# Exploratory Research:
# Moisture Control with Radon Mitigation

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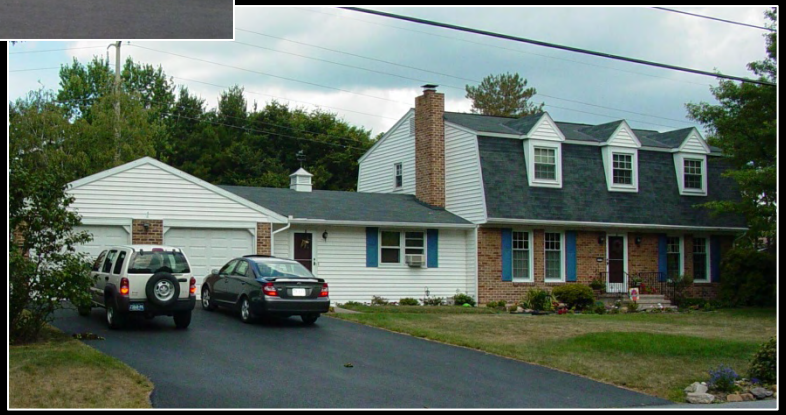
# Background
## ASD = Active Soil Depressurization

- Anecdotal reports of reduced ‘musty odors’ and dampness
- Asthma & respiratory ailments related to damp indoor environments
- Contractors now installing ASD, claiming moisture benefits
- Possibility of multi-pollutant control with a single technique (radon & moisture)
- Initial steps:
  - EPA literature search
  - Meeting of experts to draft project design

# Overview of Exploratory Study

- Develop simple conceptual model
- Conduct field study in 3 PA houses
    - Full basements
    - Mostly unfinished & unoccupied
    - Slightly elevated radon
    - Moisture problems - but no liquid water
    - 2 with block walls, 1 with poured walls
  - Install re-configurable ASD systems - cycled on/off (1-day to 14-day)
  - Multi-parameter monitoring for 12 - 18 months

# Study Houses



# Configurable ASD System

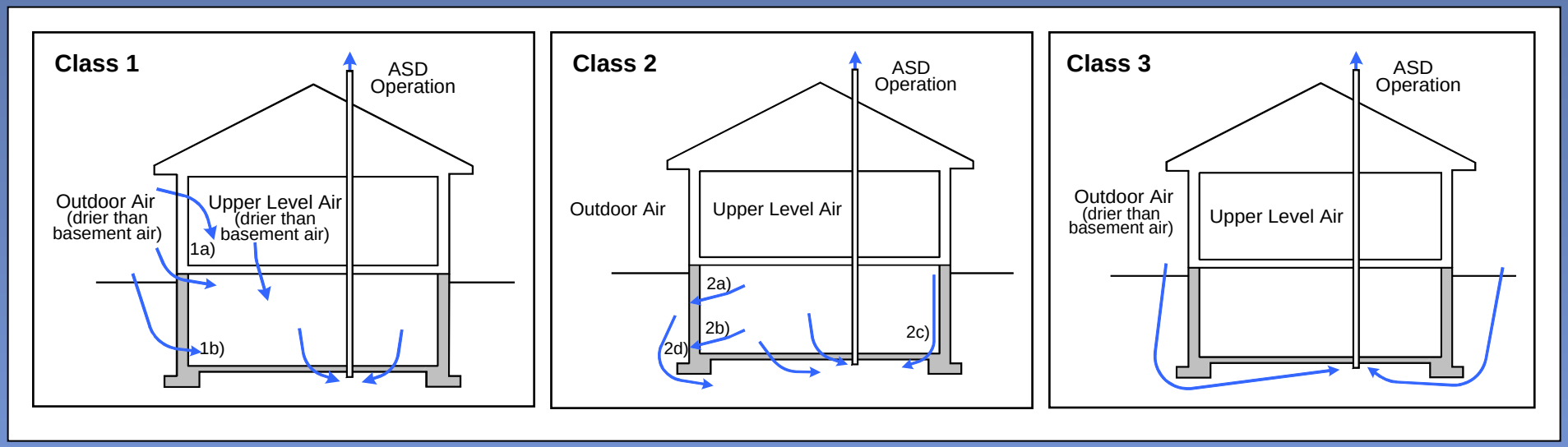
# Conceptual Model

- 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*

# Field Tests & Measurements

## 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*

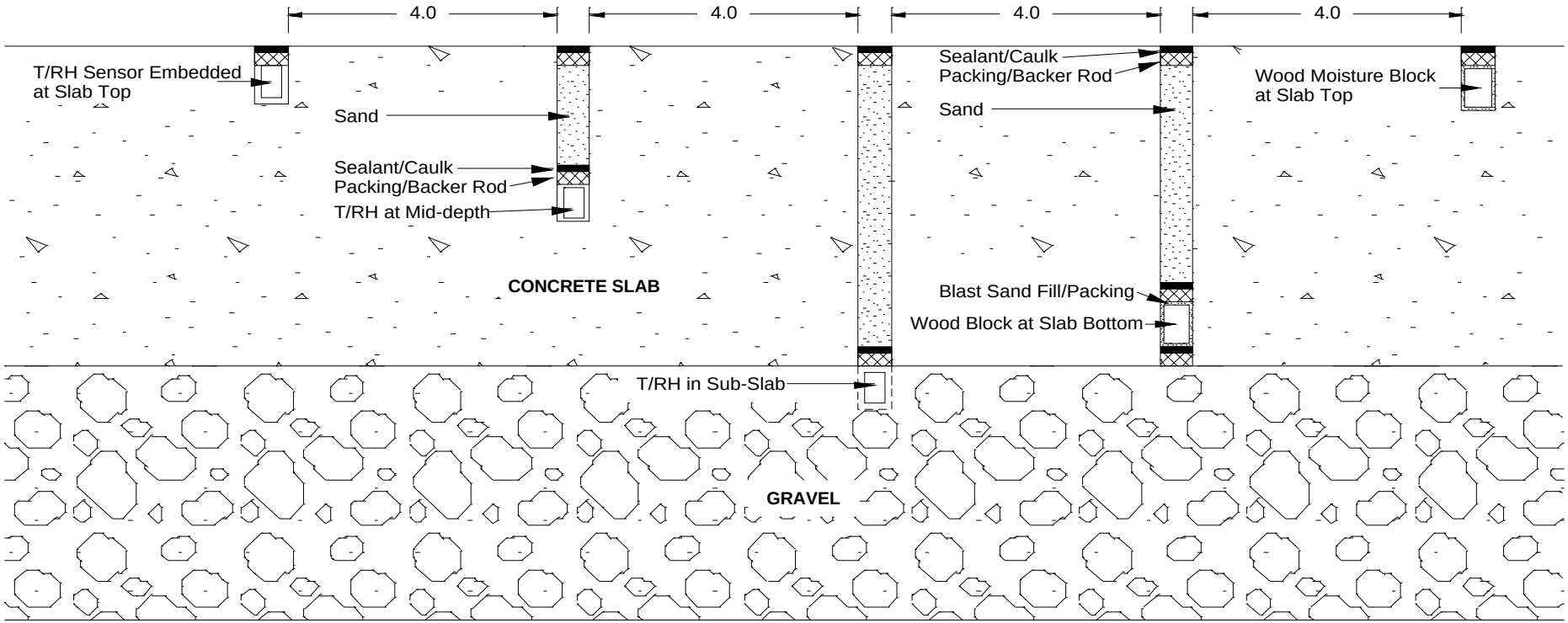
## Moisture Storage & Diffusion

Walls, Floors, Wood Framing

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

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

# Slab & Wall Moisture Sensor Placement



74
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2
WESTC
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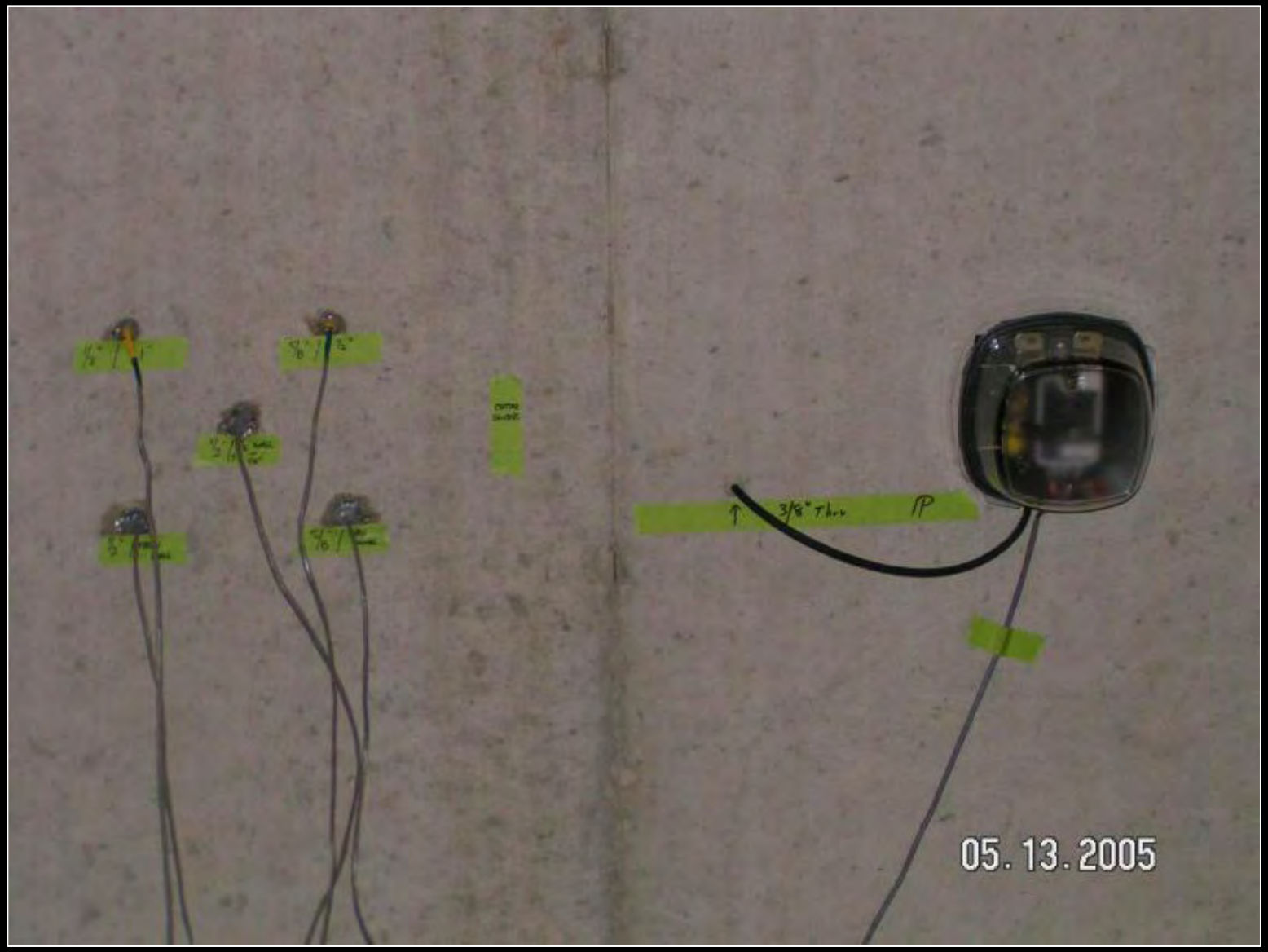
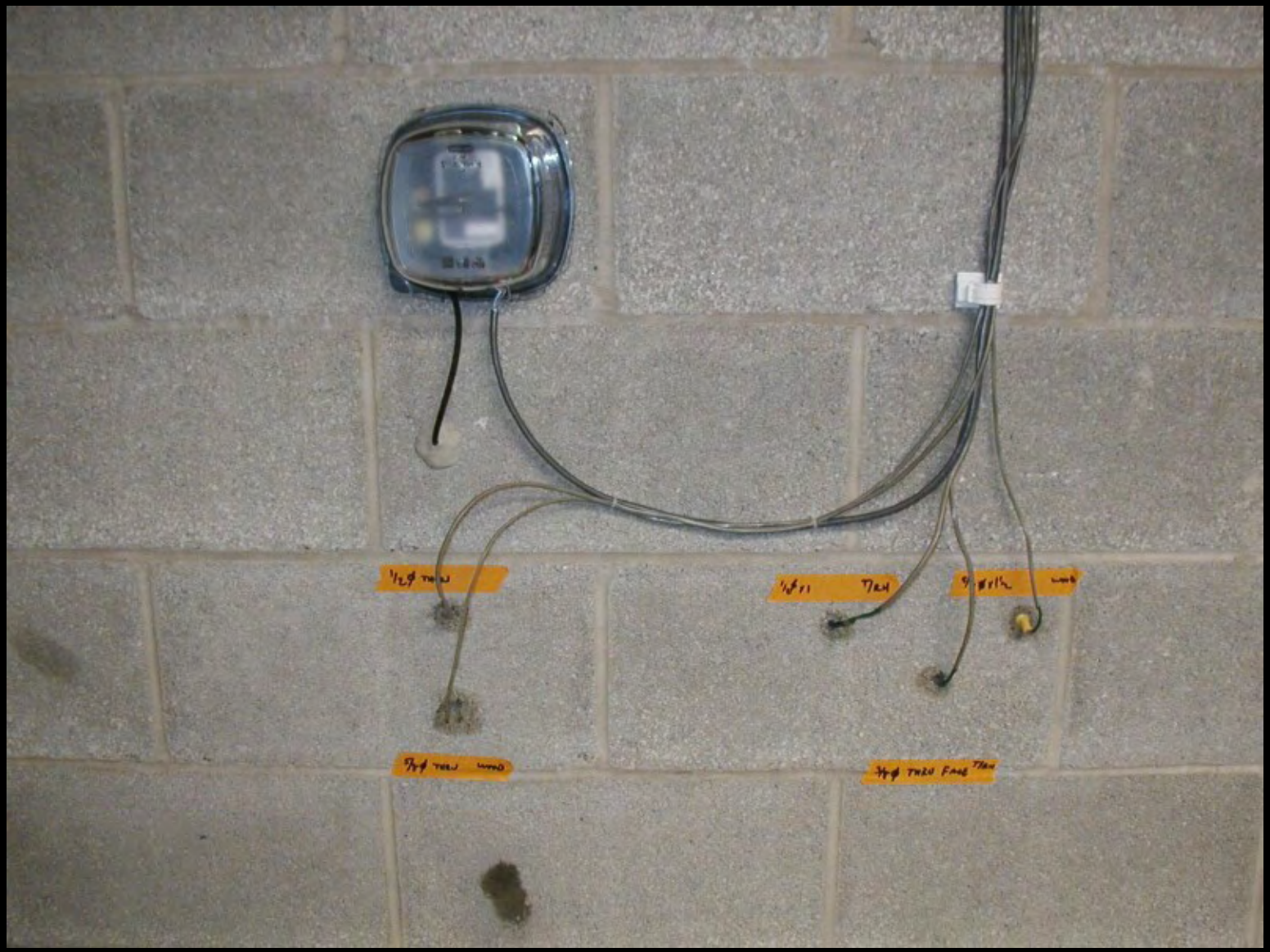
32

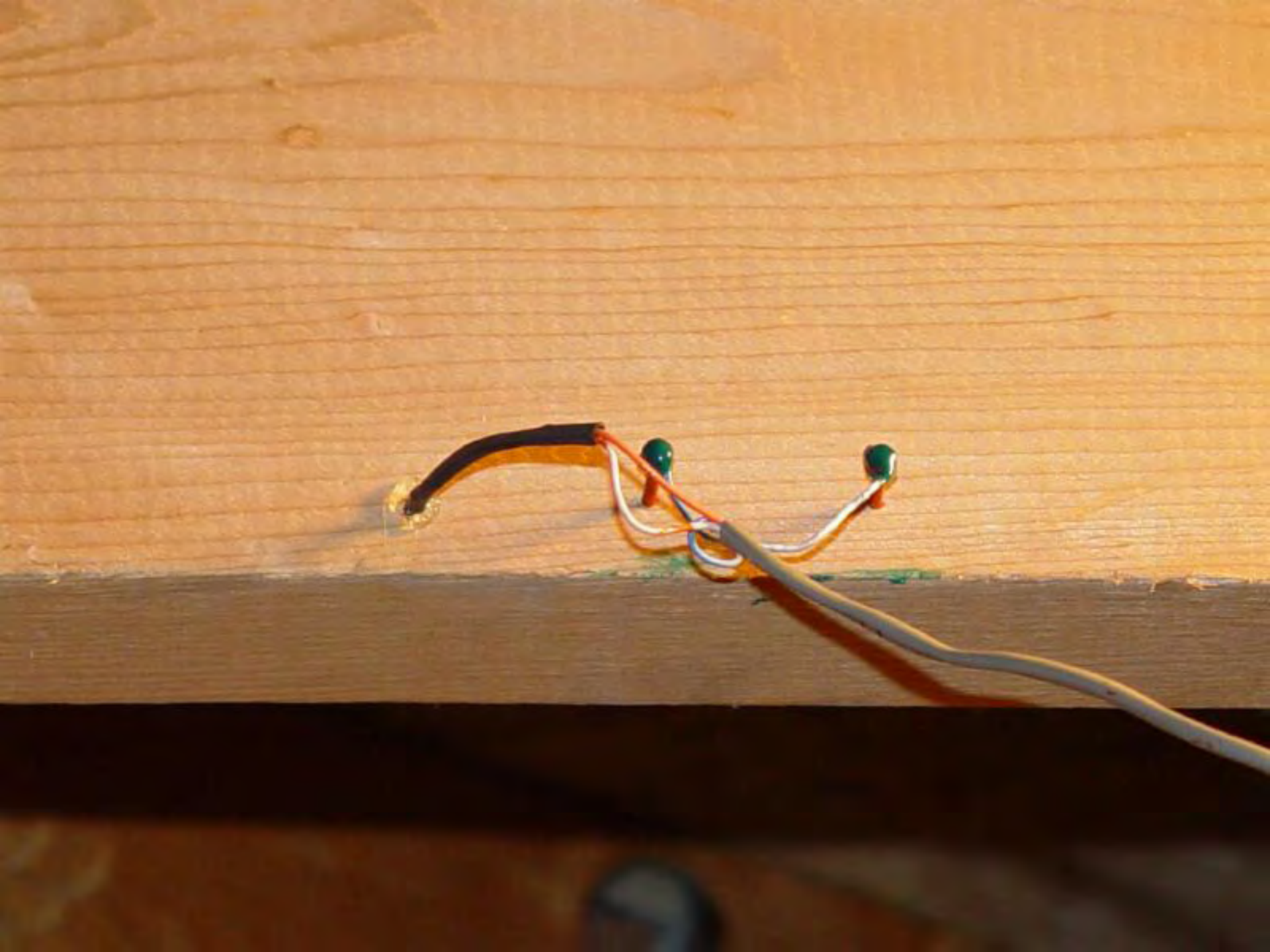
# Moisture, Temperature, & Pressure Sensors



