Healthy Homes, Healthy Lives

Can We Design a Reliably Low-Moisture Affordable House?

Presented at The 2008 National Healthy Homes Conference
Baltimore, Maryland
By Melissa Malkin-Weber

Study Partners

- HUD Office of Healthy Homes and Lead Hazard Control
- National Institutes of Environmental Health Sciences (NIH)
- UNC School of Medicine Center for Environmental Medicine, Asthma, and Lung Biology
- Habitat for Humanity
- Advanced Energy

Presentation Overview

- Origin of the study
- What kind of houses and what did we do to them?
- Relative Humidity
- Allergens
- Ventilation
- Where do we look from here?

High Performance Homes

- 1,500+ *SystemVision* homes in North Carolina
- Primarily affordable housing
- 40% savings on heating and cooling compared to code-built

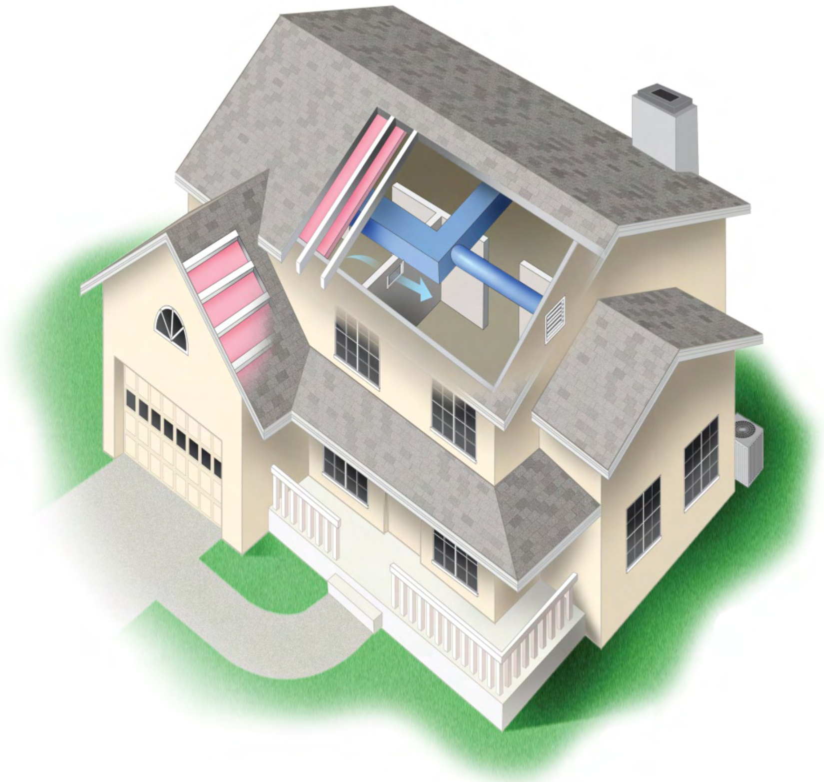
Can the construction standard deliver "healthy"?

- Program houses have promising features
  - Moisture Management
  - Combustion safety
  - Planned ventilation
    - Dilution using outdoor air
    - Exhaust
- Can they overcome factors like…
  - Exhaust fan use (or not)
  - Building product + furniture emissions
  - Consumer products

Methods - Study Participants

- 36 homeowners in Central North Carolina
- 4 Habitat Affiliates
- ~ 1200 SF per house, 2-3 beds, 2 baths
- Similar socioeconomics

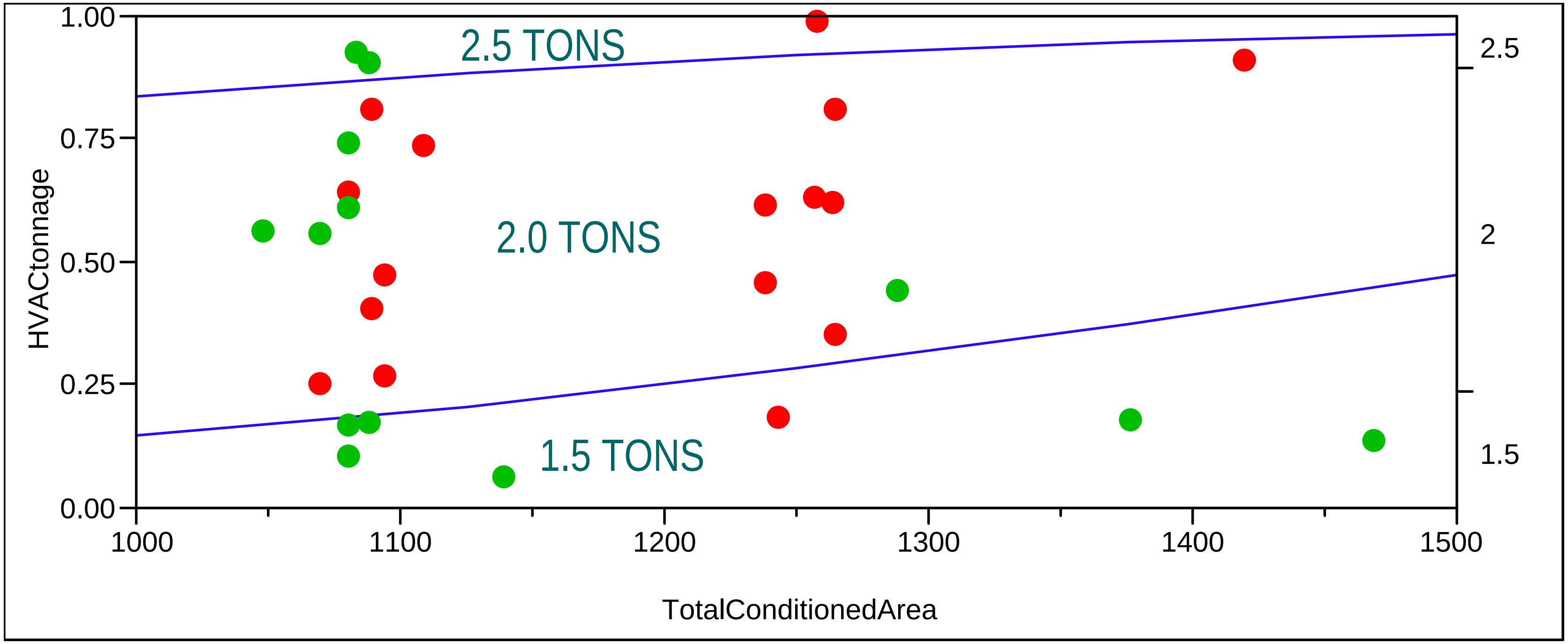
High Performance Houses - *Plus*



- Tight construction
- Interior moisture management
- Improved insulation
- "Right-sized" HVAC
- Outdoor air ventilation
- Pressure balancing
- *Closed crawl space*

- Outdoor air intake

HVAC tonnage



Intervention green
Non-intervention red

The Crawl Space Intervention

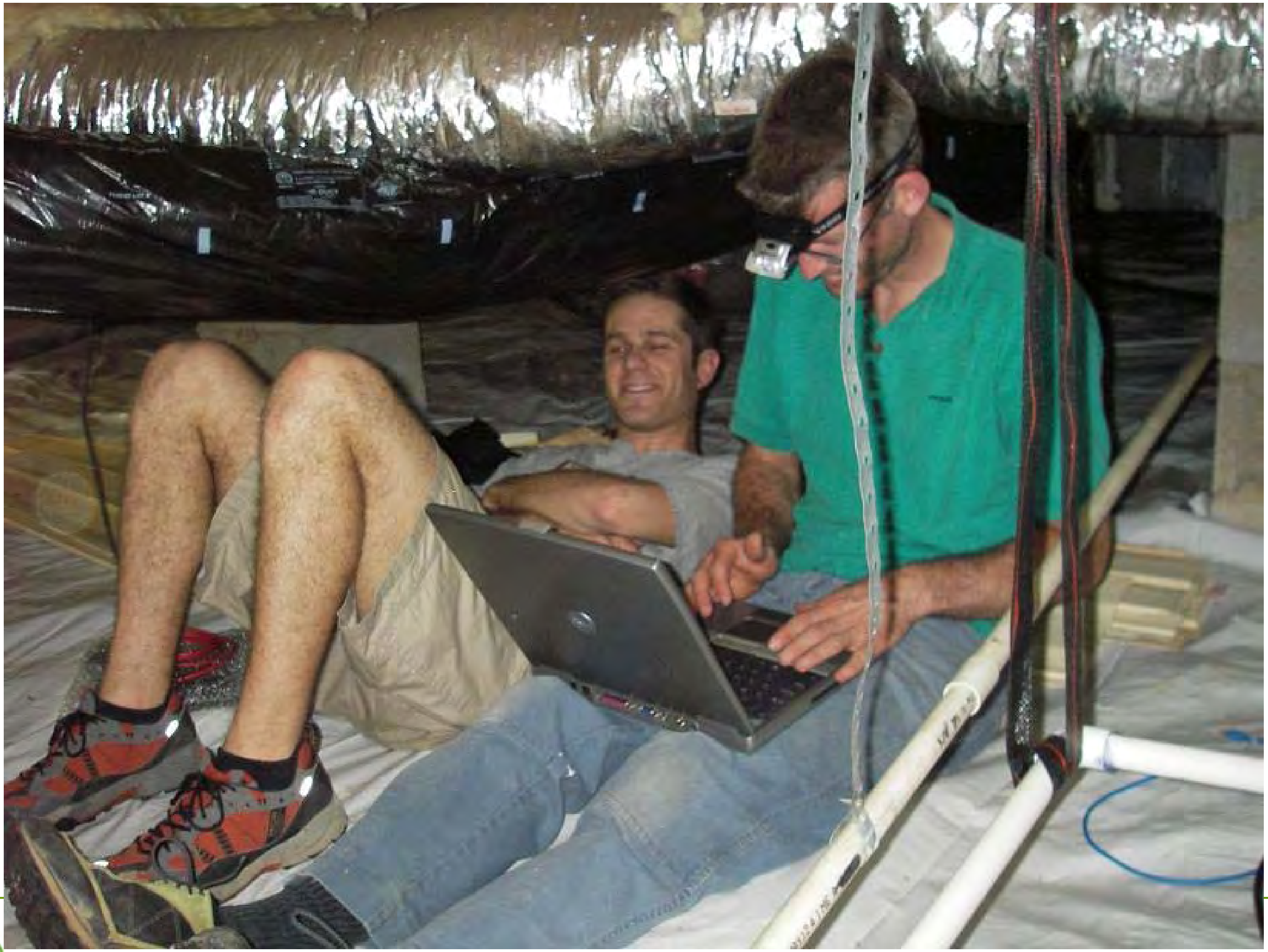
Liner sealed to piers and wall, 3” termite view strip

Supply air provides drying

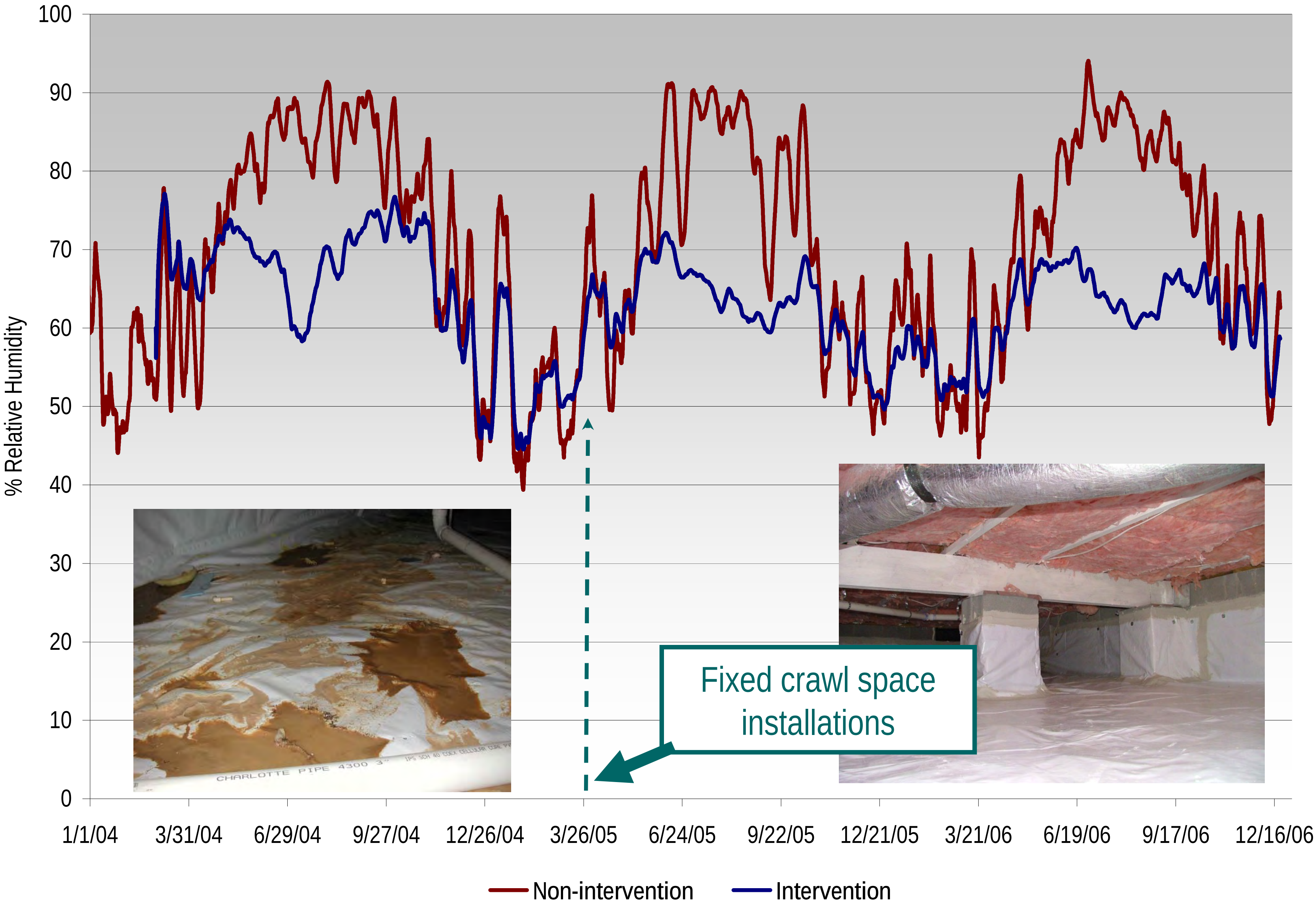
Details found at www.crawlspaces.org

Remote Temperature RH and Wood Moisture Sensors

Project Meetings



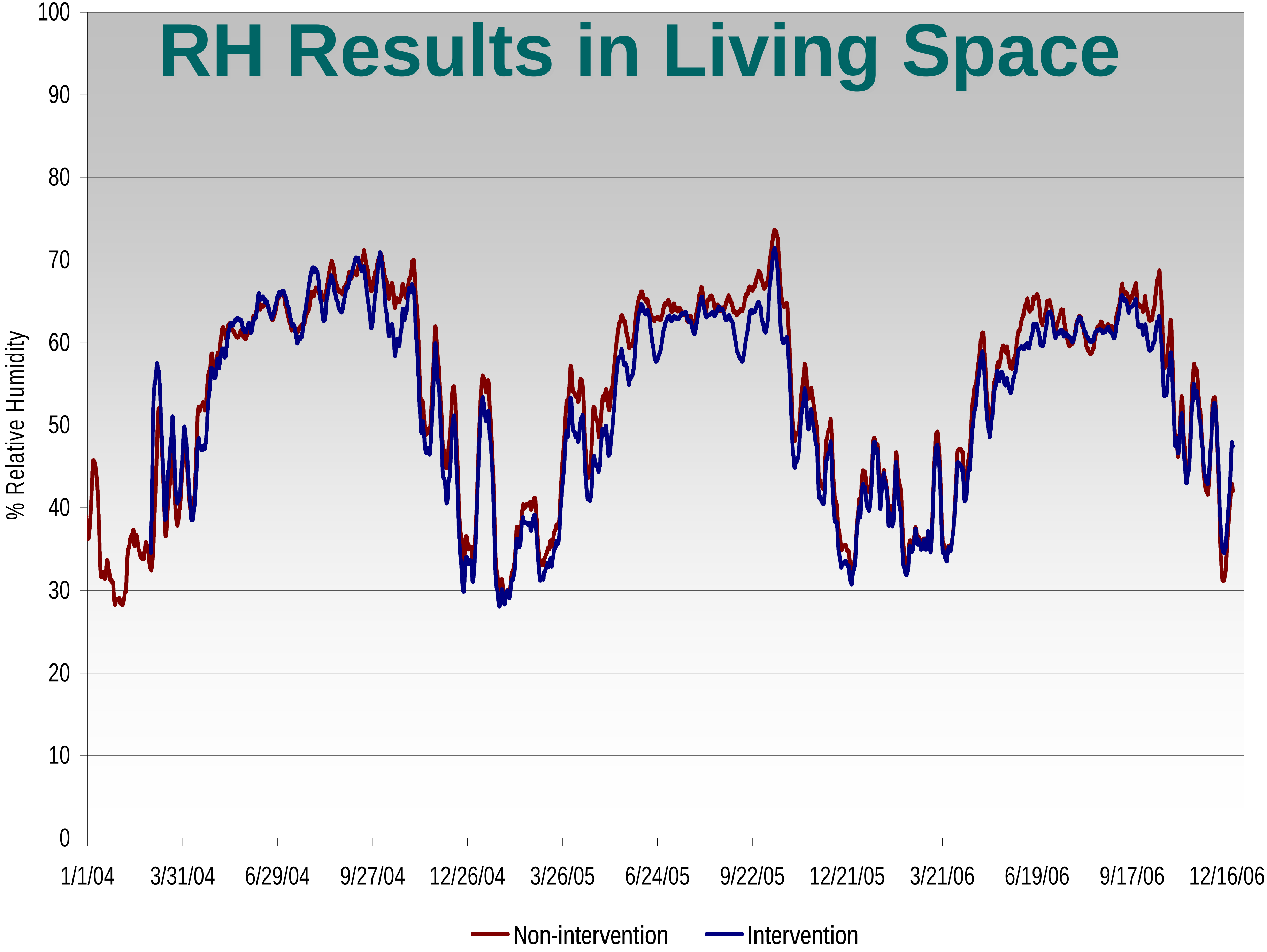
How the crawl spaces perform – RH



Conclusions About RH Controlled Crawl

- Maintains RH below 70% -- the “mold suppressing” zone
- Demonstrates suppression of moisture load from soil and outdoor air
- Avoids issues common to southeast wall vented crawls
  - Moisture
  - Mold, rot
  - Transmission of mold to house

