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REPRODUCIBLE MEASUREMENTS: HAVE WE LEARNED ANYTHING OVER THE YEARS?

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ABSTRACT

Questions over reproducibility of radon measurements seem to permeate most radon controversies. Such questions are a cornerstone for misinformation and dismissing the radon risk message. The infancy period from 1986 – 1993 produced funded research with astounding technical expertise on all aspects of radon. During this infancy, many random pieces of information were presented. But over the years, a distilling of information has occurred.

A reproducible measurement is a high priority component when making decisions for homeowner protection. By attempting to identify test variables and their relative magnitude, we can greatly enhance confidence in both test reproducibility and a test's relationship to occupant exposure.

Conditions during any type of measurement (such as aspects of radon entry for radon measurements) possess overwhelming impact above all other factors regarding the achievement of reproducible measurements as well as the resulting interpretation of any measurement data.

To provide a scope on the issue, information has been summarized and revisited on both a wide scale basis and for individual homes. Related topics include: test device quality; short-term v/s long-term tests; basement v/s upstairs; principles of radon mitigation; and the impact of variables such as the of rain, frozen ground, temperature, barometric pressure, and wind.

Resources: Papers from AARST conferences and documents published via EPA, DOE, etc. Additionally, a Database of over 7,700 homes including 1400 simultaneous basement / 1st floor measurements. Ten years of weather service data was acquired for comparison.
Homes were mostly suburban, two-story basement homes with forced air heating-cooling systems and less than 50 years of age. The Database may represent a reasonable percentage of homes in Zone 1 areas across the North Central and North Eastern United States.

INTRODUCTION

The Past: Reproducibility and Occupant Dose

At the first radon conference in 1988, Arthur Scott[†8,9], Bruce Henschel[†26,27] and others accurately described many radon fluctuations which might affect test reproducibility. Several papers have expressed concern over test reproducibility or test validity relative to occupant dosage.[†10]

Most studies were either large surveys with little consideration for test conditions, or; single home detailed analysis (where significance to other housing stock or climate may not apply).[†3] They sought to determine uncertainty bounds for predicting long-term indoor concentrations from short-term measurements by assuming radon variability to be a random quantity.[†3]

A lot of nonsense resulted (far beyond simple differences in ideological persuasion). We still hear about it today. Large surveys reported findings such as; lower income and rented homes have less radon or that nonsmokers have higher radon in living rooms. Single home studies have reported rare and extraordinary conditions as if always occurring in all homes. Efforts focused on predetermining high-risk homes without testing. As a scientific body, we were just an infant.

The Present:

Just as the words "radon mitigation" have become virtually synonymous with "soil depressurization", many of those experiencing thousands of tests do not simply view radon entry or distribution as a random quantity. Prudent assumptions must be made daily, even though it is not possible without exhaustive research to account for all variables or to quantify specific dose for each occupant.[†22] By accounting for radon variations as a response to physical systems (i.e. stack affect), the bounds of uncertainty are shown to decrease regarding predicting long term indoor levels with short term measurements.[†3 †6 †7]

The purpose of a radon test? Health. Most tests also occur during a home sale. Like any item inspected, an inspector's obligation is not limited to guarding against adverse Health conditions. Obligations also extend to guarding against adverse Monetary impact. The average home is sold every 5-7 years and future disclosure of any adverse condition is required by law. Within the bounds of accepted standards, it is the inspector's fiduciary obligation to provide any client with complete information about a home and related published guidance. In order to meet contract timeframes, a Pass/Fail judgement must usually be made from a single chance to test. Retest arguments often enhance the chance for cheating, strained negotiations, and monetary losses unrelated to radon mitigation. Such confusion can often result in leaving homeowners needlessly at risk.

WIDE SCALE OVERVIEW:
IS THE MEASURMENT ACCURATE?

The question has two meanings: 1.) Did the device and operators make an accurate measurement? Or, 2.) Does the measurement accurately reflect an occupant's dosage?

Device Precision (or Accuracy).

Most devices are reasonably accurate for their purpose. As reported in device intercomparisons of 1995[†1] and 1998[†2], all commonly utilized device technologies for measuring radon are surprisingly precise. Assuming quality control (QC) is practiced, different devices will usually tell the same story when placed side by side under the same conditions.

Most devices varied less than 10% from chamber target values. The reference chambers (some of the best equipment in the world) agree by about + or - 3% with an uncertainty of about 5.2%.

Long-term devices are not more accurate or precise than short-term devices. [†1, †2] They are simply expected to be more reflective of actual long-term dosage. However, dosage is a moving target and variables can exist even with long-term measurements.

Short-term Measurements versus Long-term Dosage:

Wide scale surveys have reported that a strong relationship exists between short-term tests and the annual living area averages Surveys as wide as 20,000 homes over 30 states indicate that the higher the short term measurement is, the greater the odds that annual average dosage will exceed EPA's 4.0 guideline. These surveys also indicate that when readings from either basement or 1st floor reach 6-10 pCi/L, the odds begin to increase significantly that the annual living area average will exceed 4.0 pCi/L.[†4] It should be noted that BEIR VI [†18] suggests that exposures between 2-4 pCi/L do represent a definable risk. For borderline readings slightly above or below the 4.0 guideline, considerations to prevent this needless risk would seem prudent, even if determined at random by screening measurements. Arguments[†5] regarding borderline readings would remain regardless if the action level were 2, 4, or 20 pCi/L.

To aid control over obvious variables, EPA established Closed House Protocols for short-term measurements. [†25] It is noteworthy that, on the national average, less than about 30% of the year is conducive to open building conditions (according to wide scale calculations of occupant comfort and heating/cooling degree-days). [†26, 27]

BACKGROUND REVISIT: RADON ENTRY & RESULTING CONCENTRATIONS[†23]

Most variables are not a random quantity but caused by changes in source, driving force or dilution.[†23] To define the variables, we can look at the principles taught for radon mitigation as they apply to the most common soil suction system on earth: A house.[†23, 24, 25, †3, †6, †7]

Source: Radium content in soil is quite commonly a primary source of radon. Regardless of the specific source material, traces of radium will break down into radon gas at a perpetual and perfect rate until the end of time. The same soil under each home will always be there. ***Variability?*** Most often a constant. Variability sometimes occurs due to water and soil porosity.

