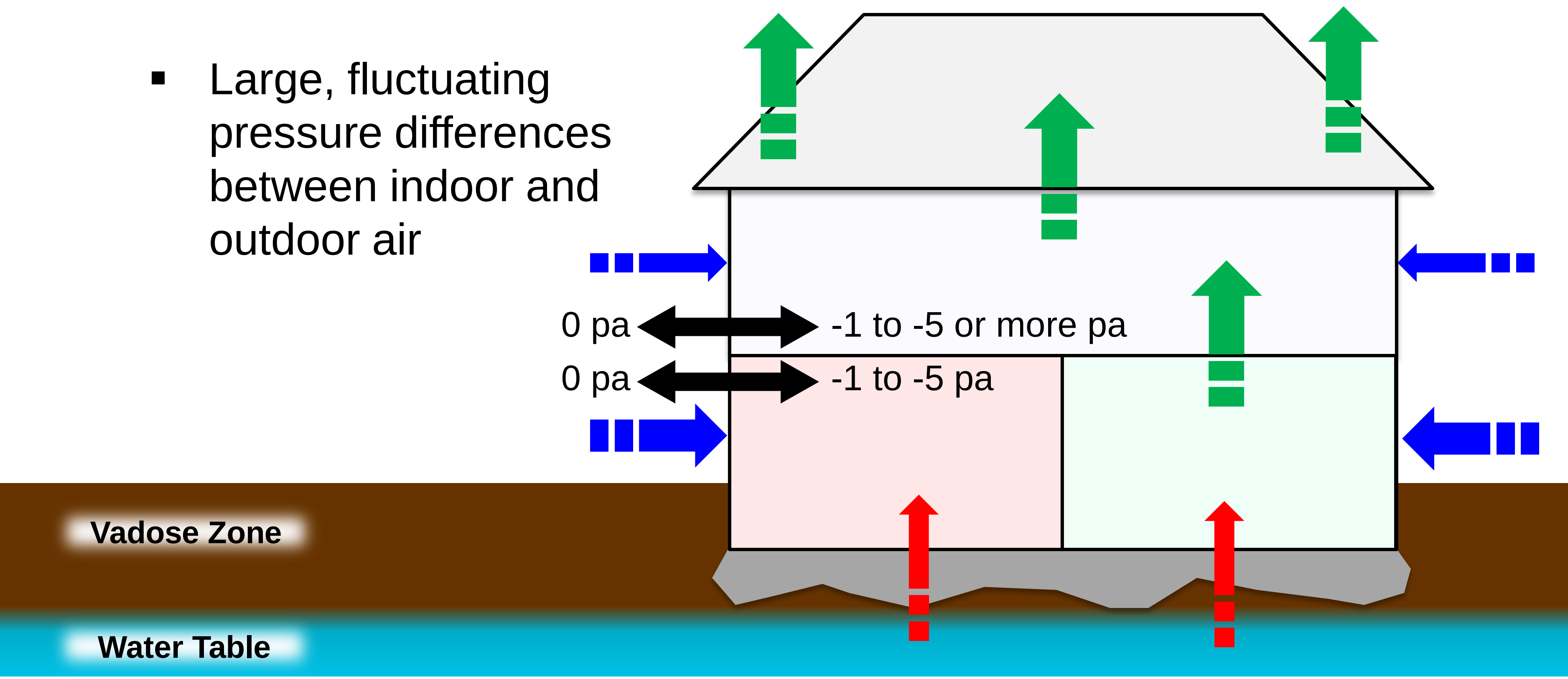
VACUUM STRENGTH - Fundamentals

- **But "0" pressure is not possible to maintain.**



Whole Building Pressure Relationships

- Large, fluctuating pressure differences between indoor and outdoor air

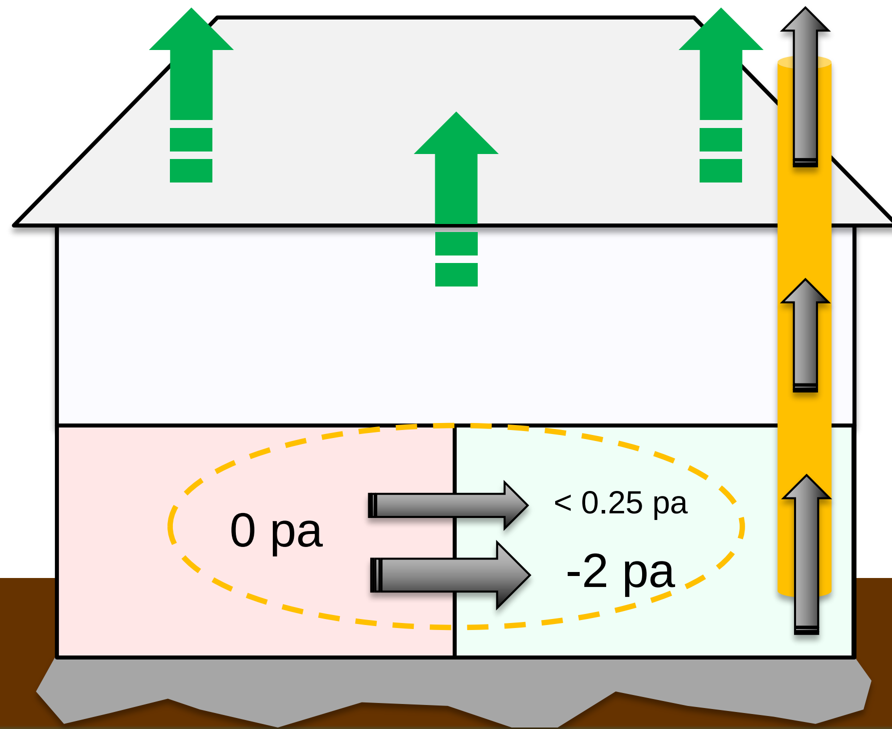


***Note:* Pressure values shown are for example purposes only and dynamically change.**

pa = pascal

Indoor Pressure Difference Relationships Across a Simple Partition

- 2 pascal (pa) is often considered as “**knowing**” if air will move across a partition.
- But air moves with pressures < 0.25 pascal