RH Results in Living Space



Average house RH and Temperature

a. DRY SEASON [DECEMBER 15 – MARCH 15]				
Status	Mean Return Temp	St Dev Return Temp	Mean Return RH	St Dev Return RH
I	70.2	2.7	37.2	5.6
N	69.7	3.1	38.6	4.5

c. WET SEASON [MAY 15 – OCTOBER 15]				
Status	Mean Return Temp	St Dev Return Temp	Mean Return RH	St Dev Return RH
I	73.7	2.4	62.3	4.4
N	73.4	2.1	64.3	4.4

b. SPRING SHOULDER [MARCH 15 – MAY 15]				
Status	Mean Return Temp	St Dev Return Temp	Mean Return RH	St Dev Return RH
I	71.1	2.6	46.4	4.2
N	69.8	2.3	50.2	4.0

d. FALL SHOULDER [OCTOBER 15 – DECEMBER 15]				
Status	Mean Return Temp	St Dev Return Temp	Mean Return RH	St Dev Return RH
I	70.8	2.7	48.0	4.8
N	70.1	2.2	52.3	4.3

Did we impact relative humidity?

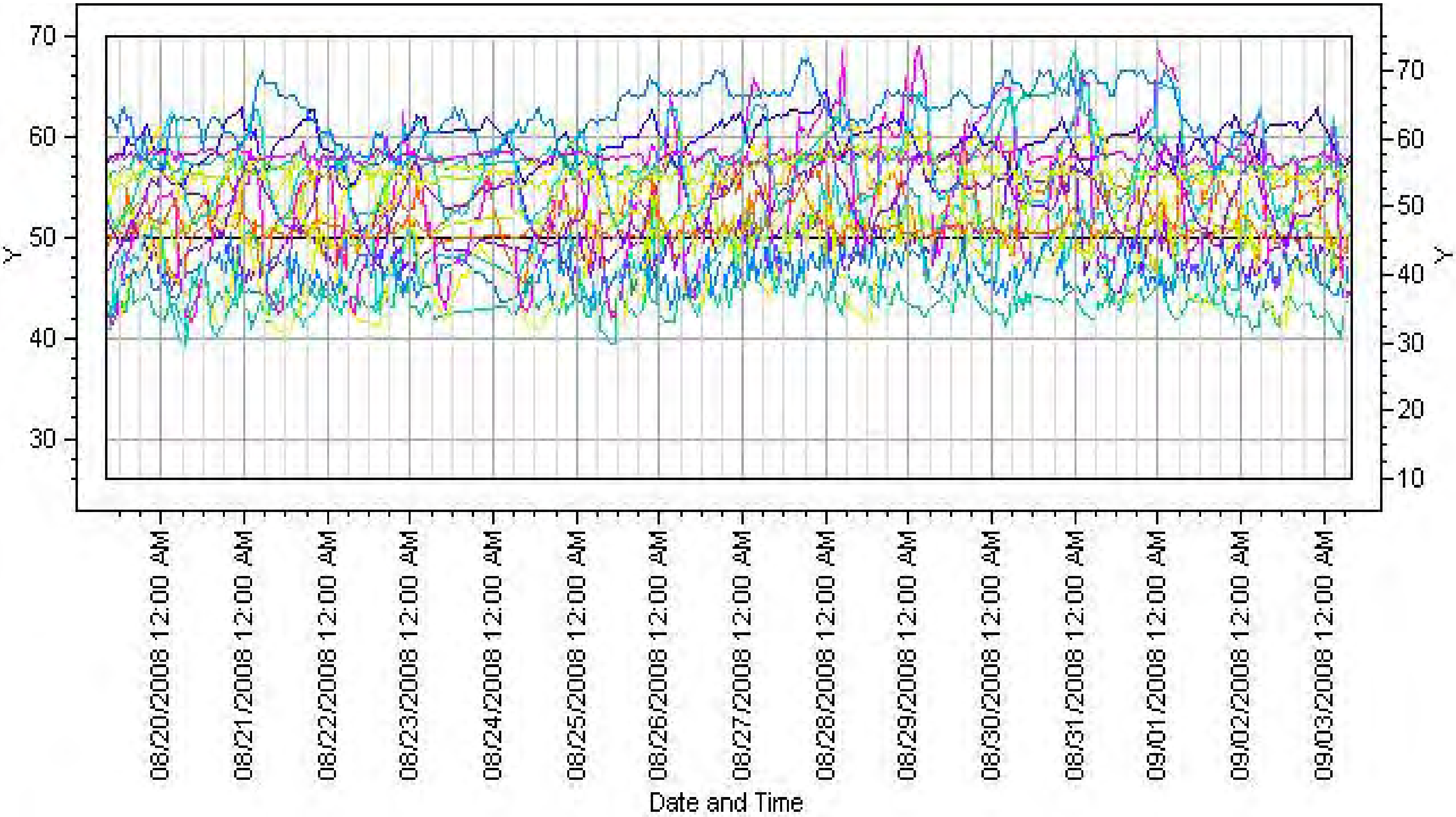
- Crawl space RH stayed below 70%
  - Expect mold suppression in crawl and reduced mold in house
- House RH was not reduced
  - Closed crawl space + outdoor air doesn't bring the living space to target RH
  - Introducing outdoor air does not dry the house
- Closed crawl couples crawl RH to house
- Wall-vented crawls remain coupled to outdoor RH

Will dehmidification deliver RH <50%?

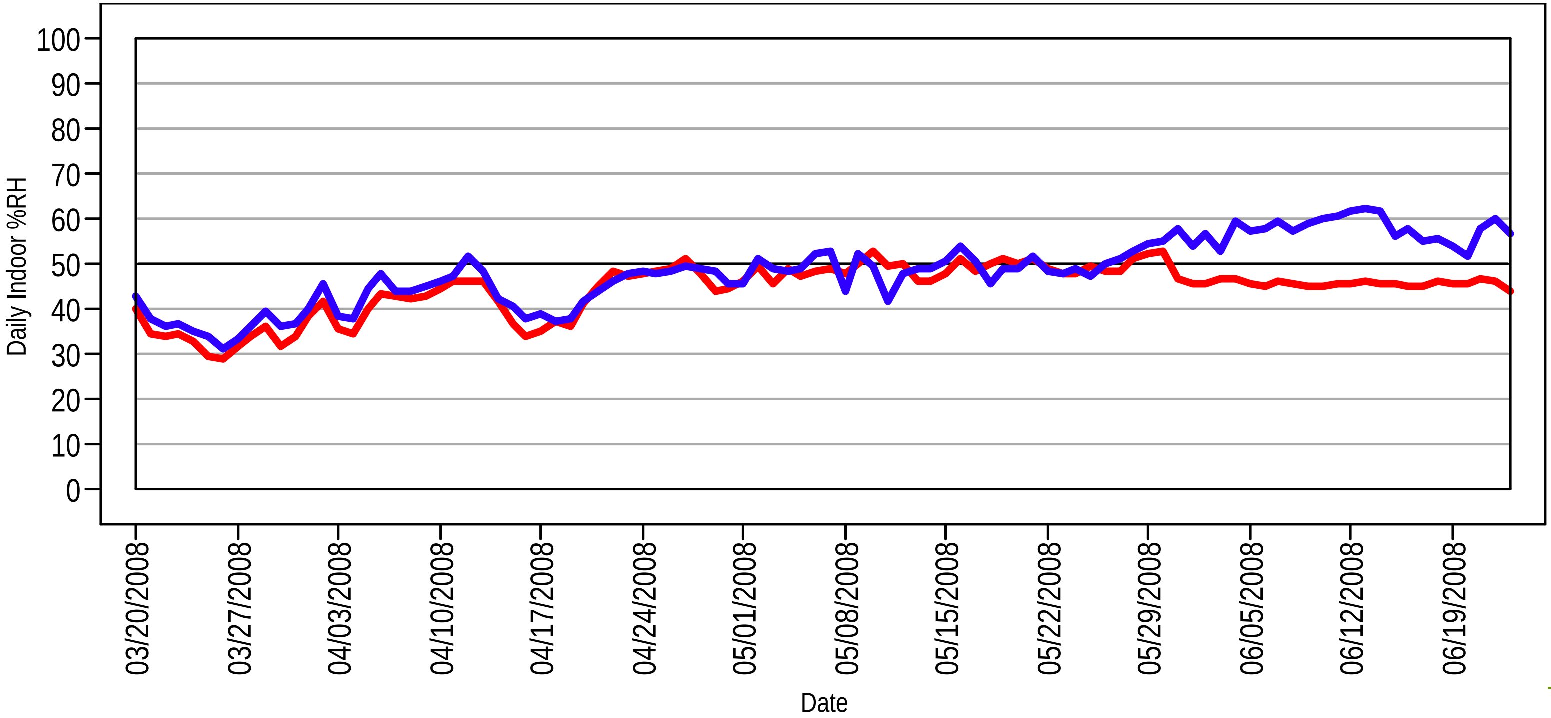
- Phase 2 study preview
- 22 houses
  - Tight envelope
  - Tight ducts
- Intervention houses retrofitted
  - Mechanical dehumidification
  - Spot exhaust
  - Outdoor air intake
  - Upgraded filtration
  - “Bare bones” closed crawl space

Ducted Dehumidifier

Got (Preliminary) Data?



Dehumdifier Controls RH compared to non-intervention houses



Allergens

- Moisture dependant allergens
  - House Dust Mite
  - Fungus (Alternaria Alternate)
- No detectable difference between intervention and control groups

“Honey, Did You Pack The Dust Mites?”

- Moving from previous to new homes
  - Only bedroom floors showed significant drop in dust mite allergen levels
- Most other allergen levels show no significant changes during next 18 months

Dust Mite Allergen Levels (Control + Intervention Group)

Median Der f1 ug/g dust (ELISA assay method)		
	At Move-In	6 months post-move in
Living Room Floor	0.82	0.05
Living Room Couch	0.05	0.05
Bedroom Floor	0.82	0.56
Bedroom Bed	1.47	0.89

Dust Mite Levels Previous Residence vs. New

Median Der f1, ug/g dust (ELISA assay method)			
	Previous Residence	At Move-In	6 months post-move in
Living Room Floor	0.75	0.82	0.05
Living Room Couch	2.0	1.55	0.05
Bedroom Floor	2.59	0.82	0.56
Bedroom	1.65		

Allergens – No Change from Old Home to New

Median Alternaria Alternate results ug/g dust, ELISA assay method				
	Previous Residence	At Move-In	6 months post-move in	12 months post move in*
Living Room Floor	5.25	3.49	4.25	5.13
Living Room Couch	4.16	4.23	4.38	3.39
Bedroom Floor	3.73	3.64	2.88	3.35
Bedroom Bed	2.39	2.79	2.72	3.17

Are we diluting chemical asthma triggers?

- Groups very close in size
- Intervention had much tighter ducts (72%)
- Somewhat tighter envelope (25%)
- Intervention adds outdoor air intake (air cycler) to make up for loss of infiltration ventilation
- Add effective spot exhaust
- No source control

House and Duct Tightness

HOUSE PERFORMANCE VALUES BY INTERVENTION							
Status	**Avg duct leakage** [CFM25]	Duct leakage per ft2 floor	**Avg house leakage** [CFM50]	House leakage per ft2 envelope	**Avg kitchen exhaust** [CFM]	**Avg bath 1 exhaust** [CFM]	**Avg bath 2 exhaust** [CFM]
Intervention	**34**	**30%**	**862**	**0.25**	**106**	**58**	**56**
Non-Intervention	**122**	**104%**	**1142**	**0.31**	**0**	**38**	**37**
% Diff (I from N)	**72% tighter**		**25% tighter**		**n/a**	**53% higher**	**52% higher**

Formaldehyde sampling

Formaldehyde Levels – No Statistical Difference Between Groups

AVERAGE FORMALDEHYDE LEVELS				
Status	Weight [µg/m^3]	St Dev [µg/m^3]	Weight [ppm]	St Dev [ppm]
I	**85**	27	**0.069**	0.022
N	**79**	31	**0.064**	0.025
All	**82**	29	**0.067**	0.025

Does the ventilation system work?

- Tight intervention houses with outdoor air intake + timer are not higher than leakier non intervention houses
- Met goal of “do no harm” – did not adversely influence the houses when tightening them
- In these houses, mechanical ventilation did not solve the indoor air pollution problem

Phase 2 -- Ventilation

- More precise
  - Air changes per hour
  - Active sampling of formaldehyde
- Measure tight houses with and without outdoor air (no air cyclers)
- Measure tight houses with air cyclers
- Measure leakier houses without air cyclers

Next Steps

- Change Intervention Configuration
  - Mechanical dehumidification (<50% RH)
  - More affordable closed crawl configuration
- Measure More Precisely
  - pollutants
  - air changes per hour
  - Does filtration change anything?