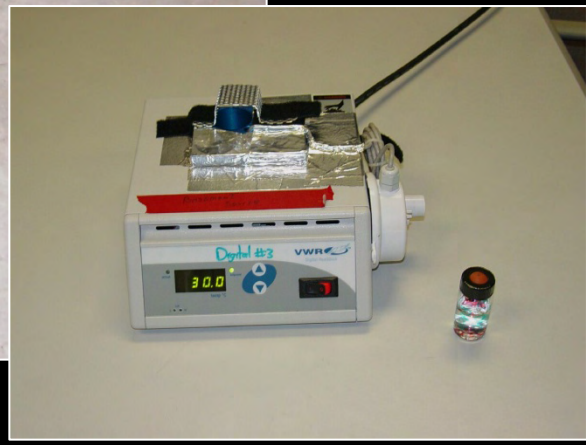
# Sensors in Block Wall



# Temp/RH Sensor at Interior Slab Surface



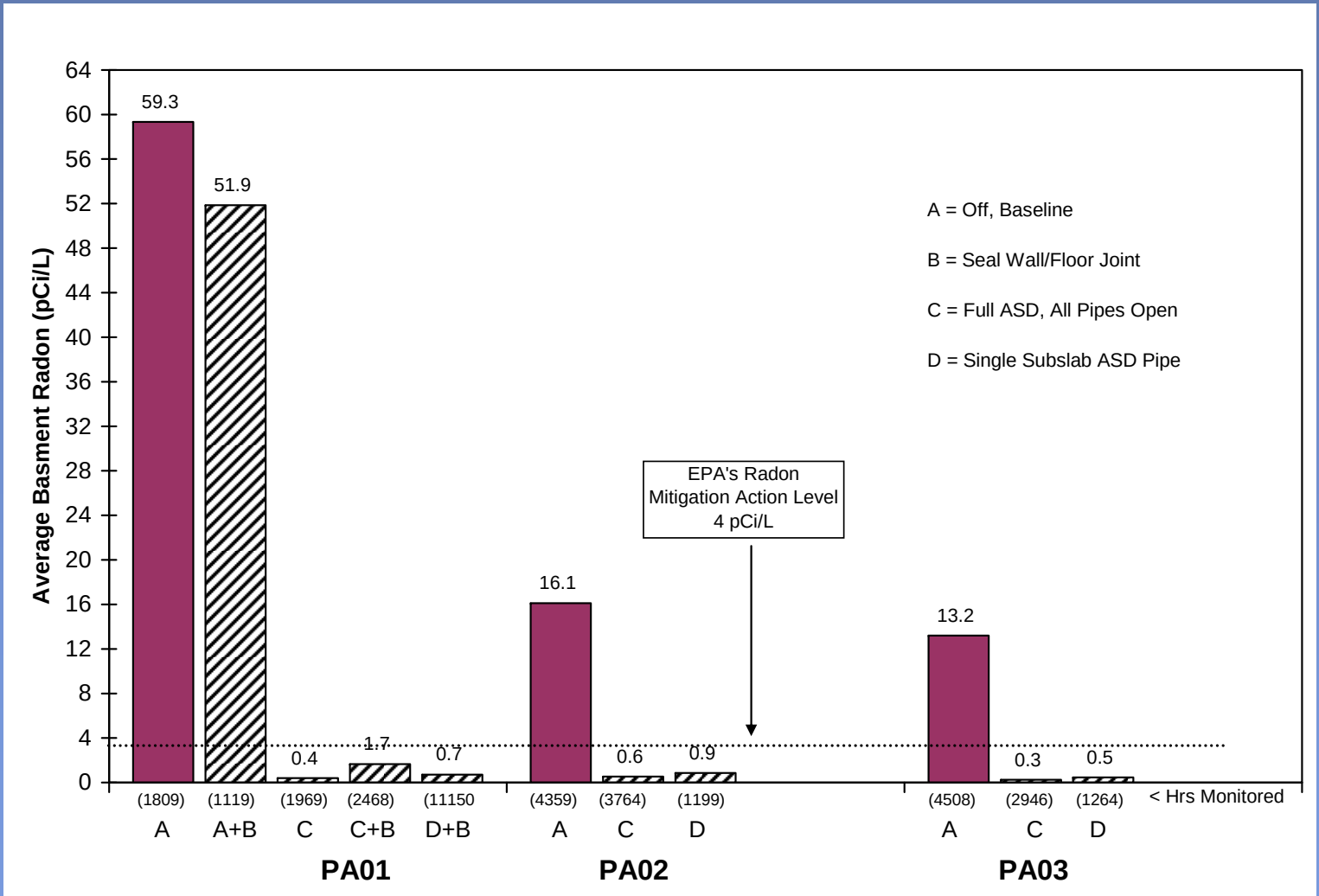
# Multi-tracer Interzonal Flow & Ventilation System



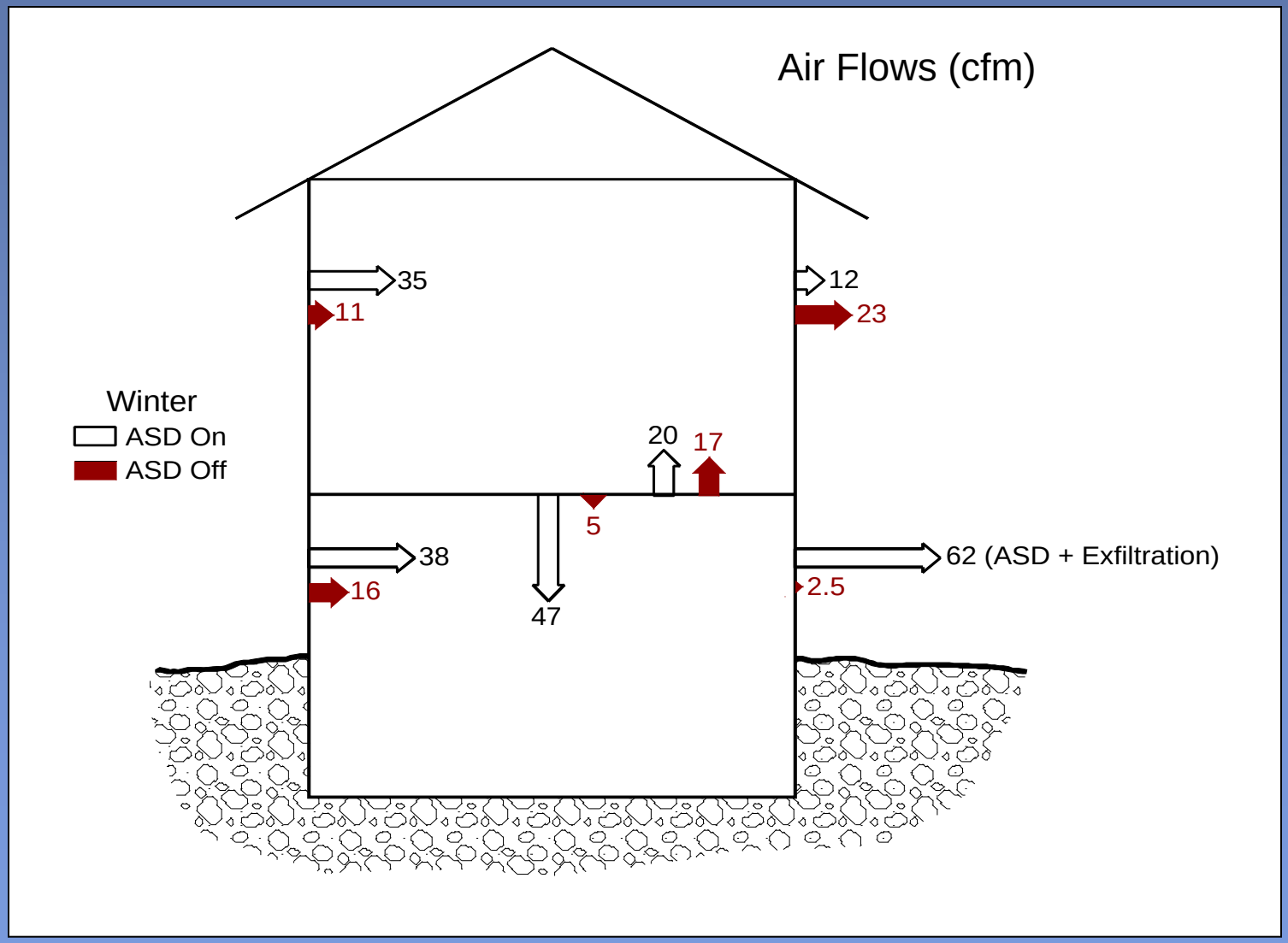
# Dehumidifier & Condensate Monitoring

# Indoor Radon

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

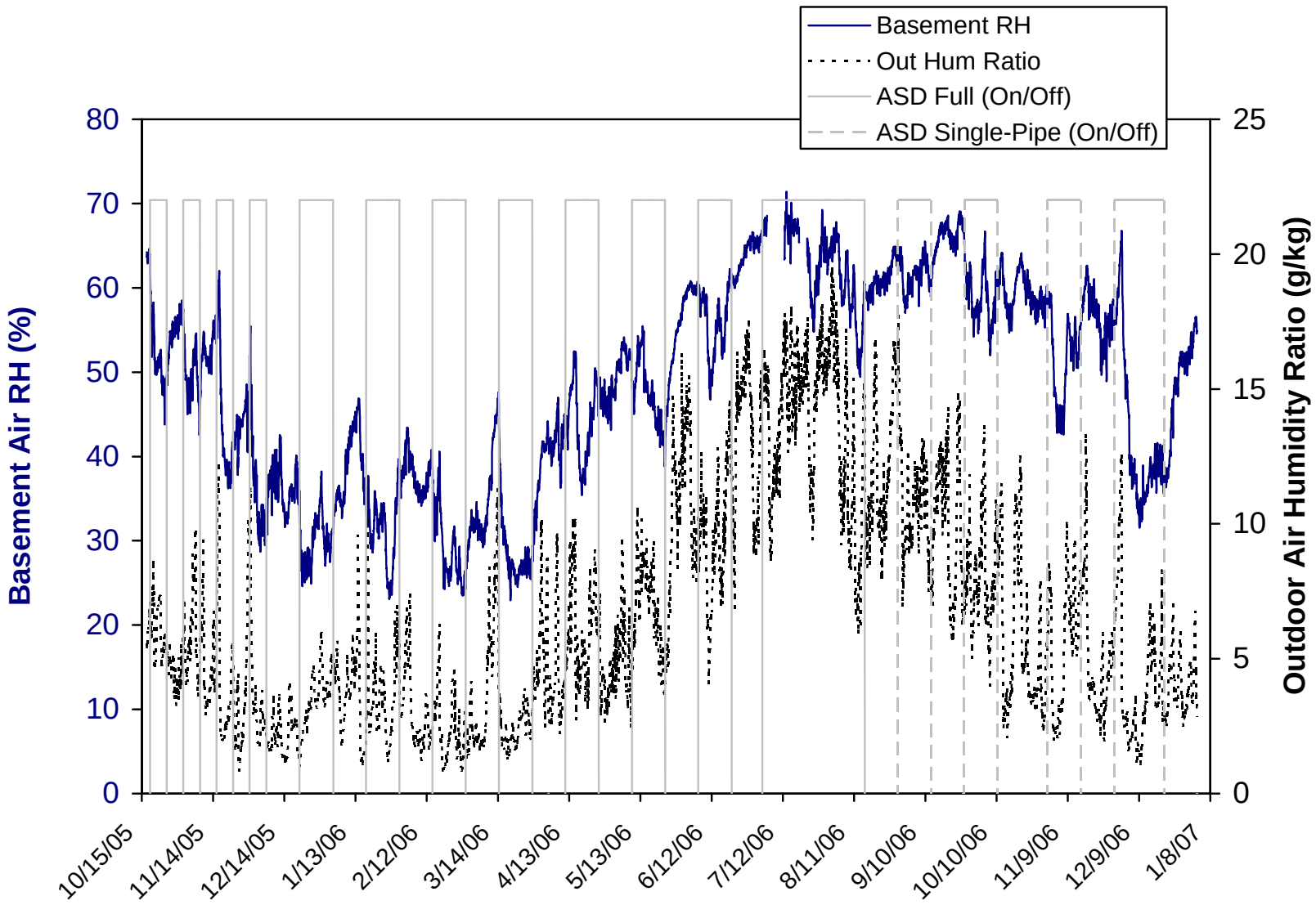


# Measured Changes in Air Flow Patterns Caused by ASD (PA02)



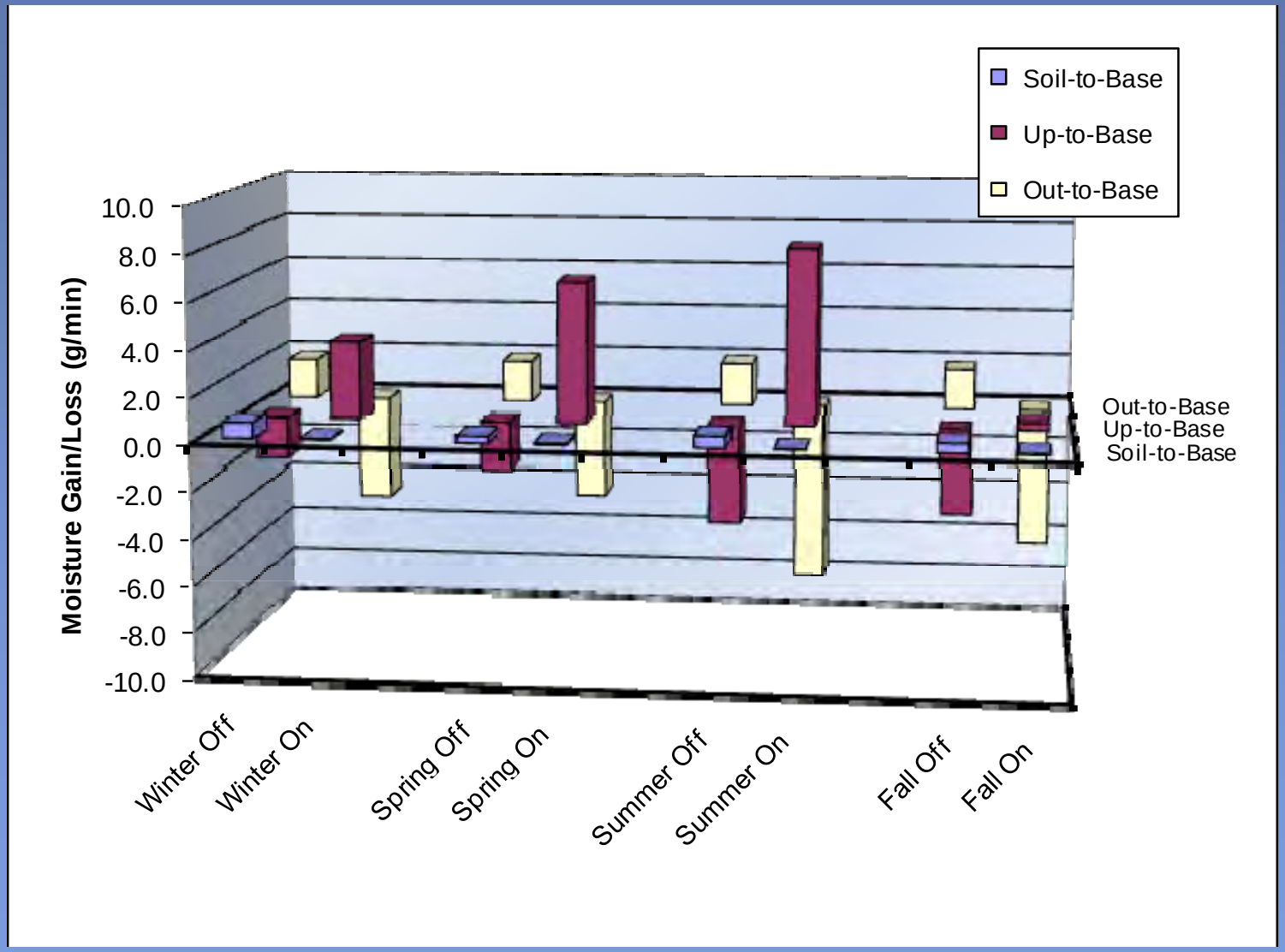

*Multi-tracer sources and sample analysis provided by David Faulkner & Bill Fisk, LBNL*