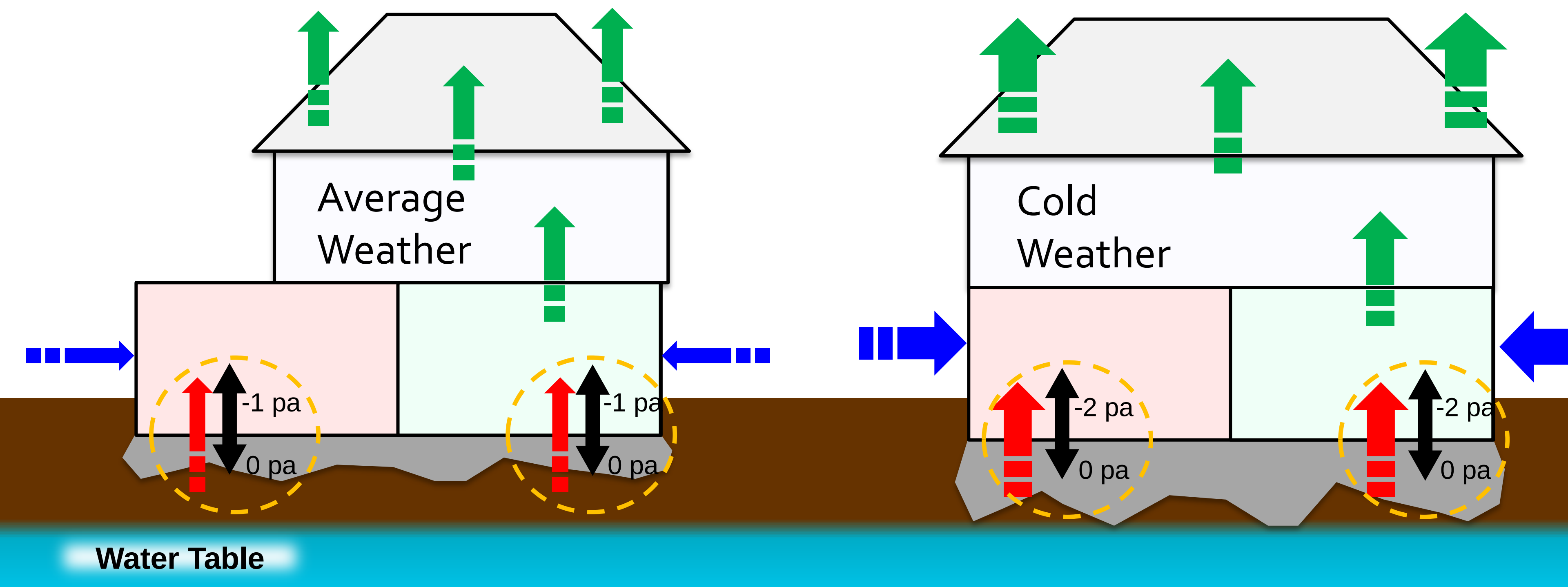


***Note:** Pressure values shown are for example purposes only and dynamically change.*

Whole Building Pressure

The Slab = One More Partition

- Negative building pressure **proportionately** impacts **all air entry (both outdoor and soil gas entry)**.



Test Results and System Design

- A **first consideration** for ASD design is the **percentage of soil gas** that must no longer enter the building.
  - If indoor air is **twice** the action level, >**50% reduction** in soil gas entry is typically required.
  - Since you can't presume to know all possible pathways, system **success can only verified by comparing pre- and post-mitigation tests of indoor air.**
- The second, but **equal consideration**, is the system's capacity to not lose control for stopping soil gas entry

VACUUM STRENGTH **NEEDS**

- Pressure differences of ~ 1 pa (4/1000 inch water column) across a slab are **commonly witnessed** to successfully reduce radon entry across the year.
  - **But such rules of thumb are oversimplified.**
- For **estimating "too little" or "too much"** pressure, the **time period when measured must be compared** to conditions known to occur at other times of the year.

24 Hour Temp Averages ZONE		Annual Avg	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
1 Very Hot	Miami, FL	76	82	79	74	69	68	69	72	75	79	82	83	83
2 Hot	New Orleans, LA	69	79	70	61	55	52	55	62	69	76	81	82	82
3 Warm	Atlanta, GA	62	73	63	53	45	43	46	53	62	70	77	79	79
4 Mixed	Phillidelpia, PA	55	68	57	47	36	32	34	42	53	63	72	77	76
5 Cool	Chicago, IL	49	65	53	40	27	22	26	37	49	59	69	74	72
6 Cold	Minneapolis, MN	45	61	50	33	19	13	18	31	46	59	68	73	71
7-Very cold	Minot, ND	39	56	45	26	14	6	11	21	41	53	61	68	67
8 SubArctic	Fairbanks, AK	27	45	25	4	-6	-8	-2	11	31	49	60	62	57
8 SubArctic	Cambridge Bay	6	32	11	-9	-21	-27	-27	-22	-7	15	36	47	44

VACUUM STRENGTH **NEEDS**

In example:

a) 1/1000 inch water column (.25 Pa) **during coldest weather**, and confirmed by indoor measurements to successfully stop soil gas entry, may need very little added protective buffer.

In **mild weather** it might likely demonstrate or **2.5 times more vacuum needed** during mild weather.

a) Similarly, 1 pa (4/1000 inch water column) **in coldest weather** might likely translate to almost **10 times more vacuum than needed in mild weather**.

VACUUM STRENGTH **NEEDS**

Examples of concern

a) **Too little:** 1 pa (4/1000 inch water column) showing success **during mild weather but if cold weather increases negative pressure by more than 1** pa (4/1000 inch water column), **the system fails**.

b) **Too much:** 5 pa (20/1000 inch water column) during **coldest weather** likely translating to almost **5 times** more vacuum than needed in cold weather and **50 times more than needed in mild weather**.

Warm weather challenges: Only a measurement under colder weather conditions can confirm the building's response to colder weather.

Limitations & Whole Building Consideration

Pressure ≠ Protection:

- It is not uncommon that success is not achieved, regardless of vacuum applied.