Get what works to market

- Market-Ready Specs
  - “Prescription” for a dry house

Advanced ENERGY

www.advancedenergy.org

www.healthierhomes.org

mweber@advancedenergy.org

919 857-9000 [phone]

- Following are additional slides with supplementary information that will be discussed further in final report and articles

7 Steps to high-performance housing

- Standards
- Plan Review
- Contractor/Subcontractor training
- On-site quality control
- Performance testing
- Certification/Guarantee
- Servicing the Guarantee

TOTAL INTERVENTION COST*		
Upgrade	Study cost per house [2003] Materials & installation	Market cost per house [2007] Materials & installation
*System**Vision***	$1,725 per house	$1,920 - $2,100 per house
*System**Vision*** fee	$1,050	$1,050
Closed crawl space	~$2.50 per square foot [$3,00 for 1200 square foot house]	$1.00 - $2.50 per square foot [$1,200 for 1200 square foot house]
Aprilaire	$170 [Spaceguard filter & frame] $200-$800 [installation]	Same
Total per house	**$6,145**	**$4,540**

*Based on 1200 square foot house at lowest estimate

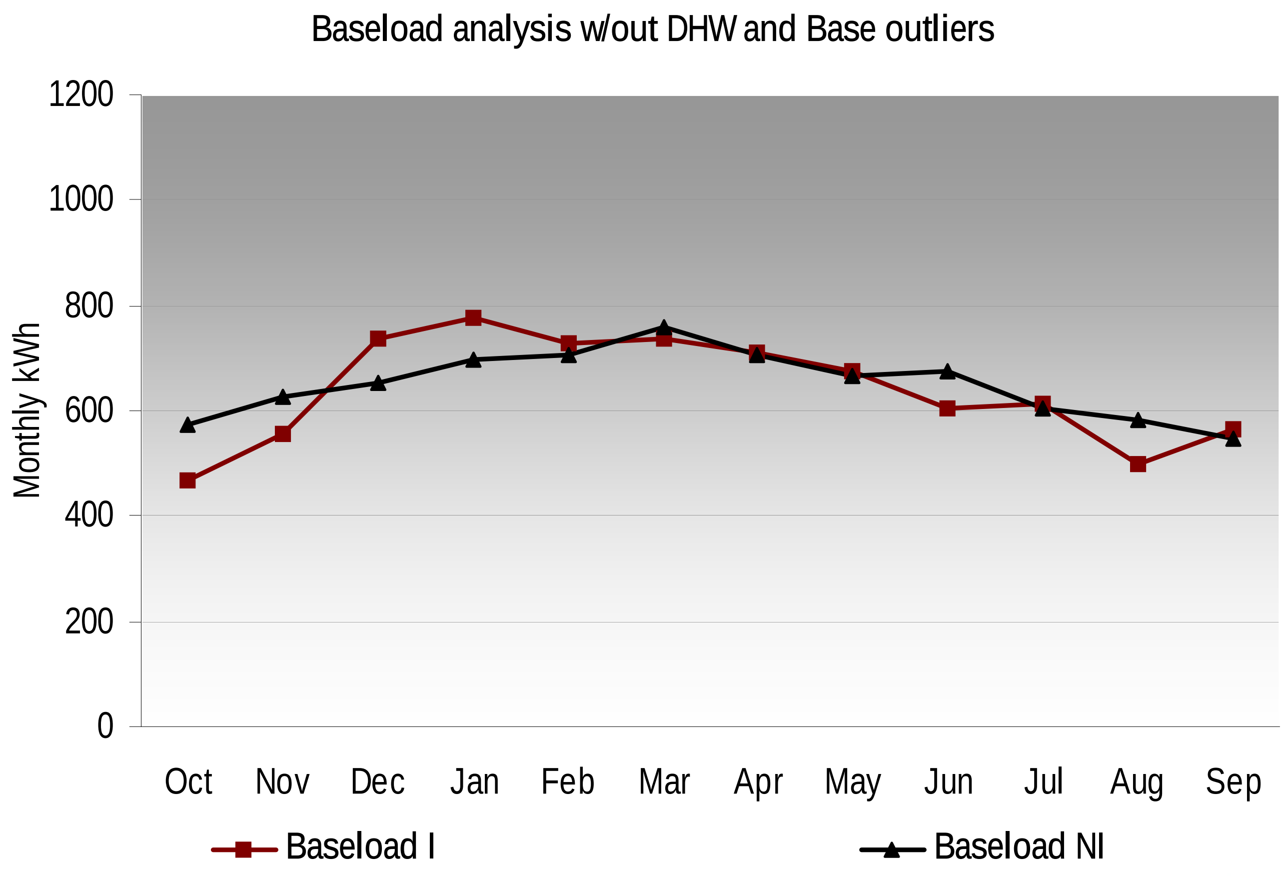
SYSTEMVISION UPGRADE ESTIMATES*			
Standard	Upgrade	Study estimate per home [2003]	Market estimate per home [2007]
1	Proper blocking and building air tightness	$75	$100
2	Whole-house mechanical ventilation	$200	$100
	Bath and kitchen exhaust upgrades	$300	$300
3	Proper insulation installation	$300	$150
	Attic insulation increase to R-38		$100
	Raised heel trusses	$250	$250
	Low-E windows	$150	$150
4	Outdoor thermostat[s] on heat pump[s]	$100	
	14 SEER heat pump		$600
	90% Efficient furnace with 13 SEER air conditioner		$400
	Proper duct sealing	$100	$100
5	Pressure balance and relief	$150	$150
6	Electric or gas water heater efficiency upgrade	$100	$100
7	Carbon Monoxide detector if applicable		$20
Total	**Electric package total [per home]**	$1,725	$2,100
	per home]	$1,725	$1,92



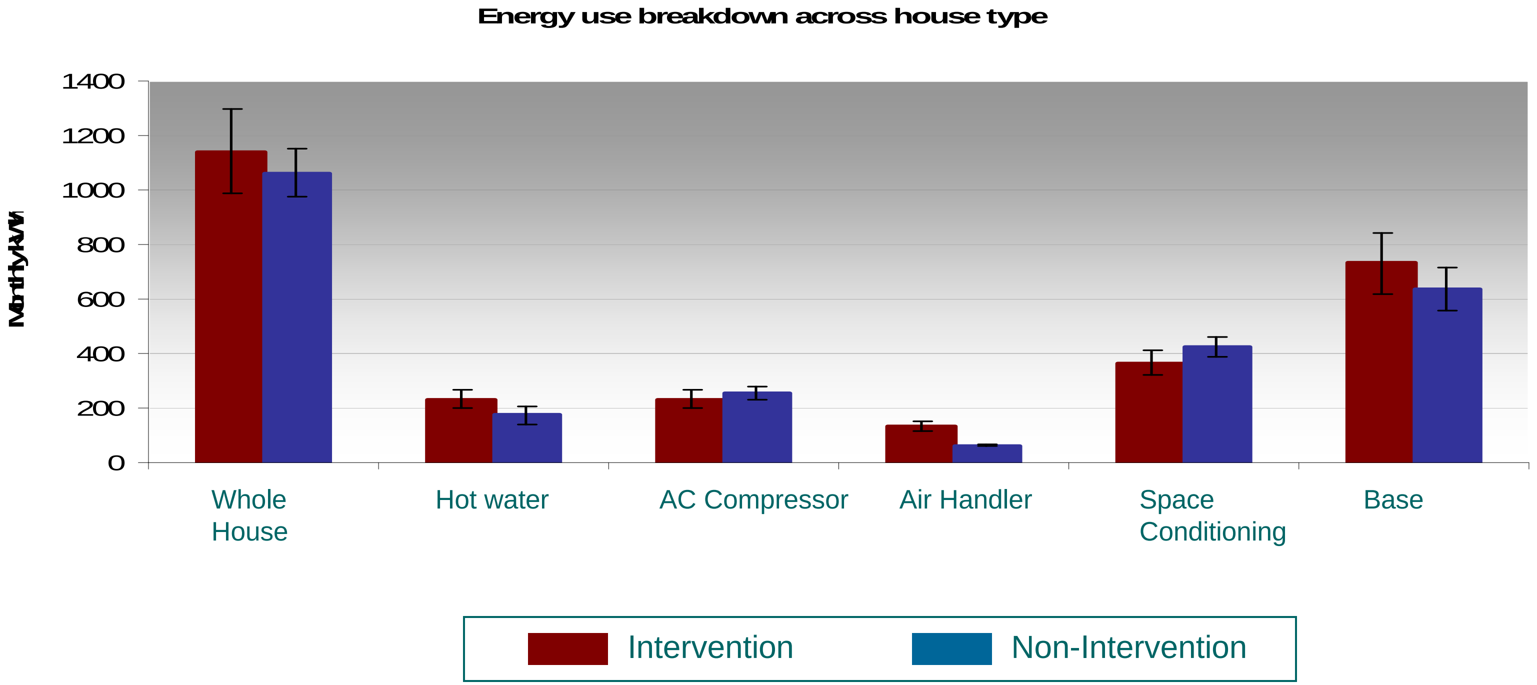
Number of homes submetered

ENERGY PERFORMANCE MEASUREMENT		
House Type	Number in Group	Number Submetered
Non-Intervention w/ Retrofit	7	7
Non-Intervention	7	7*
Intervention	16	8

* Submetered later in the study


Baseload analysis w/out DHW and Base outliers
1200
1000
800
600
400
200
0
Monthly kWh
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Baseload I
Baseload NI

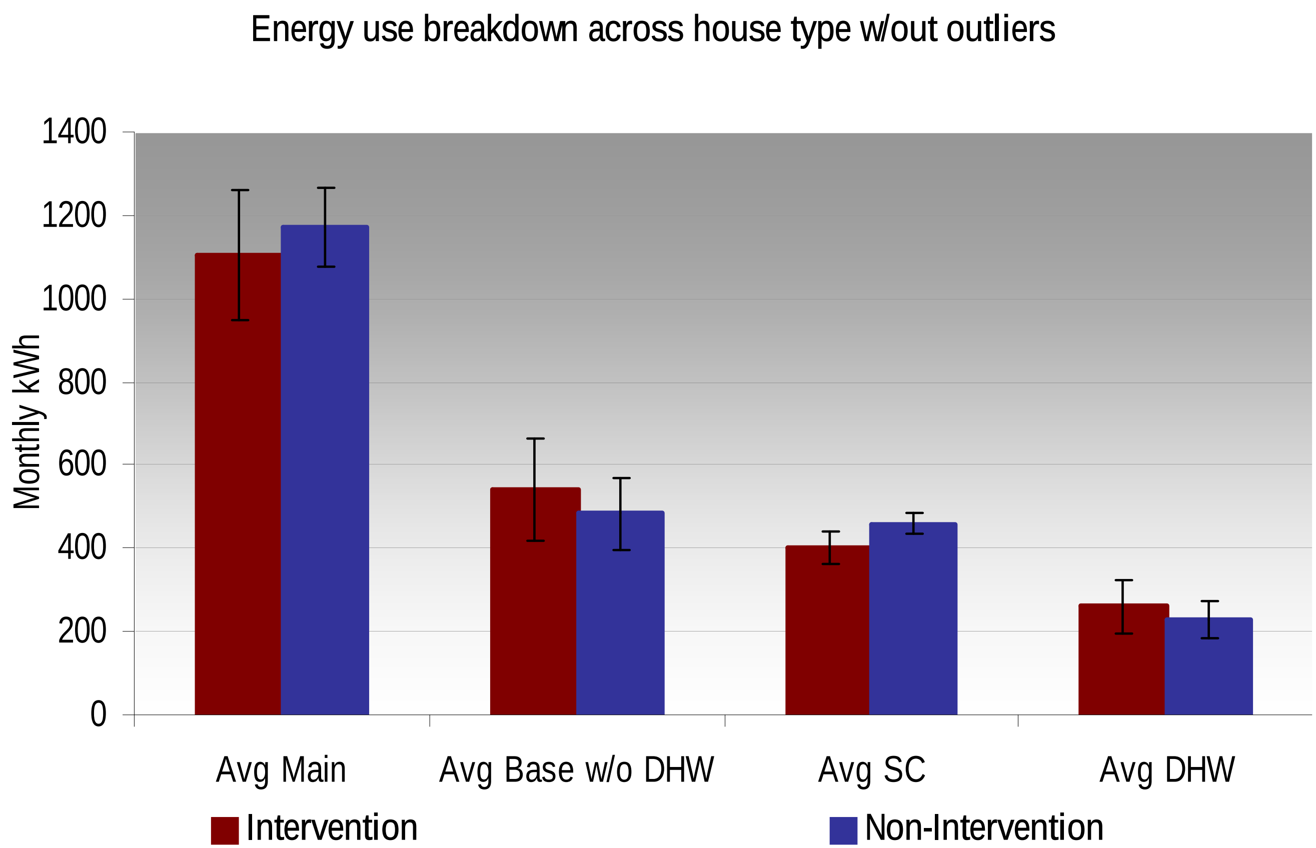
Results – energy use



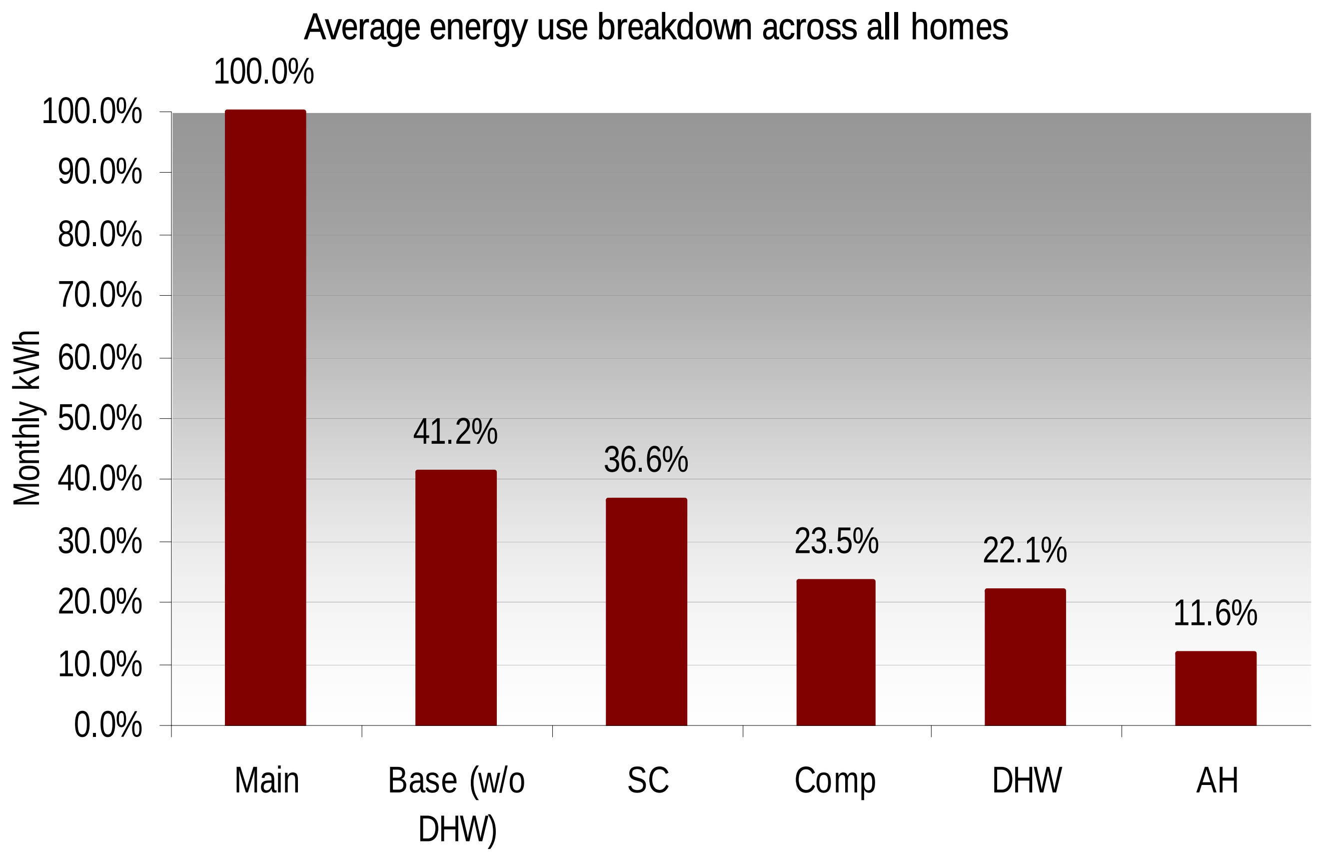
Space conditioning saving

- 13.7% total (~5.8% of total energy savings)
- 3.6% June – August/ 0.8% July – September

- Intervention homes use more energy in every other category (non-space conditioning)

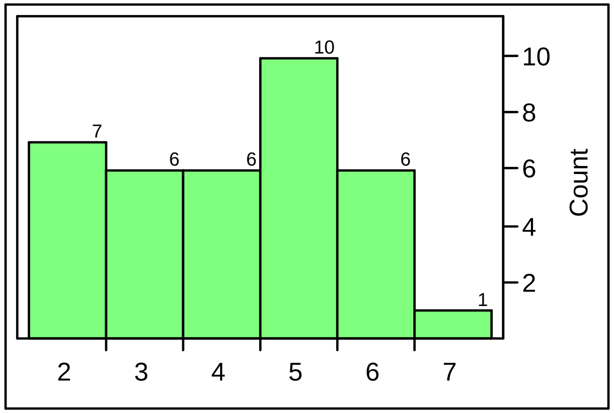


2006-2007 Space conditioning – intervention houses use 13.7% less energy


Average energy use breakdown across all homes
Monthly kWh
100.0%
90.0%
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
100.0%
41.2%
36.6%
23.5%
22.1%
11.6%
Main
Base (w/o DHW)
SC
Comp
DHW
AH

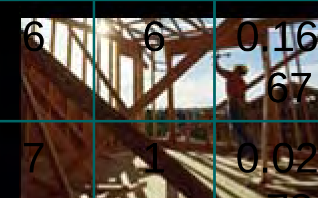
Number of people per house

- **National household size of 2.57 people**
- **2.49 for NC**
  - **2.51 for Wake Co.**
    - **2.30 for Raleigh**
  - **2.40 for**



