# The House as a Chimney
## Combustion Gas Concentrations from Unvented Fireplaces

Jeffrey Gordon
Building Research Council
University of Illinois

# HUD Healthy Homes 04 Grant

- Investigate the concentration of combustion gases in houses using “vent-free” gas fireplaces.
- Examine the factors that will impact the gas concentrations, on both the generation and dilution sides.

# Unvented Gas Fireplaces

- About 30 million sold in the U.S. since 1980
- Intended use – supplemental heat, not primary heat, and decorative ambiance
- Sizing of unit emphasized (40,000 Btu max)
- All combustion gases released into home
- Popular for cost, ease of installation, efficiency

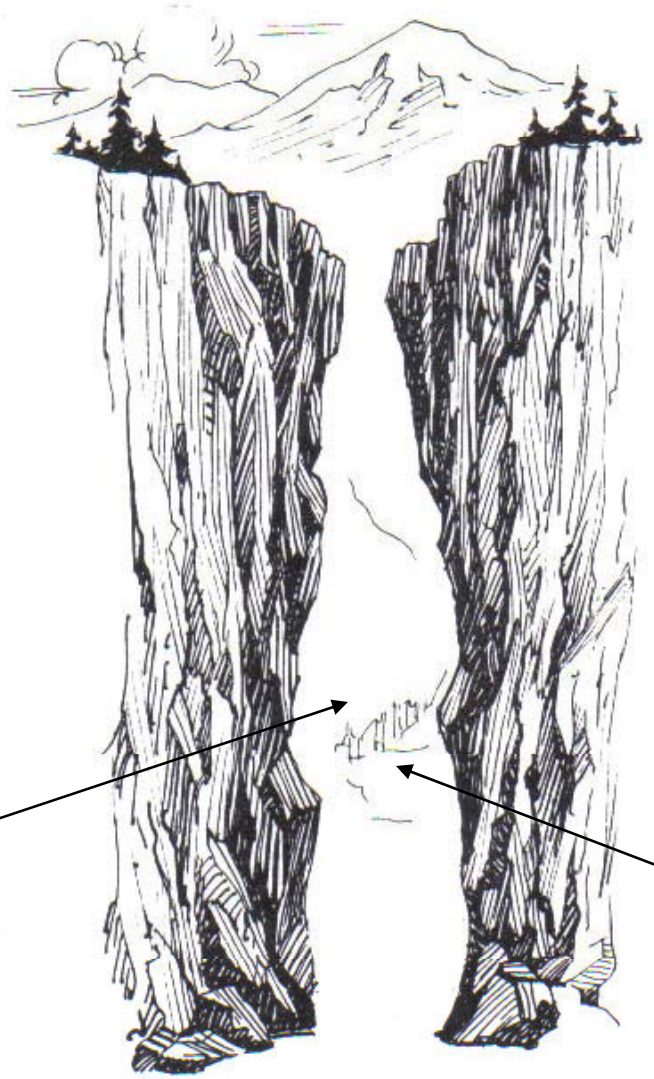
# Bridging the Chasm

<u>Industry</u>

"These things are safe. No problem.'

<u>BS and Others</u>

"What are you, nuts? This is crazy"



AGARD report

Some anecdotal studies

# Project Activities

- Field Test 30 houses – combustion gas concentrations
- Lab test new and used vent-free fireplaces
- Modeling
- Survey of Users