Pathways: Where does it enter? The answer is, "almost everywhere". All buildings have a great multitude of pathways to the soil. Some are easily identified and many are not. No building or slab is air-tight, even if all visually identifiable entryways appear sealed.
Variability? Leakage area always exists between soil and living spaces and is a constant.

Driving Force (Differential Pressure): Differential pressure (stack affect) is quite commonly the primary mechanism for radon transport into a home. It is most often a reasonably perpetual force throughout the year under closed building conditions. Radon is heavier than oxygen yet still much lighter than a dust particle. It is easily transported by the smallest amount of air pressure. ***Variability?*** Typically, driving forces are the most variable factor, regardless of origin or nature.

Dilution: ASHREA[†24] Standards for fresh air in home design recommend at least 0.35 air changes per hour for homes and the typical home may have 0.5-1.0 air changes per hour.[†25] This means that the entire volume of air in a home should leave a home about every 1-3 hours.[†24, †26, †16] If all tiny gaps where wood adjoins and around windows and doors could be put in one place, it could be said that most homes may easily have a 12-18 inch diameter hole in the wall. ***Variability?*** Dilution leakage area is substantial, yet a constant under closed protocol conditions.

As warm air rises upwards and leaves a building (by stack affect), it is replaced from somewhere. Replacement, make-up air for all the air leaving is drawn from lower regions of the home. Outside air enters a thousand places. Resulting cold drafts are easily identifiable during winter in cold climates. Dilution is perpetually occurring in all closed buildings.

The RESULTING MIX or RADON CONCENTRATION: Though a large volume of outside, make-up air is always entering a building, there often exists a large volume of available make-up air from the soil. Closed House Protocols stabilize pressure, dilution, and therefore radon concentrations in a home. BOTH RADON AND OUTSIDE AIR ARE SUCKED INTO THE HOME. WE MEASURE THE RESULTING MIXTURE OR CONCENTRATION.

Other Radon Entry Mechanisms

Variability of Diffusion and Emanation: These mechanisms for radon transport are seldom variables for a reproducible measurement. *Variability of* Radon from Water: The outgassing of radon from water is an occasional variable. Papers are available on related subjects. Due to time constraints, the scope of this paper can not properly address the variability of radon outgassing from ground water, water supplies and especially variables for radon concentration within water.

CRM OBSERVATIONS OF EXPECTED FLUCTUATION FACTORS

Stabilization rates (radon and fresh air mixture):

The taller the building and the wider the differences between indoor and outdoor temperatures, the more forceful the stack affect. The resulting mixture of radon and dilution air stabilizes at different rates depending upon season or outside temperature. Stabilization often results within only a few hours during cold weather in a two story or basement structure. However, it may take 8-12 hours in excessively mild weather. The Closed House Protocol, requiring 12 hours of prior closed conditions, has proven to be adequate in achieving stabilization regarding pressure, dilution, and therefore, reproducible radon concentrations. [†25] Essentially, a house can be completely opened to outside air yet, after closing the home for 4-12 hours, concentrations will be almost identical to concentrations before airing-out the home. [†17]

Diurnal Patterns (and Driving Forces):

The intensity of convection airflow (or stack effect) changes from hour to hour, yet is still relatively constant. Even when negative pressure in a building is too low to measure, the upward flow of radon into the building is often still occurring.

Winter: We often see the classic diurnal pattern of higher readings in the middle of night. Colder temperatures at night cause greater furnace fire activity and enhanced stack effect at those hours.
Summer: We occasionally see a reversed diurnal pattern with the middle of the afternoon highest due to heat. However, central air-conditioning blowers often dominate the fluctuations.
Spring or Fall: We occasionally see dramatic changes. For hours when inside - outside temperatures are similar, we might see dilution. As the day continues, we may suddenly see a virtual flood of radon. As stack effect regains consistency, radon, which was dormant in the soil and increasing in concentration, is suddenly drawn into the building. Retests often show more steady graphs, yet a similar average reading. **NOTE: This observation indicates that radon is slowly yet consistently being released by the soil, and, at some time during a 48 hour period, the overall volume of easily available radon most often will eventually be displaced and distributed into a home.

REVISITING REASONABLY CONSISTENT OR EXPECTED CONDITIONS

Mechanical Items: ***Variability?*** Certain designs or conditions discussed later can cause dramatic changes. However, normal activation of most appliances, such as temporary operation of bathroom fans or heating/cooling systems, typically have minor impact on a measurement. The effects of most mechanical HVAC and exhaust systems are often minor compared to the natural occurring Building Induced Suction which we call stack effect.

Momentary Events: ***Variability?*** Usually insignificant. As later discussed under Rain events, "the magnitude of expected impact" for any momentary event (such as opening a door) is not expected to have significant impact regarding the final average reading.

Occupied or Unoccupied: ***Variability?*** Usually not expected to be highly significant.

Excessive traffic in and out of a home may cause: a. extra dilution in spring, fall, and summer, or; b. extra radon entry in winter due to greater activation of combustion heating systems.

Vacant homes may display: a. Lower than typical readings in winter due to vacation settings on thermostats, or; b. marginally higher readings in summer due to thermostat settings that allow excessive heat in a home.

New Homes (revisited): ***Variability?*** As soon as typical occupied conditions are available, there are no basic variable factors different from any home test. Disturbance of native soil during new construction process does not subsequently cause temporary increase or decrease in measured radon levels and is typically not a variable factor. However, closed building controls can be a challenge due to construction schedules.

Two-Story Basement Homes: Stack-effect or outdoor/basement depressurization (ΔP) has been measured as a pressure difference of somewhere between about 0 to 5 Pascal. [†19] Only a few Pascal of consistent building depressurization may render stack-effect dominant above barometric pressure swings as a driving force for radon entry.

Single-Story Homes: Single story structures may be less dominated by stack effect. Radon entry may be dominated more by driving forces such as barometric pressure, wind, water, and mechanical equipment.

WIDE SCALE REVIEW OF COMMON QUESTIONS AND DATABASE COMPARISON

DATABASE AND LIMITATIONS: 1.) Mostly suburban, two story or basement homes with forced air heating-cooling systems. Most of the homes were less than 50 years of age.
2.) The scope of specific effects on individual homes is discussed later in greater detail. 3.) Geology, soil, home design and weather for Mountainous and Desert regions are expected to be quite different. Home design for rural, inner city, older homes and warmer or colder climates may also be quite different.