Level	Count	Prob
2	7	0.19444
3	6	0.16667
4	6	0.16667
5	10	0.27778
6	6	0.16667
7	1	0.02778





Mean crawl conditions

a. DRY SEASON [DECEMBER 15 – MARCH 15]				
Status	Mean Crawl Temp	St Dev Crawl Temp	Mean Crawl RH	St Dev Crawl RH
I	61.4	1.6	53.6	5.8
N	54.9	2.3	55.4	7.4

b. SPRING SHOULDER [MARCH 15 – MAY 15]				
Status	Mean Crawl Temp	St Dev Crawl Temp	Mean Crawl RH	St Dev Crawl RH
I	64.0	1.7	61.7	4.5
N	61.2	1.4	64.0	7.3

c. WET SEASON [MAY 15 – OCTOBER 15]				
Status	Mean Crawl Temp	St Dev Crawl Temp	Mean Crawl RH	St Dev Crawl RH
I	71.5	2.0	66.4	4.9
N	72.3	1.3	83.1	4.8

d. FALL SHOULDER [OCTOBER 15 – DECEMBER 15]				
Status	Mean Crawl Temp	St Dev Crawl Temp	Mean Crawl RH	St Dev Crawl RH
I	66.3	1.5	60.2	5.2
N	62.2	1.8	63.8	8.6

BUILDING A FRAMEWORK FOR HEALTHY HOUSING

Exploratory Study of Basement Moisture During Operation of ASD Radon Control Systems

Gene Fisher
US Environmental Protection Agency
Office of Radiation and Indoor Air

Study Overview:

- Limited, exploratory study to demonstrate whether active soil depressurization (ASD) techniques can impact moisture entry and control in residential structures
- Study conducted by Auburn University (SRRTC) via a Cooperative Agreement with the EPA, awarded in July 2004
- Three houses with unfinished basements were studied for an 18-month period (Harrisburg, PA)

Study Team Members

Auburn University:
Jan Carrington - Administration
Jack Hughes - Mitigation and Technical Specialist
Brad Turk - Principal Investigator

PA Department of Environmental Protection (PA DEP):
Mike Pyles - Radon Program Manager
Bob Lewis - Field Support
Matt Shields - Field Support

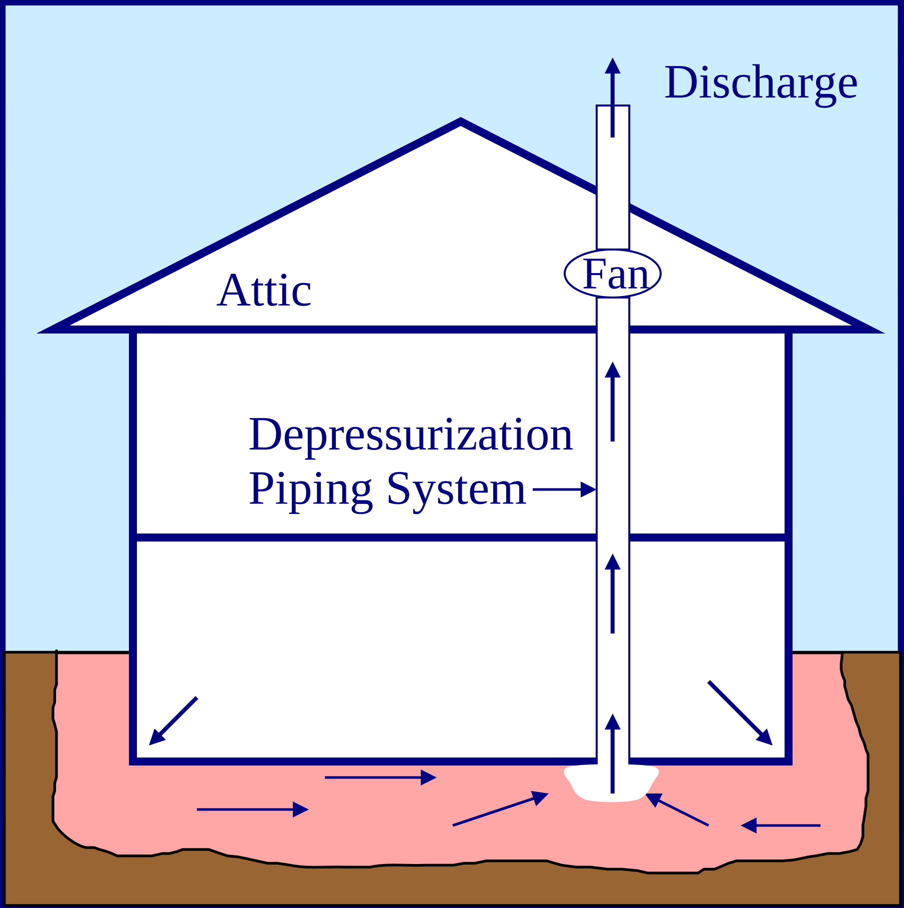
Private Contractor:
Bob Myers - PA Certified Radon Mitigator
Margaret Menache – UNM, Statistician

US EPA:
Gene Fisher - Project Officer
Patsy Brooks - Region 4 Radon Coordinator
Susie Shimek - Past EPA Radon Team Leader
Phil Jalbert – EPA Radon Team Leader

Active Soil Depressurization

- Reduces radon entry by mechanically creating a suction beneath the home's foundation that is stronger than the suction applied by the home
- Collects radon prior to entry and exhausts to a safe location outside the home
- Specific application depends on foundation type

Sub-Slab Depressurization (SSD)



- Suction created by fan draws radon from beneath the concrete slab and safely vents radon outdoors

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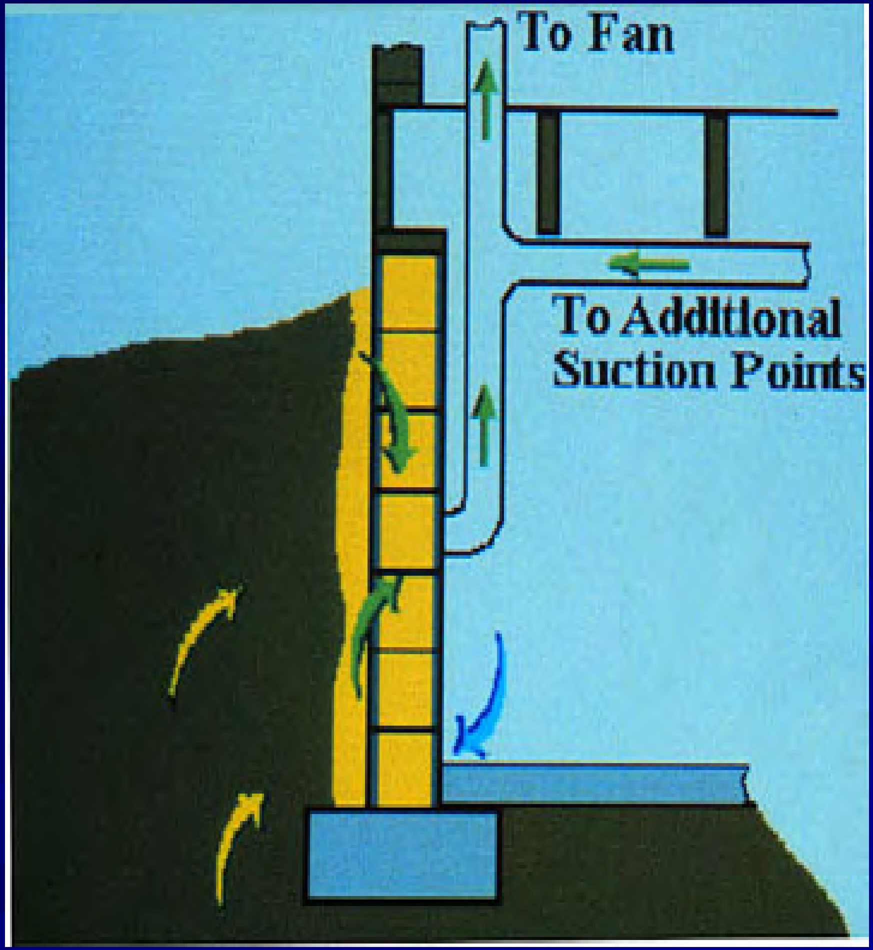
Block Wall Depressurization



- May be necessary, if a sub-slab system is unable to draw radon down through the block to the sub-slab area.
- System may require suction on more than one wall.

Active Systems

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Residential SSD Systems

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Events Leading Up to the Study

- Anecdotal information dating from 1986
- Literature/model search in 2002
- Experts meeting in June 2003
- Cooperative Agreement July 14, 2004

Accomplishments - First Year

- Developed house selection criteria
- Developed conceptual model
- Measurement protocols
- Conducted walk-through visits
- Study houses selected – criteria compromised
- Instrumented three PA houses (May, July 2005)
- Mitigated three PA houses (July, September 2005)

Study House #1 (PA01)

Study House #2 (PA02)

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Study House #3 (PA03)

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Tests & Measurements

Approx. 115 Parameters are Recorded Every Hour at Each of 3 Houses

Air Flow In & Out of Basement

Outdoors, Upstairs, and Soil

- *PFT Tracer Gas Ventilation Tests**
- *Differential Pressures*
- *Soil Gas/Radon/Moisture Entry Potentials*
- *ASD Velocity Pressures/Flow*
- *Wind Direction and Speed*
- *Air Leakage Area*
- *Effective Resistances (floor, soil)*
- *Radon Concentrations*
- *ASD Static Pressures*
- *HVAC On-time*

Temperature & Water Vapor Content of Air

Outdoor, Basement, Microclimate, Upstairs, Soil, ASD

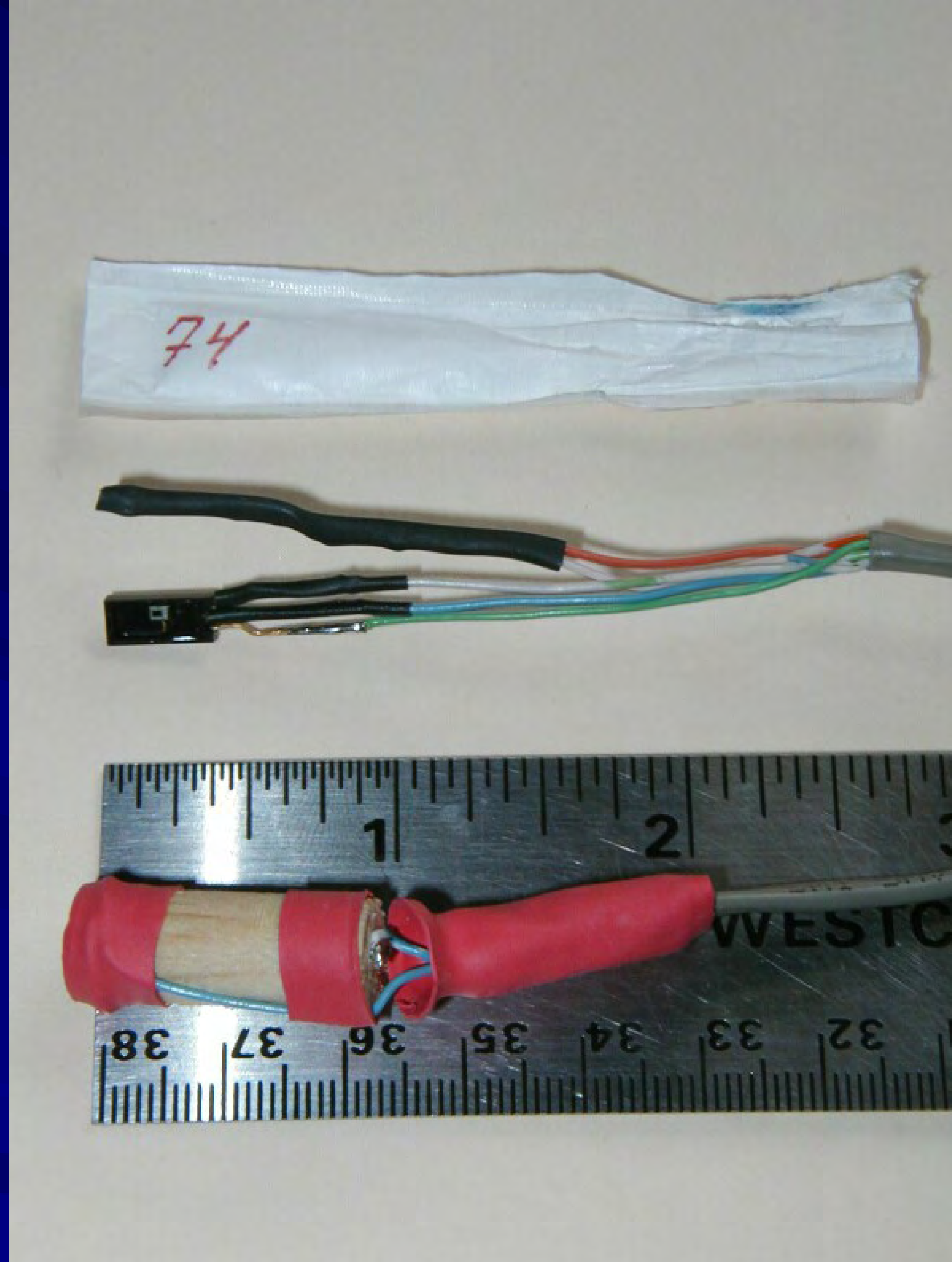
- *Temperature & Heated RH*

Moisture Storage & Diffusion

Walls, Floors, Wood Framing

- *Moisture Content Pins*
- *Wood Block Moisture Sensor*
- *Heated RH*

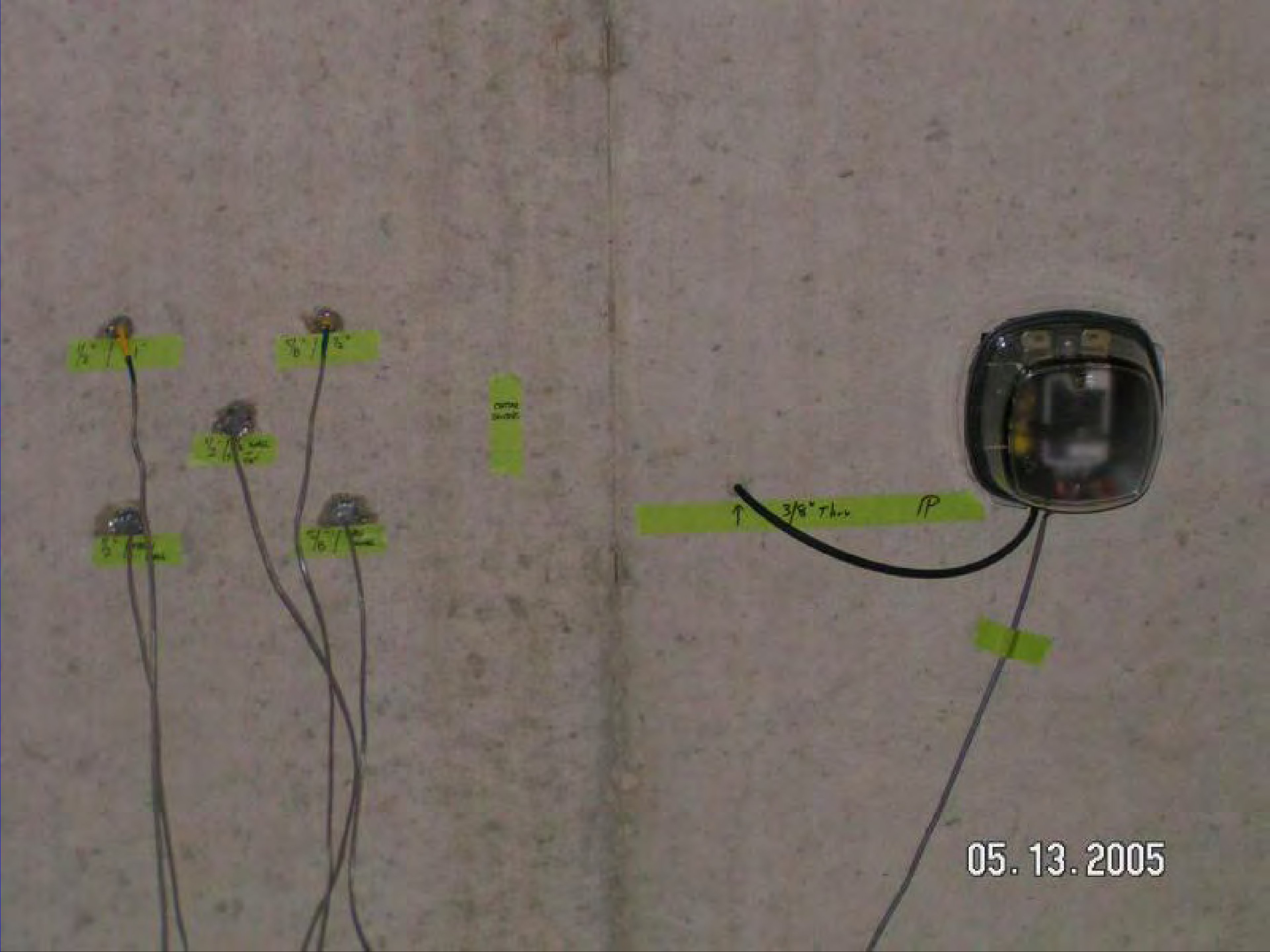
* *Lawrence Berkeley National Laboratories (LBNL) multi-zone ventilation measurements*