Analysis grew with the richness of the dataset – decay rates, moisture analysis

Will focus on the field tests today

# Gas Concentrations of Concern

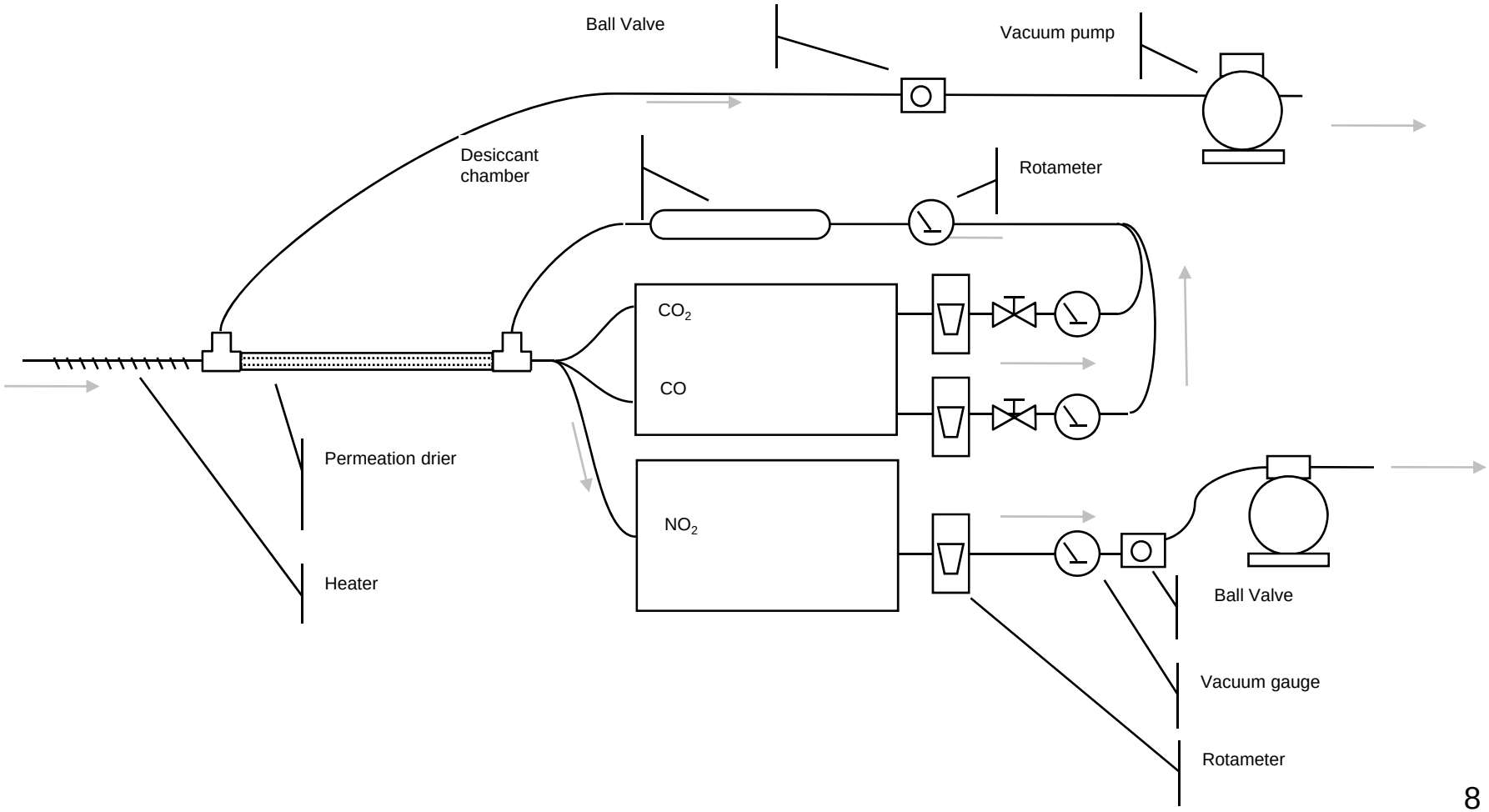
- Carbon Dioxide ($CO_2$)
- Water Vapour ($H_2O$)
- Carbon Monoxide (CO)
- $NO_x$, NO, and Nitrogen Dioxide ($NO_2$)
- Oxygen ($O_2$)

Did not study particulates or other minor gases

# BRC Researchers

- Paul Francisco, Co-PI
- Jeff Gordon, Co-PI
- Bill Rose, Instrument Guru and Scapegoat

# Experimental Setup



# Instrument Cart

- 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
- Pumps, rotameters, gauges, dryers, bells and whistles

All instruments were calibrated at each house

# HOBO Remote Sensors

- Temp/RH
- CO
- Exterior Temp/RH CO2

# Field Tests

- 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)

# Housing Characteristics

| | House Age (Years) | House Size ($ft^2$) | Blower Door (ACH50) | Fireplace Age (Years) |
|---|---|---|---|---|
| Minimum | 3 | 1195 | 5.6 | 0 (4 weeks) |
| Median | 34 | 1959 | 11.4 | 4 |
| Maximum | 100 | 3000 | 26.3 | 15 |

All houses in Central Illinois. Usage patterns were equally variable.