17. **Database consistency**: After deleting cheated and post mitigation tests, the overall average of the remaining 4,400 home tests spanning 362 weeks virtually matched the Kansas database of about 4,000 homes for this county:

Homes 4.0 or greater = 43% Average of All Database Tests = 4.71 pCi/L

2.) **Basement testing reproducibility**: As per most studies, our data verifies that basement readings are surprisingly consistent season to season. Basement locations provide the most reproducible measurements by far. Difference from total database Radon Average (DRA):

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
-13%	-12%	1%	-1%	1%	-6%	-18%	-8%	24%	33%	-1%	1%

3.) **Basement versus the Upstairs**: A strong correlation is seen between basements and upstairs. Simultaneous measurements of basements and 1st floors provided these seasonal percentages of upstairs readings compared to the basement readings:

Season→	Cold	Cool	Mild	Warm	Hot
Upstairs Rn→	69%	61%	*53%	66%	**72%
Basement:	100%	100%	100%	100%	100%

** Little air-handler activity. ** Highest upstairs and lowest basement readings occurred during hot weather and continuous air mixing. Hot season daytime temperatures averaged at 91° F and a -5% difference from all basement Rn average was indicated.*

a.) Radon distribution through homes tracked with activation of cooling/heating system blowers, which are so typical in homes of today. b.) Within our data on individual homes, we've seen many examples of potent homes reflecting low levels (outside air) on the first floor during mild weather when no air-handler activity occurs. We note that either short-term or long-term measurements taken in upper regions of a home during mild weather are very susceptible to producing false-negative results. c.) Due to central air system design, 2nd and 3rd floor readings were about the same as the 1st floor above the basement. d.) It would be

expected that, since the widespread installation of central air conditioning in the mid-1960's, actual dosage has been significantly greater for much of our population. In review of early papers suggesting failure of the (linear-no threshold theory), we saw no compensating factors for older cancer data of 1950-1969 versus upstairs measurements in the 1980's regardless of a significant differences in building and mechanical designs between those eras.

4.) **Rain** (revisited): The principles behind rain causing higher fluctuations are well documented. Enhanced radon transport can occur as a result of specific conditions of soil porosity and rain. This higher impact seems greater when dry soil conditions exist just prior to the rain. Also, single story homes where stack effect is less dominant may show greater susceptibility to variations caused by rain and accompanying barometric pressure swings. However: Our database and individual home data does not agree that typical rain events always causes higher radon.

All Weeks with:	<1" rain	→	0%	difference from all Rn Avg.
	>1" rain	→	-1%	

Often we've seen two different homes tested simultaneously and one jumps high while the other drops low during a rain event.

Magnitude of Statistical Impact for Brief Events (such as a Typical Rain Event): Typical rain events usually result in a brief impact as witnessed on thousands of CRM tests. Let's look at a common, three-hour rain anomaly on an 8.0 pCi/L test. Though it is rare to see fluctuations this wide, assume that 3 hours of the 48-hour test either fluctuated upward to 16 pCi/L or down to 0.0 pCi/L. The 48-hour average is only altered 0.5 pCi/L (or 6.25%). Regarding longer rain anomalies: On an 8.0 pCi/L test, a person must imagine that 24 hours of a 48 hour test were 0.0 pCi/L to get a resulting test average of 4.0 pCi/L. An anomaly causing such a 50% impact is rarely plausible under closed protocol and normal conditions.

Rain Extremes: Heavy rain events can cause lower fluctuations. Furthermore, the lack of rain can cause higher than typical readings.

Yearly rainfall average:	39" rain			
Floods of 1993	53" rain	→	- 3%	difference from all Avg.
Mild drought 2000	31" rain	→	+3%	

5. There is no better sealant to keep soil air from entering a home than a rising water table that floods a basement. The water table follows the contour of the land yet still varies greatly at each specific location due to differences in soil density, bedrock depth, etc. Under homes close to the water table, soil saturation may occur quickly with a minor amount of rainfall.

6. The lack of rain (or drought conditions) is seen to result in higher readings due to a lower water table and a larger, more easily available radon source. Pores between soil granules become open for a much deeper distance from the home. (I'll coin this the "tiny Karst syndrome"). Crevices may form in the soil. Even dried underground waterways may allow soil air movement from far distances. Offgassing of radon during a receding water table typically occurs over a slow period, therefore it might be expected to have less impact than the natural enlargement of pores and volume of available source.

5.) **Frozen or Capped Soil (revisited)**: We found 18 weeks in the database where temperatures were below 32° F with precipitation.

Avg. Precip.	Avg. Temp		
0.34"	25° F	→	-19% difference from all Avg.

Studies have reported higher readings with capped soil. Enhanced radon transport and source availability can be experienced with capped soil in regions where deep porosity exists under a home due to porous soil, rock or even crevices.

However, our data indicates capped soil can also produce false-negative potential. For areas without highly porous soil, radon transport can be inhibited. When above-grade air is unavailable to the soil, there may be little or no source of make-up air for allowing soil air displacement. The bottom of the soda straw is corked. Reduced make-up air for the soil would result in reduced volumes of sub-slab infiltration and overall building exfiltraton. In fact, increased fresh air infiltration in the home might be expected to result.

6.) **Barometric Pressure (revisited)**: Many studies suggest a direct correlation to low barometric pressure causing greater radon entry. Due to anticipated stack-effect dominance in most homes with a basement, we seldom see barometric pressure swings that directly correlate with hourly radon fluctuations. Individual home comparisons also support this data below.

All Barometric Avg. 28.92		
Tests conducted below 28.92	→	0% difference from all Avg.
Tests conducted above 28.92	→	0%
At more extremes: -------		
Tests conducted below 28.77	→	-2% difference from all Avg.
Tests conducted above 29.01	→	-12%

This data for two-story basement homes indicates that high swings in barometric pressure serve to increase false-negative potential relative to other times of more typical barometric pressure. Single story homes may react differently.

7.) Wind (revisited): The effects of wind are well documented and EPA protocols can cause invalidation of tests during excessive winds. [125] High winds are expected to produce significant pressure changes in a home. It is therefore commonly suggested that high winds may usually result in higher radon concentrations in a home.