74
1
2
WESTC


Calb
6/22/05
LOW
HIGH
TRANSDUCER
SERIAL NO.
346809
RANGE in WC
EXCITATION 12 to 24VDC
COM
EXC
OUT

Measurement Clusters

- Key measurement locations of temp/RH/moist
  - 4 wall locations
  - 2 to 3 slab floor locations
- Temp, RH, and moisture content at different depths in wall and floor materials
  - Poured wall & block wall configurations differed
- Also Delta P (all) and Radon (at 2 clusters)


3/8" Thru
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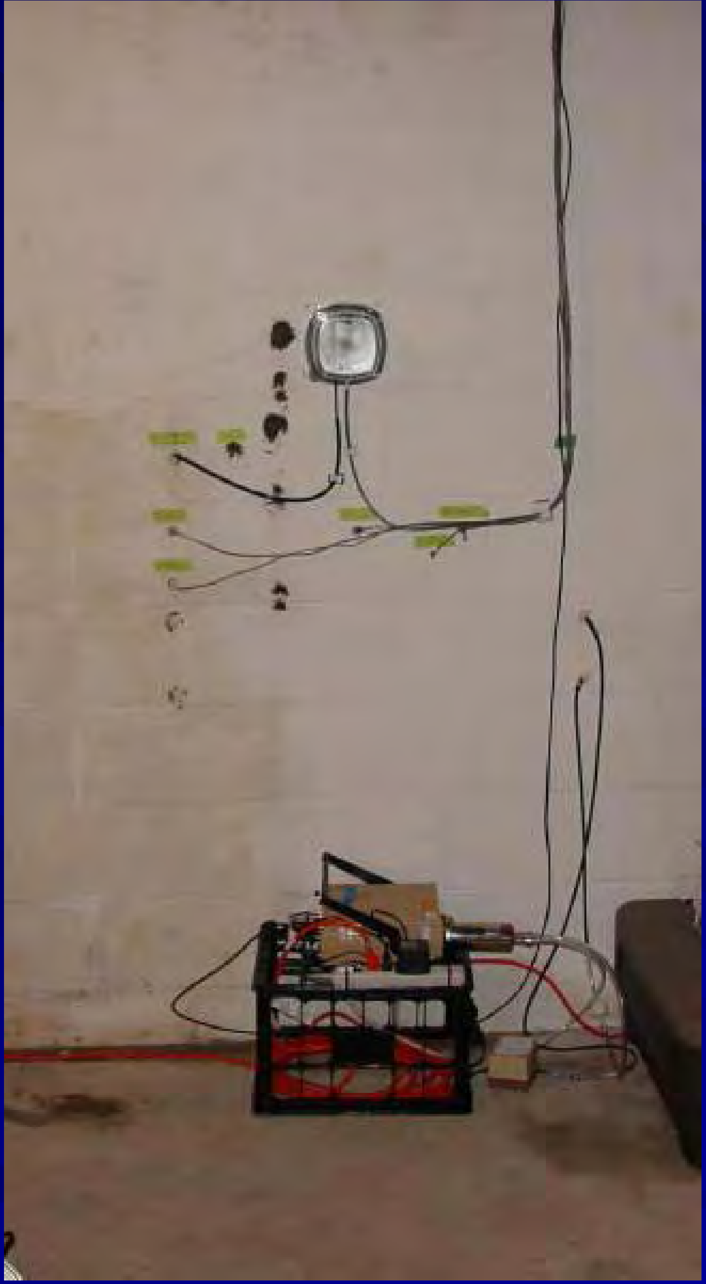
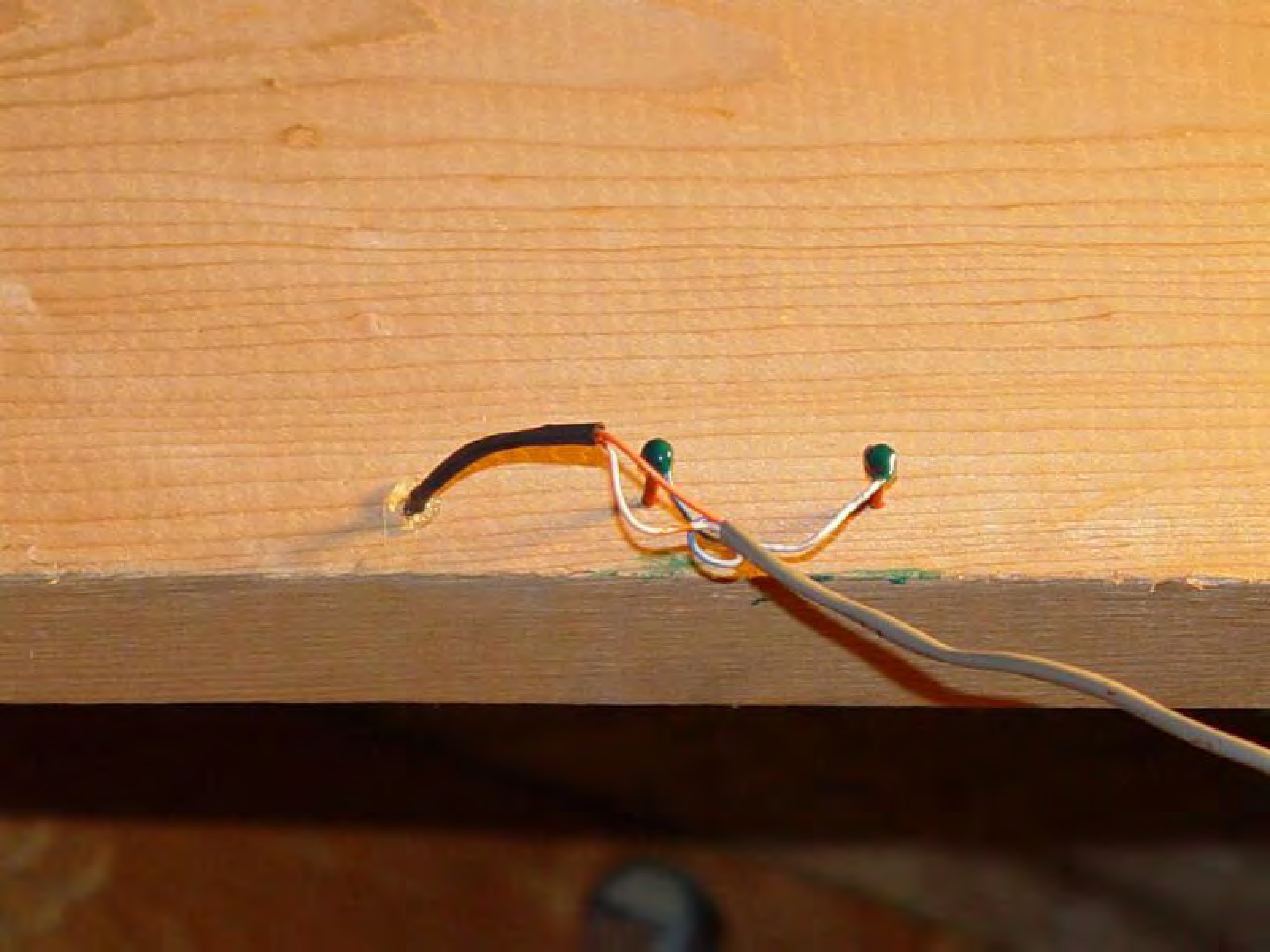





T-FAL
705
FRAGILE
THIS SIDE UP
138-00
Modess

Multi-tracer Interzonal Flow & Ventilation System

BUILDING A FRAMEWORK
FOR HEALTHY HOUSING


L061
21X MICROLOGGER
CAMPBELL SCIENTIFIC INC.
A/C Switches 12V


06.17.2005

Activities (2006-2007):

- Comparison of dehumidifier and ASD performance and energy use in one house
- Study ASD configurations more similar to typical radon control installations
- Continue to monitor response of moisture levels during overlapping seasons
- Evaluate alternate less intensive measurement protocol using handheld instruments
- Houses were decommissioned in January 2007

Study Report: *Exploratory Study of Basement Moisture During Operation of ASD Radon Control Systems*

See Website: www.epa.gov/radon/pubs/index.html

- Appendix A - Report on Experts Meeting/Recommendations
- Appendix B - Forms, Logs, and Checklists
- Appendix C - House Selection Criteria
- Appendix D - ASD System Diagnostics, Design, Description
- Appendix E – Monitoring/Testing Techniques, Instrumentation
- Appendix F - Description of Electronic Data Files
- Appendix G - Conceptual Model: Impact of ASD Operation on Basement Moisture Conditions
- Appendix H - Summary of 14-Day Mean Daily Moisture Changes
- Appendix I - Summaries of Handheld Surface Moisture Data

Activities (2007-2008):

- Analyze data to further establish relationships between inside and outside moisture levels (in progress)
- Create statistical model relating indoor moisture levels to outdoor moisture levels (in progress)
- Examine more closely ASD impact on basement pressures and moisture discharge
- Extend analysis of the sources of air and moisture in the ASD exhaust

Exploratory Study of Basement Moisture During Operation of ASD Radon Control Systems:

Results & Analysis

Bradley Turk

Environmental Building Sciences, Inc. - Las Vegas, New Mexico, USA

U.S. EPA Indoor Environments Division -- Project Sponsor

Eugene Fisher, Patsy Brooks, Phil Jalbert, Susie Shimek

Auburn University SRRTC

Jack Hughes

PA Department of Environmental Protection (PA DEP)

Robert Lewis, Michael Pyles, Matthew Shields

University of Waterloo (Ontario, Canada)

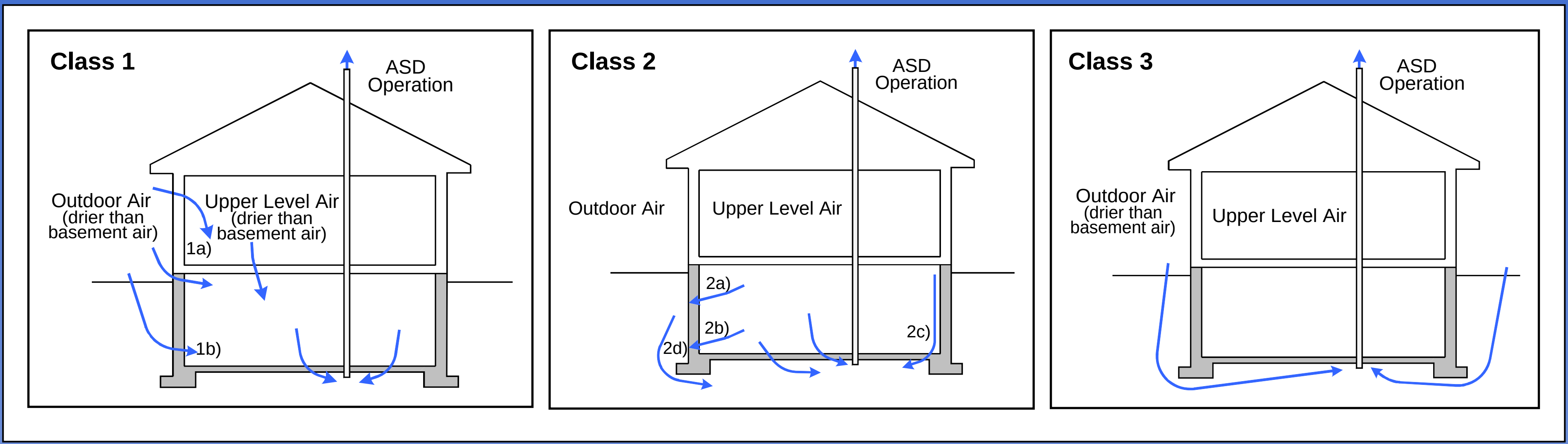
John Straube

Conceptual Model

- Question: How would ASD affect moisture in basements?
- Premise: ASD could alter air flow patterns into, within, and out of building

Conceptual Model

3 classes of air flow



- *Moisture in buildings has many sources*
- *Air flows occur concurrently & can vary over time*
- *Upstairs & outdoors air can add/remove large amounts of moisture in basement*

Estimates of Moisture Contribution

- Air flows to basement from outdoors, 1st floor, and soil can deliver > 25 kg/day
  - *50 cfm at 11g/kg entering air*

- Diffusion through poured concrete walls and floors is typically < 2 kg/day

  (2 liter/day, 0.5 gal/day, 1.4 g/min)
  - *1500 ft^2 basement*
  - Diffusion becomes important when:
    - » ventilation rates are low
    - » more permeable materials (block walls)

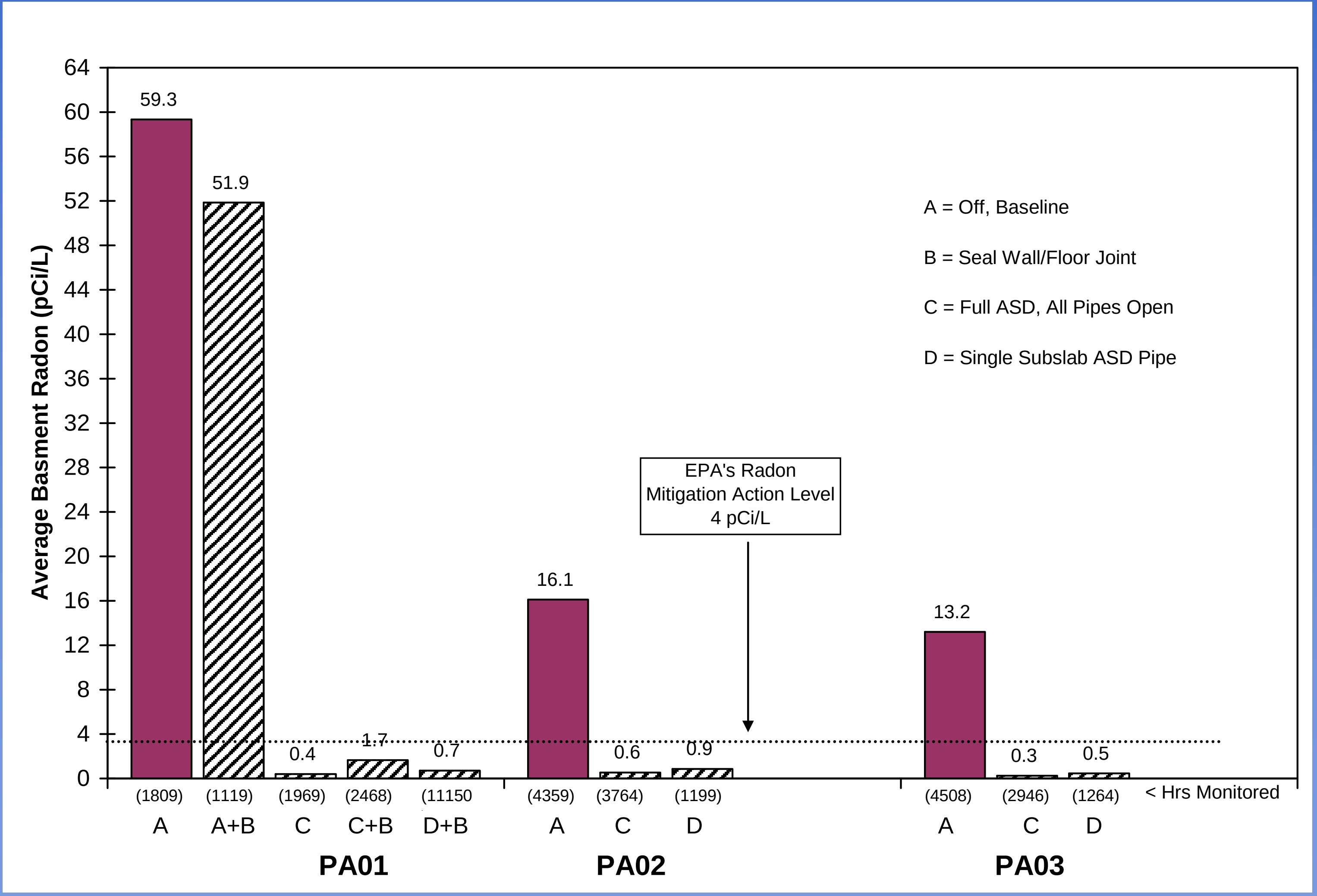
ASD System Characteristics

	Static P (Pa)	Total Flow (cfm)
PA01:	69-110	62-85
1- interior drain tile loop*		
1- center of slab		
PA02:	190-210	90-140
1- interior drain tile loop*		
1- sump/ext. drain tile loop		
PA03:	74	87-180
1- slab*		
2- block wall		