- **Seldom** is ASD initially applied to all portions of a building that touch ground.
  - **Tests are often not high enough to warrant it.**
- But **soil gas DOES enter occupied spaces to some degree from every portion of a building that touches ground**, regardless if the path of entry is identifiable.

Missed Sources

For illustration

If even the **slightest** vacuum is consistent and indoor air tests do not indicate success, **a common mistake has been made**…….

A source area has been missed.

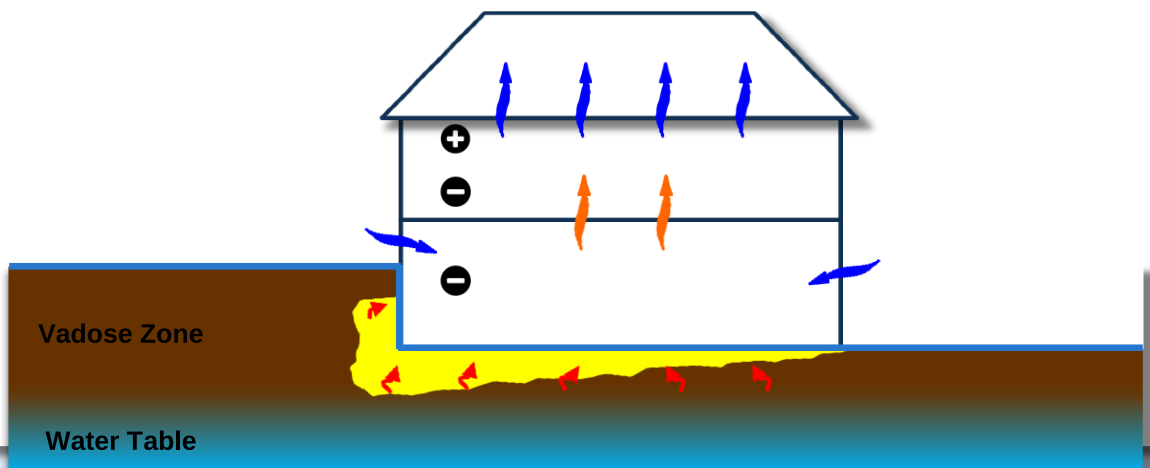
There are two types of source areas often missed

Limitations & Whole Building Consideration

Missed Sources

a) Those ***internal* to the slab** area of interest, such as:

- inconsistent permeability, or
- a sizable void remote from the suction point
  - Regardless of system vacuum strength, the air volume transfer capacity severely limited by pores in soil or granular fill is insufficient to overcome leakage around the sizable void.