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

The negative impact in radon seen in our data during high winds indicates that greater dilution is forced into many homes which also results in less negative pressure in a home.

RED FLAGS (GENERIC) – POTENTIALLY SEVERE VARIABLES

Wide fluctuations are most often caused by substantial changes in building operation, weather changes, or artificially induced by an occupant to alter readings.

Severe weather (i.e. tornado, flood, or hurricane): Severe air pressures accompany tornadoes and hurricanes. The magnitude of impact is different for each home and impossible to estimate. Hurricanes are often accompanied with severe rain and flooding. Protocols support that any severe weather condition may produce an impact on tests that will not be reproducible. [125]

Building Mechanical Operation and Design.

Certain mechanical system designs and conditions of a building can have major impact on the reproducibility of measurements. Substantial changes in pressure or dilution can occur even with seemingly minor events.

Homes With Return Air Ducts Under the Slab: This building design is common in certain regions. The suction from a furnace fan is massive and ductwork under a slab is never airtight. These homes may demonstrate massive increases in radon during air blower activity, such as during summer for cooling or winter for heating. Its called "radon mining".

Open Crawl-Space Vents: Open crawl space vents can impact readings by as much as 90% [27]. However, this can represent a false negative impact on measurements. Crawl vents are often left closed much of the year to avoid significant energy penalties or frozen water pipes.

Severely Unbalanced Heating/Cooling Ductwork: Systems with return vents in the basement yet all supply ducts going to the upstairs will cause greater radon entry during times of blower activity. Inversely, systems with only supply ducts in the basement and all return ducts upstairs can cause pressurization and dilution in the basement during times of blower activity. Duct balancing is almost never performed when a home is built.

Test Location: Different areas of the home may have significantly different radon concentrations due to mechanical air-handler activity. Though the concentration within a given zone or area of a home is mixed very consistently across the zone or area, significant differences can exist between different areas such as basement and upstairs or even between one room and the next. The magnitude of variability most often tracks with blower activity.

Test Cheating: Its surprising how many "good people" view test cheating as only a white lie.

SUMMARY OF DATABASE OBSERVATIONS:

For suburban, two story or basement homes with forced air heating-cooling systems which are typically less than 50 years of age:

On the whole, significant consistency is noted for the reproducibility of radon tests. Occasionally, dominance of a rare or unexpected variable is seen for an individual home or area and becomes the exception that proves the rules. A strong correlation is seen between basement readings and annual average exposure as a response to central-air system activity. Basement tests are, by far, the most reproducible. Severe False-negative potential exists for either short-term or long-term tests conducted above a basement during mild seasons.

Typical rain is often seen to have very minor impact on tests. When an impact is witnessed, combined factors of rain intensity and soil porosity have shown potential for higher or lower impact on tests. Capped or frozen soil conditions indicated false-negative impact potential however may be expected to enhance radon entry where rocky or highly porous earth conditions exist. Stack effect for basement or two story homes is a more dominant force than changes in barometric pressure. Single story homes or other home styles in certain regions may show greater susceptibility to variations caused by rain and barometric pressure swings.

SUMMARY: HAVE WE LEARNED ANYTHING OVER THE YEARS?

In the Past: We saw many random pieces of information. We still suffer from the inevitable confusion of those early years.

In the Present: A reproducible measurement is a high priority component in a decision making process. It relates to homeowner protection, legal contracts and even courtrooms.

On the whole, we have experienced that typical radon tests performed as per EPA protocols are usually reproducible and effective for their purpose. Assuming quality control is in tact, all approved test devices have surprisingly good precision (or accuracy). In the hands of trained professionals, there are far fewer erroneous tests than many people believe.

We've heard people say, "I would never test a basement if I did not live there. It has no correlation to my dosage". We have learned that there is a strong correlation between basement readings and annual average exposure to radon. The data suggests that exposure may be significantly greater since the 1960's due to central air systems.

People say, "If you test next week, we'll see a completely different reading". Many of us have learned this is not usually the case. Many of us have learned we can not afford to simply assume radon fluctuations are a random quantity. The principles behind factors affecting tests are not magic. From the wide scale overview, the magnitude of impact due to variable factors is usually less than many people believe.

In the Future: I hope to see continued efforts, both nationally and region by region, to update all health consultants and to encourage updates and training of the over 10,000 professionals in the United States who routinely offer radon services. These people touch more lives each year than any promotional effort on earth.

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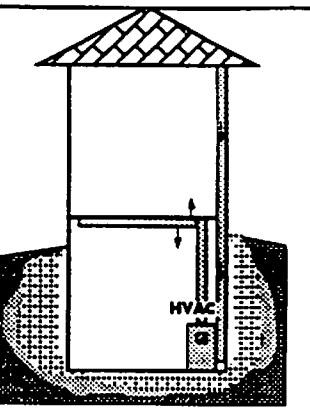
ABOUT THE DATABASE



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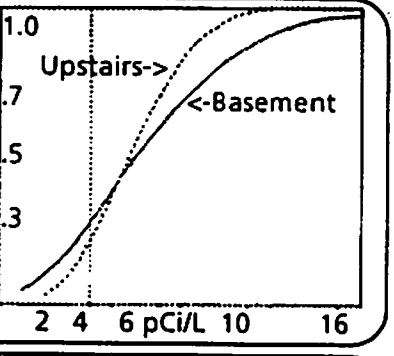
<u>May Not Represent:</u> The geology, soil, home design and weather for Mountainous and Desert regions which are expected to be quite different. Home design for rural, inner city, older homes and warmer or colder climates may also be quite different.

<u>For comparisons of monthly averages and weather effects:</u> A 4,400 home database spanning 362 weeks resulted after deleting cheated, questionable, and post mitigation tests.

<u>For Basement versus Upstairs comparisons:</u>
A 1,400 home database resulted after deleting cheated tests, retests, post mitigation tests, duplicate tests, and test results less than 2 pCi/L.