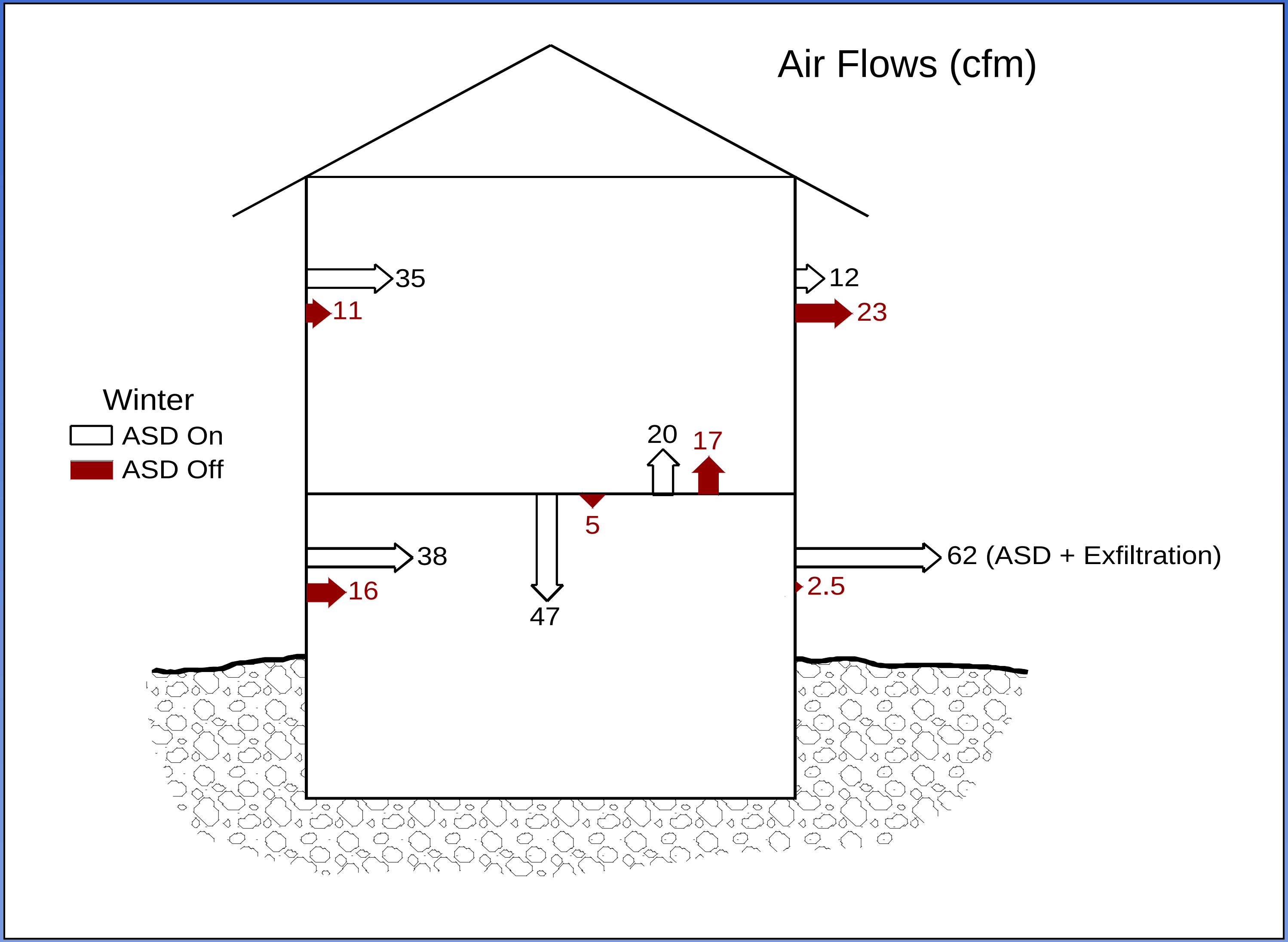
-- Systems were initially operated to be more robust than typical installations, then later reconfigured to be more typical*.

Indoor Radon

- Radon is dramatically reduced
- Usually, the dominant source of radon is the soil

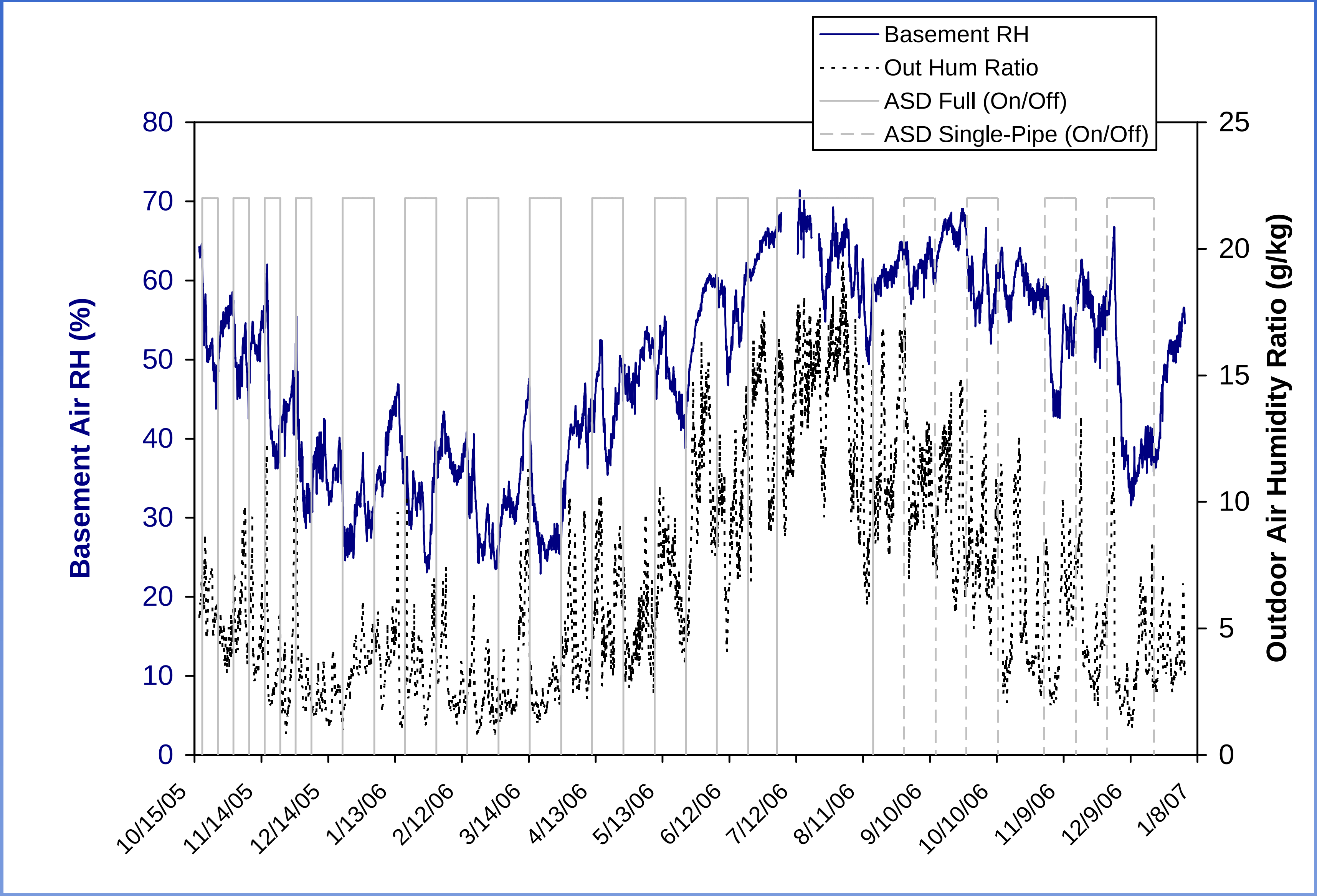


Measured Changes in Air Flow Patterns Caused by ASD (PA02)



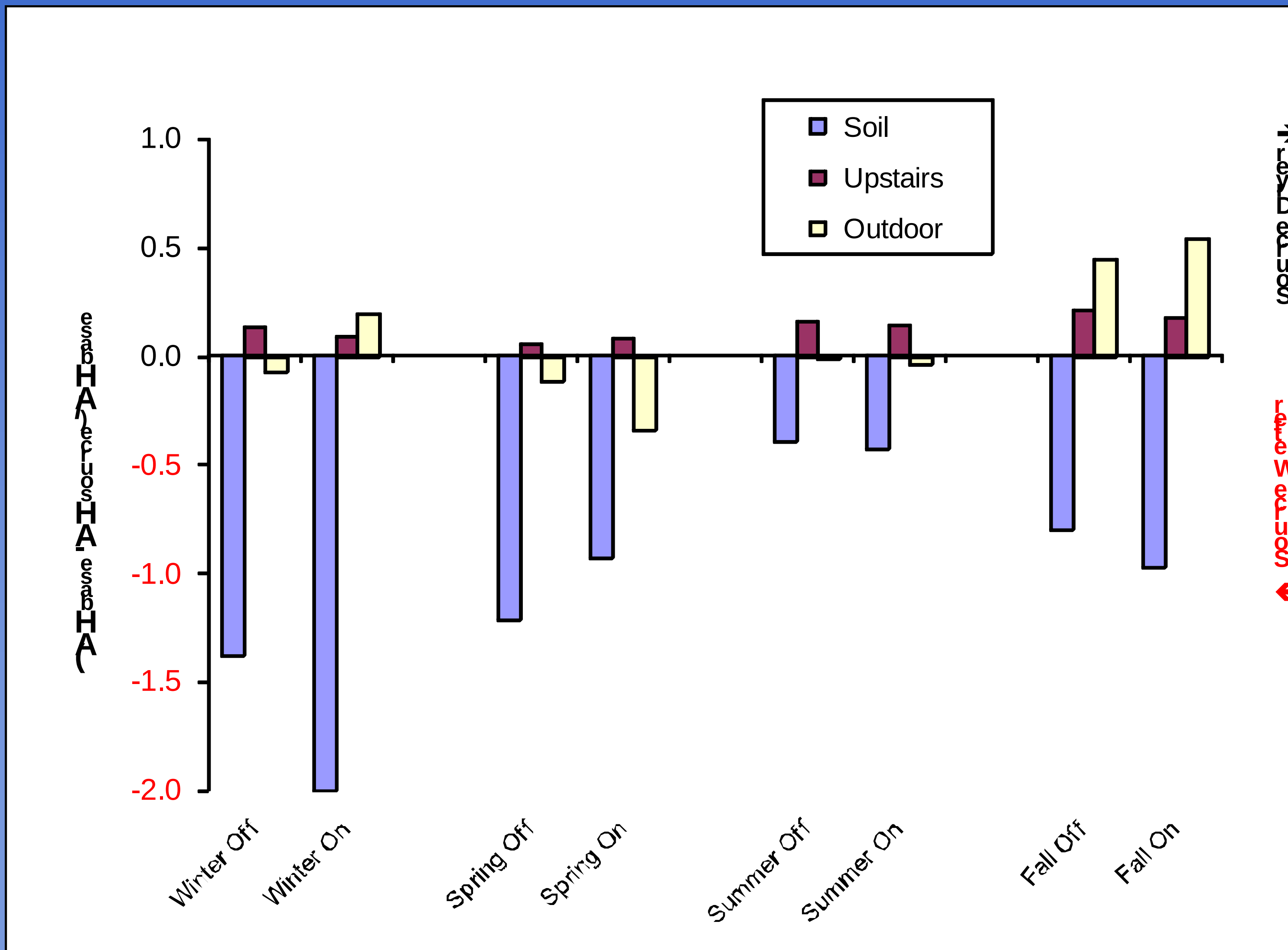
Multi-tracer sources and sample analysis provided by David Faulkner & Bill Fisk, LBNL