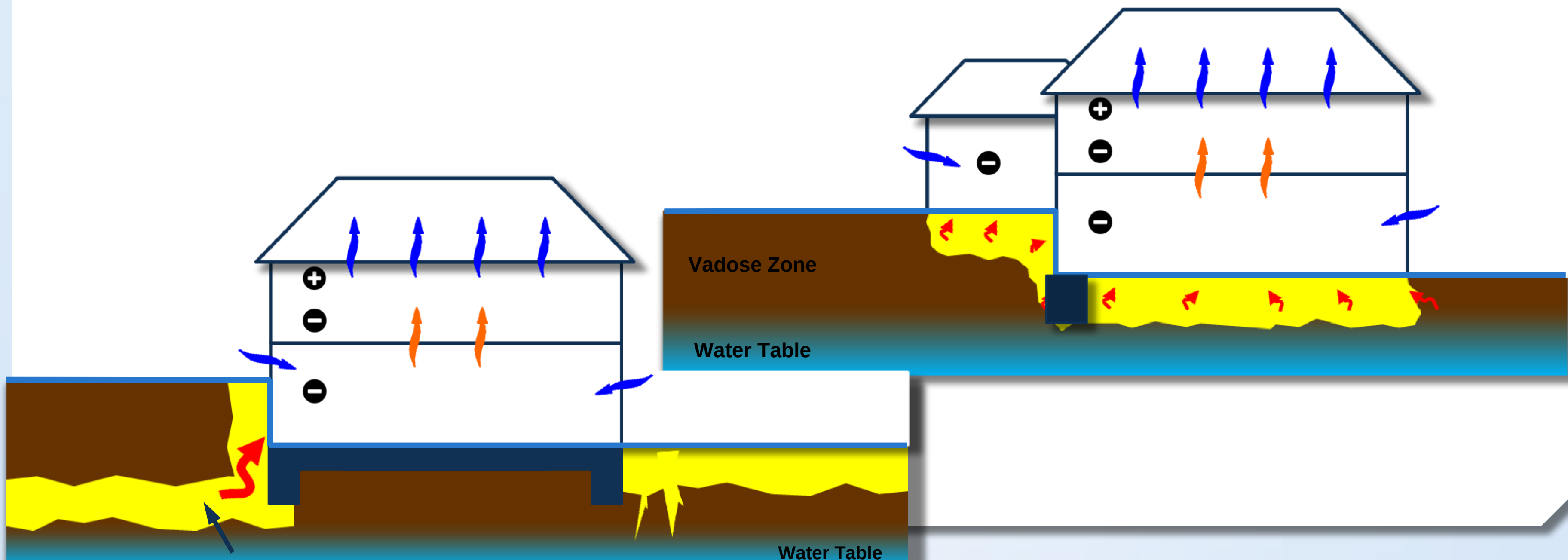


Limitations & Whole Building Consideration

Missed Sources

b) Those ***external* to the slab** or area of interest.

- These are areas divided by footings, walls or other obstructions (e.g., adjoining or upper slab areas, garages, crawl spaces, etc.)



Limitations & Whole Building Consideration

Missed Sources

+ Looking at a population of homes rather than individually, a database of > 20,000 post-mitigation radon tests in Kansas that anecdotally agrees with Pennsylvania state tracking:
  - ~ **90%** of barebones ASD systems achieve < 4 pCi/L
  - ~ **75%** achieve < 2 pCi/L (~ outdoor ambient).