SHORT-TERM TESTS AND LONG-TERM EXPOSURE

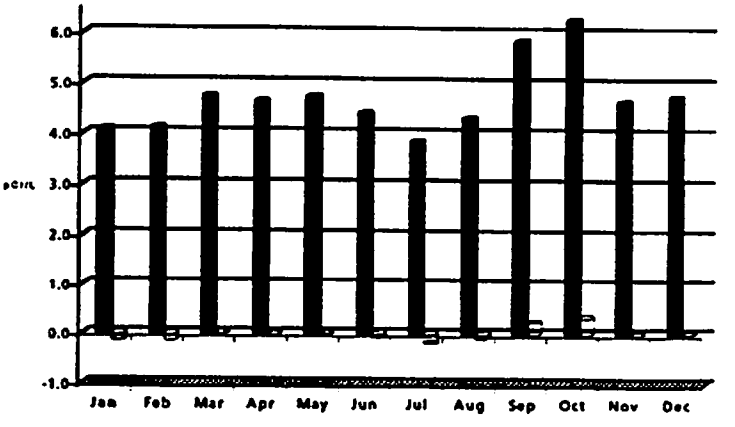
Other studies as large as 20,000 homes in 30 states have reported a strong relationship between short-term tests and the annual living area averagesregardless of basement or 1st floor test location.



PROBABILITY THAT ANNUAL LIVING AREA AVERAGE EXCEEDS 4.0 PCI/L.
1991: S.B. White, N.F. Rodman, B.V. Alexander, Research Triangle Institute and J. Phillips, F. Marcinowski, U.S.E.P.A.

BASEMENTS: COMBINED MONTHLY AVERAGES OVER 8 YRS.

As per most studies, our data verifies that basement readings are surprisingly consistent season to season.

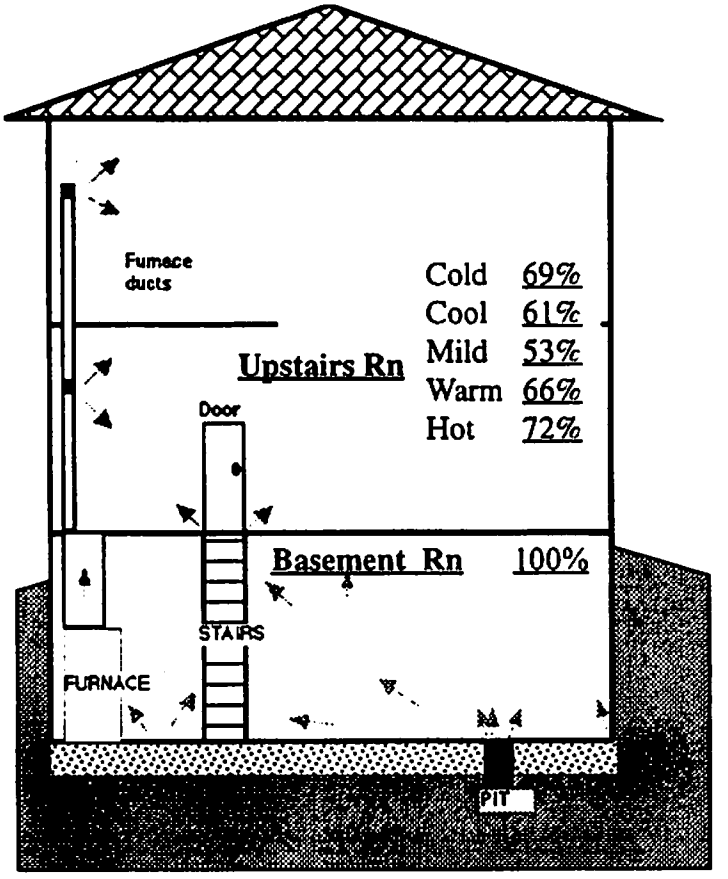


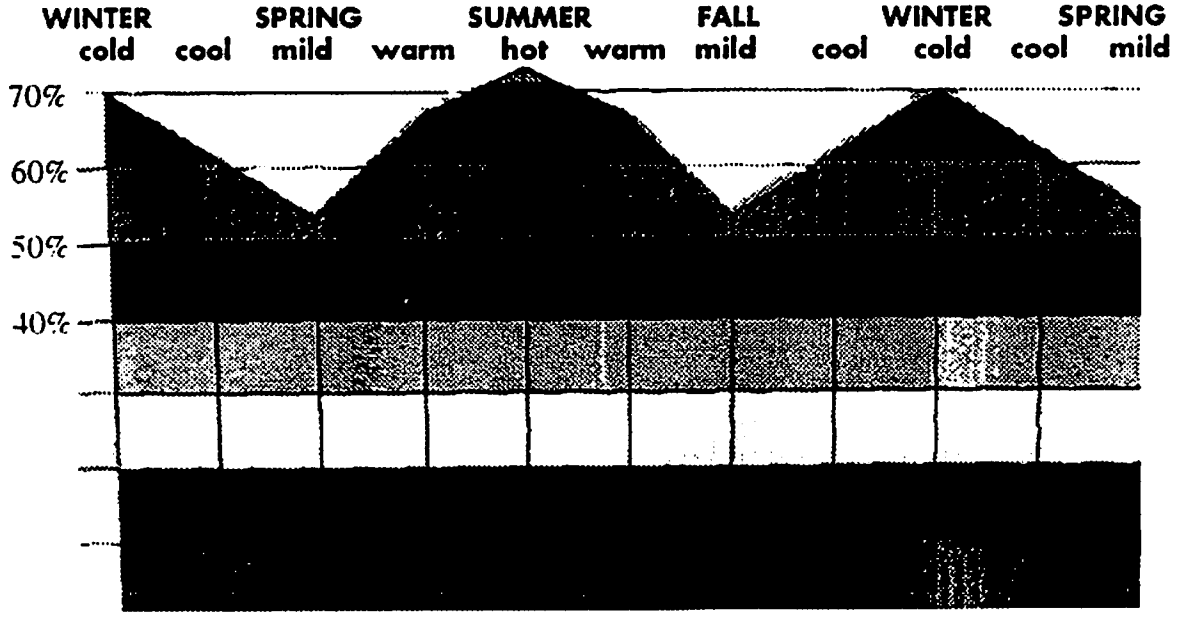
UPSTAIRS RELATIONSHIP TO BASEMENT READINGS

Distribution tracks with activation of cooling/heating system blowers.

Hoever: We've seen many examples of potent homes reflecting low (outside air) on the first floor during mild weather. Short-term or long-term measurements during mild seasons may be expected to provide false-negative results.

Since the widespread installation of central air conditioning in the mid-1960's, actual dosage appears significantly greater for much of our population.