In these 3 houses, moisture in basement air tracks outdoor air moisture



Basement-Source Air Relative Moisture Index

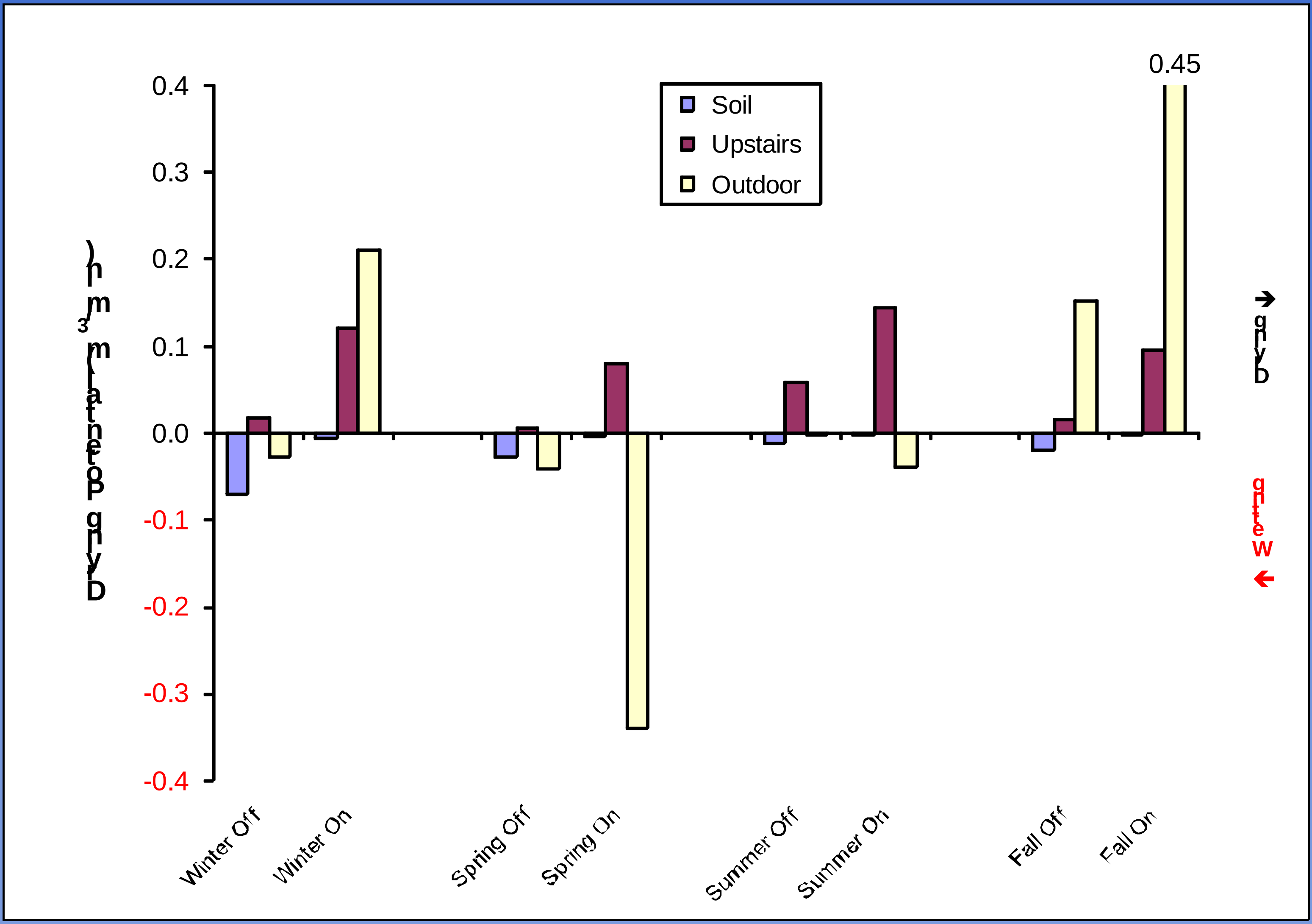
PA02



Relative Drying/Wetting Potential

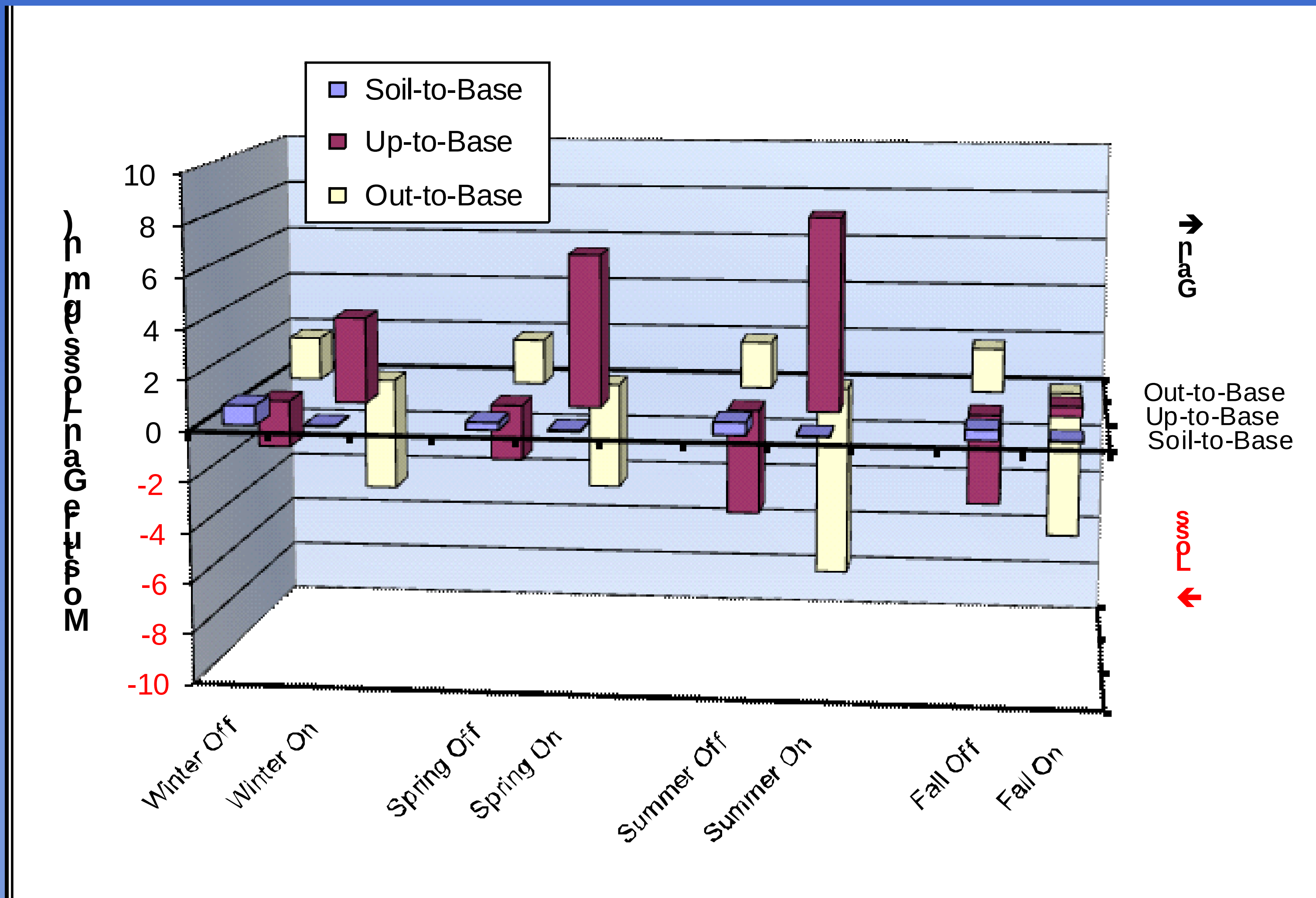
PA02

$(AH_{base}-AH_{source)}/AH_{base})$ x $Flow_{IntoBase}$

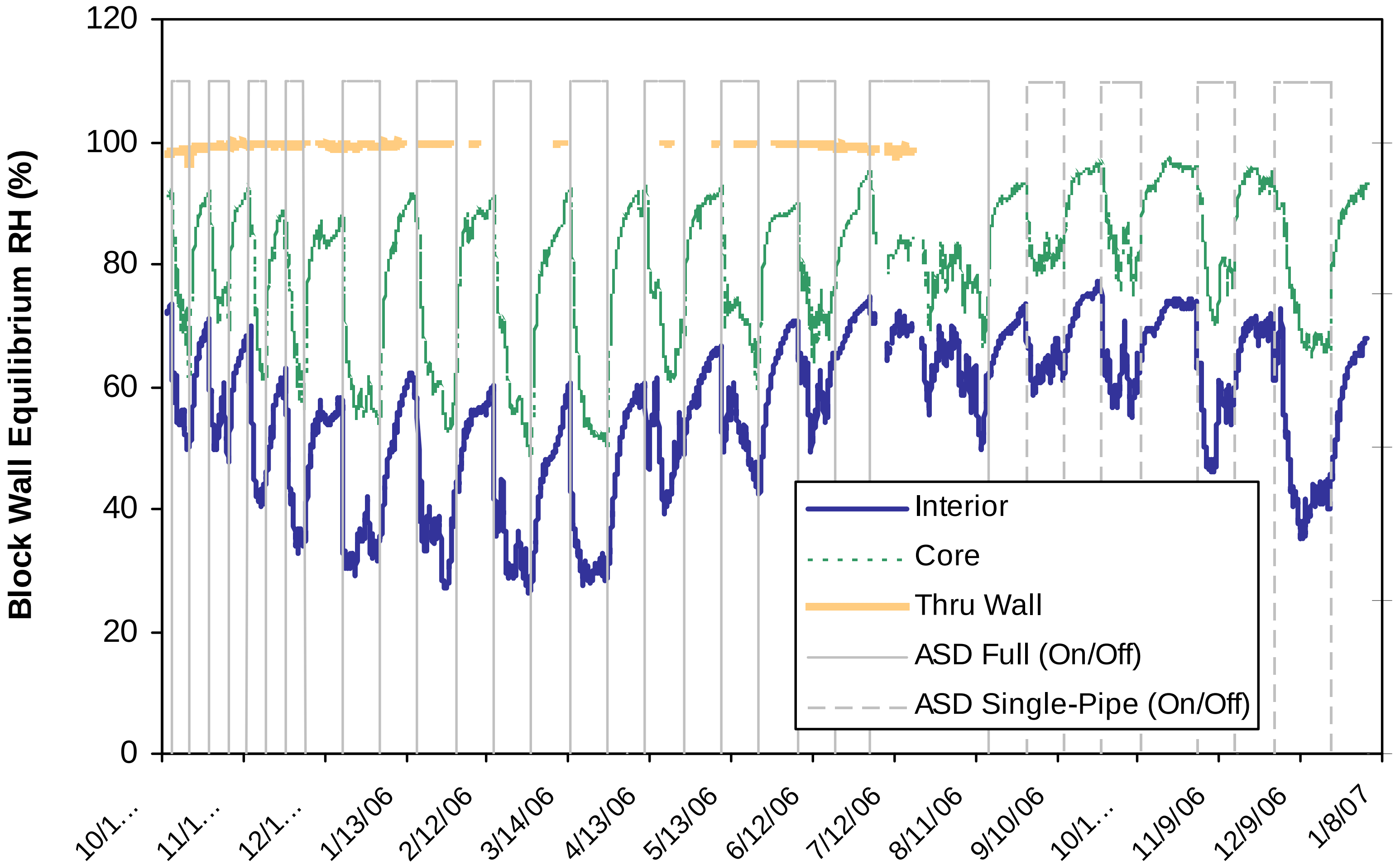


Net Convective Moisture Flow

PA02

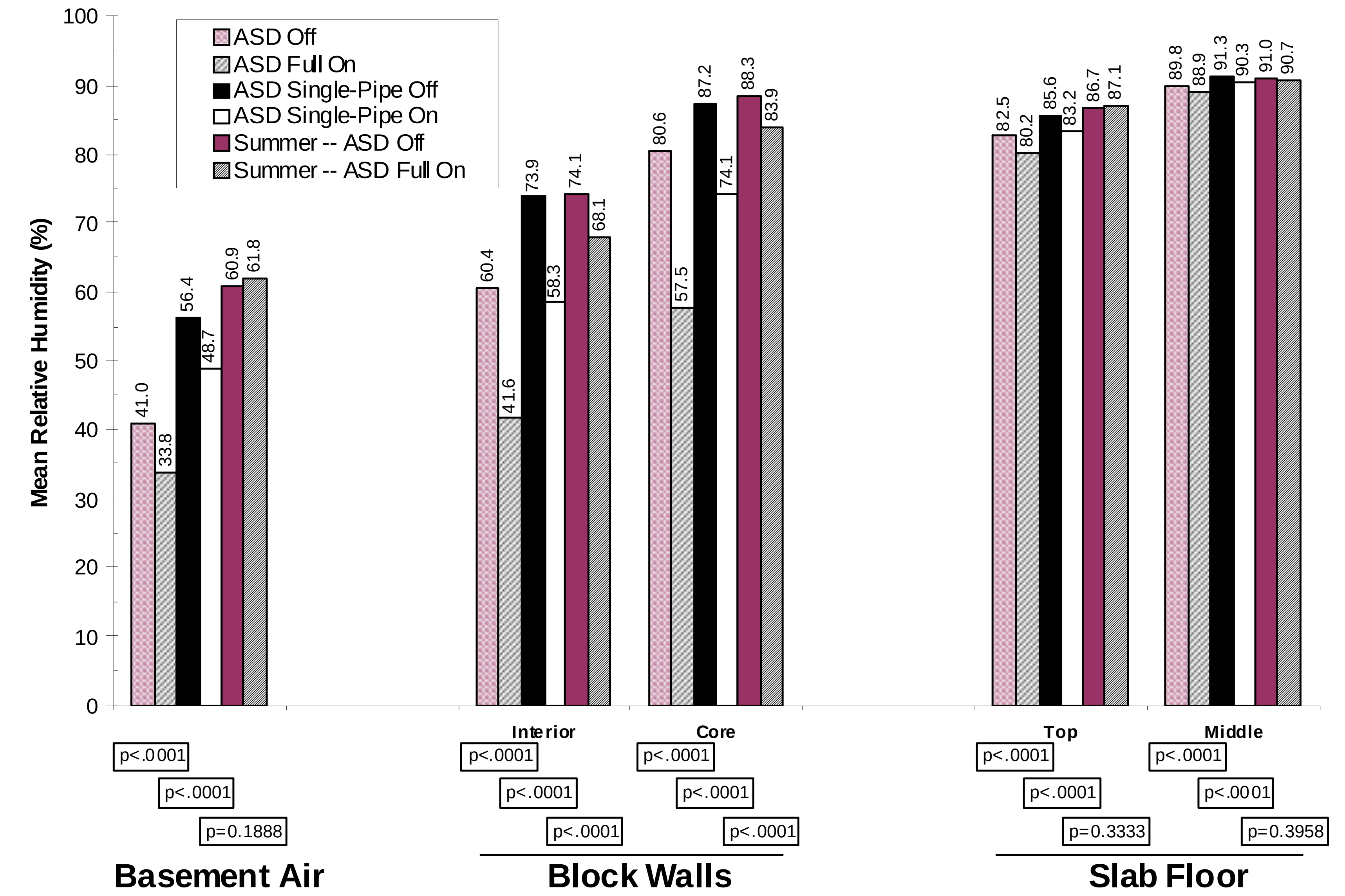


Wall Moisture -- PA02



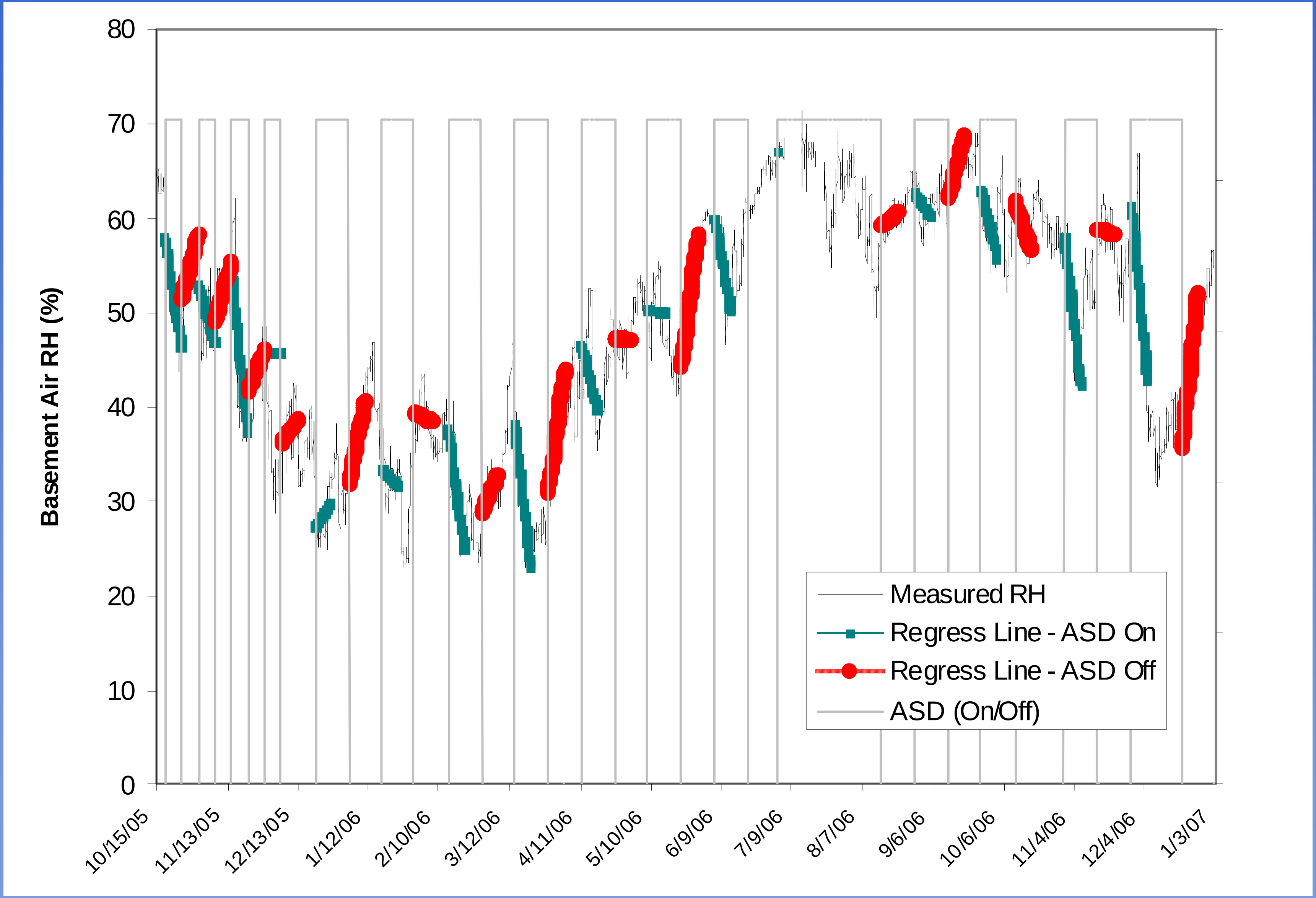
Mean RH -- PA02

Dec 2005 -- Jan 2007



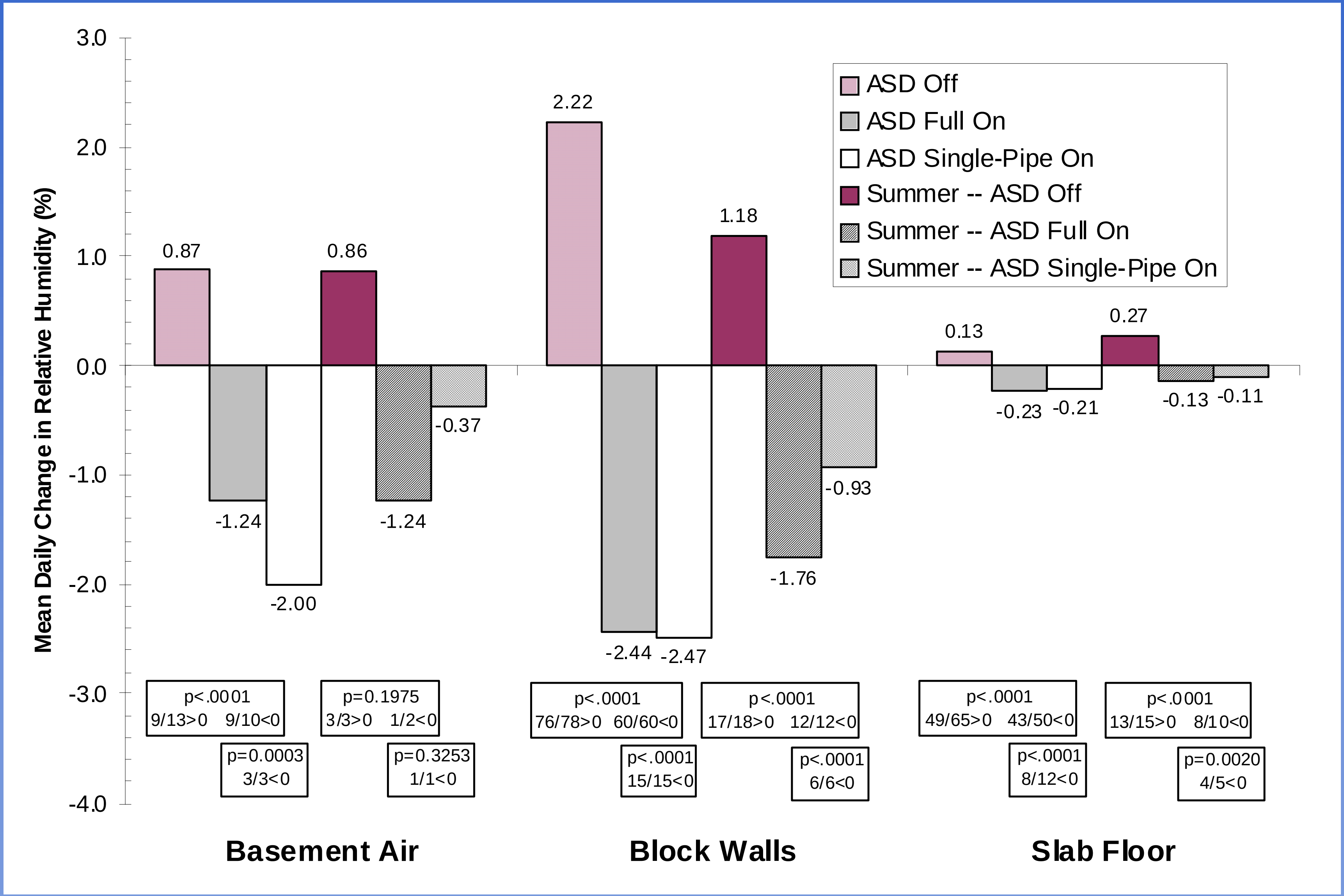
Second 7 days of 14-day, or longer, cycling periods

Autoregression on 1st Seven Days of Each Cycle PA02 Basement Air



Mean Daily Change in RH -- PA02

Oct 2005 -- Jan 2007

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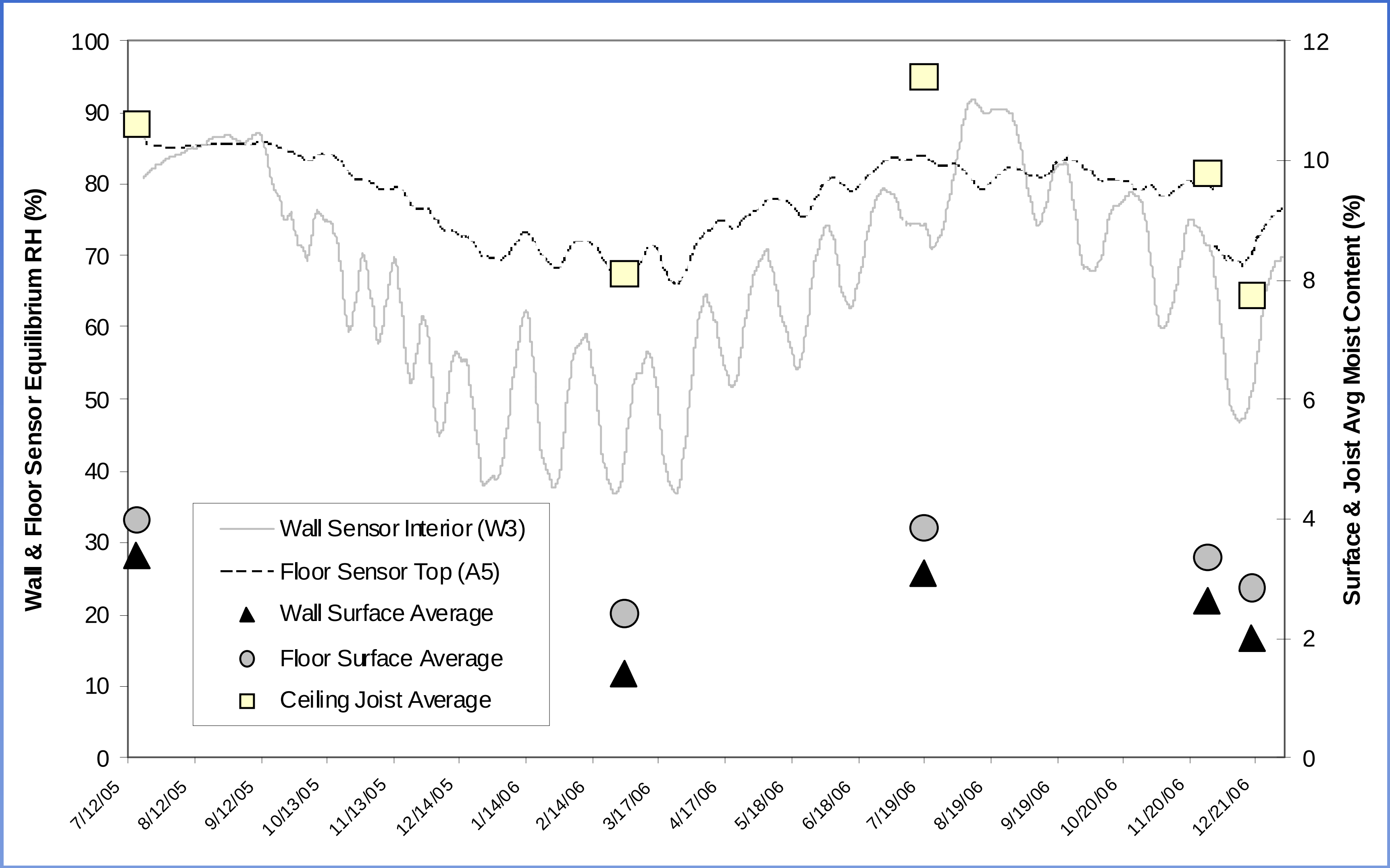
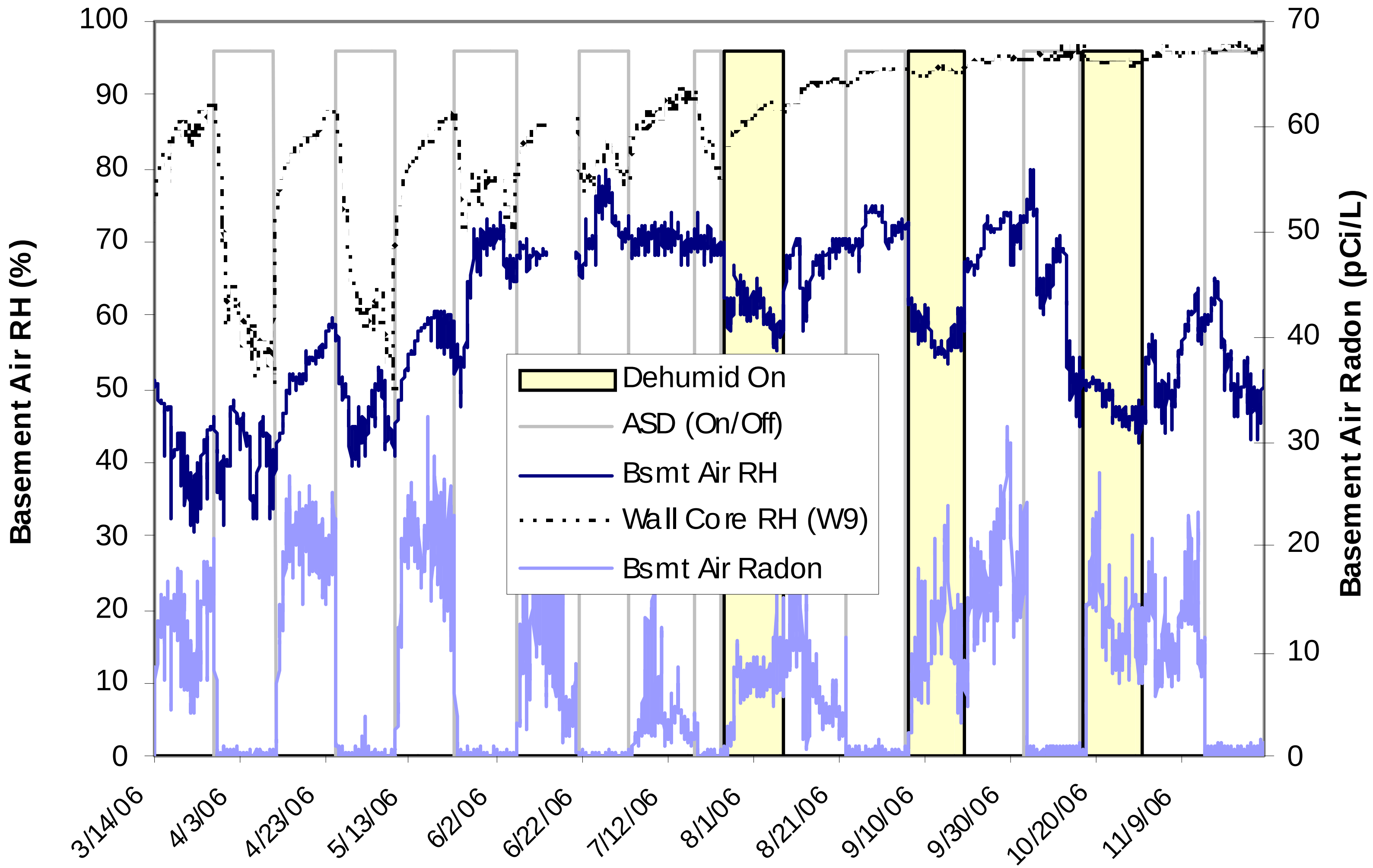
Surface & Joist Measurements vs. Embedded Sensors (PA02)



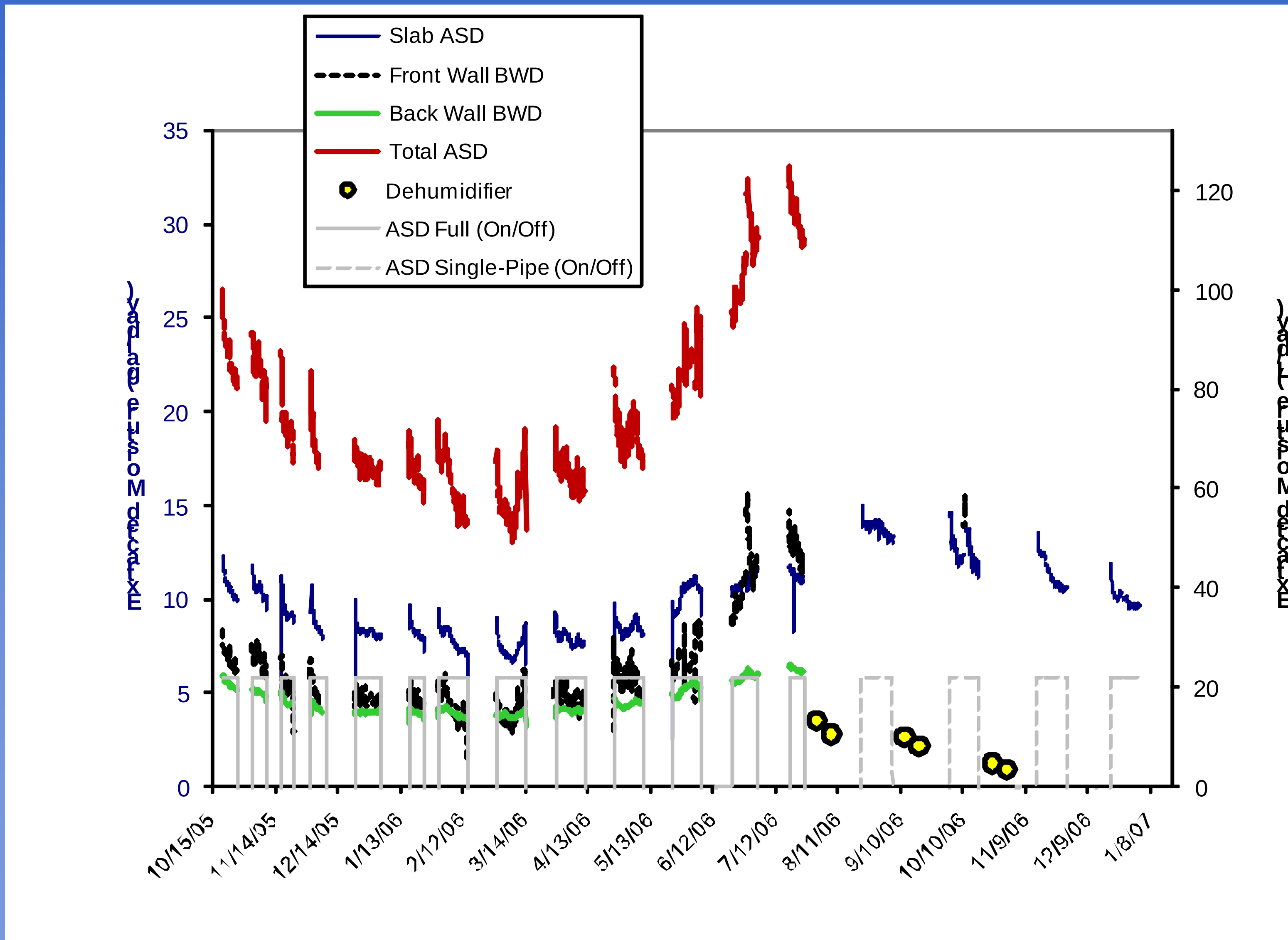
Dehumidifier & Condensate Monitoring

Dehumidifier Impact in Air & Wall vs. ASD

PA03



Moisture Extracted During Cycles
PA03



Average Moisture Extraction

(gal/day)

House ID	Full System	Single Pipe	Dehumid.	% ASD Exh. from Base.
PA01	13	10	--	46
PA02	15	13	--	72
PA03	19	11	1-4	72

Est. Additional Yearly Energy Costs

House ID/ Season	Out-1st Flr Flow Change (cfm)	Add. Heat Cost ($)	Add. Cool Cost ($)	Radon Fan Elec. Cost ($)	Total Add. Cost ($)
PA01	3.3 - 3.9	10	2	70	83
PA02	22 - 41	60	24	70	154
PA03	30 - 63	80	41	70	191
Dehumid.					180

Summary for These Houses

- During non-summer months ASD caused significant reductions in basement moisture (and likely reduces summer dehumidification)
