EPA Vapor Intrusion Workshop

Measurement-Based Methods for Protective &
Defensible Chlorinated VI Exposure Determinations

Methods for Measuring Temperature, Pressure and Radon
What, Where, When, and How?

Chris Lutes, Jacobs

Mention of trade names and commercial products does not constitute endorsements or recommendation for use.

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Coming Soon – A Series of Two Page Fact Sheets on ITS – i.e. *"Measuring Temperature as an Indicator for VI Studies"*

- **What temperatures?**
- **Where to measure indoor temperature?**
- **Where to measure outdoor Temperature?**
- **When to measure temperature?**
- **With What?**
- **How?**
- **Why?**
- **Sample Data Quality Goals for Indicator Measurements**

Temperature Methods

1. What? Temperature’s role in the vapor intrusion conceptual site model
2. When? Temperature variability at various scales – diurnal, seasonal etc.
3. How? Current guidance document language
4. How? Low cost data sources and measurement equipment available
5. How? SOPs – can be pretty simple for temperature
6. Suggestions for future data gathering and interim thoughts for practitioners

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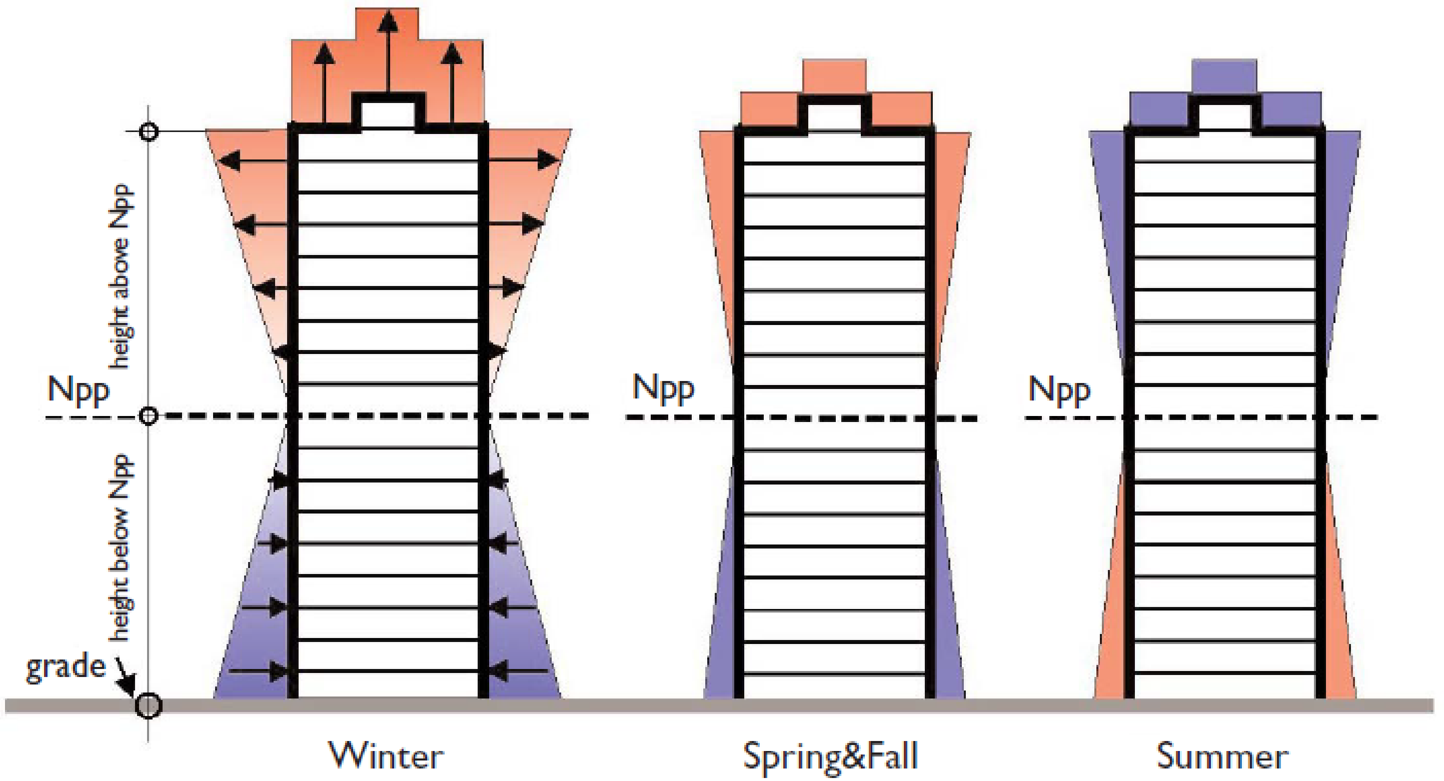
Why? Stack Effect Influences Soil Gas Entry and Air Exchange

Figure Credit: Quirouette, R. L., and B. Arch. *Air pressure and the building envelope*. Ottawa: Canada Mortgage and Housing Corporation, 2004.

Equation Credit: Hui, S.C. 2003. *Lecture: Air Movement and Natural Ventilation*. Department of Mechanical Engineering, The University of Hong Kong. Used by Permission from Dr. Hui. Available at http://www.arch.hku.hk/teaching/lectures/airvent/sect03.htm.



3.3 Flow caused by thermal forces

If the building's internal resistance is not significant, the flow caused by stack effect may be estimated by:

$$Q = K \cdot A \cdot \sqrt{2 \cdot g \cdot \Delta h \cdot \frac{T_i - T_o}{T_i}} \quad \text{if } T_i > T_o$$

$$Q = K \cdot A \cdot \sqrt{2 \cdot g \cdot \Delta h \cdot \frac{T_o - T_i}{T_o}} \quad \text{if } T_o > T_i \qquad (7)$$

where Q = air flow rate (m^3/s)

K = discharge coefficient for the opening (usually assumed to be 0.65)