+ Corrections to treat all ground contact slabs resulted in
  - ~ **98% < 4 pCi/L**
  - ~ **85% < 2 pCi/L.**
  - Most remaining buildings between 2-4 pCi/L were older homes with packed soil beneath them.

Limitations & Whole Building Consideration

Enhanced Pressure ≠ Enhanced Protection:

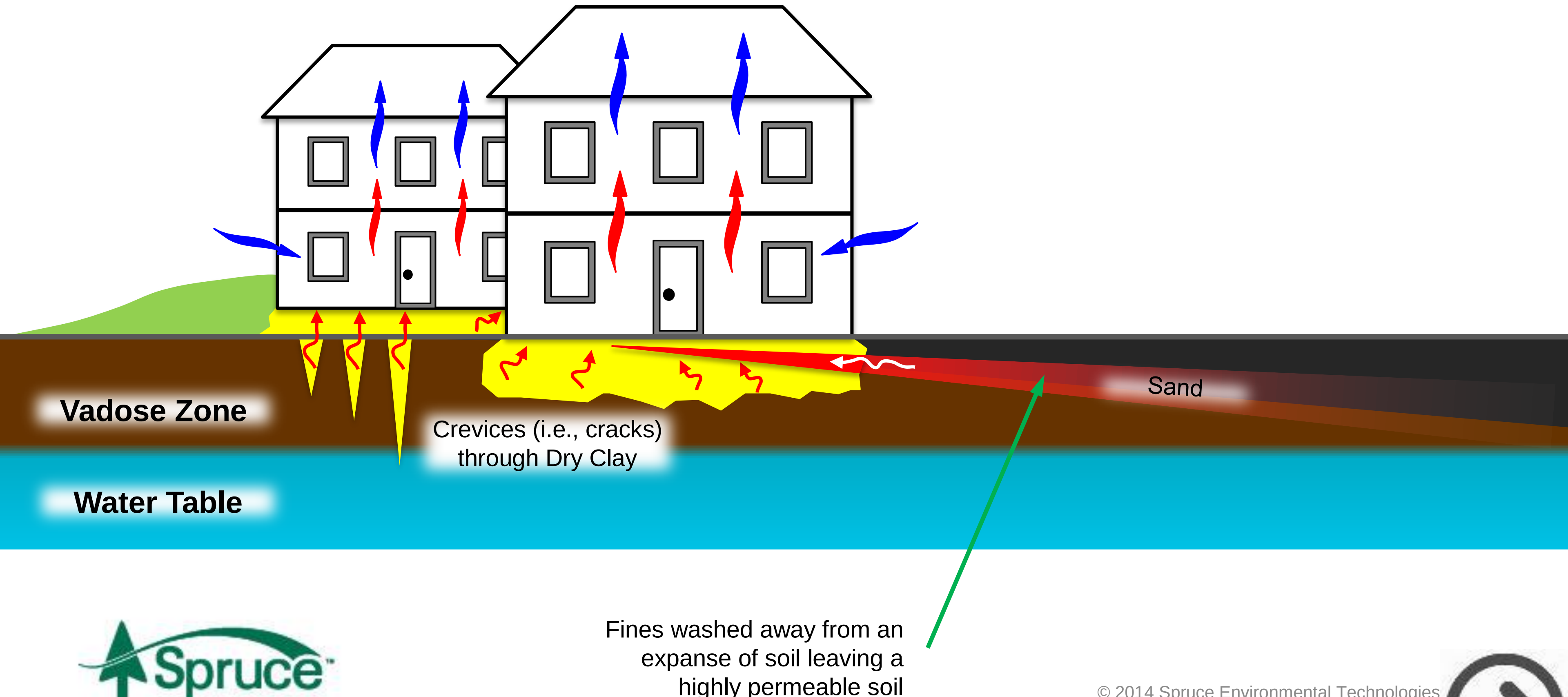
- The benefit of **enhanced pressure, is mostly limited to extending a vacuum through materials with poor permeability**.
- and only within the specific area(s) ASD is applied.
- Vacuum witnessed to extend to other portions of the building is inadvertent and limited in reliability as a sustainable condition.