# 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 $C^o$ |

# What does the data look like?
# Case Study: House #18

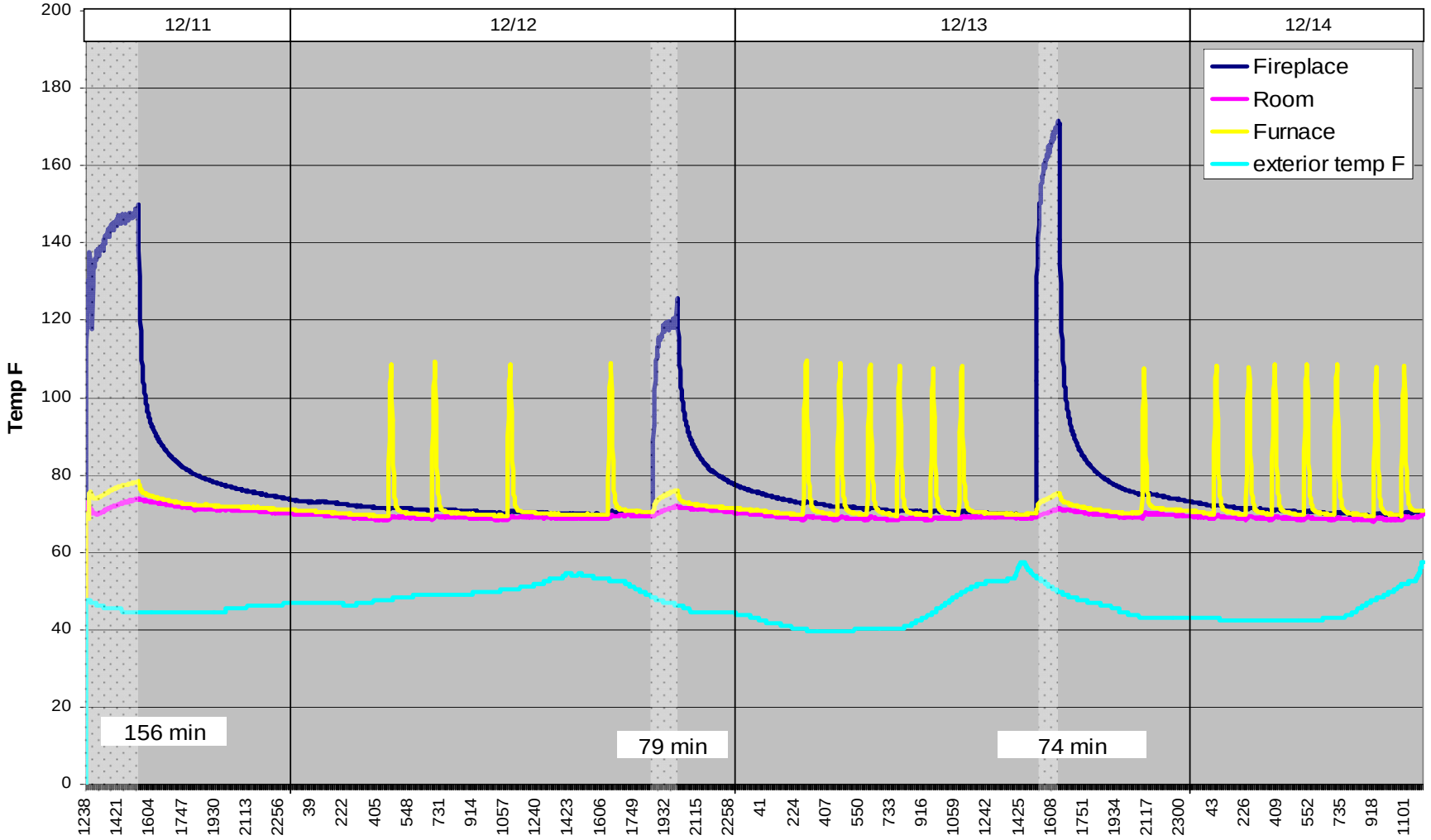
One study of n = 30, but also 30 studies of n = 1