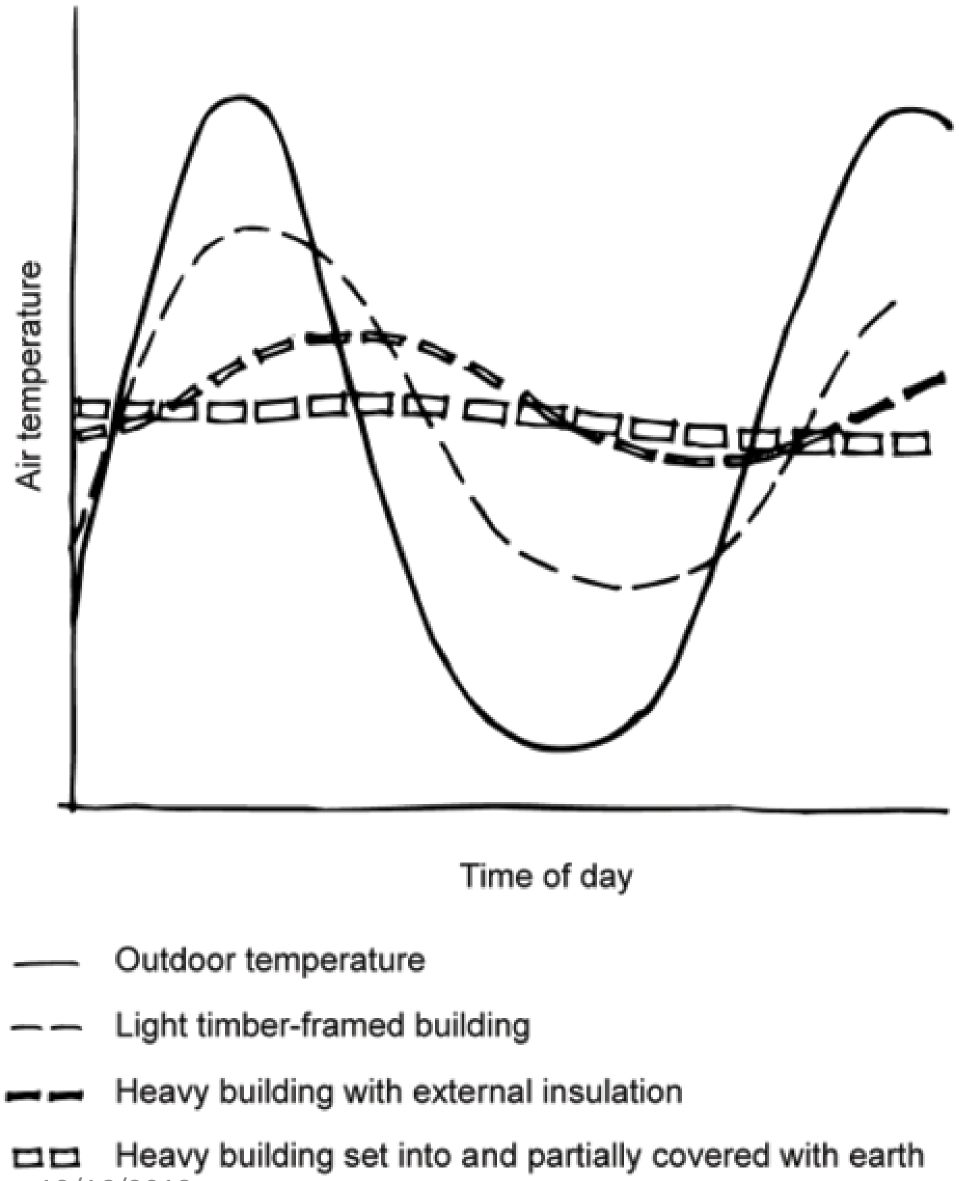
A = free area of inlet openings (m^2)

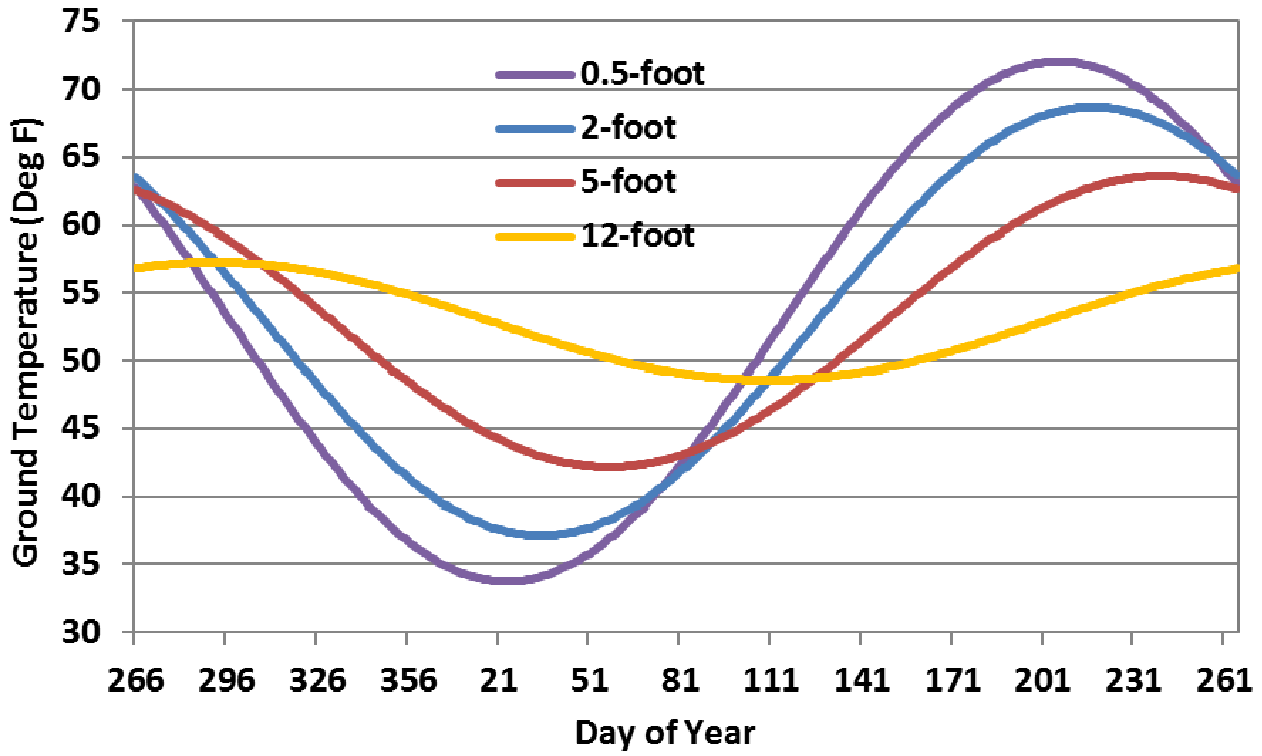
Δh = height from lower opening (mid-point) to neutral pressure level (m)

T_i = indoor air temperature (K)

T_o = outdoor air temperature (K)

Where/When: The Importance of Thermal Mass





Thermal mass moderates the diurnal, seasonal and climatological cycles of temperature.

Above Graphic from: https://igws.indiana.edu/Geothermal/HeatPumps

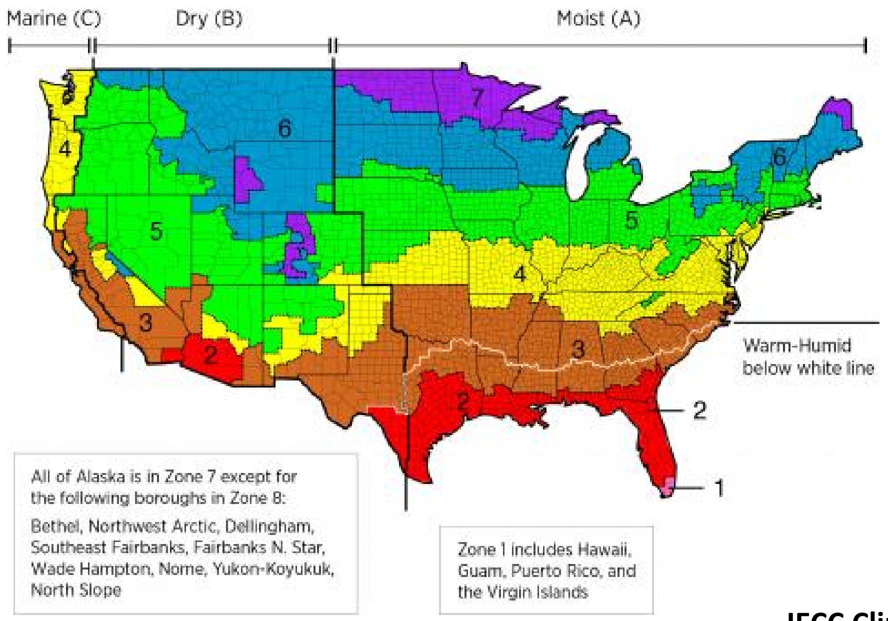
Left Graphic from: http://www.yourhome.gov.au/passive-design/thermal-mass