Limitations & Whole Building Consideration

Enhanced Pressure ≠ Enhanced Protection:

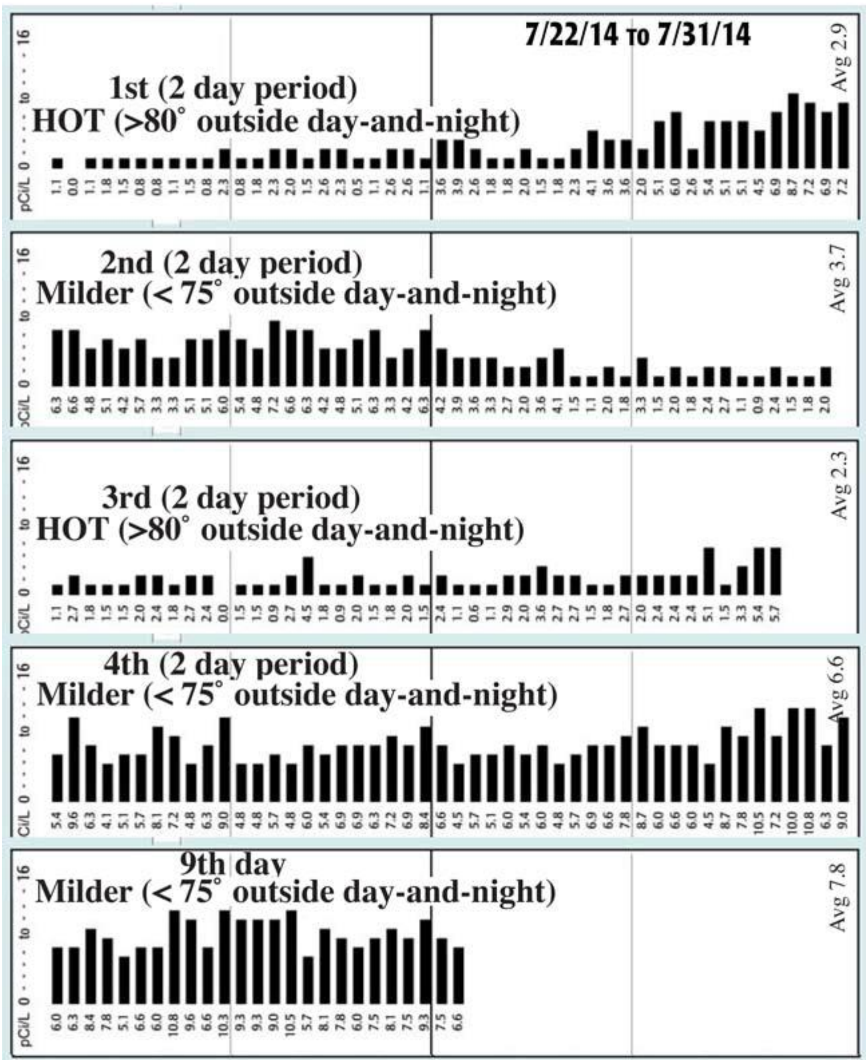
- Inversely, a moderate vacuum is often found to easily reduce excessively high concentrations (e.g., 100 times the action level) to outdoor ambient concentrations.
- Why? High indoor concentrations can be due to highly permeable pathways allowing the **slightest vacuum to transport *large* volumes of *moderately* potent soil gas**.