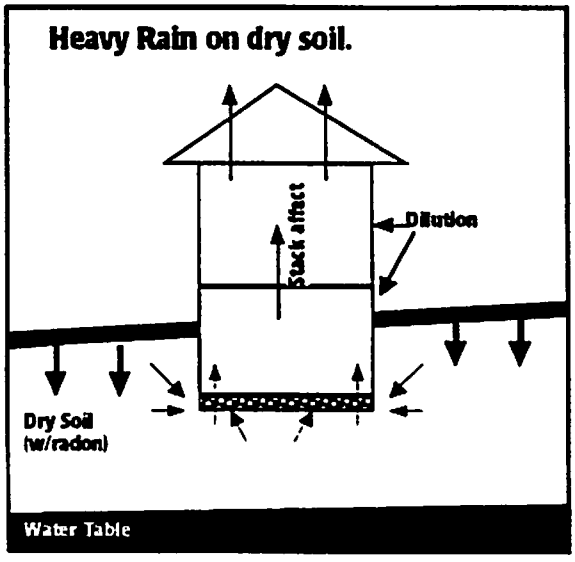




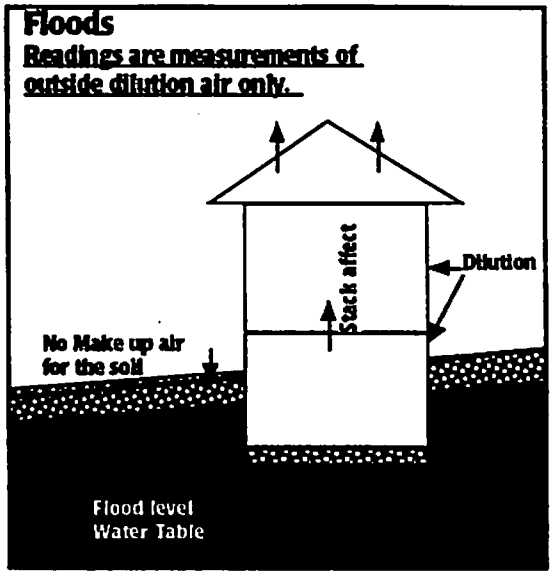
REVISITING WEATHER VARIABLES

RAIN

The impact of rain has been seen to increase radon readings.



It has also been seen to inhibit radon entry and cause lower readings.



Examples of the impact of rain are seen commonly in the database. However, the wide scope comparisons of all tests ran during weeks with rain and weeks without rain show no appreciable difference.

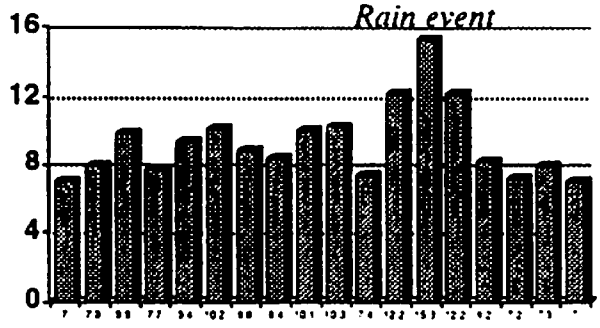
All Weeks with:	<1" rain	-->	0%	difference from all Rn Avg.
	>1" rain	-->	-1%	

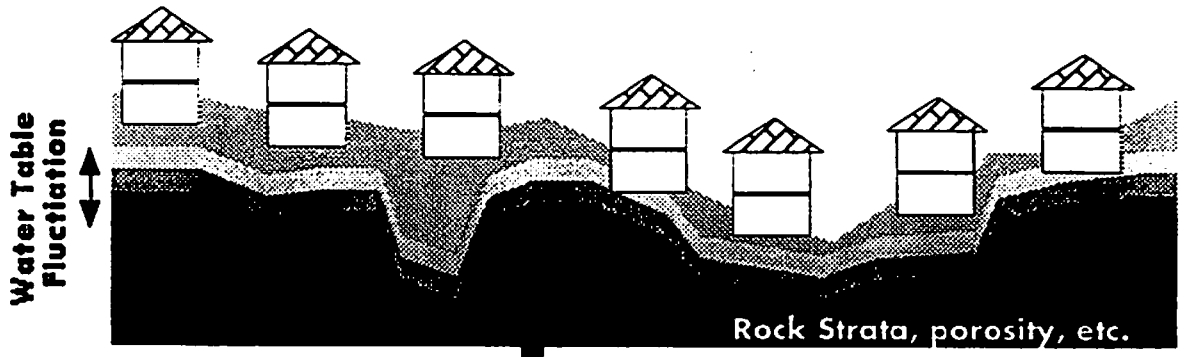
Extreme flooding rain or droughts without rain do show up in the wide scope data. Flood events can cause lower fluctuations. The lack of rain can cause higher than typical readings.

Yearly rainfall average:	39" rain			
Floods of 1993	53" rain	-->	- 3%	difference from all Avg.
Mild drought 2000	31" rain	-->	+3%	

Magnitude of Statistical Impact for Brief Events (such as a Typical Rain Event):
Typical rain events usually result in a brief impact as witnessed on thousands of CRM tests.