Where and When to Measure Temperature

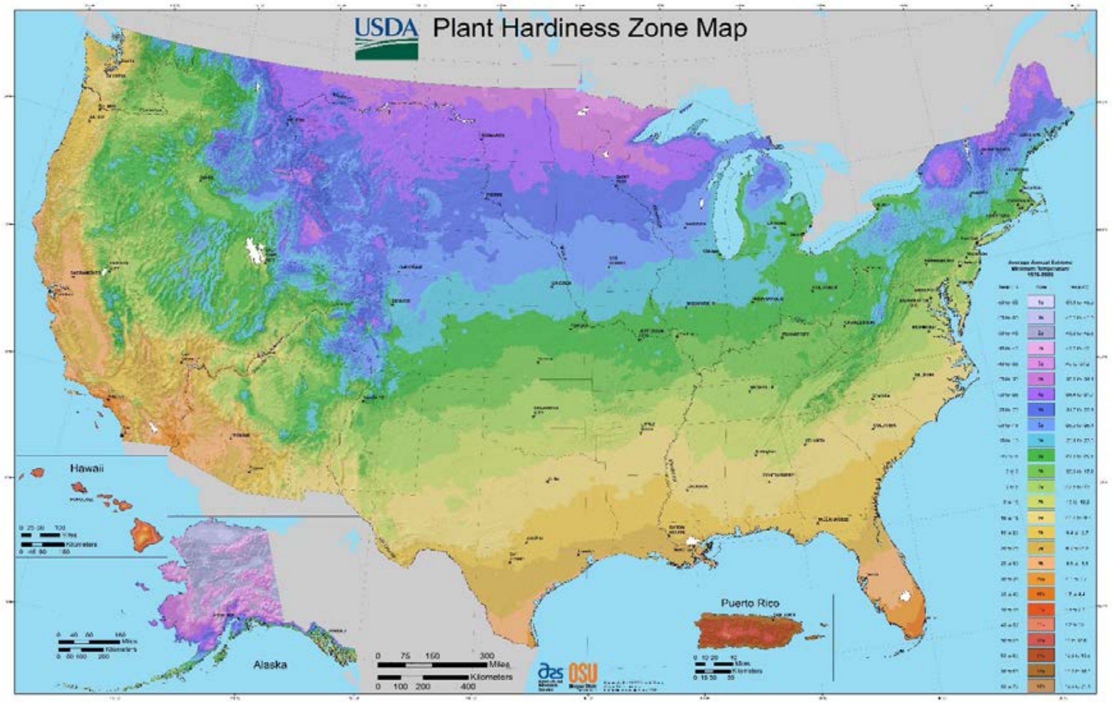
- **Where to measure indoor temperature?** In the main living space - definitely, ideally also in the basement/crawlspace and attic.
- **Where to measure Outdoor Temperature?** At a location near the house sheltered from direct sun, or use your local weather station
- **When to Measure Temperature?** At least hourly is a good start – temperature has a diurnal and seasonal cycle. It typically doesn't change more than a few degrees per hour .

How? Climate Zones are Your First Clue

- Different climate zone systems give us short term or whole winter measures of how cold it gets



IECC Climate Zone Map (2012 IECC – International Energy Conservation Code) – Based on Temperature and Moisture



USDA Plant Hardiness Zones (Reprinted from https://planthardiness.ars.usda.gov/PHZMWeb/Downloads.aspx)

How? – Temperature Data Sources

- Differential temperature – almost always available, because
  - Inside temperature often as easy as “where do you set your thermostat in winter?” “how about in fall?”
  - Historical outside temperature data for thousands of locations cataloged either for specific period or normal values

    https://www.ncdc.noaa.gov/cdo-web/
    https://www.wunderground.com/history/
    https://www.ncdc.noaa.gov/cdo-web/datatools/selectlocation
  - Its Free!!!! You can do it Retroactively

- Want to Measure Yourself – Inexpensive loggers are available for <$100
- Some Pressure instruments give temperature as a bonus

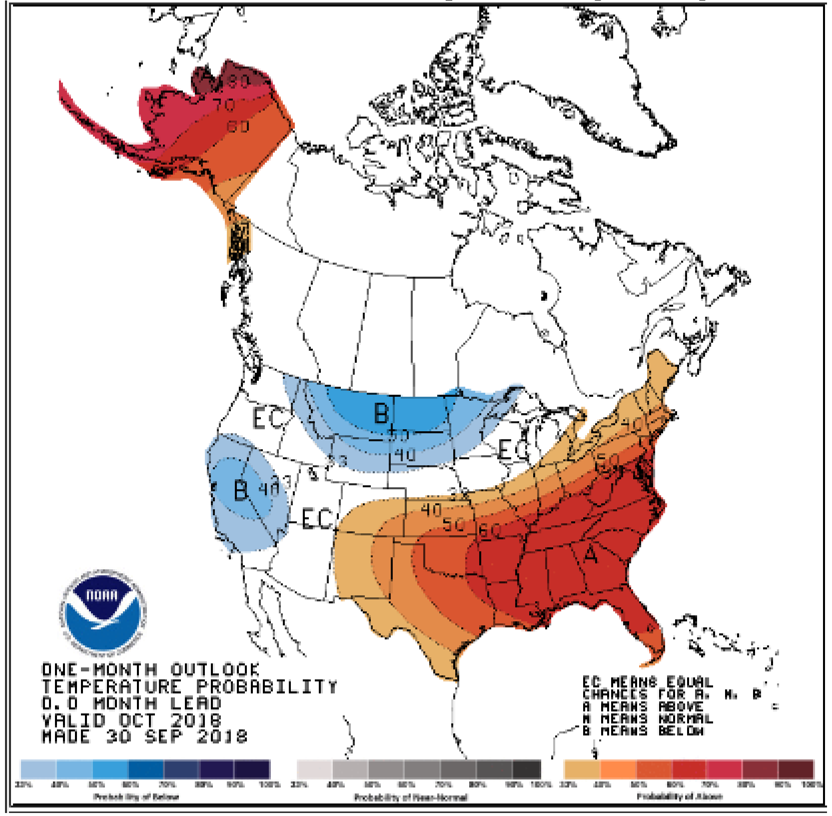
Temperature logger images reprinted from https://www.microdaq.com and www.onsetcomp.com
Temperature and pressure logger from www.omega.com, Thermostat from https://sites.psu.edu/mfsblog/2015/02/08/how