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

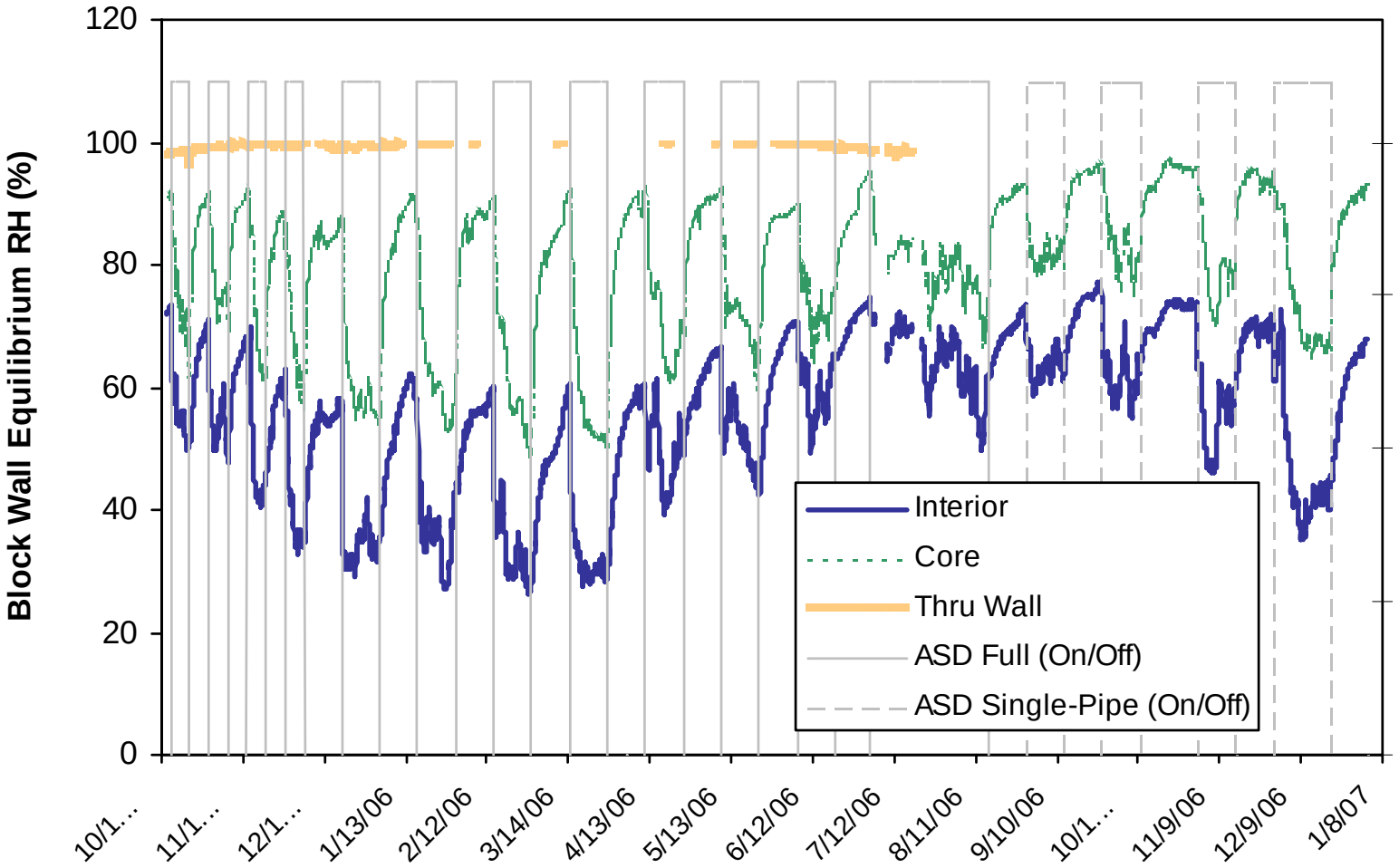


# Net Convective Moisture Flow

## PA02

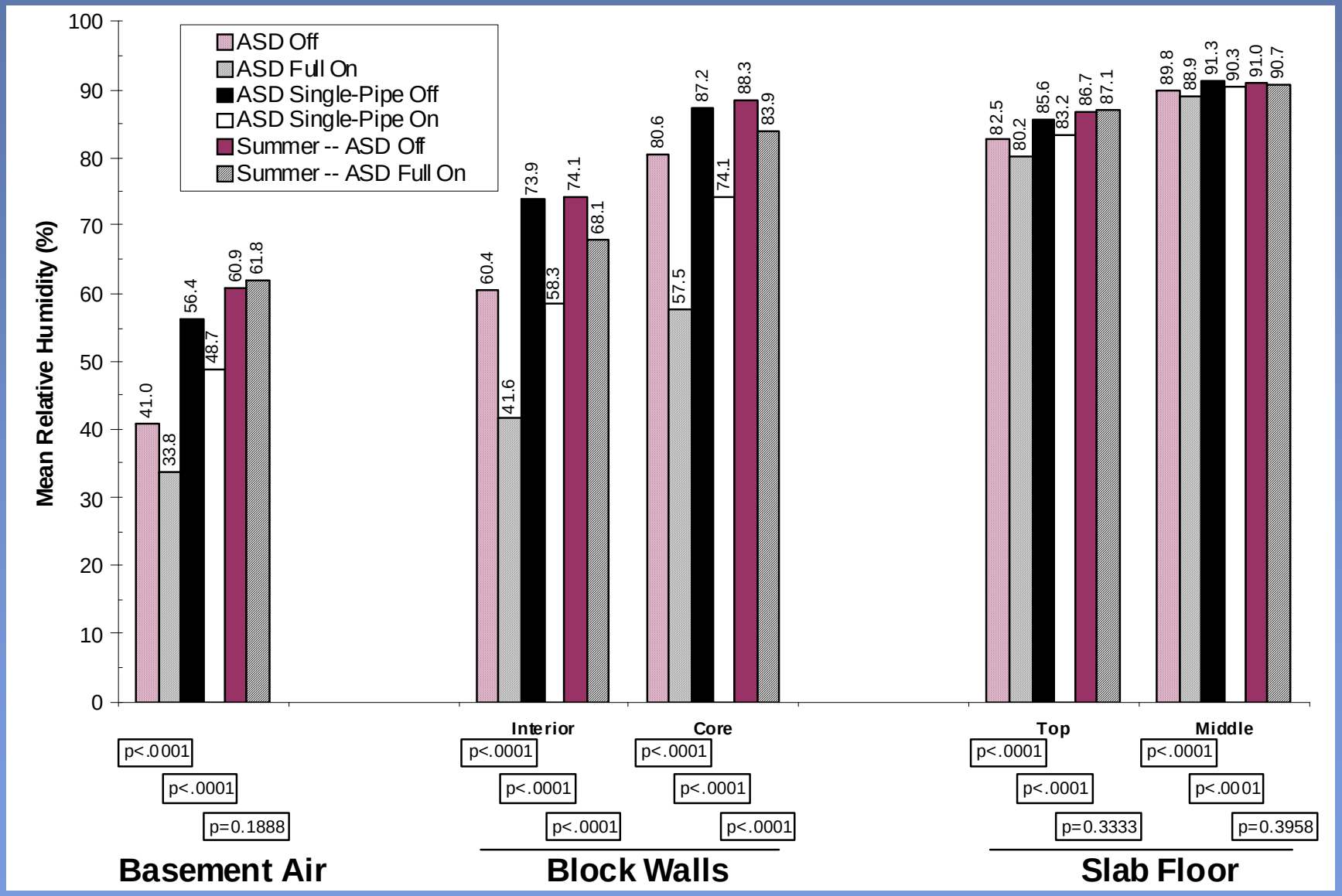


# Wall Moisture -- PA02



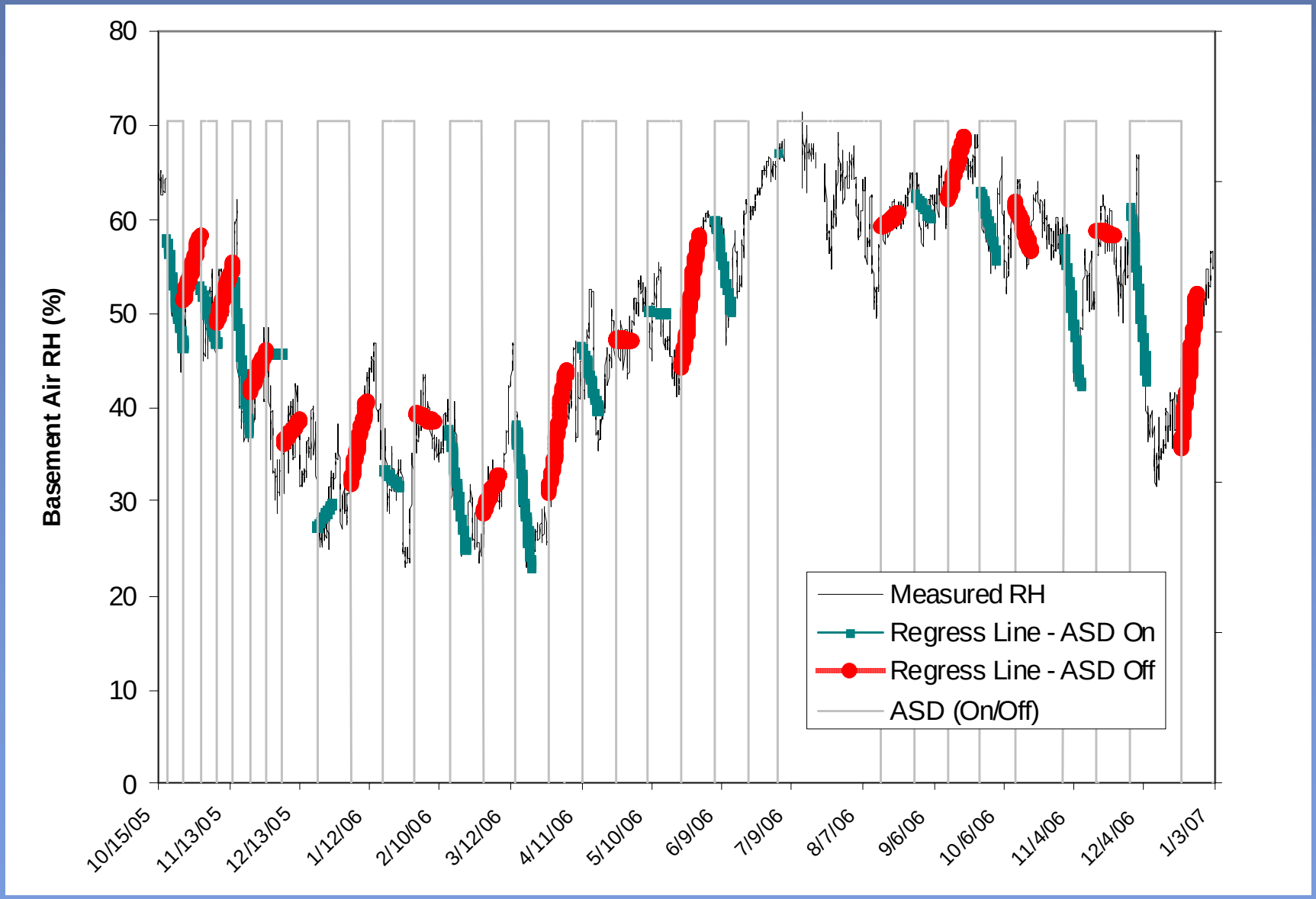
# Mean RH -- PA02

## Dec 2005 -- Jan 2007



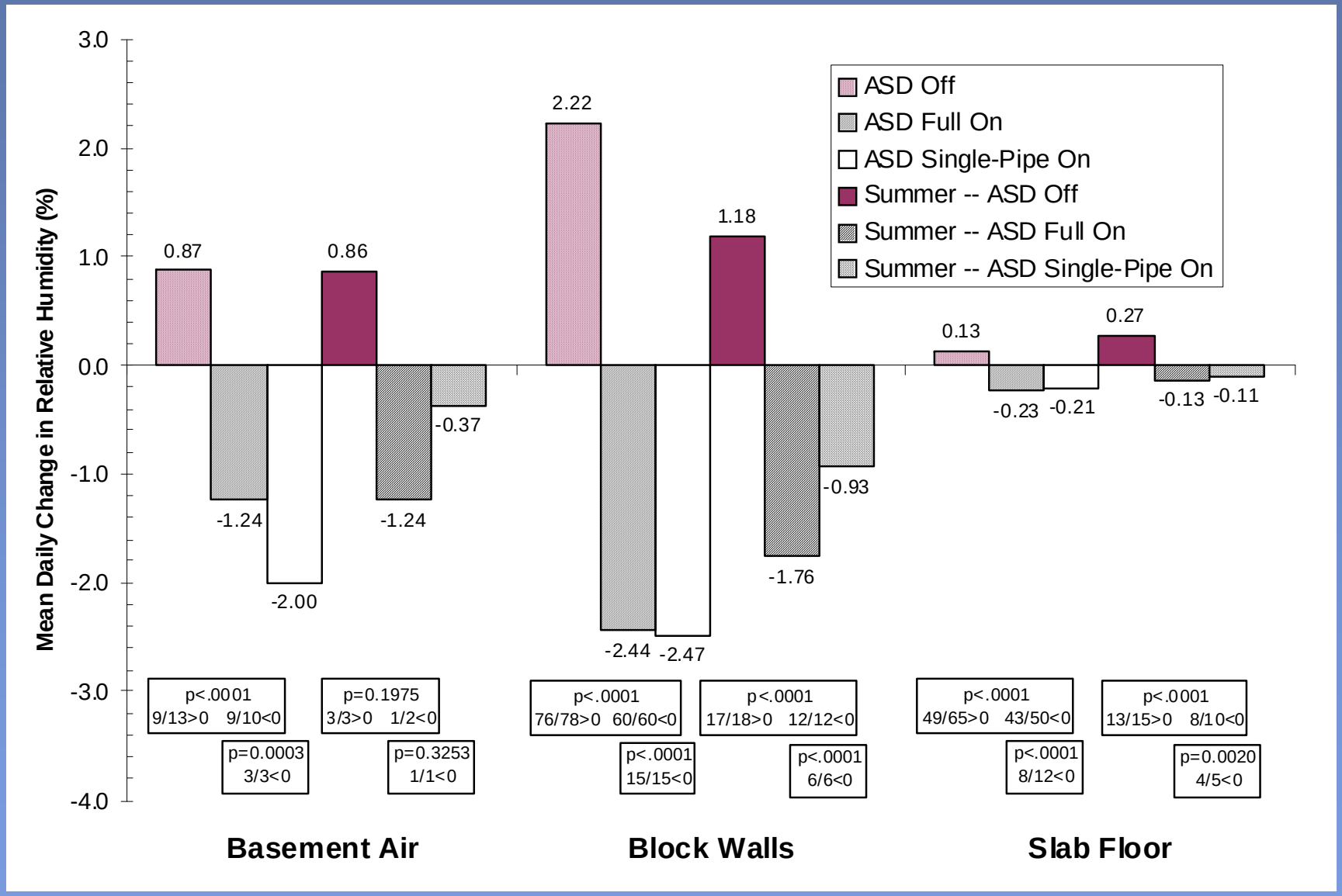

*Second 7 days of 14-day, or longer, cycling periods*

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



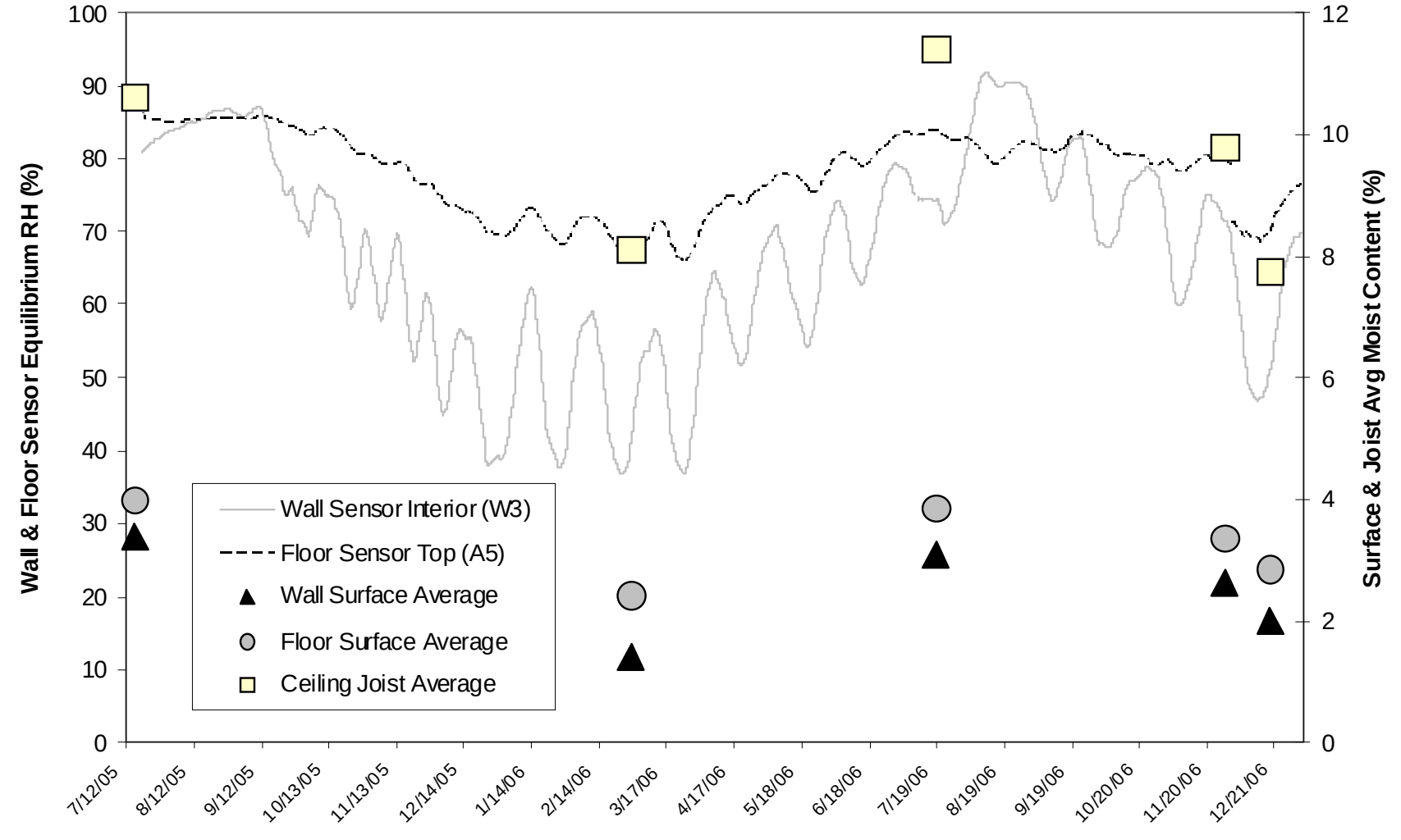
# Mean Daily Change in RH -- PA02

## Oct 2005 -- Jan 2007

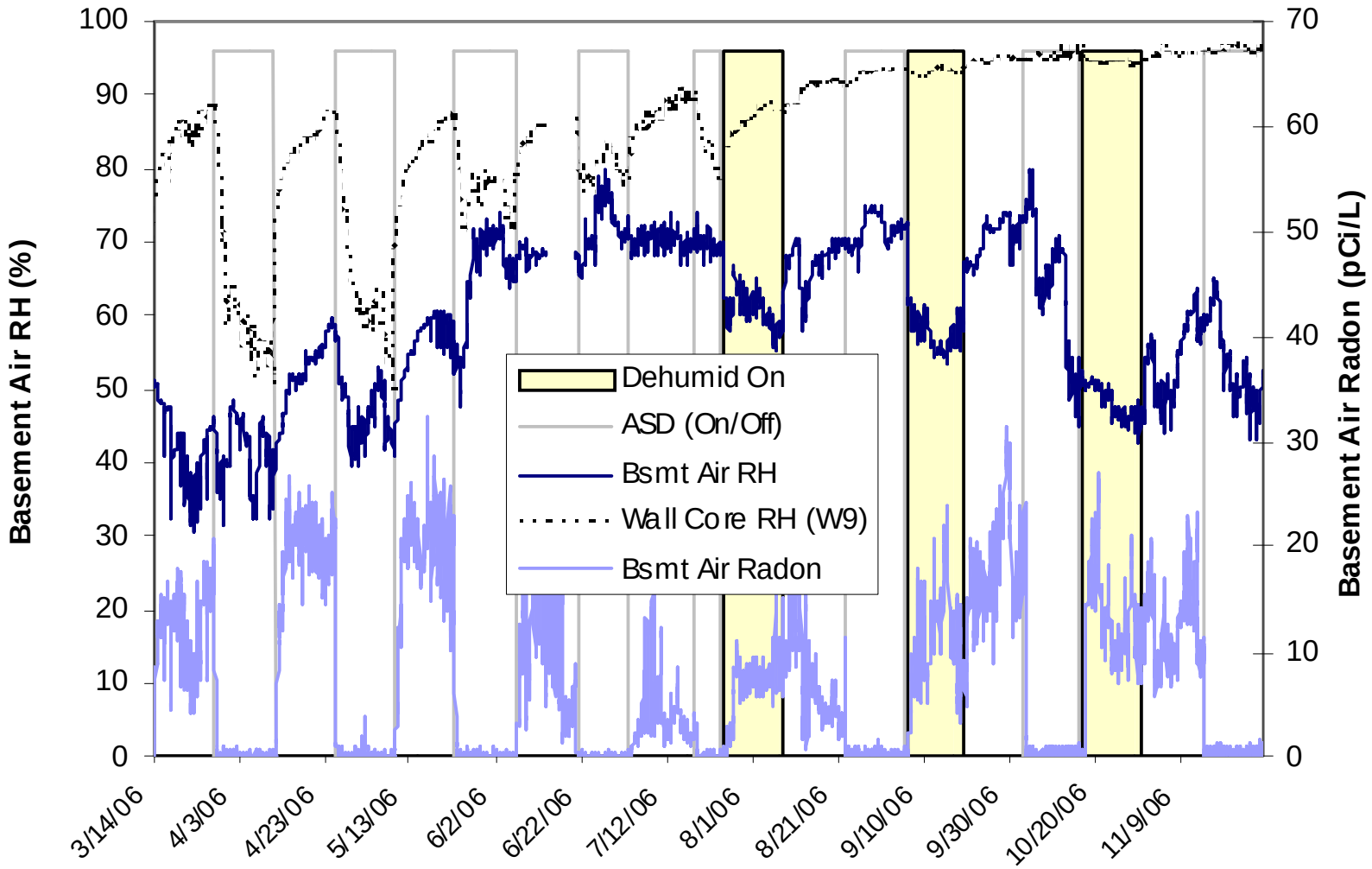


HUSKY
HUSKY

# Surface & Joist Measurements vs. Embedded Sensors (PA02)



# Dehumidifier Impact in Air & Wall vs. ASD



# 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)

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# Residential Ventilation and IAQ
## *Update on ASHRAE Standard 62.2 and Research Needs*

Steven J. Emmerich
Building and Fire Research Laboratory
National Institute of Standards and Technology
Chair, ASHRAE SSPC 62.2
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# What is ASHRAE Standard 62.2?

- The only national residential ventilation and IAQ standard
- Developed using ANSI consensus procedures
- Maintained by ASHRAE SSPC 62.2
  - Anyone may submit change proposals

# What's in 62.2?

- Code-intended minimum requirements for ventilation rates and building construction to provide acceptable IAQ
- Min mechanical flow rate (20 cfm to 80 cfm)
- Bathroom and kitchen exhaust
- Limited source control
- Sound and flow ratings for equipment

# Who uses it?

- Recently adopted into California and Maine building codes
- Being considered in other states
- All major ‘green’ programs
  - EPA Energy Star Indoor Air Package
  - LEED for Homes
  - NAHB proposed Green Building Standard
  - Building America programs

# What's new?

- Only modest changes to technical requirements since 2004 publication
- Companion Guideline 24-2008 available soon
- More significant changes being considered: ventilation credits by system type, multifamily housing, existing homes

# Residential Ventilation and IAQ Research Needs – SSPC 62.2 view

- Focus on short-term, engineering issues that would impact Standard 62.2 requirements
- Ongoing simulation study comparing effectiveness of different ventilation system types
- Only plans for ASHRAE-sponsored research is on transport of contaminants from attached garages

# Residential Ventilation and IAQ Research Needs – Big Picture

- 2000 ASERTTI & DOE
  Priority agenda for energy-related IEQ research
- 2004 National Academy of Sciences' Institute of Medicine report *Damp Indoor Spaces and Health*
- 2005 Surgeon General's Workshop on Healthy Indoor Environment
- 2005 EPA Healthy Buildings, Healthy People

# ASERTTI Research Recommendations

- Characterize ventilation rates and IEQ conditions in energy efficient and conventional new housing. **Top22**
- Relate ventilation rates in residences to health symptoms and to satisfaction with IAQ.
- Quantify the relationships between indoor chemical and biologic contaminants of greatest current concern and health effects on occupants. **Top22**
- For various climates, develop best ventilation and insulation practices for crawl spaces and attics to minimize moisture problems. **Top22**
- Characterize dependence of microbiologic growth … on the materials, airflows, humidities, moisture contents, etc.; and develop …strategies for material selection, design, and construction … that minimize risk of microbiologic contamination. **Top22**

# ASERTTI Research Recommendations

- Based on a cost/benefit analysis, determine the appropriate minimum ventilation rates in building codes. **Top22**
- Combine current scientific and practical knowledge on health effects of building design operations and maintenance, including ventilation, into guidelines for best building practices. **Top22**
- Use existing knowledge to develop recommended maximum pollutant concentrations for pollutants and pollutant mixtures of particular concern. **Top 22**
- For design professionals and code officials, develop and deliver education programs in HVAC and building science related to best practice for IEQ.

# Residential Ventilation and IAQ Research Needs – A few thoughts

- Comparison study of houses with & without 62.2 compliant ventilation