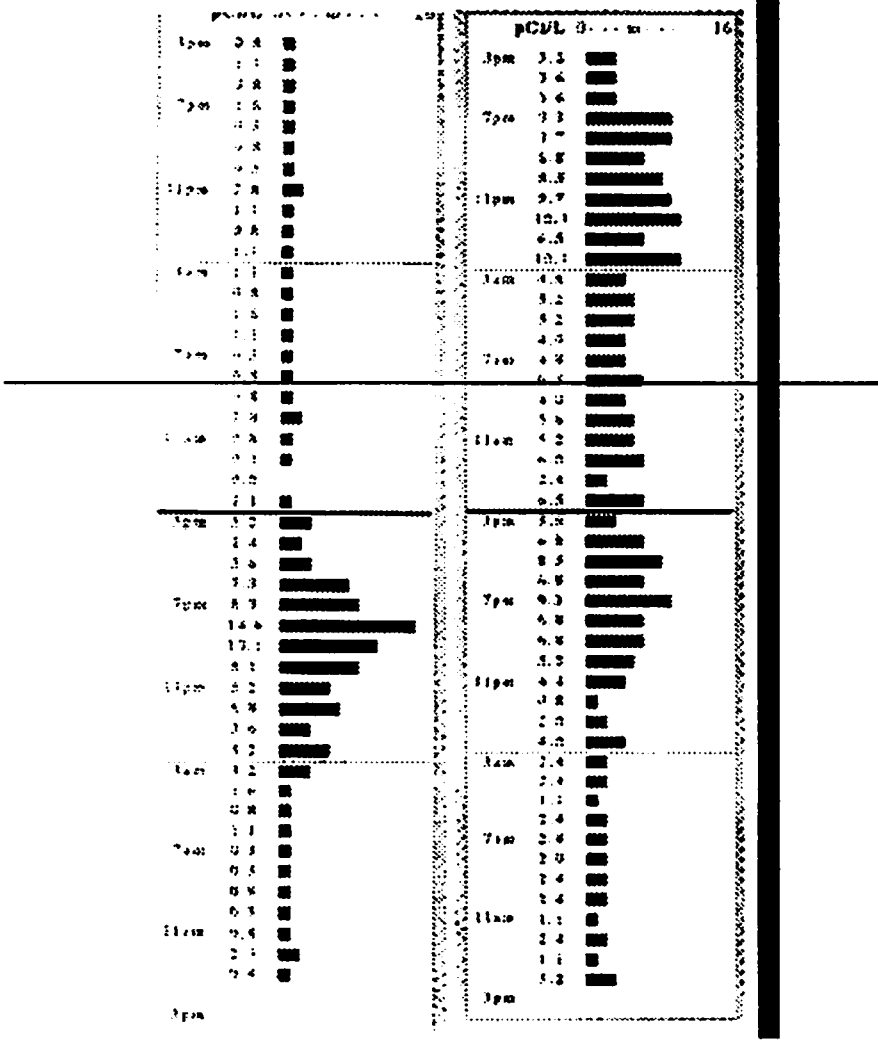
A typical three-hour rain anomaly on an 8 pCi/L test would only alter the average by 0.5 pCi/L (or 6.25%). You'd have to imagine that 24 hours of a 48 hour test were 0.0 pCi/L to cause the test average to be 4.0 pCi/L.





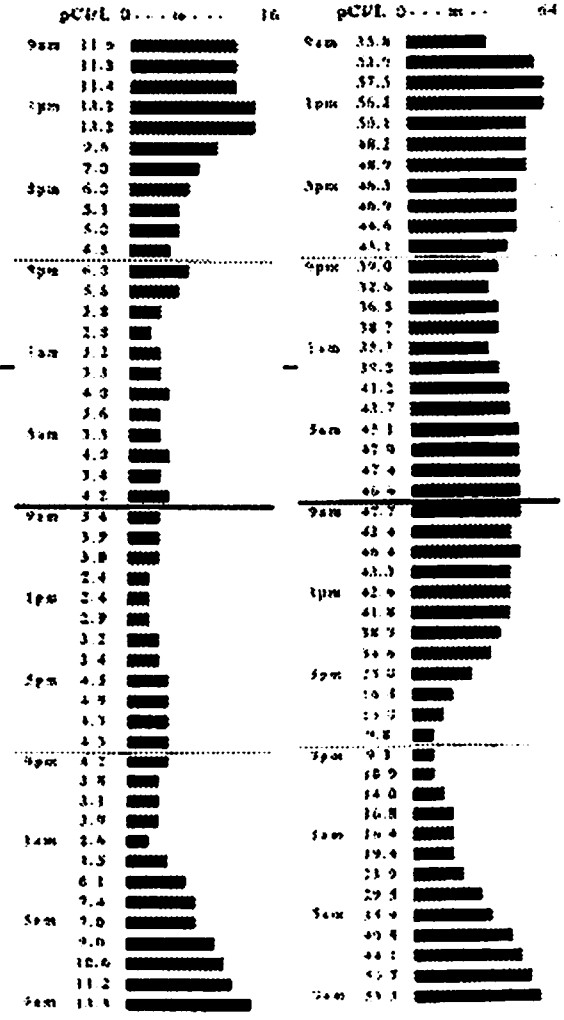
TWO SIMULTANEOUS TESTS OF DIFFERENT HOMES DURING RAIN

SPIKE UP CAUSING DROP

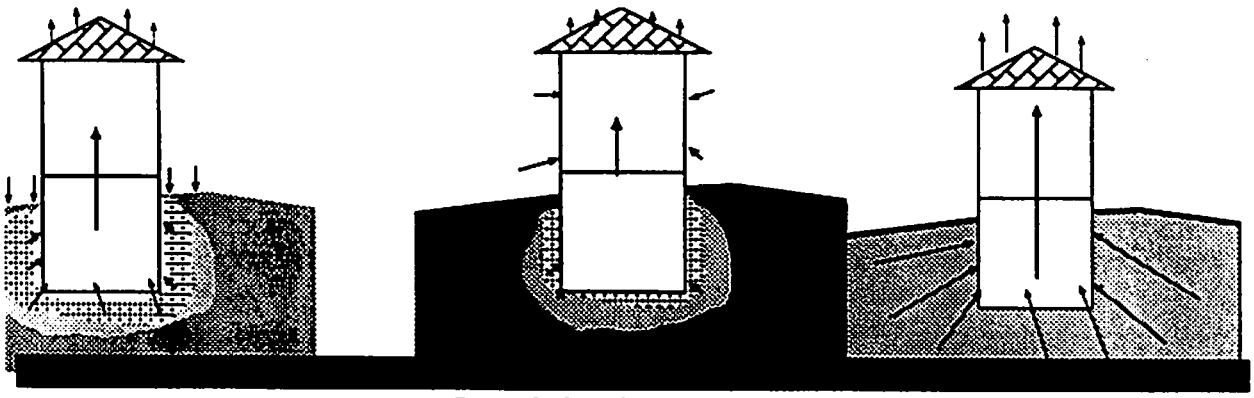


EXAMPLES OF MOMENTARY EVENT AND STABILIZATION OF RADON/DILUTION AIR MIXTURE

CHEATED TESTS



FROZEN OR CAPPED SOIL (rain, ice, snow, etc.):