How – Retroactive Temperature Analysis of Existing Sites

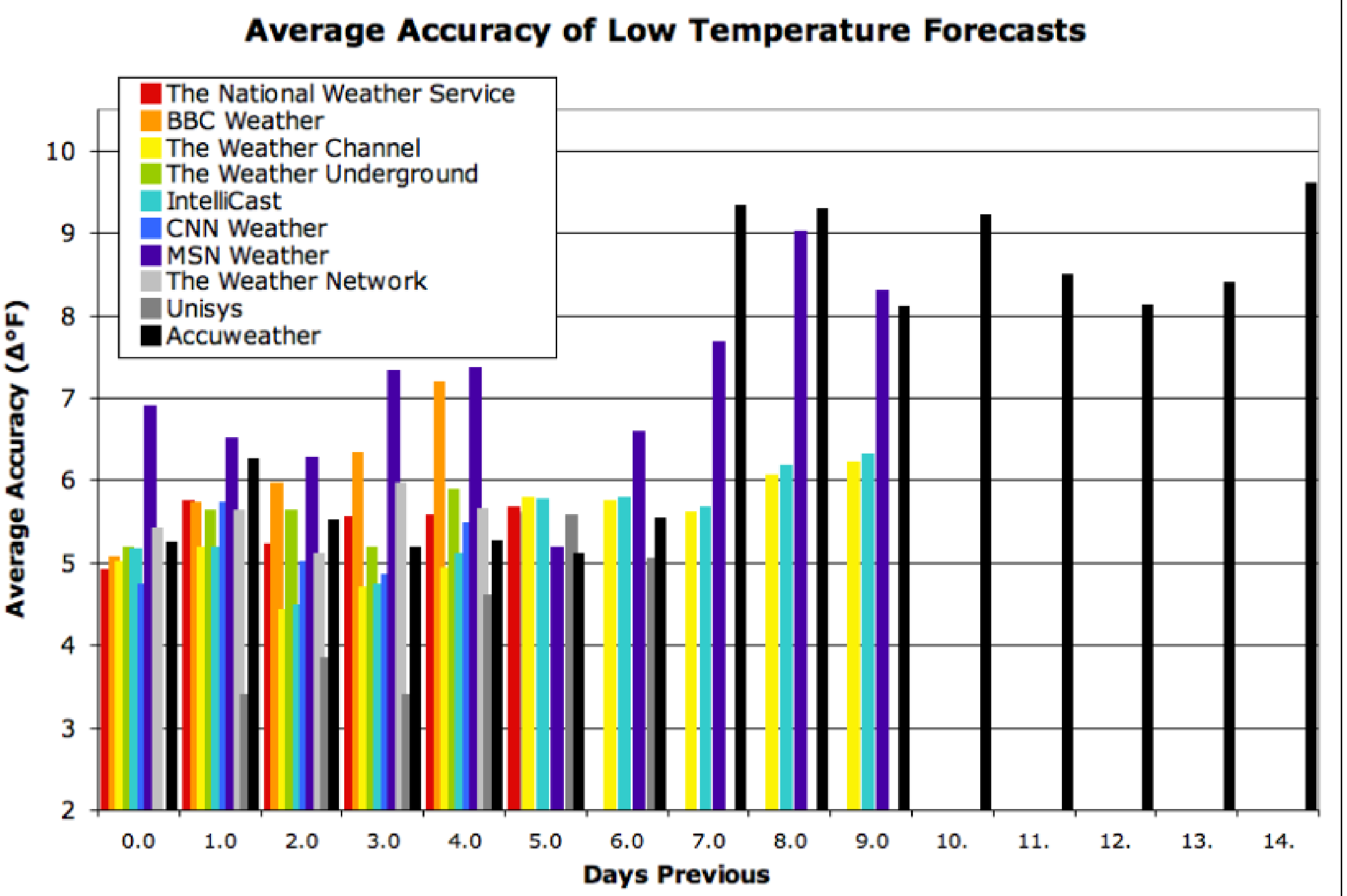
- Do you have sites where you have numerous historic rounds?
- As long as you have sample date/time, you can look up external temperature on line…..
- Then you have a data set that you can use to check differential temperature's predictive value
- Do you have survey forms that document heating status?
- Annual expected range of differential temperature for a building can be calculated merely by knowing how the thermostat is set/if the HVAC is used, and looking up climate data online – available for most towns. Historical data can then be used to evaluate how close to likely maximum stack effect conditions sampling rounds were likely to have been.

How? – Advanced Predictions On-line

- Temperature – readily available forecasts, probably sufficient short term accuracy for purpose



http://www.cpc.ncep.noaa.gov/products/forecasts/



Graphic reprinted from: http://blog.extension.uga.edu/climate/2015/07/when-weather-apps-go-bad/

What: Pressure in VI Conceptual Site Model

- Natural/Environmental Factors:
  - Barometric pressure
  - Wind effects
  - Stack effects
- Anthropogenic/Building Factors:
  - Opening and closing of windows and doors
  - Operation of HVAC systems, fans, other air exchangers