In this case:

- One story ranch house
- Retired couple
- Infrequent fireplace usage – ambience

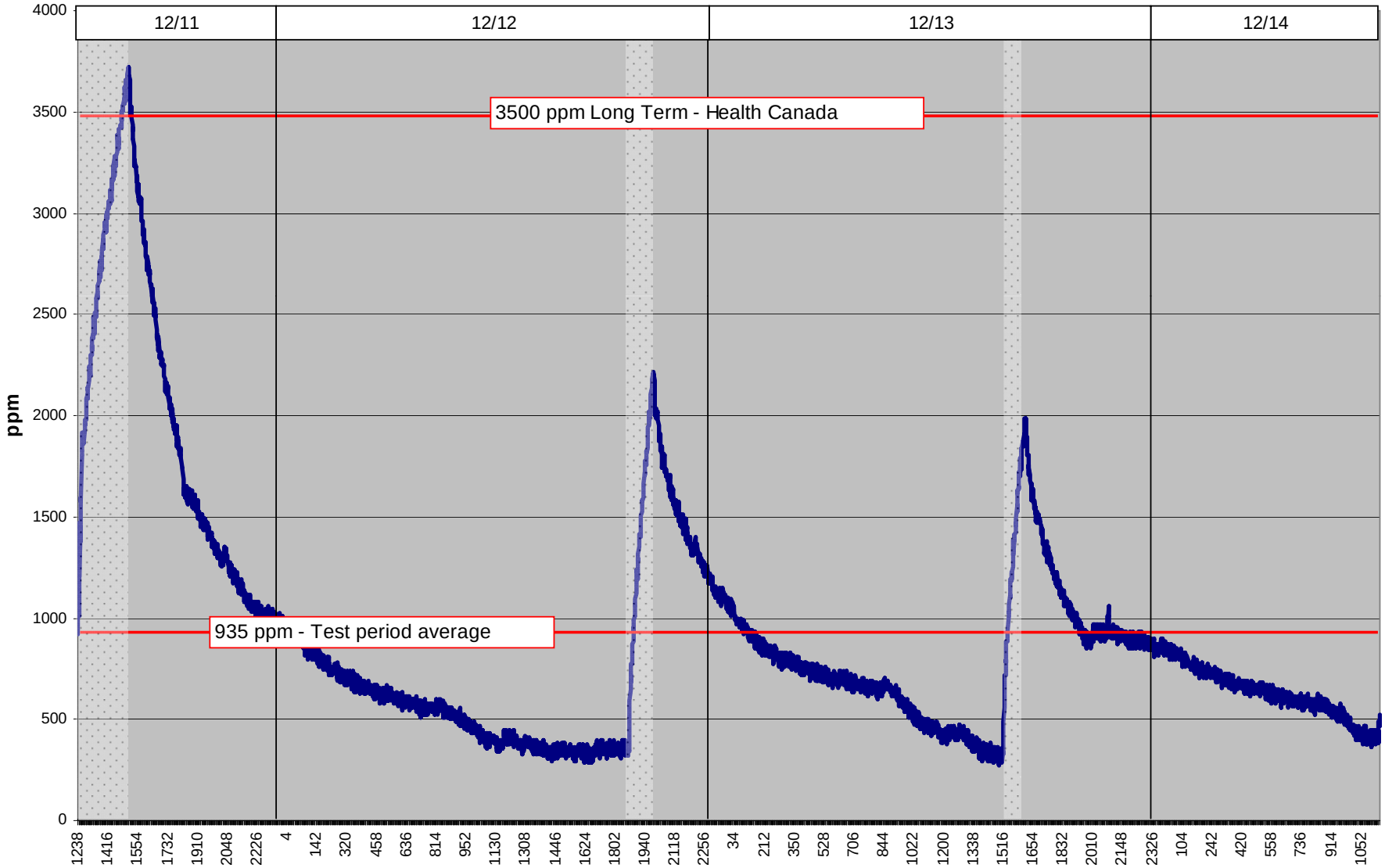
# What does the data look like? – Temperature Timeline