- Study of ventilation in humid climates
- Analysis of ‘green’ building options & requirements

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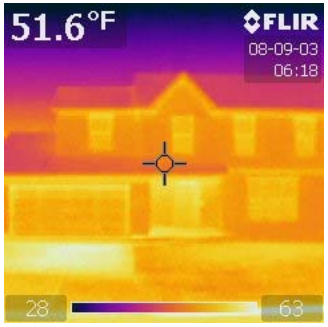
# Integrating IAQ into Energy Efficient Homes – Findings from the Field

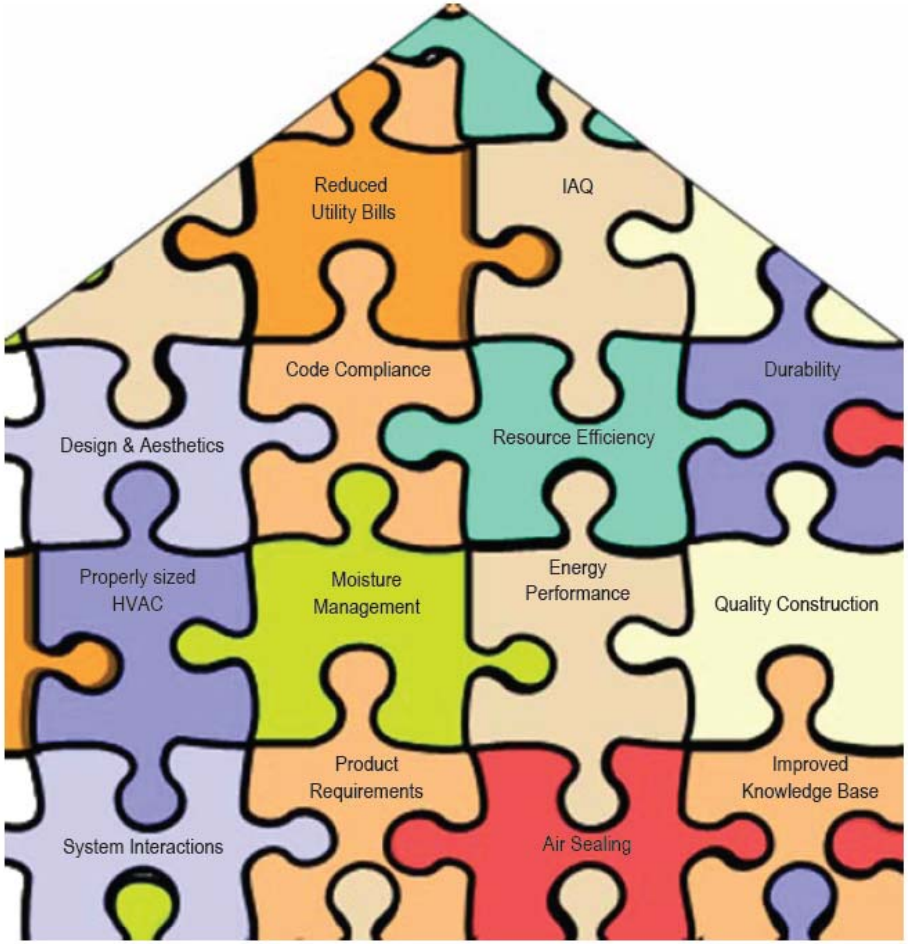
Jamie Lyons, P.E.

Newport Partners LLC


September 16, 2008



# A Systems Approach to High Performance Homes



# Efficiency Upgrades in High Performance Homes – Typical Cold Climate Package

- Reducing air infiltration (building shell tightening) with spray foam, caulks/sealants, gaskets/glues, etc.
- 95%+ furnace systems or dual fuel fired heat pump
- 95% efficient gas tankless water heaters
- 2x6 (R-21) walls with 1.5” foam (R-9.8) exterior sheathing
- 100% CFL lighting
- Energy Star appliances
- Tightly sealed duct systems in conditioned space with passive return air outlets (jump ducts)
- Energy Star windows or better
- Whole house ventilation w/high fan efficacy and/or heat recovery

# IAQ in High Performance Homes

- Fresh air exchange with outdoors – whole house ventilation
  - Goes hand in hand with a very tight building envelope
- Removal of odors/pollutants – spot ventilation – exhausted to outdoors!
  - Kitchens
  - Bathrooms
  - Garages
- Radon control
- High quality duct systems
- Material & finish selections
- Moisture Management (liquid water and water vapor) – broad

# Reducing Air Leakage Saves Energy

Spray foam insulation provides 1.5” of polyiso exterior foam R-value, dew point control, and insulation (R 9.8) with taped and also expands to fill cracks seams provides added wall R-value and also reduces outside building cavities – eliminating air leakage

Air sealing with spray foam and voids in difficult to reach behind tub/shower enclosures on exterior walls

# Whole-House Ventilation

In tight homes, whole-house ventilation is needed to supplement natural air infiltration and provide fresh air to the indoor environment

- Air sealing efforts in high performance homes greatly reduce gaps in the building shell to reduce air leakage and save energy

# How Much Ventilation Air is Needed?

- ASHRAE 62-2 is the national standard on residential ventilation requirements
- Blower door testing also permits a demonstration of air leakage and assigns a value to it

# Whole-House Ventilation Systems Options

- Balanced systems – which both supply and exhaust air to the house
- Supply-type systems (introduce fresh air into return air ducts)
- Exhaust-type systems (draw air from the house via 1 or more exhaust fans)
- Trade-offs exist on first cost, comfort implications, effectiveness, energy consumption, and consumer satisfaction

# Ventilation Systems Used in High Performance Homes in Cold Climates (NE, NY)

- HRV Systems
  - Provide roughly equal flows of fresh air intake and stale air exhaust
  - Internal heat exchanger allows the cold fresh air to be warmed by exiting stale air before it leaves the building – saving energy
  - Reliable and can be integrated with the central duct system
  - More costly than other system options (first cost)

# Ventilation Systems in High Performance Homes in Cold Climates (NE, NY)

- Exhaust-based systems
  - Some make-up air accommodation can be important in very tight houses (e.g. passive make-up air dampers) depending on other systems in the house – like a commercial grade range hood or natural-venting combustion appliances
  - Exhaust fan systems typically are very energy efficient systems

- "Smart" systems available which actually "credit" the whole-house system for times when bath fans run for ventilation – saves energy

# Control of Odors with Spot Ventilation Systems – Bathrooms & Kitchens

- Bathrooms – should have systems of at least 50 cfm (real flow – not nominal) exhausted to outdoors

Fans with integrated humidity sensors or timer controls can help automate ventilation and remove moisture

- Kitchens – should have systems of at least 100 cfm (real flow – not nominal) exhausted to outdoors
  - Size range hood/flow capacity based on unit (1 cfm per 100 Btus – rule of thumb)

# Control of Odors/Pollutants with Spot Ventilation Systems – Garages

- Indoor air contamination from attached garages is a growing concern:
  - bedrooms above garages, living spaces adjacent to garages
  - Contaminants from cars, stored chemicals and cleaning agents