- ASD robustly controls radon; may affect IAQ and energy use
- Moisture Sources: Soil gas minor contributor, outdoor air moisture appears to dominate ASD effects
- Moisture Drying: Upstairs air, outdoor air (winter)
- ASD impact on moisture related to many factors: air leakage from outdoors, upstairs, and soil, HVAC systems, outdoor conditions, soil types

Summary for These Houses (cont)

- Moisture performance during continuous, long-term operation not studied
- Changes in air flow patterns consistent with model
- ASD can significantly increase outdoor air ventilation by exhaust: pros and cons
- At 1 house: dehumidifier more effective controlling indoor air RH, but ASD also reduced wall moisture
- Dehumidifier extracted approximately 8% to 25% of the moisture removed by the ASD system

Conclusion

ASD Can Have Significant Moisture Impact, But . . .

- ASD designed for radon control may not be optimal for all moisture concerns
- Uncontrolled, additional ventilation may not be desirable
- ASD impact on moisture may not be the same for different climates, seasons, and house construction and systems

Future Research Needs

- Results of this study of 3 houses insufficient for national design & policy guidance
- Research framework:
  - Enhance conceptual model: predict performance in other climates, house construction & soil types
  - Develop simplified field evaluation, test and measurement protocols
  - Field validation studies in other regions of US
  - Monitor microclimate & moisture in wall assemblies (e.g., frame & gypsum board) during ASD
  - Examine system performance during continuous long-term operation

Get the Full Report

http://www.epa.gov/radon/pubs/index.html

(about the 6th publication on the list)