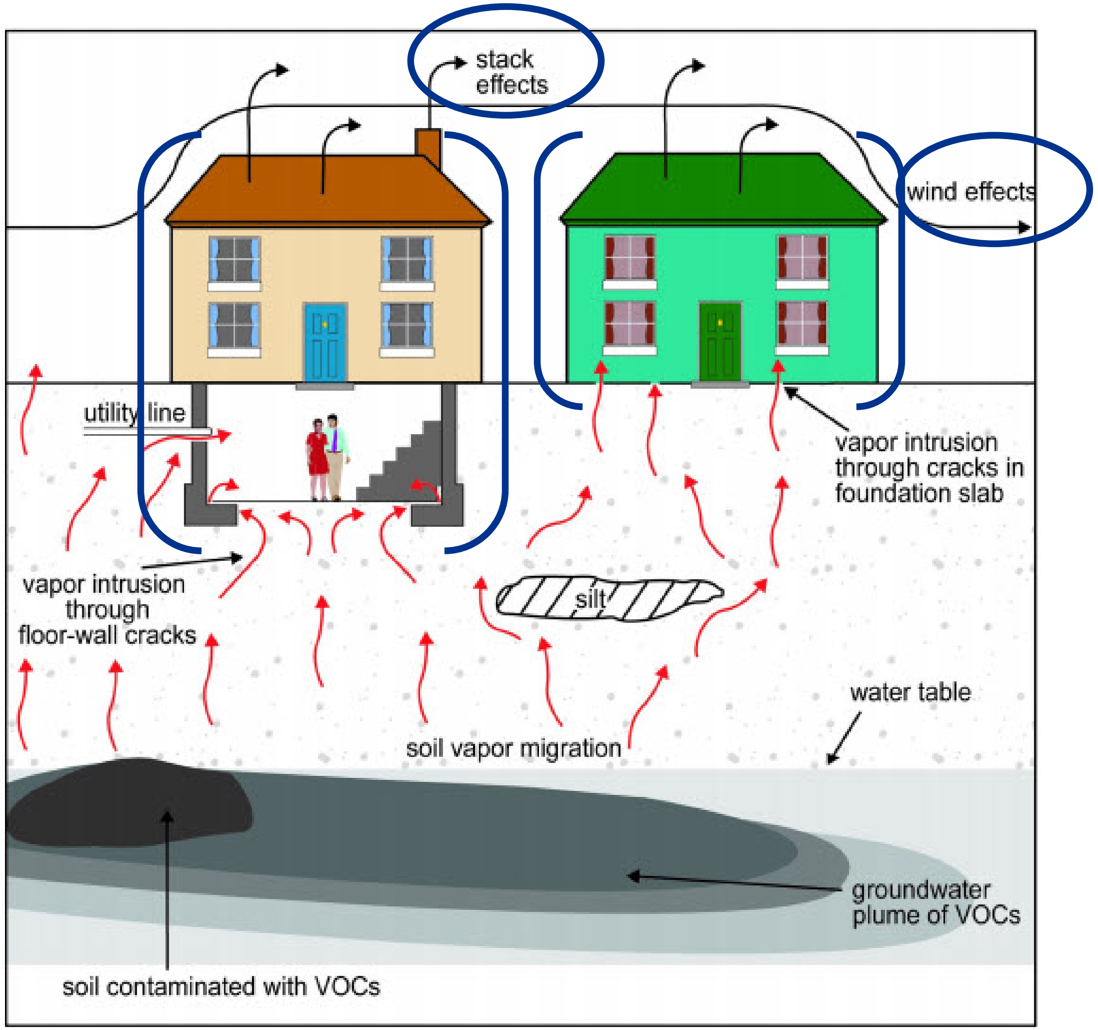


Image: USEPA, 2002

Where: Pressure Measurements For VI

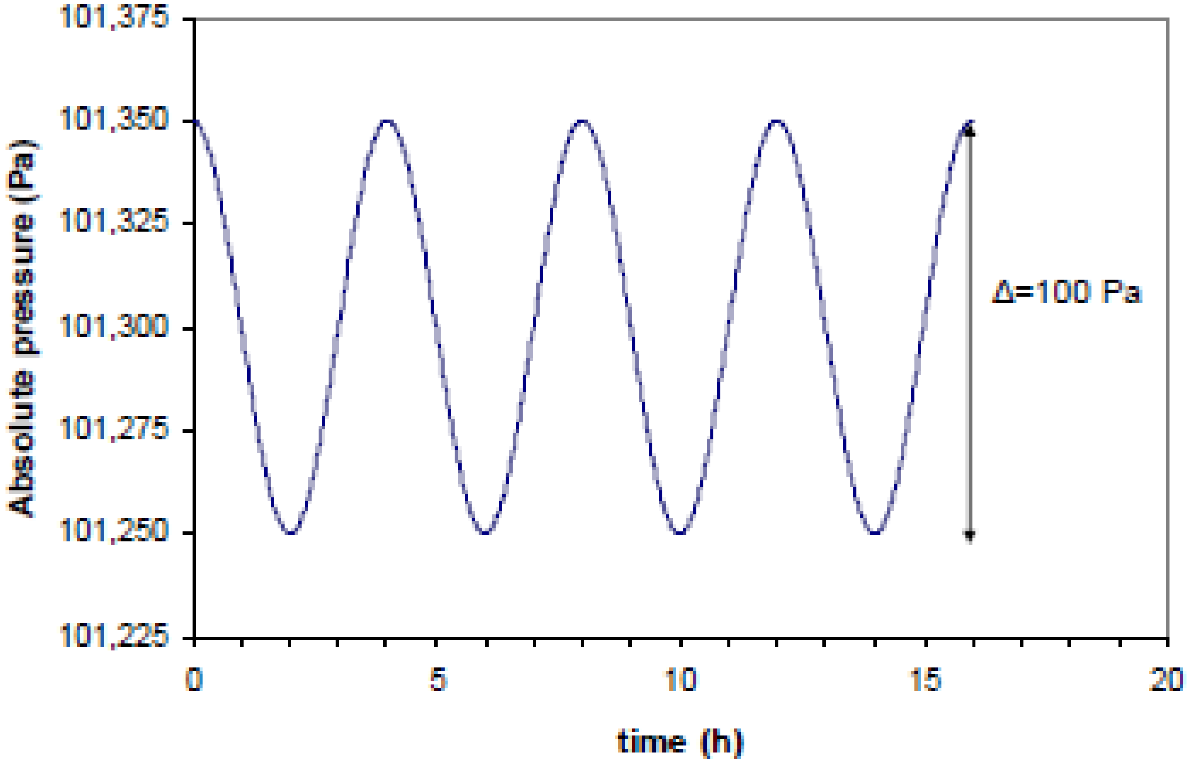
- Atmospheric Pressure (Barometric)
  - Weight exerted by air at given point
  - Decreasing #s associated with worst-case VI conditions[1]
- Differential Pressure (ΔP or dP)
  - Difference in pressure between two points
  - Pressure gradient is indicative of flow direction

Common units:
- atmospheres (atm)
- millibars (mb)
- inches of mercury ("Hg)

Common units:
- **pascals (Pa)** ☆
- inches of water ("H_2O)

(1) MassDEP, 2016

Barometric Pressure Variation Is Larger than Differential Pressure



US EPA “Conceptual Model Scenarios for the Vapor Intrusion Pathway” EPA 530-R-10-003, February 2012, Section 6.3.

Figure 1: Barometric Pressure Variation Example (US EPA, 2012)

Where to Measure Pressure?

- dP (Indoor : Subslab Soil Gas)
  - Indicative of subslab soil gas to indoor air exchange (i.e., vapor entry rate)
  - Requires subslab soil gas monitoring location (generally requires utility clearance/locate to install)
- dP (Indoor Air : Outdoor Air)
  - Indicative of outdoor air and indoor air exchange
  - Outdoor reference locations may be influenced by wind, making it difficult to distinguish trends
- dP (Indoor Air : Exterior Soil Gas)
  - Requires exterior soil gas monitoring point (utility clearance)

Where VI CSM: Differential Pressure

- Differential pressure caused by environmental factors (e.g., wind) and building operations, can *indicate*…
  - Building under-pressurization (VI “on”)
  - Building over-pressurization (VI “off”)
- Pressure fluctuation may be more dominant driver than time-averaged dP

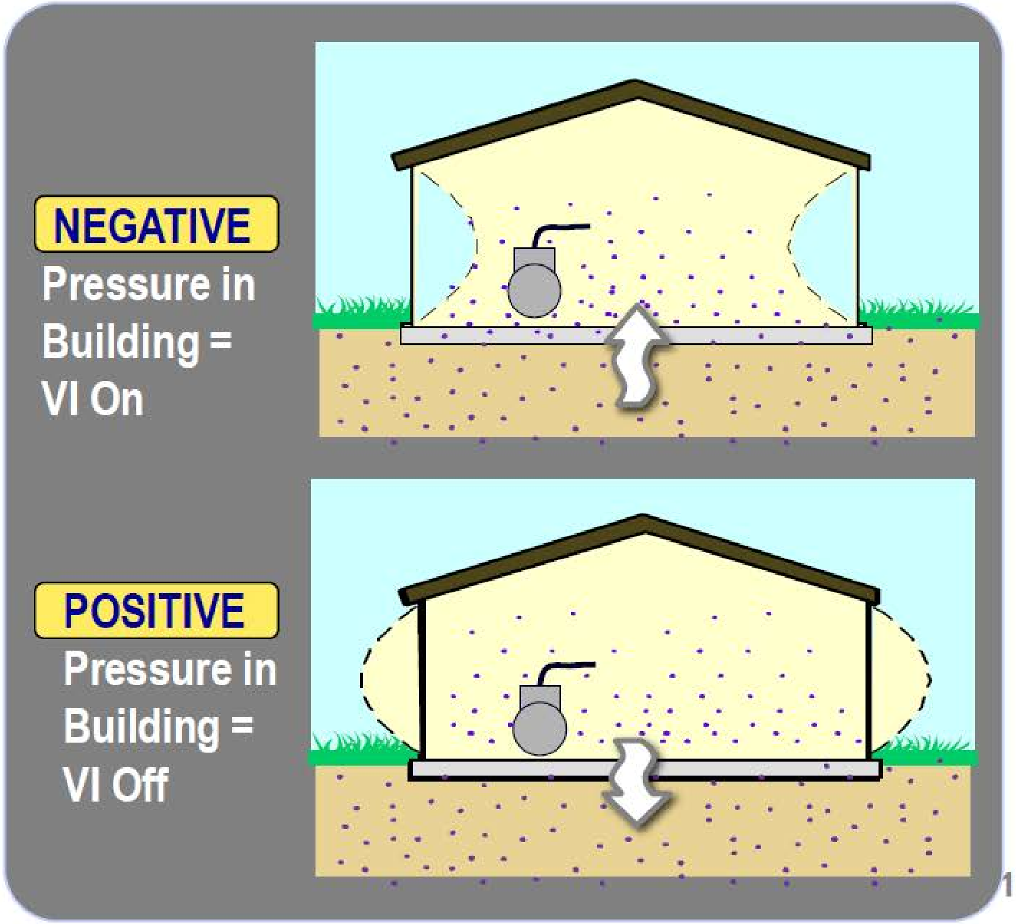
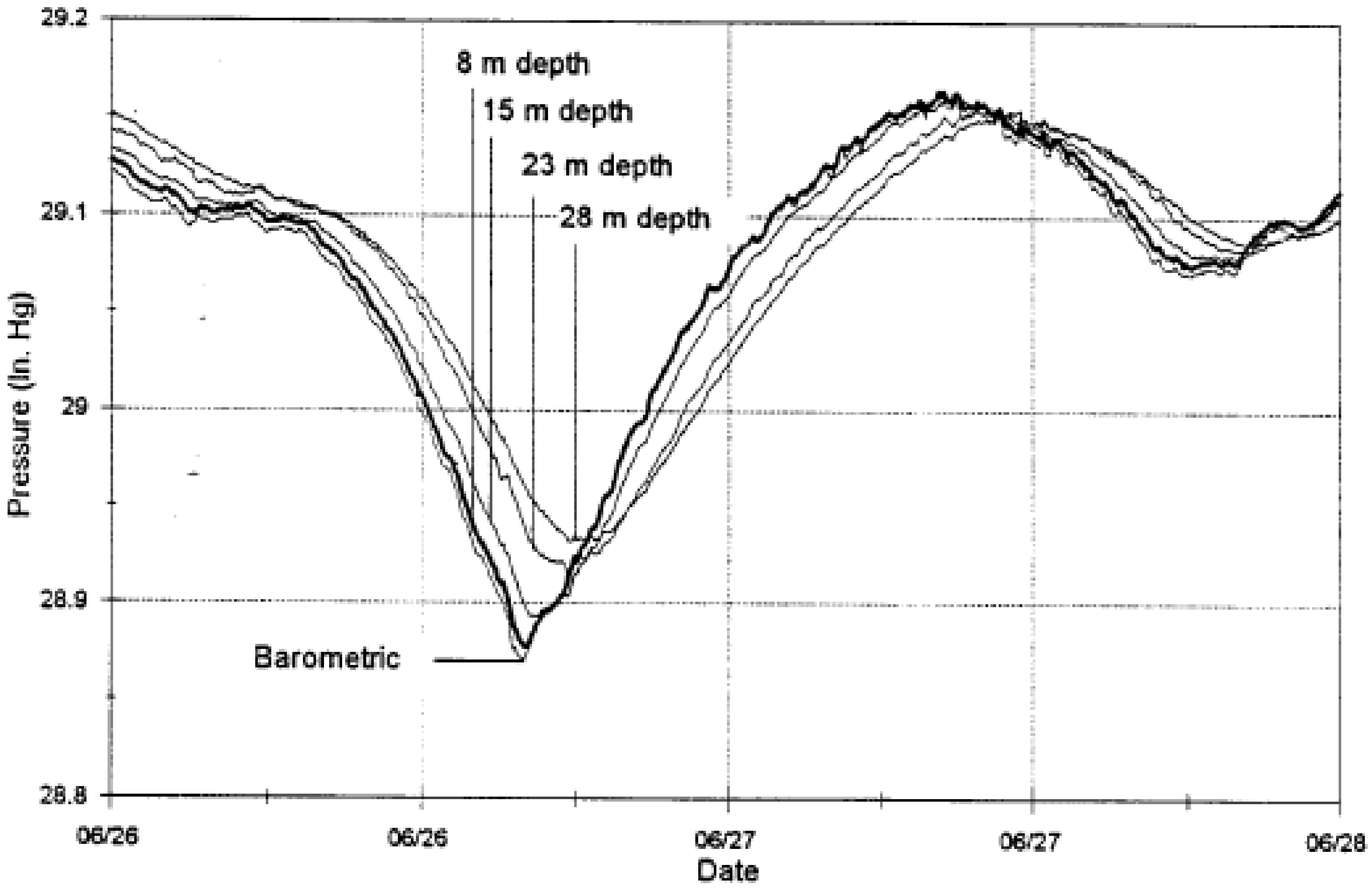