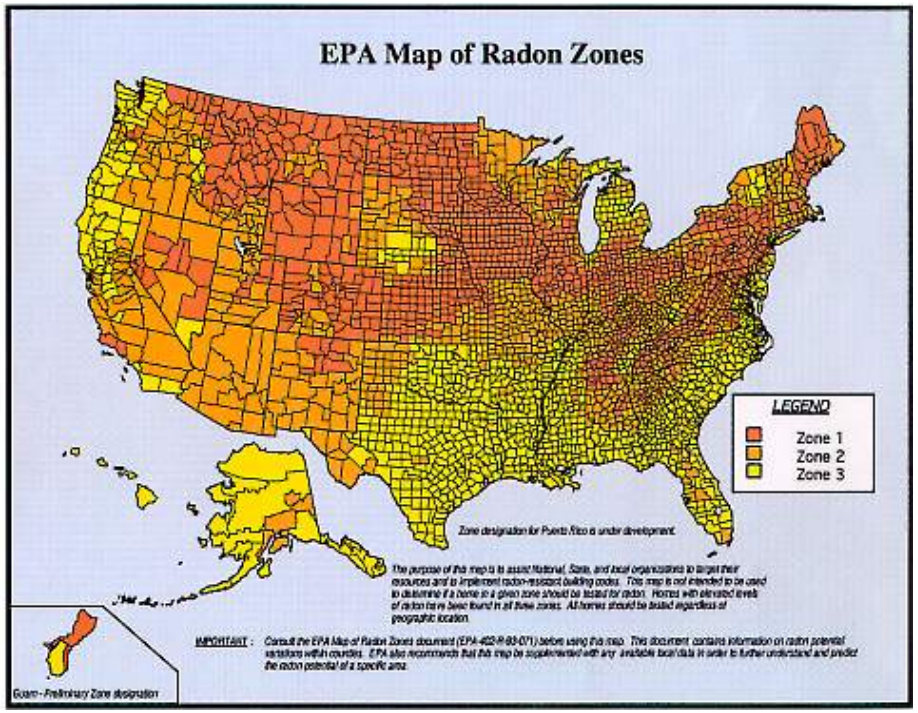
- Data on this issue is mostly anecdotal
  - Groups like ASHRAE are investigating the issue
  - Other programs like LEED Homes and the National Green Building Standard **already** recognize and award points for garage exhaust ventilation systems

# Garage Exhaust Ventilation Systems - Options

- Continuous exhaust systems that exhaust garage air to outdoors 24/7
- Intermittent exhaust fans which run based on occupancy, garage door activation, CO levels, garage lights, or other triggers
- Continuous systems – simpler but will consumer more fan energy.  For intermittent systems, some sizing guidance is found in LEED and NGBS

# Radon Control

- Significant IAQ concern in some areas of the country
- Passive or active mitigation approaches available
- In some areas with elevated radon levels, the issue may still be overlooked



# Radon Control – Field Applications

- Passive sub-slab depressurization system with option to upgrade system to active (fan-based) system if necessary
- Open house to educated contractors on the radon issue and mitigation strategies – the interest is there!

# Duct Systems & IAQ

## High Quality Duct Systems

- Tightly sealed, so air is delivered to the intended location
- Located inside the thermal envelope of the house, to minimize energy losses
- Sized properly and installed in accordance with industry best practices, so air flows provide the required heating/cooling to the living spaces

## Poor Quality Duct Systems

- Leaky systems can draw in hot attic air, moist/moldy air from crawlspaces, etc. – leading to energy, moisture, and IAQ problems
- Air flows to specific rooms do not meet design flows, leading to temperature variations and comfort problems
- Pressure imbalances can increase energy losses, drive carpet soiling, etc.

# Duct Systems in High Performance Homes

- All joints sealed
- Ducts located in conditioned space
- System designed with engineering sizing/design tools
- System tested to measure duct leakage
- No panned returns – central returns used in conjunction with jump ducts

# Material/Finish Selections & IAQ

- Very broad field
- Project examples:
  - Low VOC, spray-able paints
  - Linseed oil based flooring
  - Soy-based spray foam insulation
  - Natural clay based wall finishes
  - Low formaldehyde furniture and wood products

# Research & Educational Needs Related to Residential IAQ

## Technology Needs

- Energy efficient and reliable systems for 62.2 compliance
- Specialized systems for high performance homes
- Tailored systems for garage exhaust ventilation

## Education & Training – Design & Installation

- As-installed flow rates are often just 25-50% of design flows
- Widespread builder and contractor unfamiliarity with ASHRAE 62.2 (e.g., duty cycles, fan/duct sizing, noise requirements)

## Continued Standard Development

- Appropriate flow rates in light of ongoing indoor air contaminant research; guidance on garage exhaust ventilation rates

# Thank You!

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2008 National Healthy Homes Conference

# Research Results: Indoor Concentrations of Combustion Gases from Unvented Gas Fireplaces

Jeffrey Gordon
University of Illinois – Building Research Council

# Acknowledgements


- Funding provided by U.S. Department of Housing and Urban Development – Office of Healthy Homes and Lead Hazard Control – HH Technical Studies Grant
- Paul Francisco – Co-PI on the Project
- Bill Rose – Senior Researcher
- Numerous graduate assistants

# In 15 – 20 minutes . . .

- Background – Unvented fireplaces, what are they, what do we know?
- Research design – what the data looks like
- Research results – what did we find?

# Background - Unvented Gas Fireplaces

- Can be built-in, freestanding, or gas log set placed in existing fireplace
- Popular for cost, ease of installation, 99% efficiency
- All combustion gases released into home
- About 20 million sold in the U.S. since 1980

# What did we know – how big was the hole in our knowledge?

AGARD Report
Everything is good

Unvented Combustion?
That is crazy!

# AGARD Report

- American Gas Association Research Division
- Douglass DeWerth, Robert Borgeson, and Michael Aranov
- March 1996
- Used very successfully

# AGARD Report

- Primarily a computer model to gauge the affect of unvented units on indoor air quality
- Develop sizing guidelines to keep indoor air pollutants below certain thresholds.
- The AGARD report concludes that, when properly sized for a particular climate zone, health-based threshold will not be exceeded.
- Intended use – supplemental heat, not primary heat, and decorative ambiance
- Numerous assumptions on both the generation and dilution sides

# The Factors - Generation

- Generation
  - Size (BTU/hr) of appliance - output
  - Duration of Use
  - High vs. low settings
  - Maintenance and cleaning
  - Primary vs. Secondary heat source
  - Continuous vs. Cycling operation
  - Insulation – heat loss
  - Undefined fireplace characteristics

# The Factors - Dilution

- Dilution
  - Air change rate (blower door test)
  - House size, configuration, CAZ size
  - Ventilation provided at installation
  - Supplemental ventilation during operation (window use, door use)
  - Age of house
  - Weather conditions at any given time

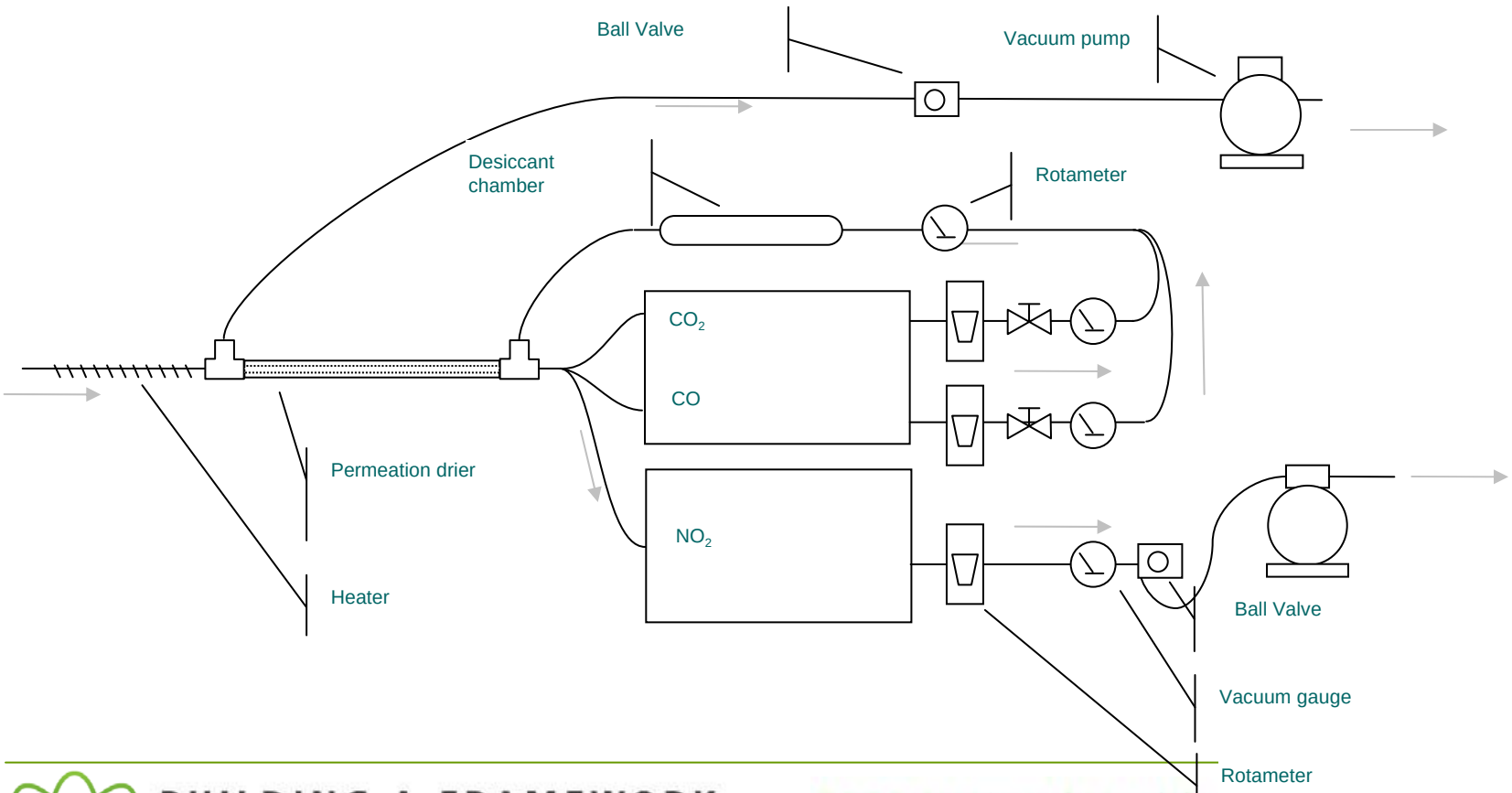
# Research Components

- Field test 30 homes with unvented gas fireplaces, measuring combustion gas concentrations
- Laboratory testing
- National survey
- Modeling
- Combustion gas decay – tracer gas

# Unvented Fireplace Project

- Tested 30 homes using unvented gas fireplaces
- Measurements every minute for 3-4 days
- Indoor combustion gas concentrations: $CO$, $CO_2$, $NO_x$, $NO$, $NO_2$, $O_2$, $H_2O$
- Also measured temperatures (on/off times of fireplace and primary heating – furnace)

# Experimental Setup



# Field Test Equipment

- CO and $CO_2$ - non-dispersive infrared analyzer
- $NO_x$, NO, $NO_2$ – chemiluminescence analyzer
- $O_2$ – paramagnetic analyzer integral to the $NO_x$ analyzer

All instruments were calibrated at each house

# Threshold Values

| Combustion Product | Threshold Value | Source | Notes |
|---|---|---|---|
| $NO_2$ | 250 ppb – 1 hr avg | Health Canada | No US standard |
| | 110 ppb - 1 hr avg | WHO | |
| CO | 9 ppm – 8 hr avg | US EPA | 9 ppm WHO |
| | 35 ppm – 1 hr avg | US EPA | 25 ppm WHO |
| $CO_2$ | 3500 ppm | Health Canada | "Long-term" avg |
| $O_2$ (depletion) | 19.5% continuous | NIOSH | "Oxygen depleted environment" |
| $H_2O$ | 60% RH | ASHRAE 55-92 | Also Dewpoint > 10 $C^o$ |

# Housing Characteristics

| | House Age (Years) | House Size ($m^2$) | Blower Door (ACH50) | Fireplace Age (Years) |
|---|---|---|---|---|
| Minimum | 3 | 111 | 5.6 | 0 (4 weeks) |
| Median | 34 | 182 | 11.4 | 4 |
| Maximum | 100 | 279 | 26.3 | 15 |

Usage patterns were equally variable.

# Study Sample

- A 30 house study, n = 30
- 30 case studies, n = 1 thirty times

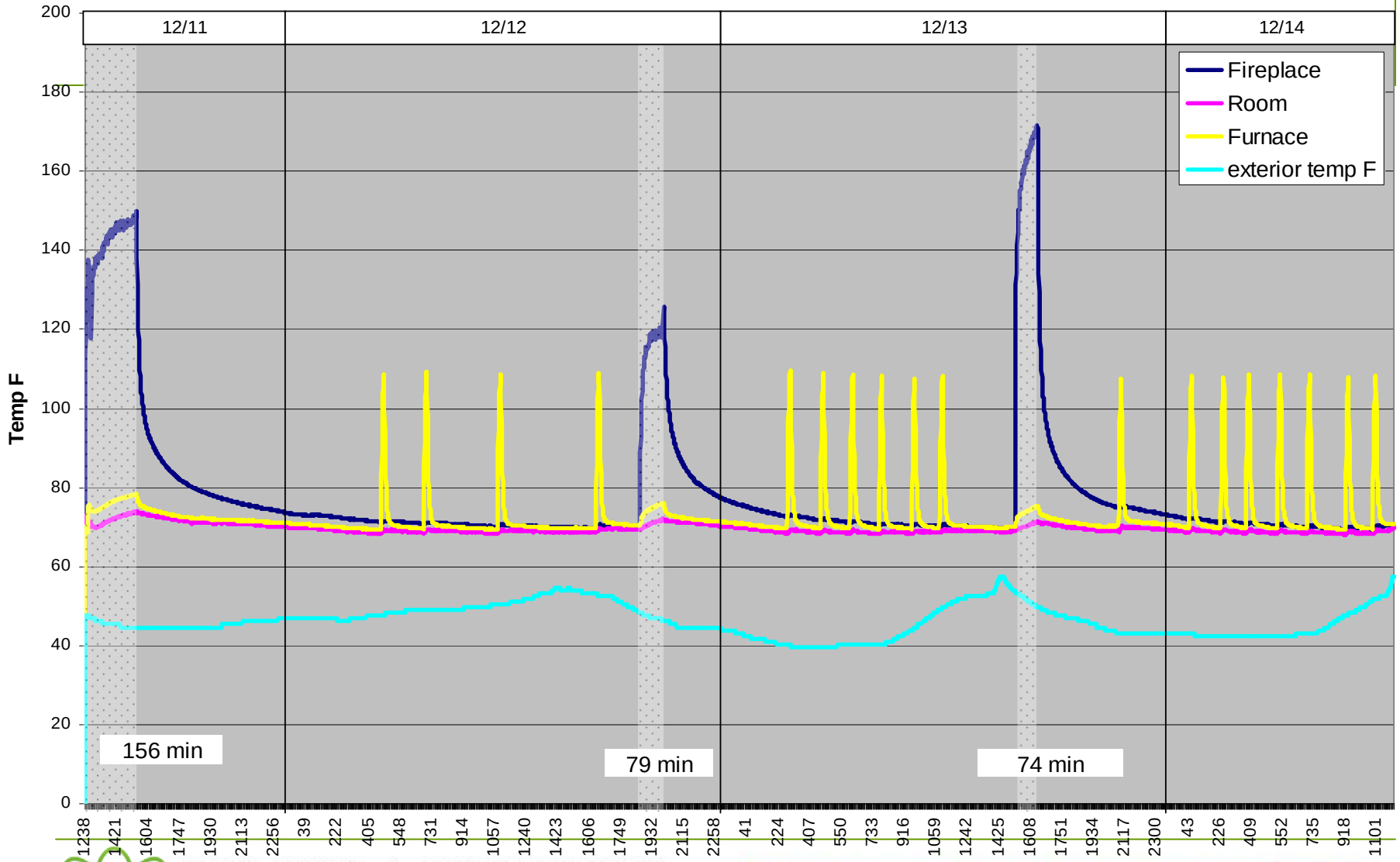
What does the data look like?