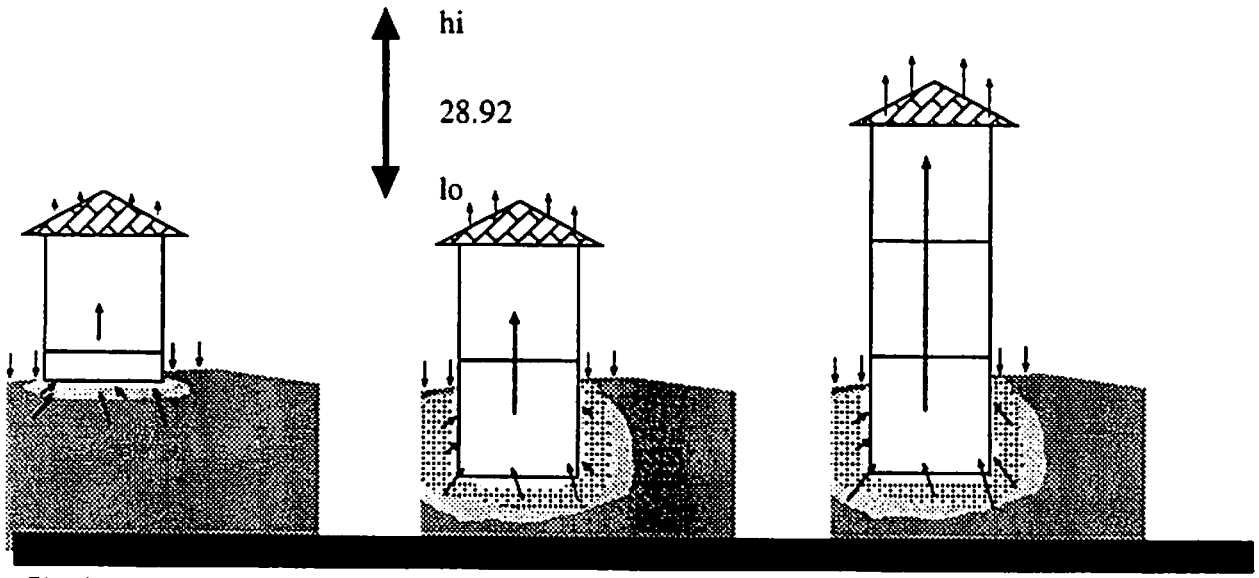


Average conditions

Impeded radon entry due to moisture and loss of available make-up air for allowing soil air displacement. The bottom of the soda straw is corked.

Enhanced radon entry where deep porosity exists under a home due to porous soil, rock or even crevices.

BAROMETRIC PRESSURE



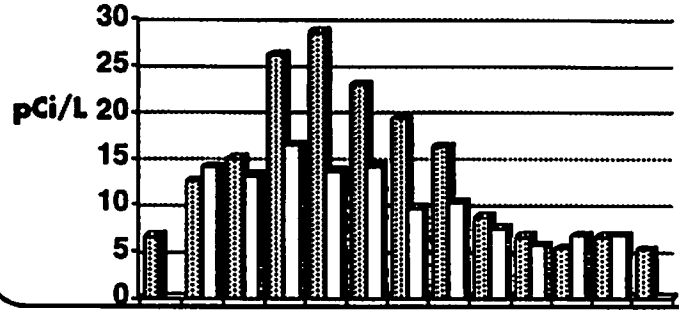
Single story homes may show greater susceptibility to variations caused by rain and barometric pressure swings.

Stack effect for basement or two-story homes is seen to be a more dominant force than changes in barometric pressure. Our data for two-story basement homes indicates that high swings in barometric pressure actually serve to increase false-negative potential relative to other times of more typical barometric pressure.

RED FLAGS (GENERIC) - POTENTIALLY SEVERE VARIABLES

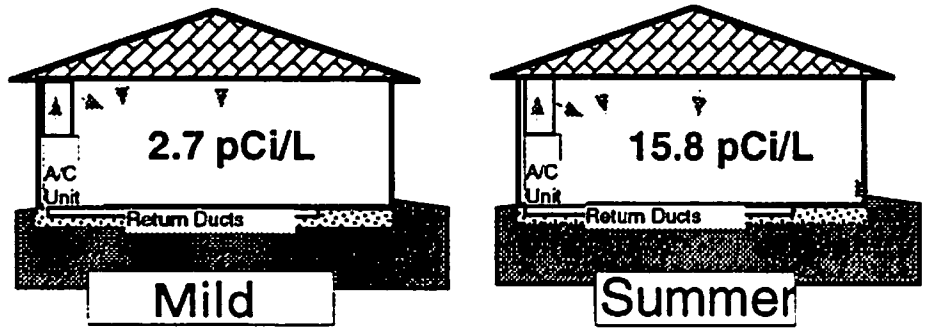
Severe Weather:

Two different houses during a Tornado Front.



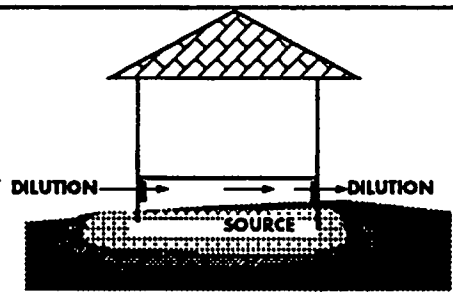
Building Mechanical Operation and Design:

Return air ducts under slab



Crawl Space Vents

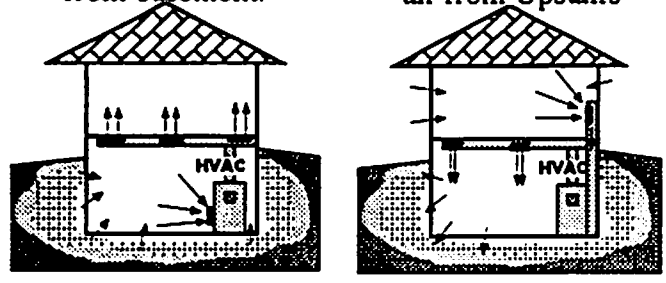
Many homes might be expected to have vents closed most of the year. False low tests may result if left open during such tests.



Unbalanced Ductwork

Most return air coming from basement.

No return air and supply air from Upstairs



TO DEFINE VARIABLES,

WE MUST REVIEW THE MOST COMMON SOIL DEPRESSURIZATION SYSTEM ON EARTH: <u>A HOUSE</u>