Image: Beckley, L. 2014. AEHS, San Diego, CA

When: Current VI Guidance and Pressure

- On data representativeness and interpretation…
  - "*The collection of ambient temperature and barometric pressure readings during the collection of IA samples including ambient air samples (or sub-slab pressure differential during SSSG sampling) are appropriate to verify data representativeness*" – NJ DEP VI Technical Guidance (August, 2016)
  - "*Measurement of the pressure gradient between the subslab and overlying structure can assist in interpreting the direction of vapor transport, whether into or out of the structure*." – OH EPA VI Guidance (May, 2010)

When? Be Aware of Time Lags in Soil



Rohay, W.J. et. all "Well Venting and Application of Passive Soil Vapor Extraction at Hanford and Savannah River" Prepared for US DOE Office of Environmental Restoration and Waste Management, WHC-SA-2064-FP

Figure 1: Time Lags in Barometric Pressure Observed in The Atmosphere and Soil Gas (Reprinted from Rohay, 1993)

How: Example ΔP Monitoring Options

Dwyer Series 477 Handheld Manometer - $80 to $100 a Week Rental

- Handheld manometers:
  - Can be useful during building surveys; assessing connections between building zones
  - Assessing VI mitigation system performance
  - Generally not capable of long-term data logging
  - Sensitivity varies

Image(s): Pine (http://www.pine-environmental.com/)

How: Example ΔP Monitoring Options

- Stationary units:
  - Best for long-term monitoring, due to data acquisition/logging capabilities
  - Can be setup for remote monitoring

Omniguard 4 Differential Pressure Recorder
Rental: $200-350/month

Image(s): Pine (http://www.pine-environmental.com/)

How Do I Measure or Predict BP?

- Weather station barometric pressure is available in near real-time, and typically hourly archived data: https://www.ncdc.noaa.gov/cdo-web/ https://www.wunderground.com/history/ https://mesonet.agron.iastate.edu
- Barometric pressure is forecast up to 6 days ahead https://www.weather.gov/forecastmaps
- Digital barometers cost about $130 example https://www.fishersci.com/us/en/products/I9C8L6RW/barometers.html
- Consumer grade weather stations cost $100-$400 examples at https://www.weathershack.com/listing/complete-home-weather-stations.html

How: Sensitive Micromanometers are Available

Make/Model	Range	Accuracy	Resolution
Omniguard 4 Differential Pressure Recorder	+/- 0.25” w.c. or +/- 62.5 Pa	+/-0.003” w.c. or +/- 1% of reading	0.001” w.c. +/- 0.5 Pa
Infiltec DM1 Micro-Manometer	-3” to +2.5” w.c. -750 Pa to 620 Pa	+/-1% of measurement or display digit	Serial output 0.0001”w.c. (0.025 Pa) Displays to 0.001” w.c. (0.25 Pa)
Setra Model 264 Pressure Transducer	Various available down to +/- 0.05 in w.c. (+/- 12.5 Pa –one we use)	+/- 1% FS optional accuracies to 0.25% FS	Limited only by the noise of the datalogger
Veltron II Pressure and Flow Transmitter	Various available, we use +/- 0.1 in w.c. +/- 25 Pa	0.1% of natural span	0.0001” 0.025 Pa

How: Best Practices

- How/Where should I setup monitoring equipment?
  - dP sensor/recorder should be located on surface/wall with little to no vibration
  - Minimize tubing length (trip hazard, loss of accuracy)
  - Select reference points that can be easily repeated, similar elevation
  - Seal around tubing that crosses through window, door, or wall
- How do I calibrate the pressure sensor?
  - Generally calibrated by manufacturer (annually or as recommended)
  - Zero calibration (setting zero point) may be necessary, comparing inlets to same reference point

How: Pressure References

- Holton, C. Evaluation of Vapor Intrusion Pathway Assessment Through Long-Term Monitoring Studies, Doctoral Dissertation, Arizona State University, May 2015.
- Schuver, H., Lutes, C., Kurtz, J., Holton, C., Truesdale, R. Chlorinated Vapor Intrusion Indicators, Tracers, and Surrogates (ITS): Supplemental Measurements for Minimizing the Number of Chemical Indoor Air Samples – Part 1: Vapor Intrusion Driving Forces and Related Environmental Factors. *Remediation*, 2018, *28*(3), 7-31.
- Nazaroff, W. W., Feustel, H., Nero, A. V., Renzan, K. L., Grimsrud, D. T. Radon Transport into a Detached One-Story House with a Basement. *Atmospheric Environment*, 1985, *19*(1), 31-46.
- United States Environmental Protection Agency (USEPA). Fluctuation of Indoor Radon and VOC Concentrations Due to Seasonal Variation; USEPA: Washington, DC, 2012.
- Hosangadi, V., Shaver, B., Hartman, B., Pound, M., Kram, M. L., Frescura, C. High-Frequency Continuous Monitoring to Track Vapor Intrusion Resulting from Naturally Occurring Pressure Dynamics. *Remediation*, 2017, *27*(2), 9-25.