# House Example #1 – Site 18

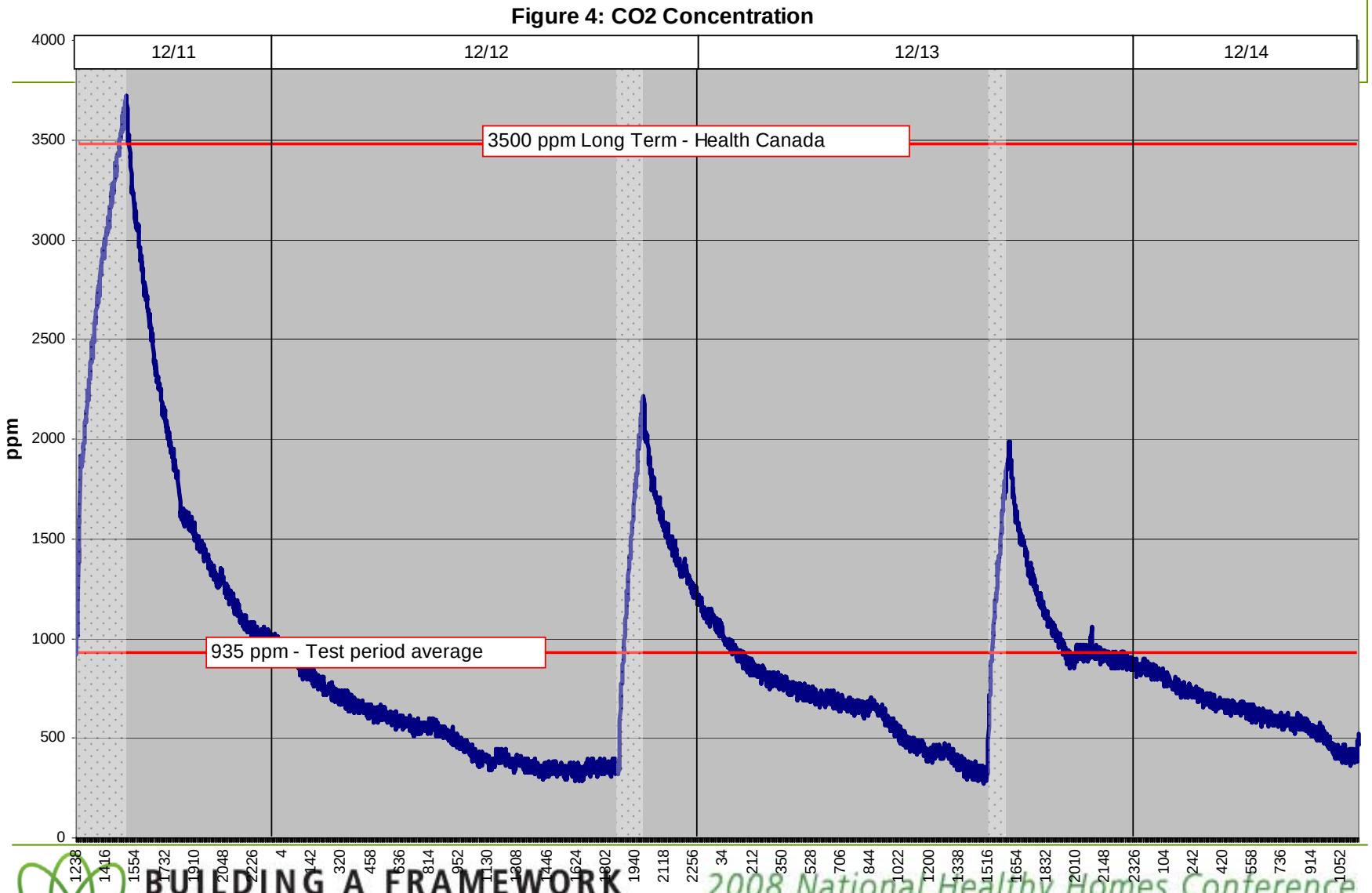
- 8.2 ACH50
- 5 year old fireplace
- 3 events, from 74 – 156 minutes

# Fireplace Use – Temp Timeline

**Figure 1: Fireplace Use**



# Carbon Dioxide Timeline

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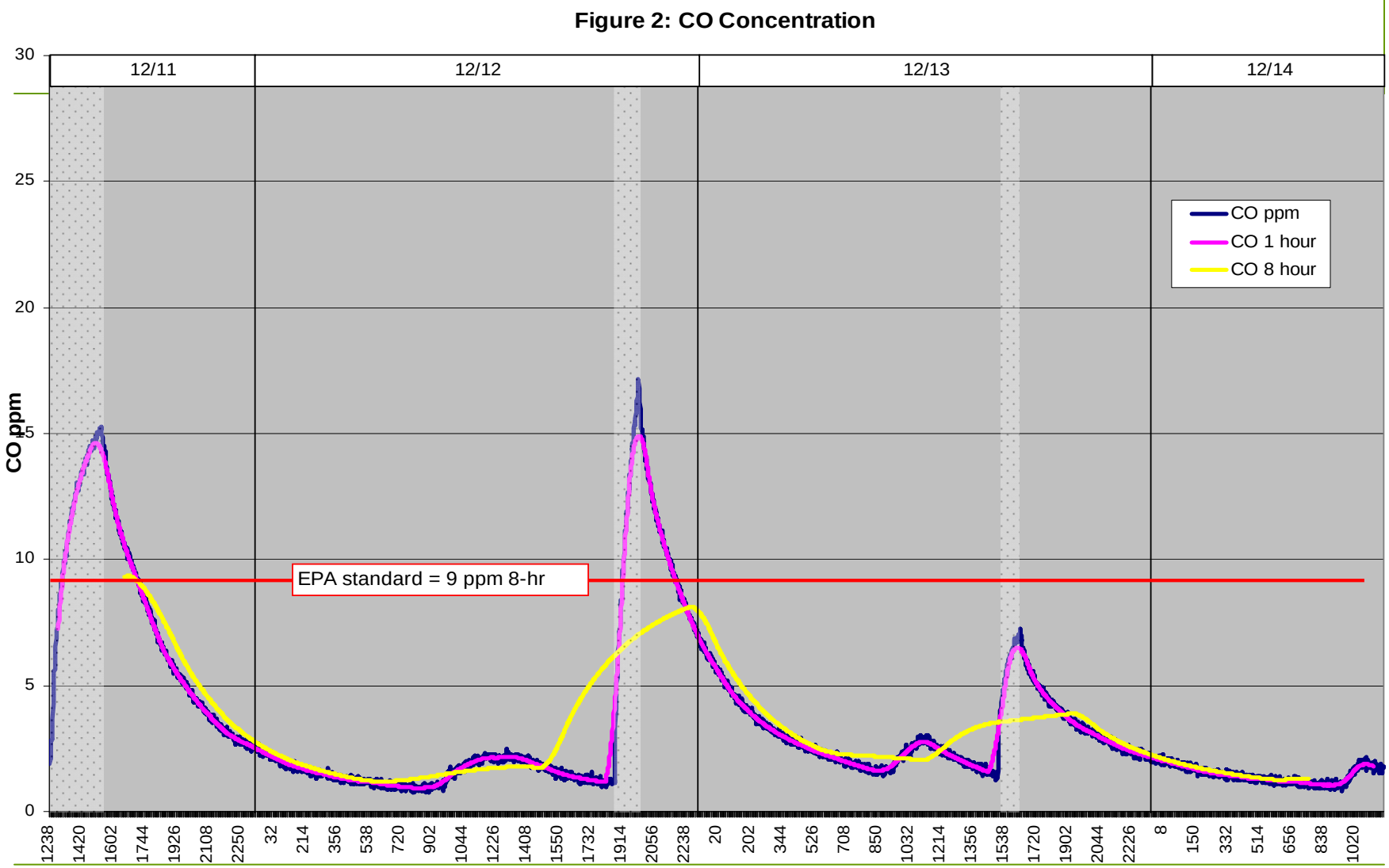
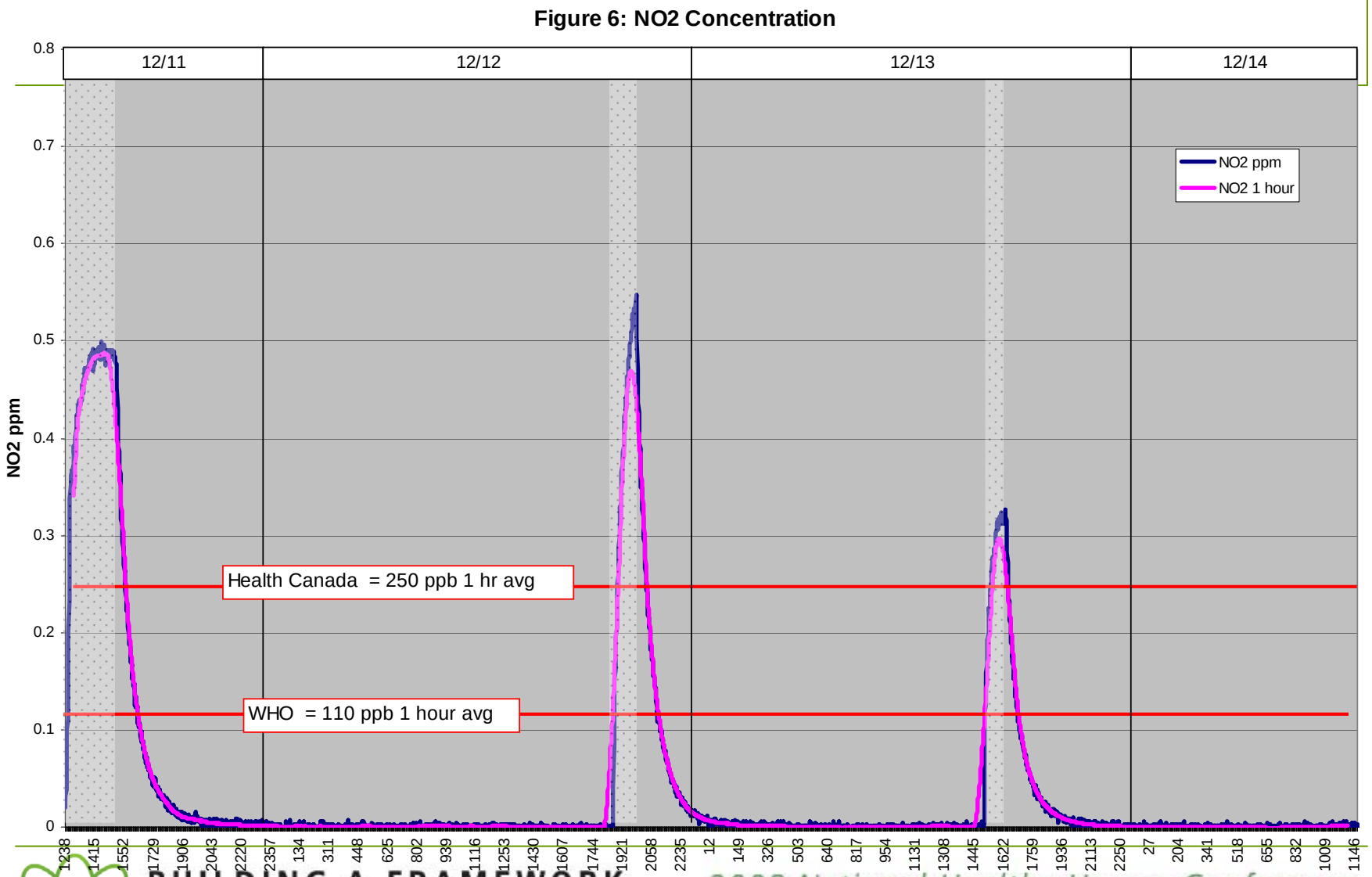
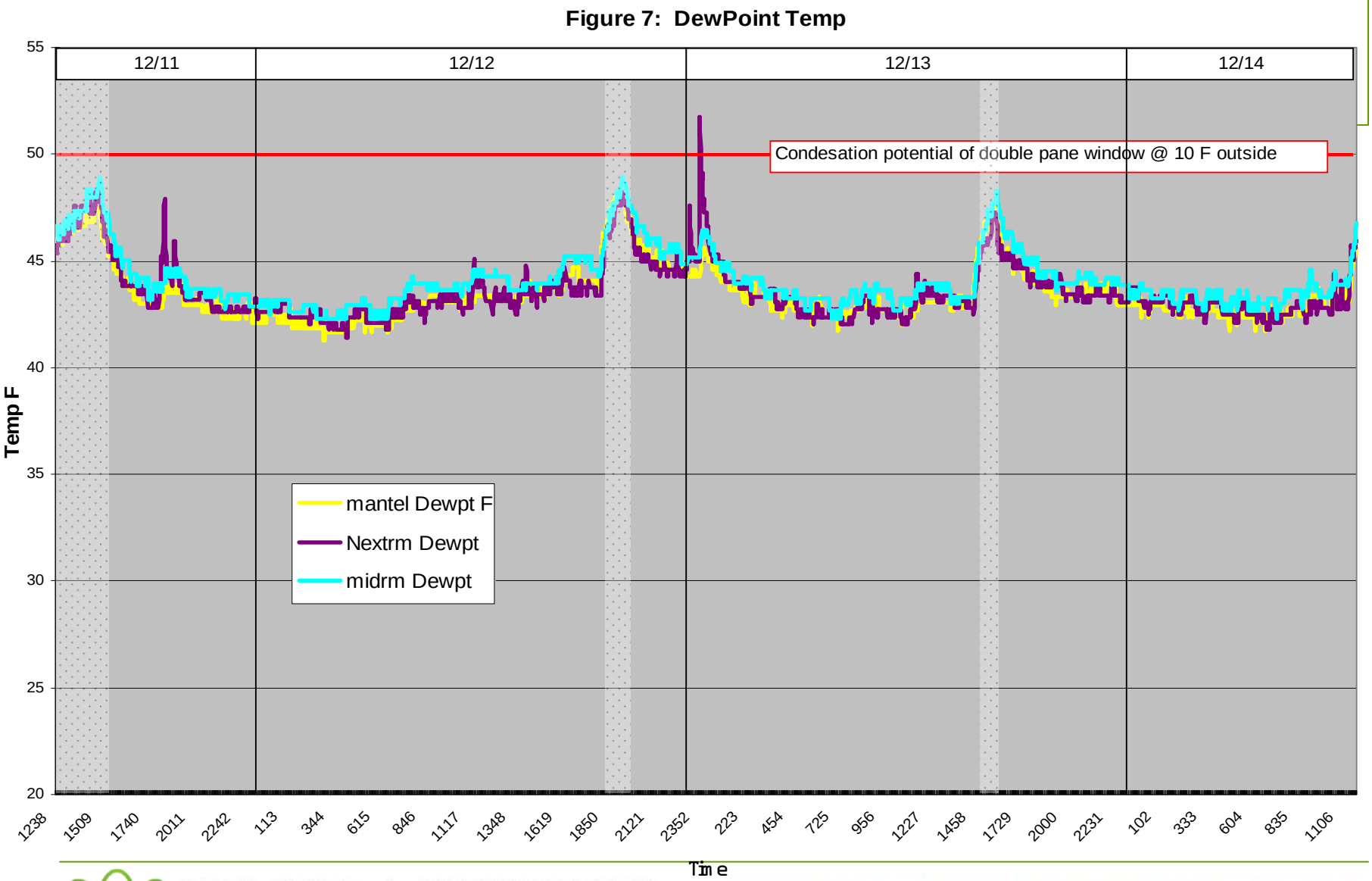
# Carbon Monoxide Timeline