Extent of Building Influence.… You don't know!

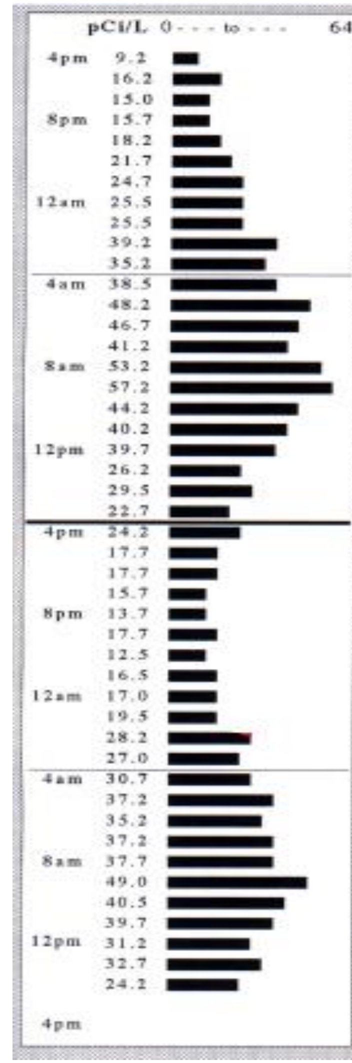


Radon Tests and Use in VI Stewardship

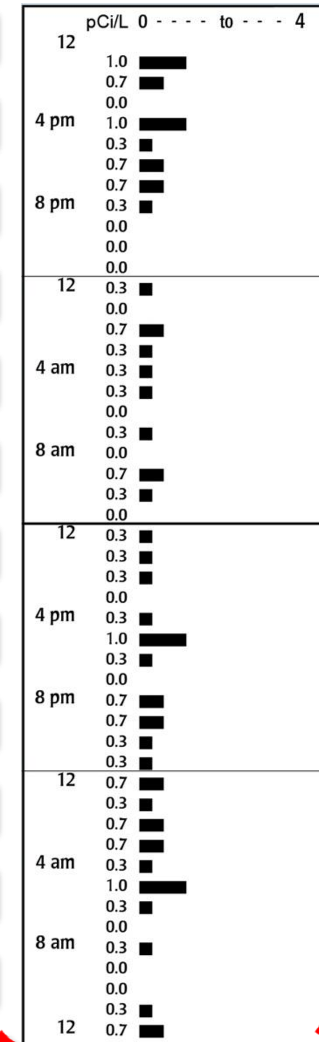
Useful Information



Before



Post-Mitigation



*Adverse Effects of **Excessive** Vacuum*

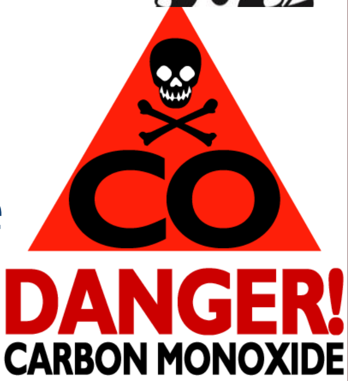
- An **unintended but inevitable** consequence of any soil depressurization system is that often **> 50%** of the discharged air comes from inside the building (the path of least resistance).