Radon Methods

1. What? Radon's role as a tracer in the vapor intrusion process
2. When? Radon variability at various scales – diurnal, seasonal etc.
3. Why? Is Radon a good tracer or even a surrogate?
4. How? Low cost data sources and measurement equipment available
5. How? EPA, AARST Methods, Lab and Instrument Certification Programs

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Radon

- What?: a naturally occurring, colorless, radioactive gas that comes from the natural decay of uranium and radium found in most soils.
- Why?: A relatively unique tracer for soil gas with few indoor sources.
- Why? Significant public health benefits
- When? would radon be expected to be a good surrogate for VOC vapor intrusion?
  - When there is a well mixed subslab plenum
  - Above ambient range – when are indoor concentrations likely to be above it (Judging from likely attenuation factor and radon susceptibility zones)

Where to Measure Radon?

- Can monitor in subslab soil gas, external soil gas, crawlspace, ambient, entry pathway and/or indoor air
- Select subslab locations – representing each major section of the foundation and accounting for spatial variability
- Select indoor locations to represent the zones in which exposure likely occurs – for example breathing zone height in occupied basements and first floors.
- Ambient air radon can be an important comparison because it can be significant as compared to indoor levels. Various estimates of ambient radon in the US average 0.4 to 0.7 pCi/l.
- Ambient radon is higher at night, and over land then over oceans. Radon seasonality in ambient air depends on wind direction and precipitation .
- Monitoring of crawlspaces and air in preferential pathways (for example wall cavities) can provide insights to the times and places of soil gas entry. Radon surveys can be used to identify entry points such as functioning cracks.
- Radon is likely to be detectable in soil gas almost everywhere in the US. But concentrations strong enough to be clearly observable after attenuation into indoor air are most likely in medium to high radon risk areas (zones 1 and 2). https://www.epa.gov/sites/production/files/2015-07/documents/zonemapcolor.pdf
- Very roughly high risk radon zones are likely to have soil gas radon >1350 pCi/l, medium risk radon zones 270 to 1350 pCi/l (Lewis and Houle, 2009).

How: Screening Whether Radon is Likely Useful at Your Site

- Consider ambient concentration and relevant range of attenuation factors
- Radon susceptibility maps are most often portrayed at the county level "The Map was developed using five factors to determine radon potential: indoor radon measurements; geology; aerial radioactivity; soil permeability; and, foundation type." http://www.epa.gov/radon/zonemap.html
- Underlying data discussed in series of reports on line i.e.

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

GEOLOGIC RADON POTENTIAL OF EPA REGION 3

- But in some areas more detailed town or zip code level maps are available

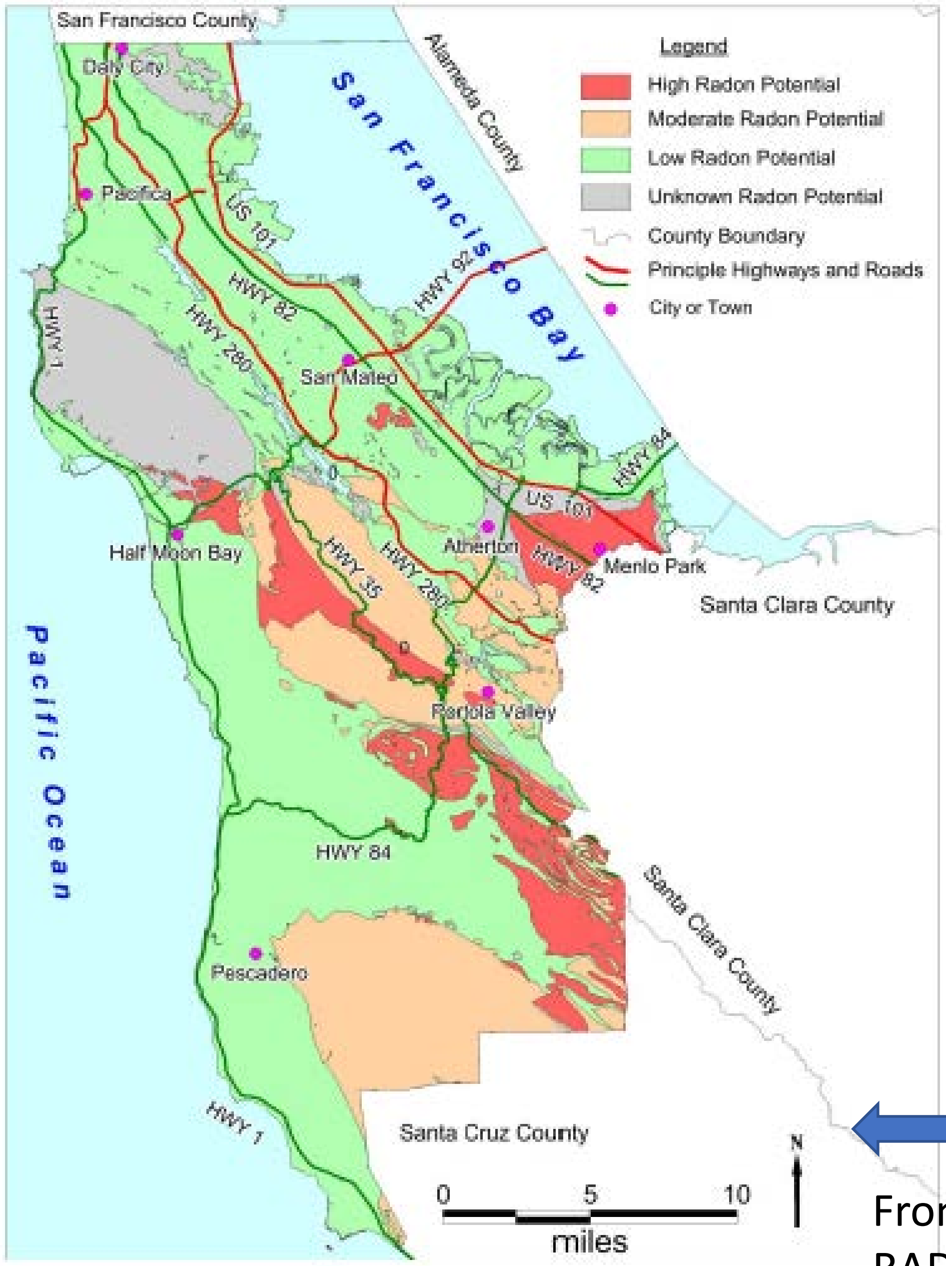
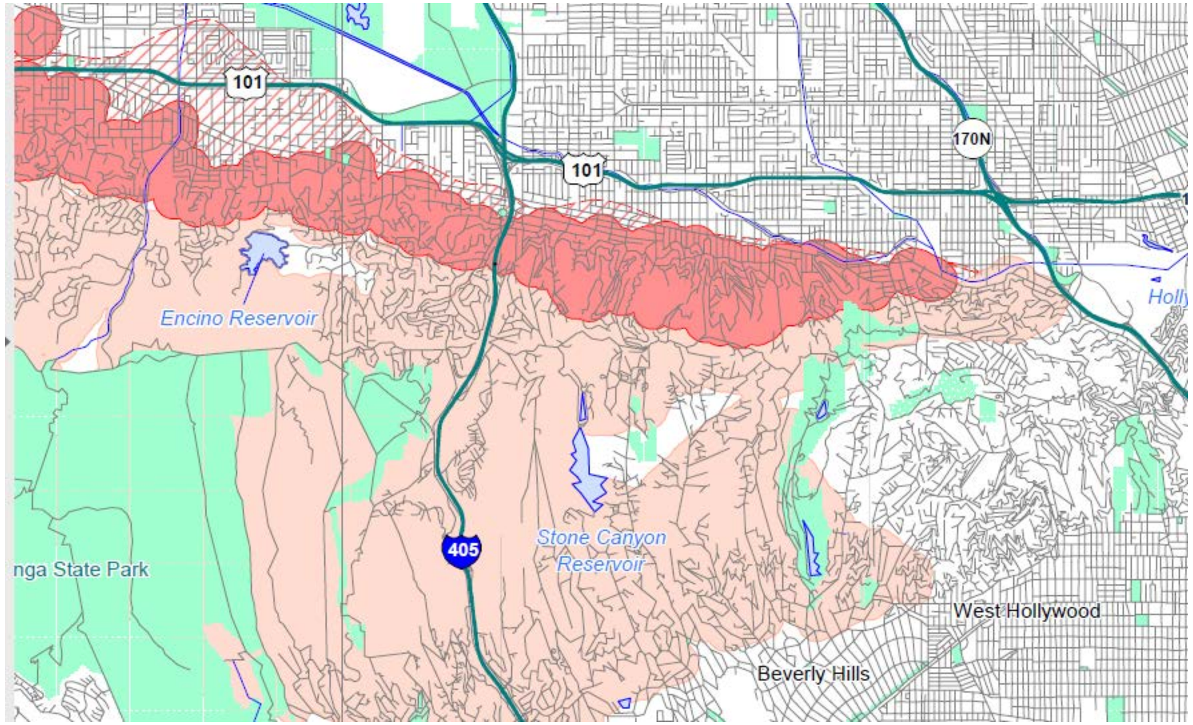