# Nitrogen Dioxide Timeline

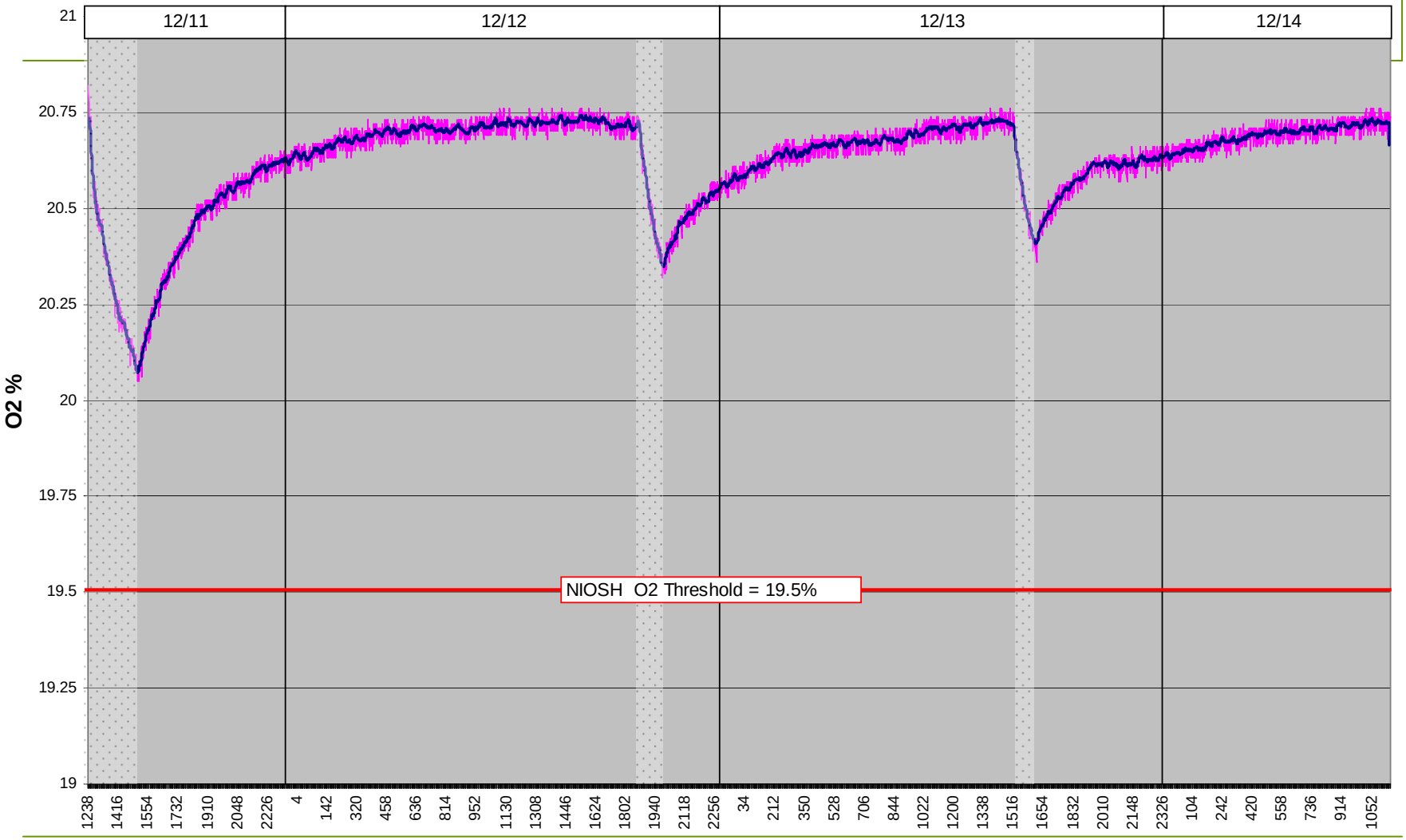


# Dewpoint Temperature Timeline



# Oxygen Timeline

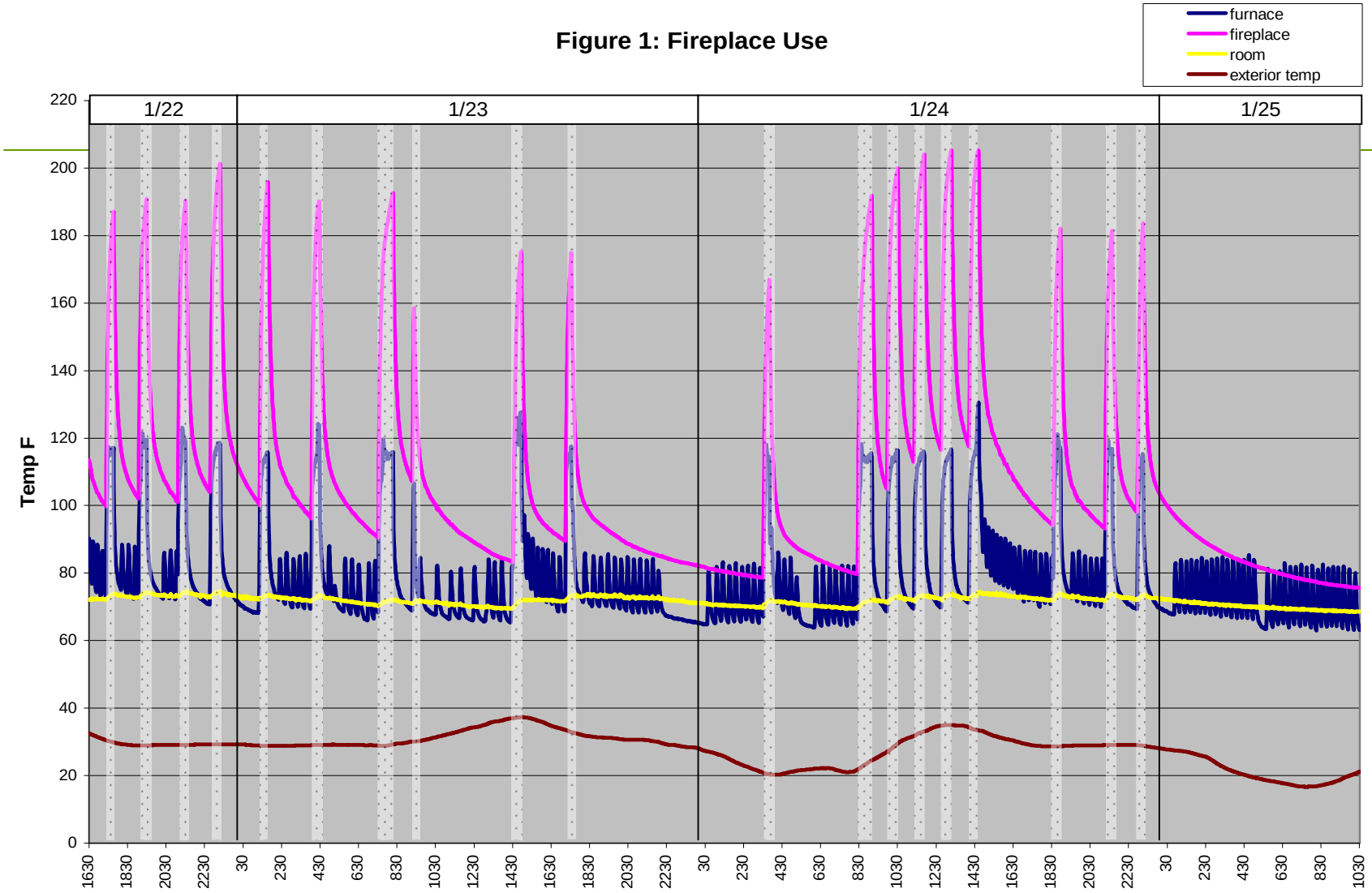
**Figure 5: Oxygen Concentration**



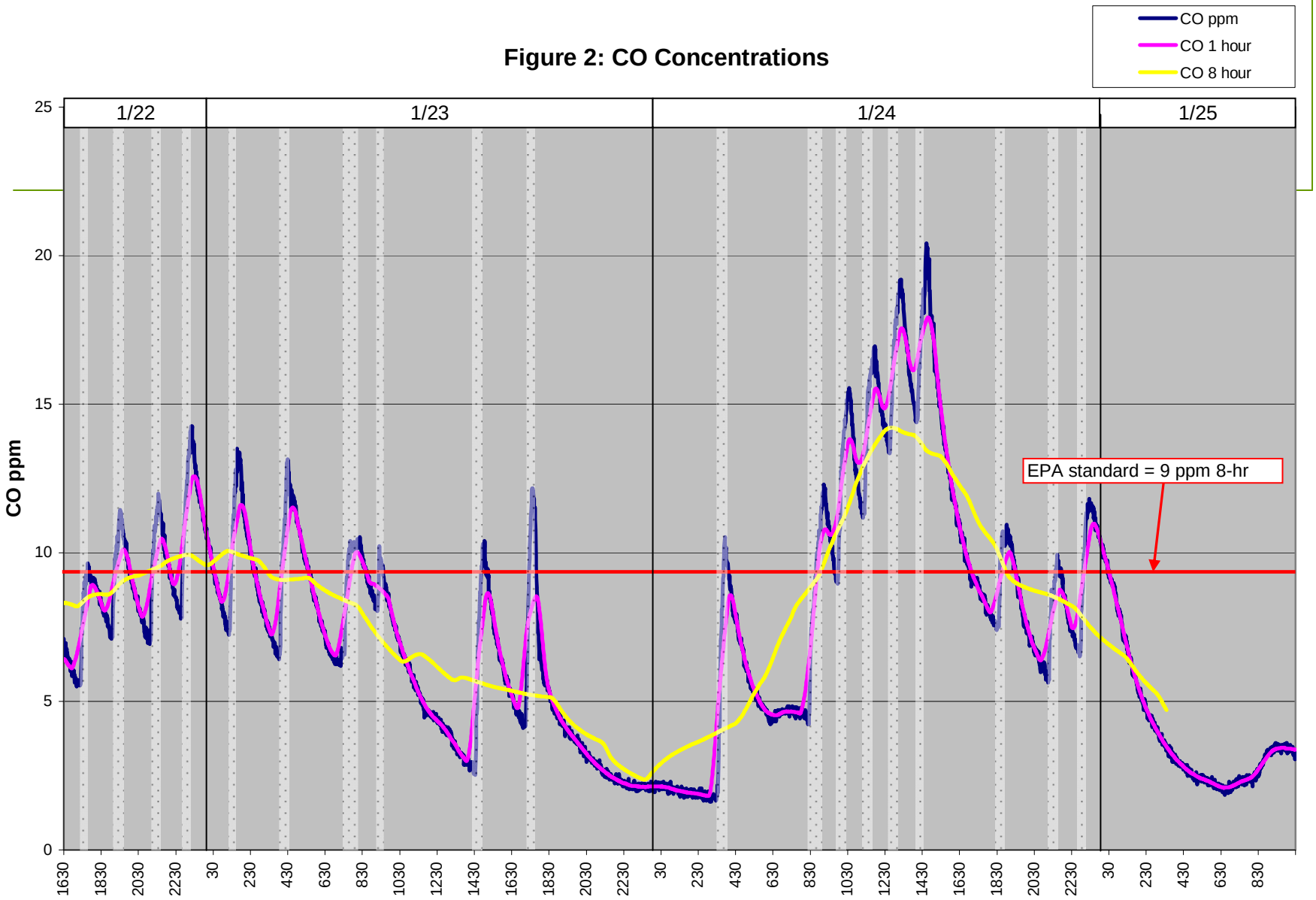
# House Example #2 – Site 26

- 12.5 ACH50
- 15 year old fireplace
- Cycling on thermostat
- Installed in tight basement