In the example of 5 pa applied in cold weather that translates to **50 times more vacuum than needed** in mild weather, adverse consequences can certainly result:

a) **Energy Consequences:** Additional heating and cooling expenses occur for conditioning the additional volume of outside air entering around window and door frames.

*Adverse Effects of **Excessive** Vacuum*

b) **Atmospherically Vented Combustion Appliances**: Should the airspace where a furnace is located lose make-up air, flue spillage and **backdraft of carbon monoxide** can occur.



c) **Humidity and Condensate:** The resulting relative humidity can be **uncomfortable** but also meet dew point temperatures to form condensation that enhances growth of **biological contaminants**.

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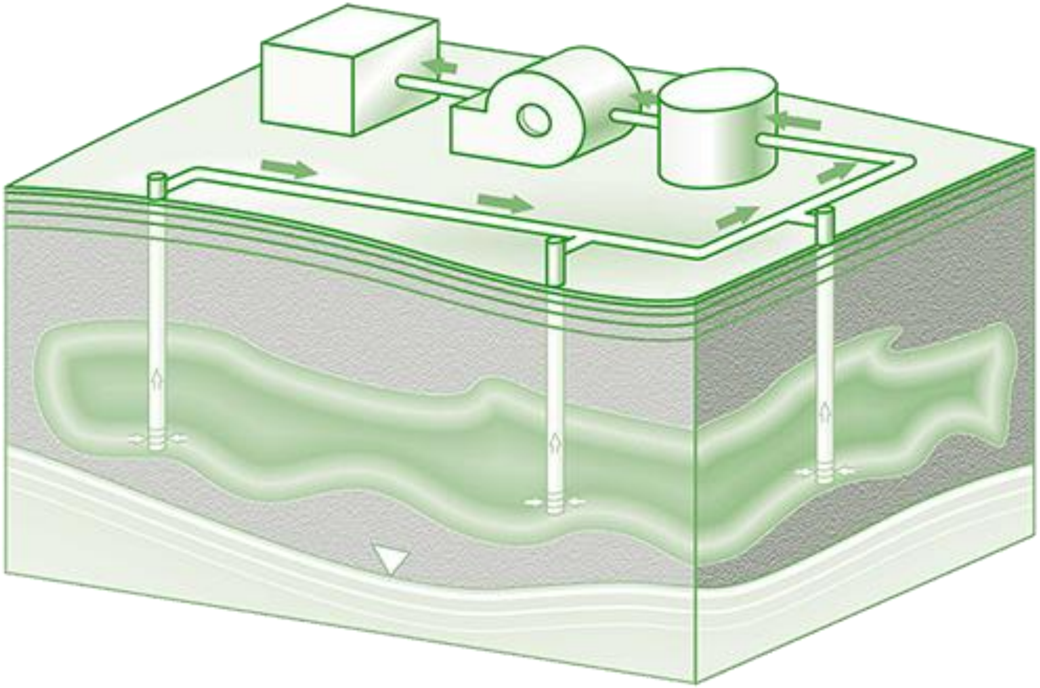
*Adverse Effects of **Excessive** Vacuum*

d) **Foundations:** Significant increases in outdoor air ventilation under a building, when not considered in design, hold possibilities of **foundation damage due to frozen sub-slab** conditions or **alterations to the moisture content in expansive soils**.

SVE and ASD

- These potential adverse consequences extend to the **casually prescribed high vacuum fans** intended to serve dual purpose of soil vapor extraction (SVE).



SUMMARY AND CONCLUSIONS:

1) The most common mistake made when trying to enhance ASD effectiveness is assuming that enhanced vacuum strength is an enhancement in effectiveness.

2) Enhanced effectiveness entails whole building considerations.

3) The degree of vacuum and airflow has limits for required considerations of health, safety, comfort and other interests of building occupants.

4) Compare vacuum against seasonal pressure influences. Only verification under different seasons can prove continuous effectiveness.

Thanks for putting up with me.

Thanks for putting up with me.

I hope this information will be useful. It will be published in the 2016 Symposium proceedings.

Any final questions?

gary hodgden

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