Figure 6. San Mateo County radon potential zones



Expanded Section from:

Radon Potential Zone Map for Southern Los Angeles County, California

Ron Churchill

California Geological Survey

January, 2005

From: CA Geological Survey SPECIAL REPORT 226 RADON POTENTIAL IN SAN MATEO COUNTY, CALIFORNIA By Ronald K. Churchill, Ph.D. PG 2014

How: Radon – Example Consumer Grade Monitors

- All three are configured for indoor/ambient air ONLY
- Safety Siren Pro3
  - $149 reads out the average of 48 hours to 7 days.
  - Performed well in comparision against electret in the 0-5 pCi/l range (EPA, 2012) but no data logging.
- Airthings "Wave"
  - $199, data acquisition one hour frequency, can store up to a year; downloads to app or csv file.
  - Alphaspectrometry based device, claimed to be tested against the Alphaguard
  - range claimed to 1350 pCi/l
  - Software produces nice date/time stamped record with temperature, humidity and pressure records
- Radon "Eye" RD200
  - <$200; one data point per hour, no time stamp in low cost version, one year data capacity
  - Plug in, Pulsed ion chamber; connects to app
  - The sensitivity of the radon eye is 0.5 cpm/pCi/l.
  - Range 0.1 to 99.99 pCi/l; accuracy is <10% at 10pCi/l
  - Has an NRPP certification

Image reprinted from www.homedepot.com

Image from https://support.airthings.com/hc/en-us/articles/115004781245

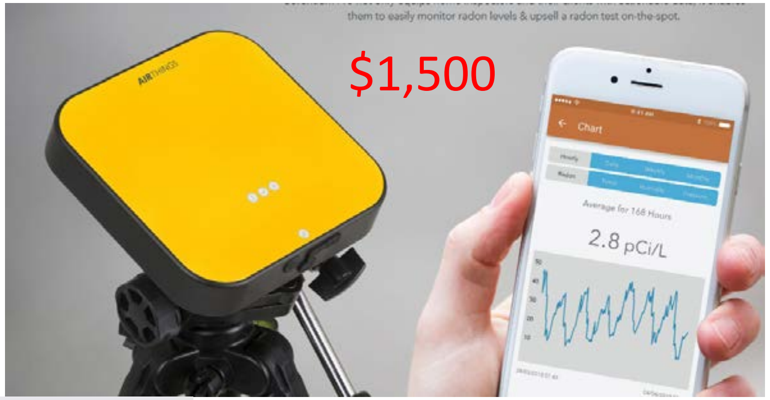
Image from RadonFTlab.com

How: Radon Example Pricing of Professional Grade Certified Equipment

- List of all certified devices:

http://aarst-nrpp.com/wp/certification/approved-devices/

- Air Things Corentium Pro - $1,500 purchase; $120/month rental - hourly data radon, temperature, humidity,; USB or wireless data logging https://airthings.com/us/pro/#rent
- Durridge RAD7 $6,887 purchase; has data logging. Rental $57/day; $486/month
- Femto-Tech CRM-510 $4,595 purchase $149/mont Rental
- Sun Nuclear model 1028: $995 purchase, 720 data point storage; USB data transfer
- Some of these units can do either indoor/ambient air OR Soil Gas (has a hose barb!)



How: Radon – Time Integrated Sampling with Certified Labs - Methods described in USEPA 402-R-92-004

- Charcoal with analysis by liquid scintillation in lab
  - typical price $17 to $25 per sample, lower in bulk ($11.50
  - Typically 2 to 7 days, typically 0.1 pCi/l detection limit
  - See for example https://www.radonzone.com/product/short-term-radon-test-kit.html https://www.emsl.com/ProdCatSearchResults.aspx?action=prod&ProductID=rradngtk&Name=radon-gas-test-kit---retail

- Alpha track Detectors – plastic or film device counted in lab
  - $25 per, $22 in bulk
  - Typically used for longer tests – i.e. 1 to 12 months
  - https://www.rssi.us/sunshop/
  - https://www.accustarlabs.com/radon-testing-product-specifications/alpha-track.aspx
- Electret's – readable in field – claimed price $2 per sample in bulk – starter kit $2,595

- http://aarst-nrpp.com/wp/certification/database-search/aarst-nrpp-certified-analysis-laboratories/
- http://aarst-nrpp.com/wp/certification/approved-devices/

Radon Measurement References

- ANSI/AARST Methods: "Protocol for Conducting Measurements of Radon and Radon Decay Products in Homes" MAH 2014, "Protocol for Conducting Measurements of Radon and Radon Decay Products in Schools and Large Buildings" MALB 2014 and "Radon Measurement Device Requirements" MS_PC-2015 https://aarst-nrpp.com/wp/store/aarst-standards/
- Mosley, R.B., D. Greenwell, and C.C. Lutes. 2010. Use of integrated indoor concentrations of tracer gases and volatile organic compounds (VOCs) to distinguish soil sources from above-ground sources. Poster presented at the *Seventh International Remediation of Chlorinated and Recalcitrant Compounds Conference*, Monterey, CA, May 24–27.
- Lewis, Robert K., and Paul N. Houle. "A living Radon Reference Manual." *Pennsylvania Department of Environmental Protection Bureau of Radiation Protection, Radon Division and University Educational Services, Inc* (2009). http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.371.9318&rep=rep1&type=pdf
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- U.S. EPA (Environmental Protection Agency). 1992b. *Indoor Radon and Radon Decay Product Measurement, Device Protocols*. EPA 402-R-92-004, Office of Radiation Programs, Washington, DC, July (revised). https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=94001H1B.txt