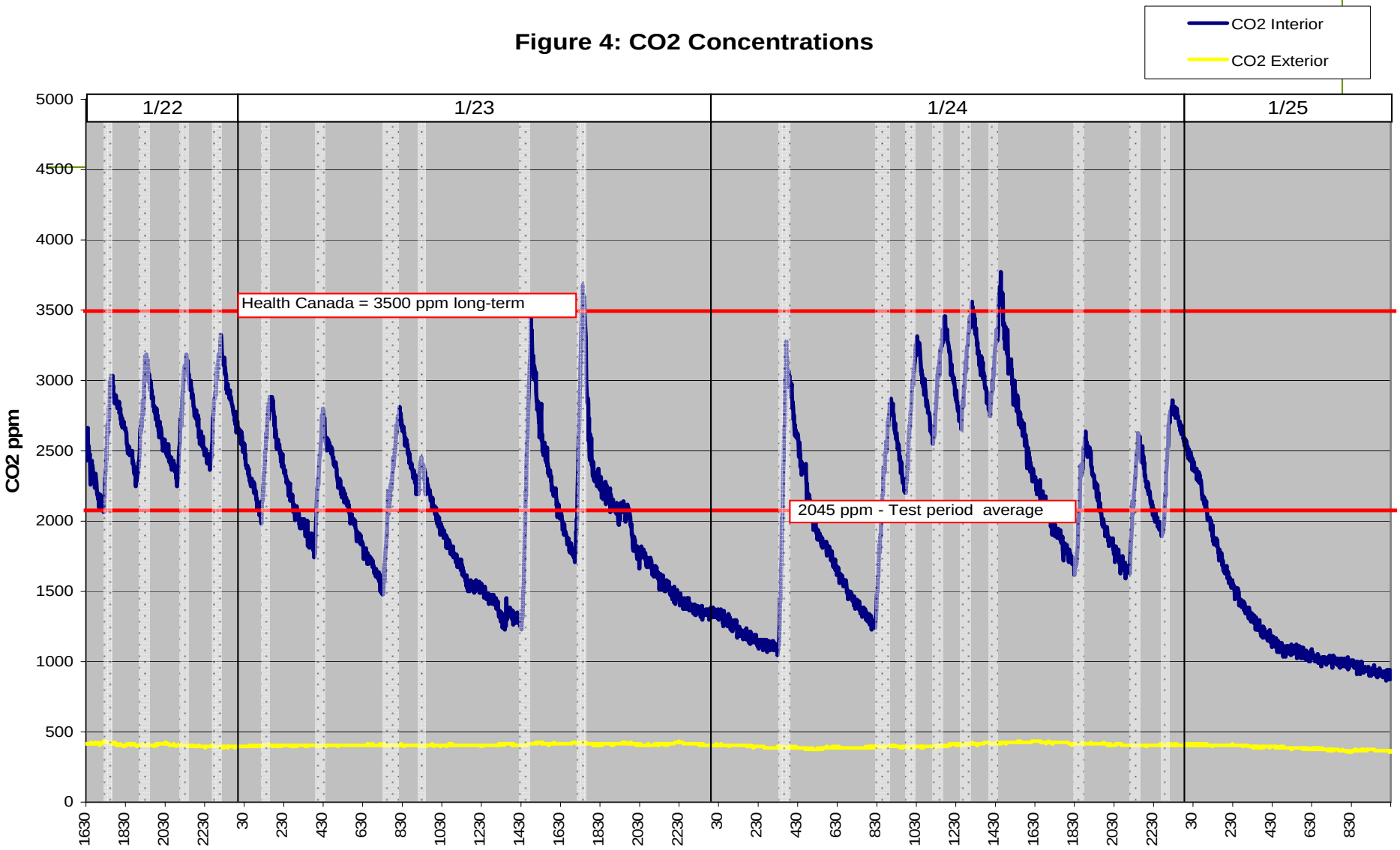
## Figure 1: Fireplace Use



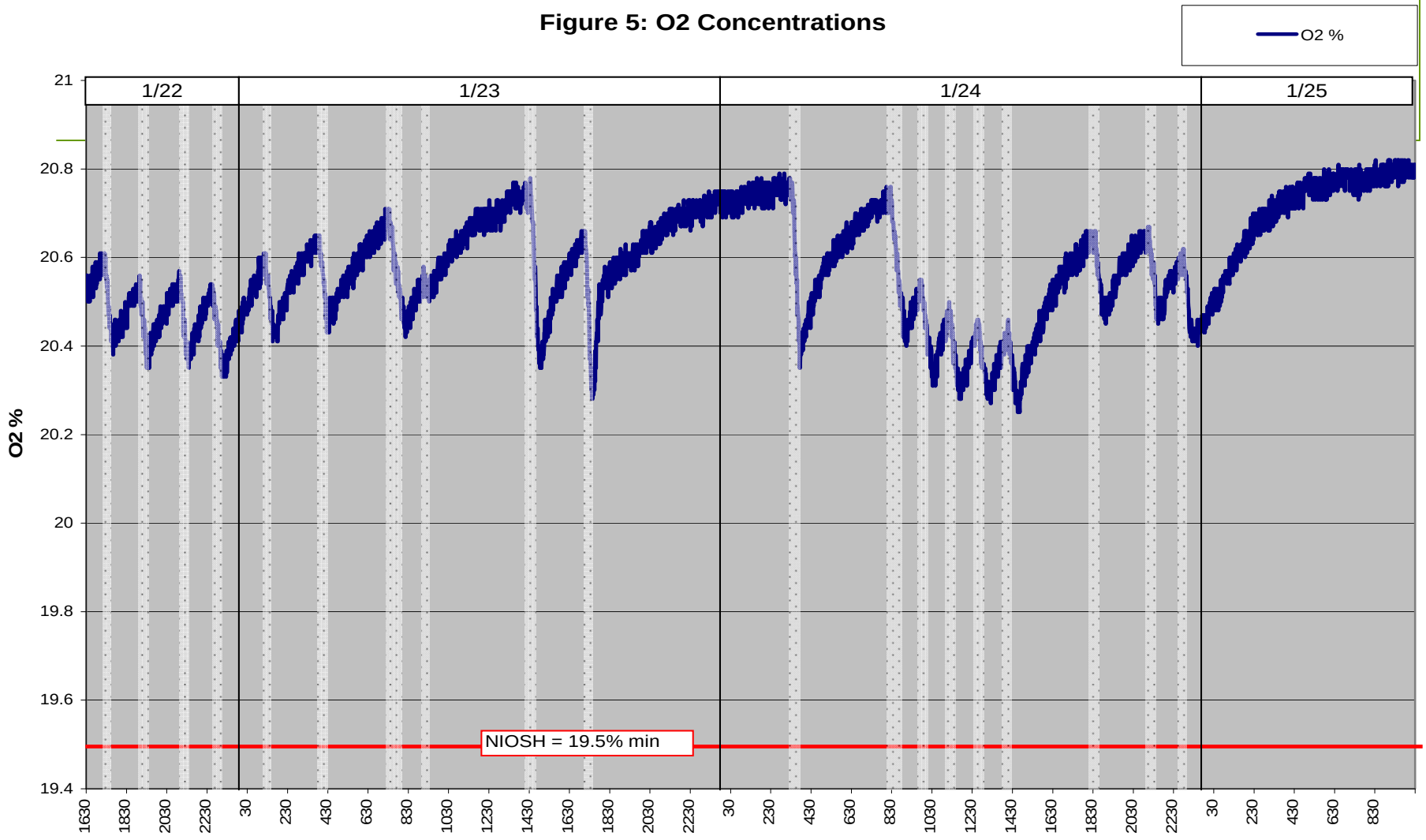
## Figure 2: CO Concentrations



## Figure 4: CO2 Concentrations



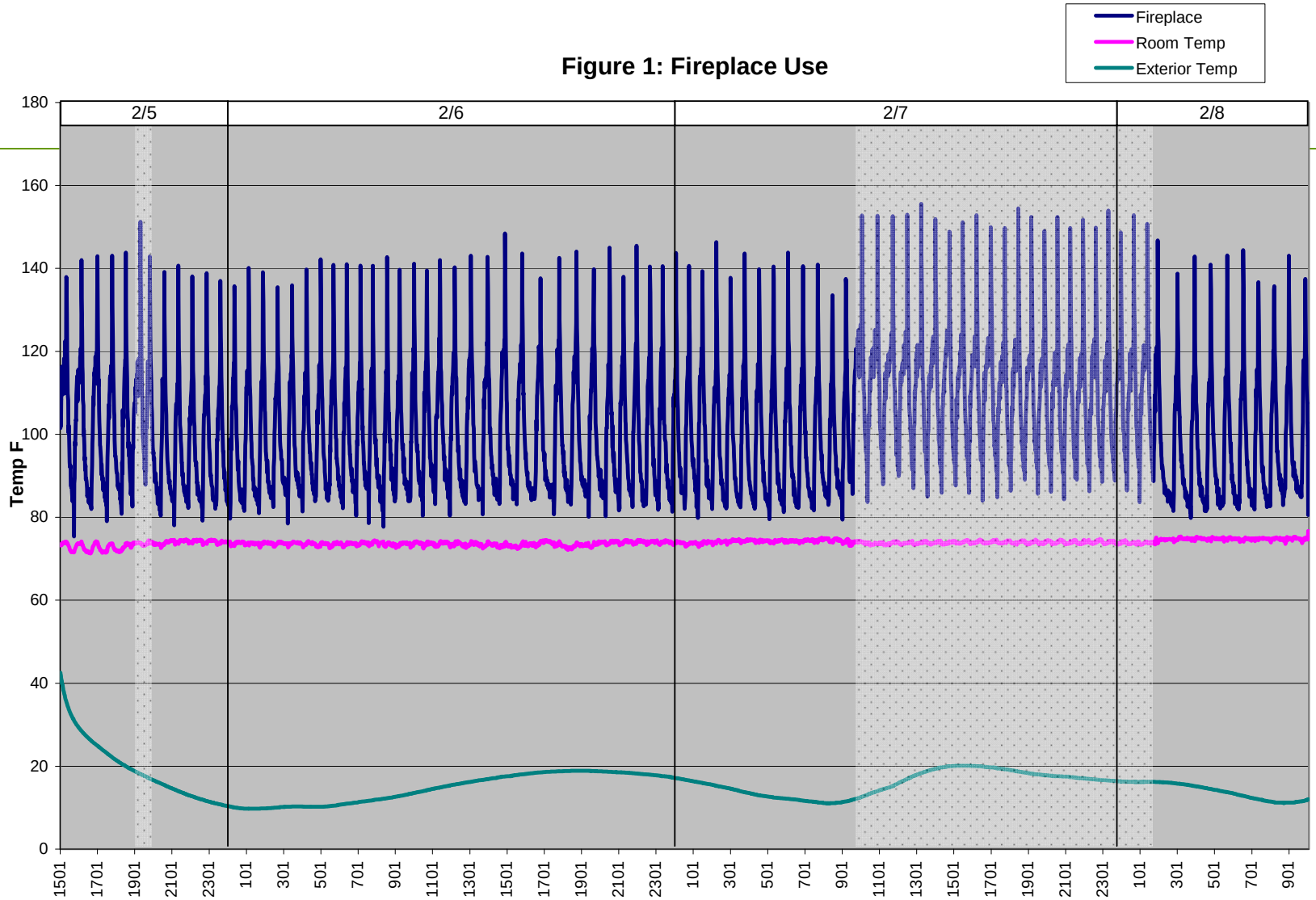
## Figure 5: O2 Concentrations



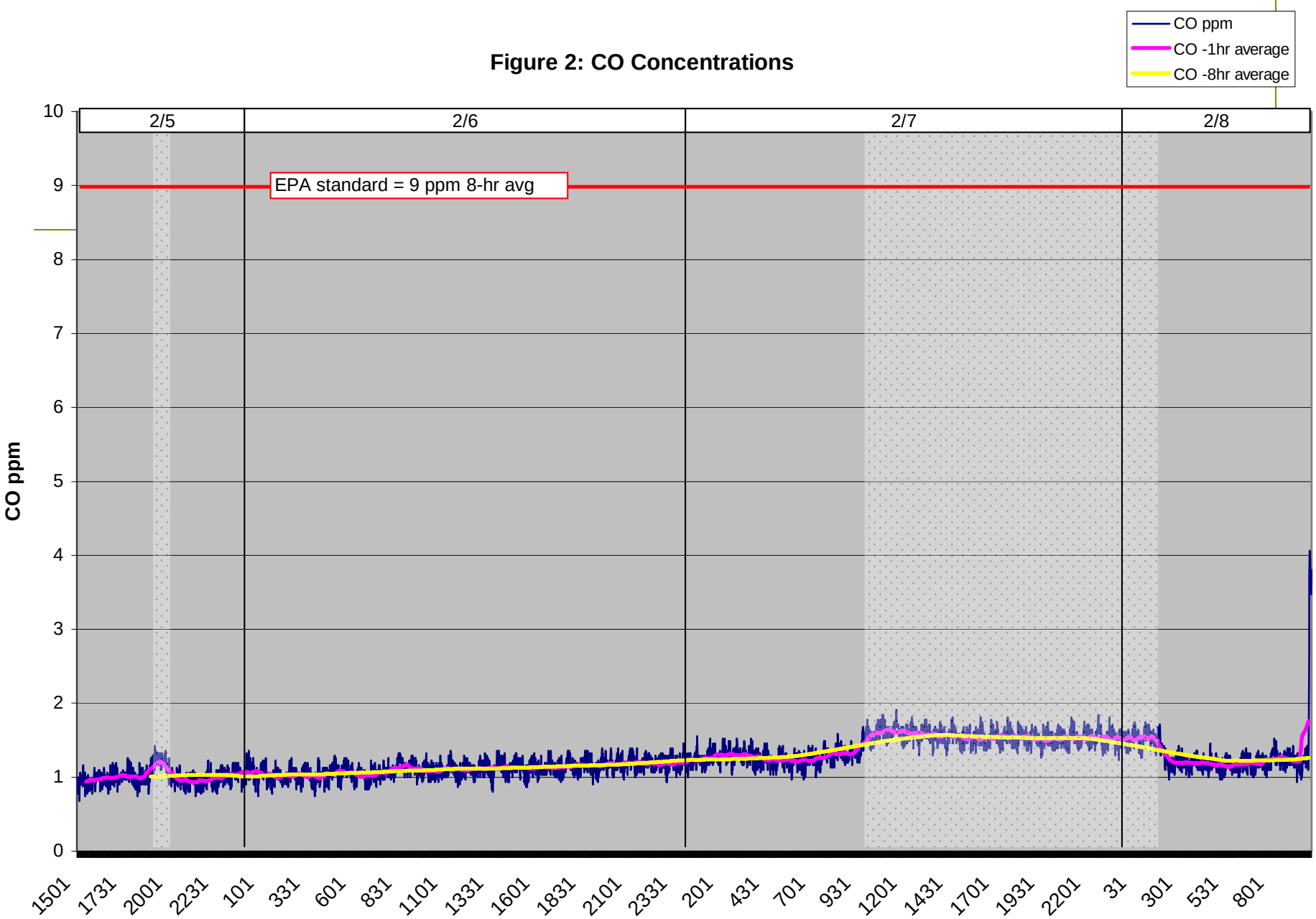
# House Example #3 – Site 28

- 26.3 ACH50
- 2 year old fireplace
- Constant cycling on thermostat

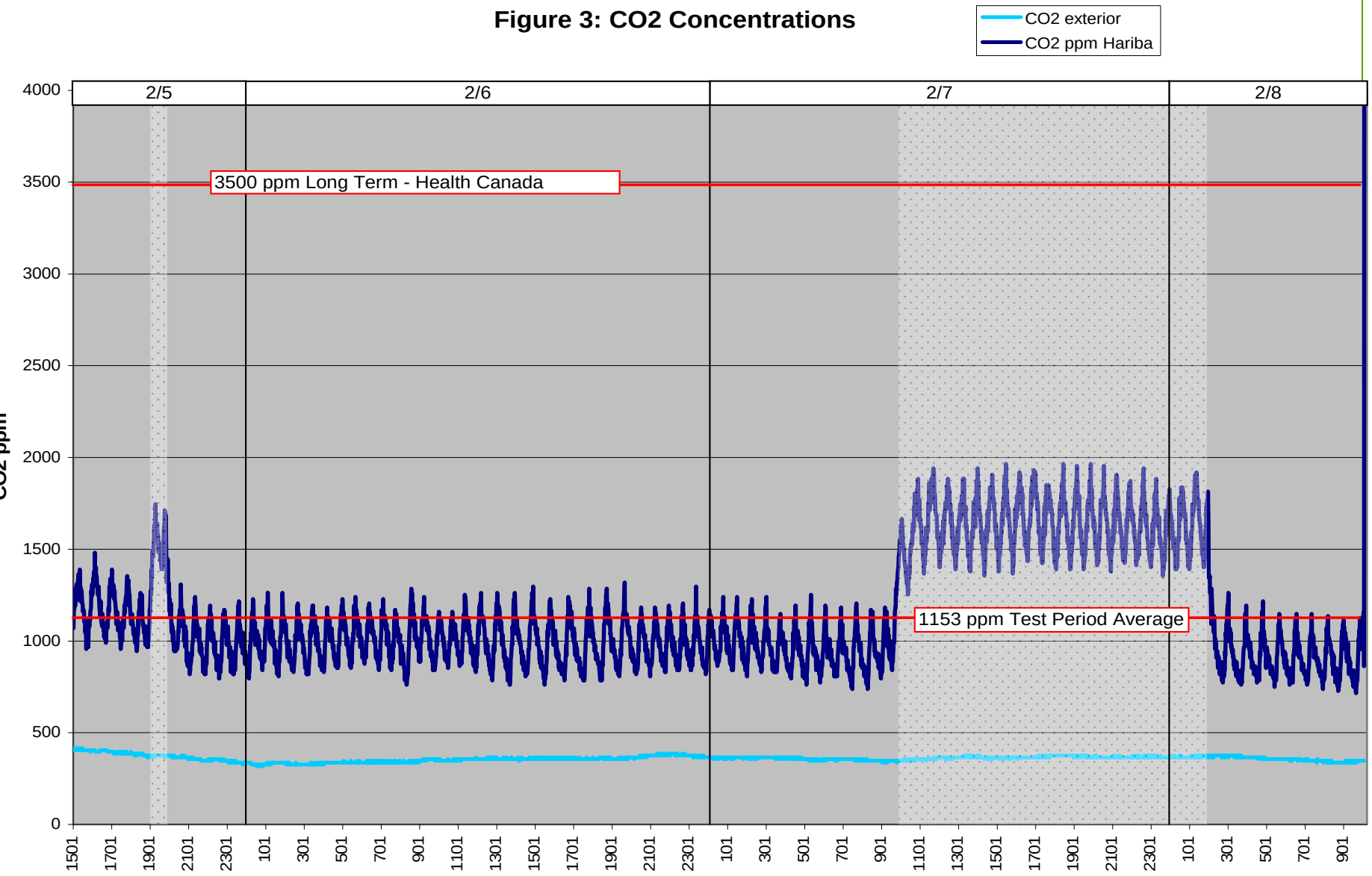
## Figure 1: Fireplace Use



## Figure 2: CO Concentrations



## Figure 3: CO2 Concentrations



# Other Houses

There are 27 more, just as interesting. The cards can be shuffled into many combinations.

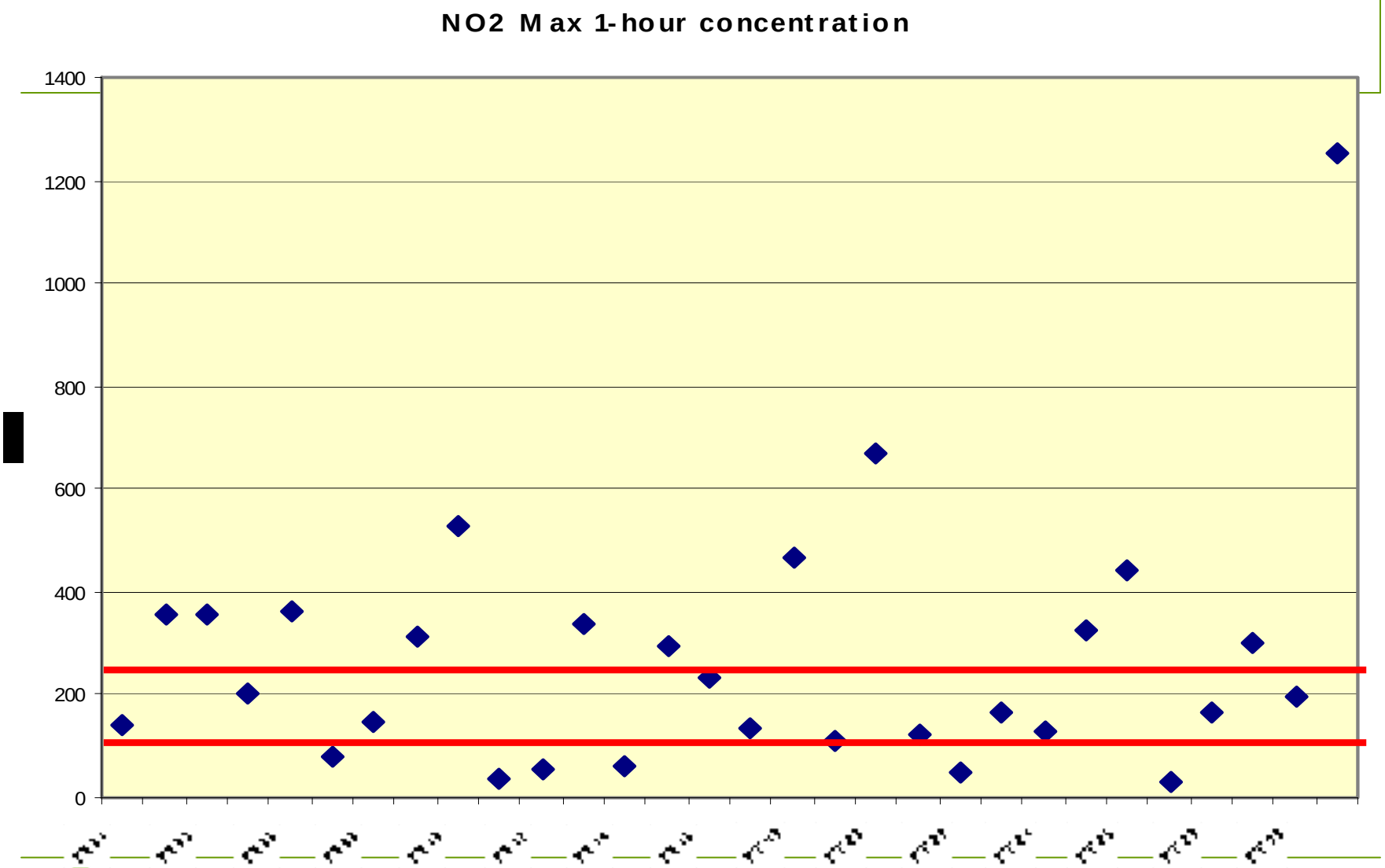
However, we need to return to . . .

$$n = 30.$$

# Vent-Free Field Tests Results

| FIELD TEST SUMMARY | | CO | | CO2 | NO2 | | O2 | H2O |
|---|---|---|---|---|---|---|---|---|
| | | > 35 ppm 1hr avg | > 9 ppm 8hr avg | > 3500 ppm test avg | > 250 ppb 1hr avg | > 110 ppb 1hr avg | <19.5 % | DP > 10 C° |
| Year 1 Field Tests (n=15) | Count | 0 | 2 | 0 | 7 | 11 | 0 | 4 |
| | % | 0.0% | 13.3% | 0.0% | 46.7% | 73.3% | 0.0% | 26.7% |
| Year 2 Field Tests (n=15) | Count | 0 | 4 | 0 | 6 | 13 | 1 | 3 |
| | % | 0.0% | 26.7% | 0.0% | 40.0% | 86.7% | 6.7% | 20.0% |
| All Field Test (n=30) | Count | 0 | 6 | 0 | 13 | 24 | 1 | 7 |
| | % | 0.0% | 20.0% | 0.0% | 43.3% | 80.0% | 3.3% | 23.3% |

# NO2: 43% > Health Canada, 80% > WHO



# Conclusions

- 20% of homes exceeded the 8-hour avg. threshold for CO, typically during extended use of the fireplace. Only one of these exceeded 10.1 ppm. None of the homes exceeded the 1-hour avg. threshold of 35 ppm.
- Most problematic combustion product was $NO_2$. 43% exceeded the 250 ppb threshold. 80% exceeded the 110 ppb threshold.
- Humidity was not a problem in any house.
- Oxygen depletion was rare, and never triggered the oxygen depletion sensor. One house fell below the 19.5% threshold.

# Other Observations

- **Correlations.** There was no specific house or fireplace characteristic that predicted the concentration of any of the combustion gases measured.
- **Primary vs. Secondary heating**. This was an elusive distinction. Some occupants turned down the thermostat to the furnace. In many cases, proximity to fireplace overrode the furnace thermostat. Fireplace was often the primary heat source. One house used it exclusively as primary, and had extremely high $CO_2$ and $NO_2$ levels
- **Room size.** Small rooms can be especially problematic, with very high rates of gas accumulation.

# Thanks for your attention