**Figure 1: Fireplace Use**



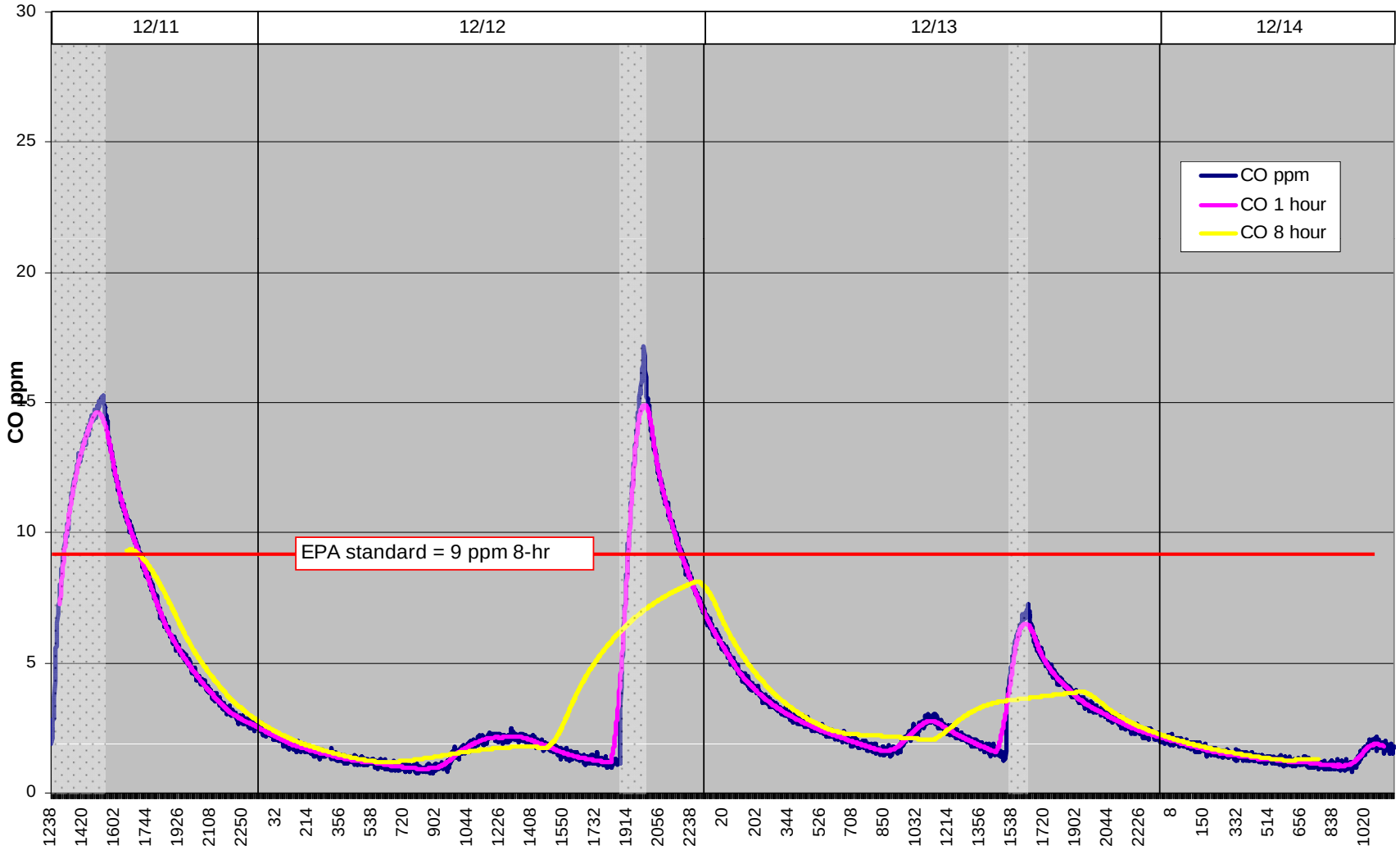
# Carbon Dioxide Timeline

**Figure 4: CO2 Concentration**



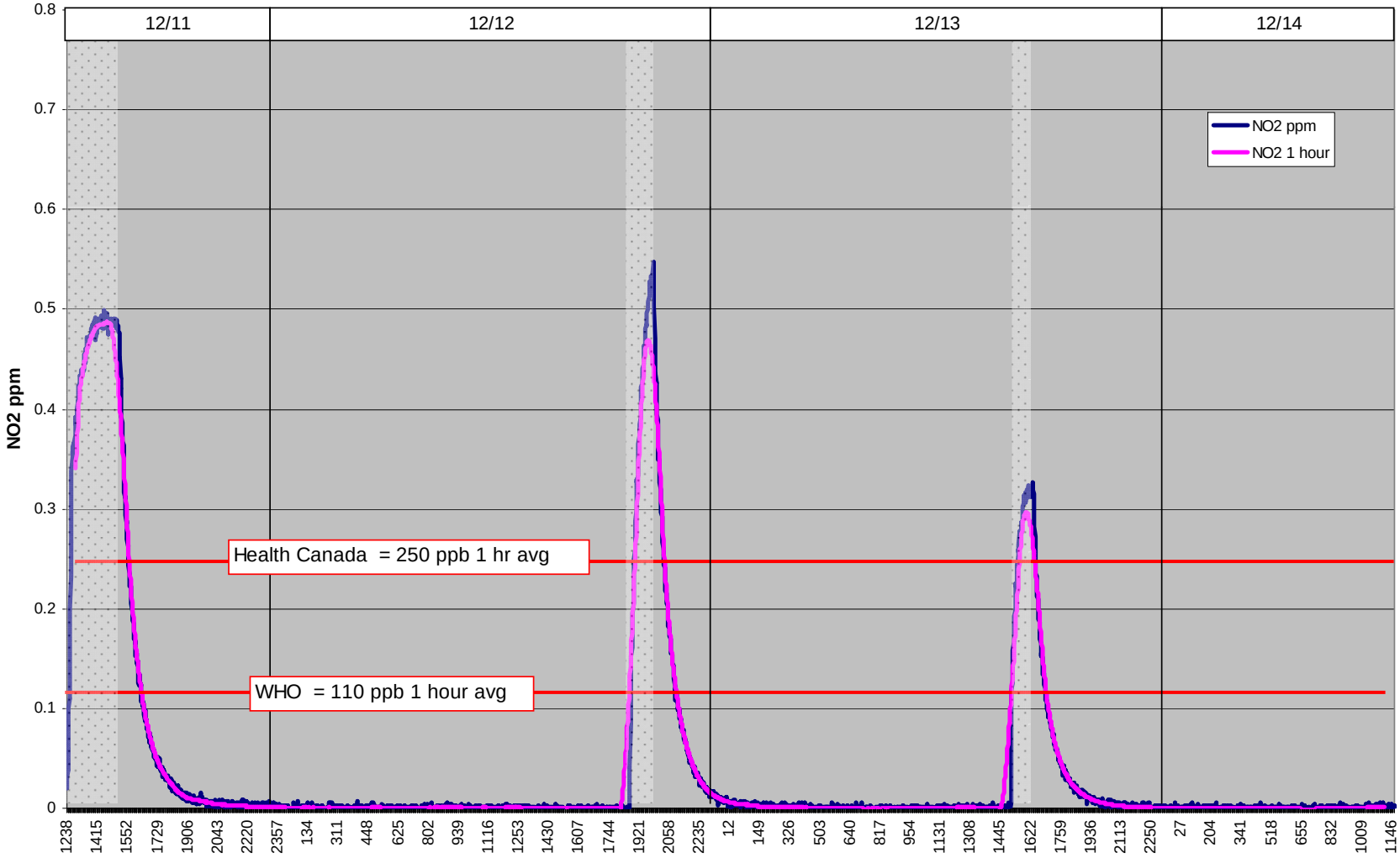
# Carbon Monoxide Timeline

**Figure 2: CO Concentration**



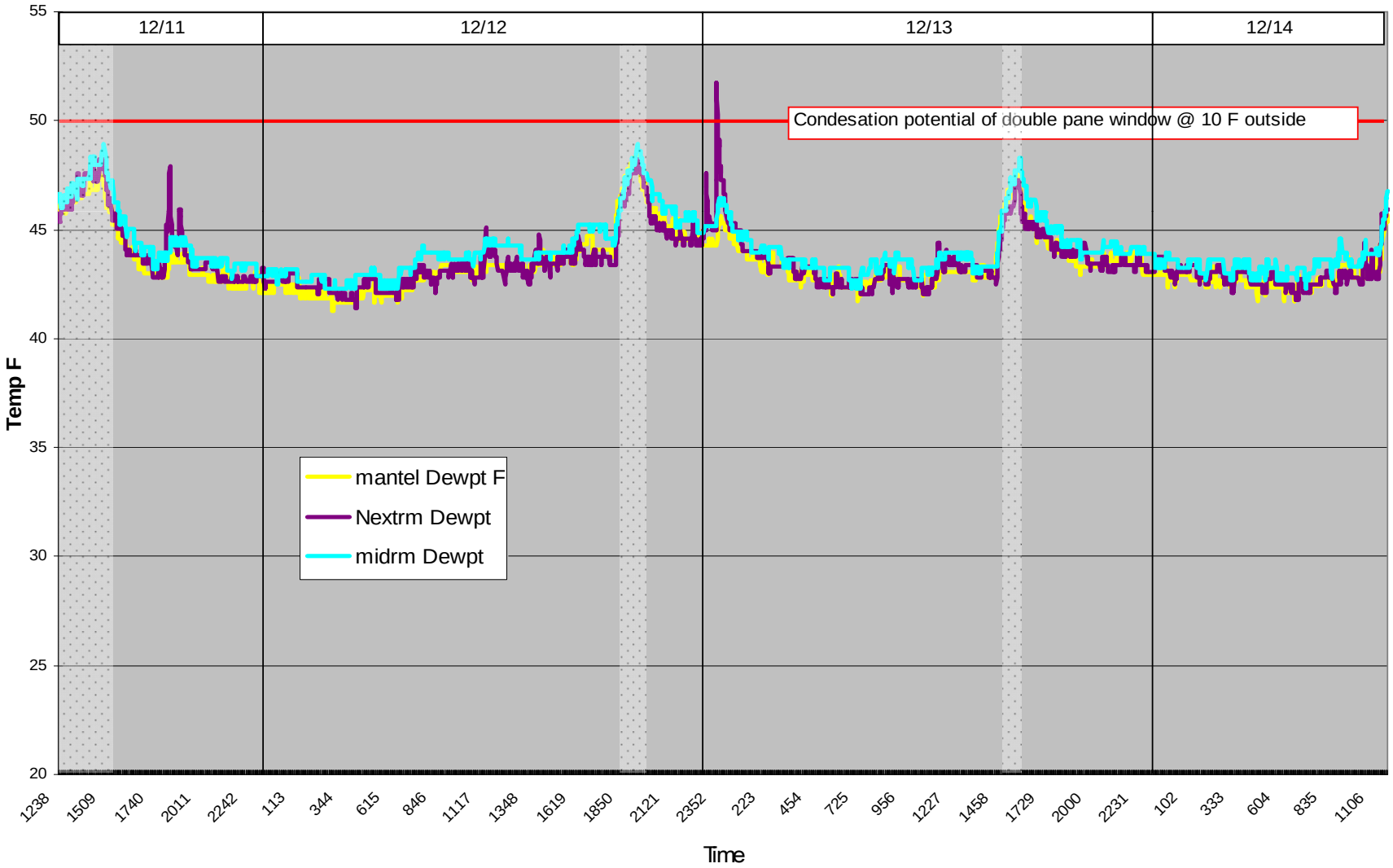
# Nitrogen Dioxide Timeline

**Figure 6: NO2 Concentration**



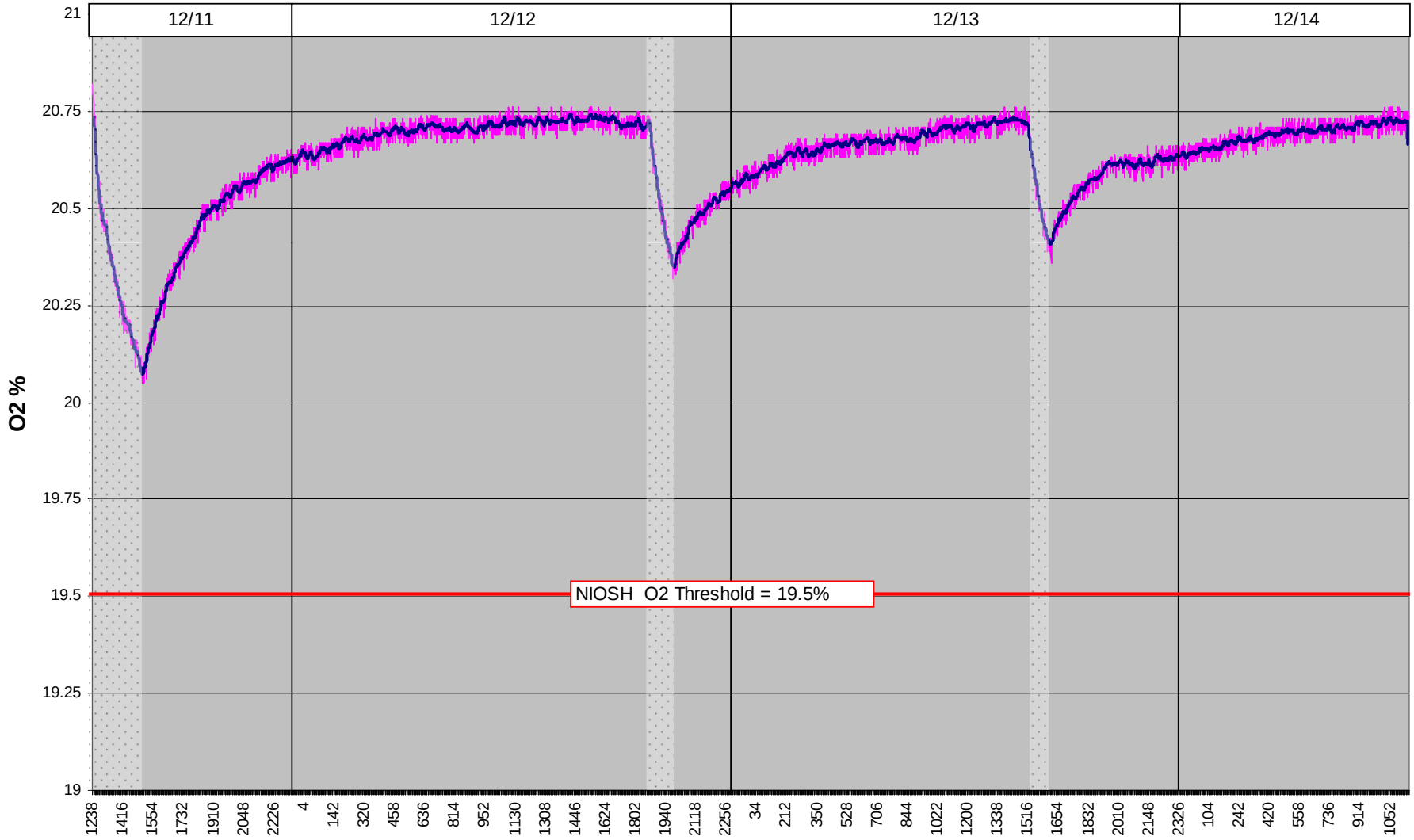
# Dewpoint Temperature Timeline

**Figure 7: DewPoint Temp**



# Oxygen Timeline

**Figure 5: Oxygen Concentration**



# 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% |

# N = 30 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.

# N = 30 Conclusions

- **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
- When the fireplace is operating it usually acts as primary – furnace does not operate

# Gas Concentration Factors

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

# Gas Concentration Factors

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

# Conclusions: Correlations

- **Correlations.** Based on single and multi-variable analysis, there was no specific house or fireplace characteristic that predicted the concentration of any of the combustion gases.
- None of these factors had a statistically significant correlation to any gas concentration or accumulation rate
- Indicator of many influences, too small of a dataset to extricate causality

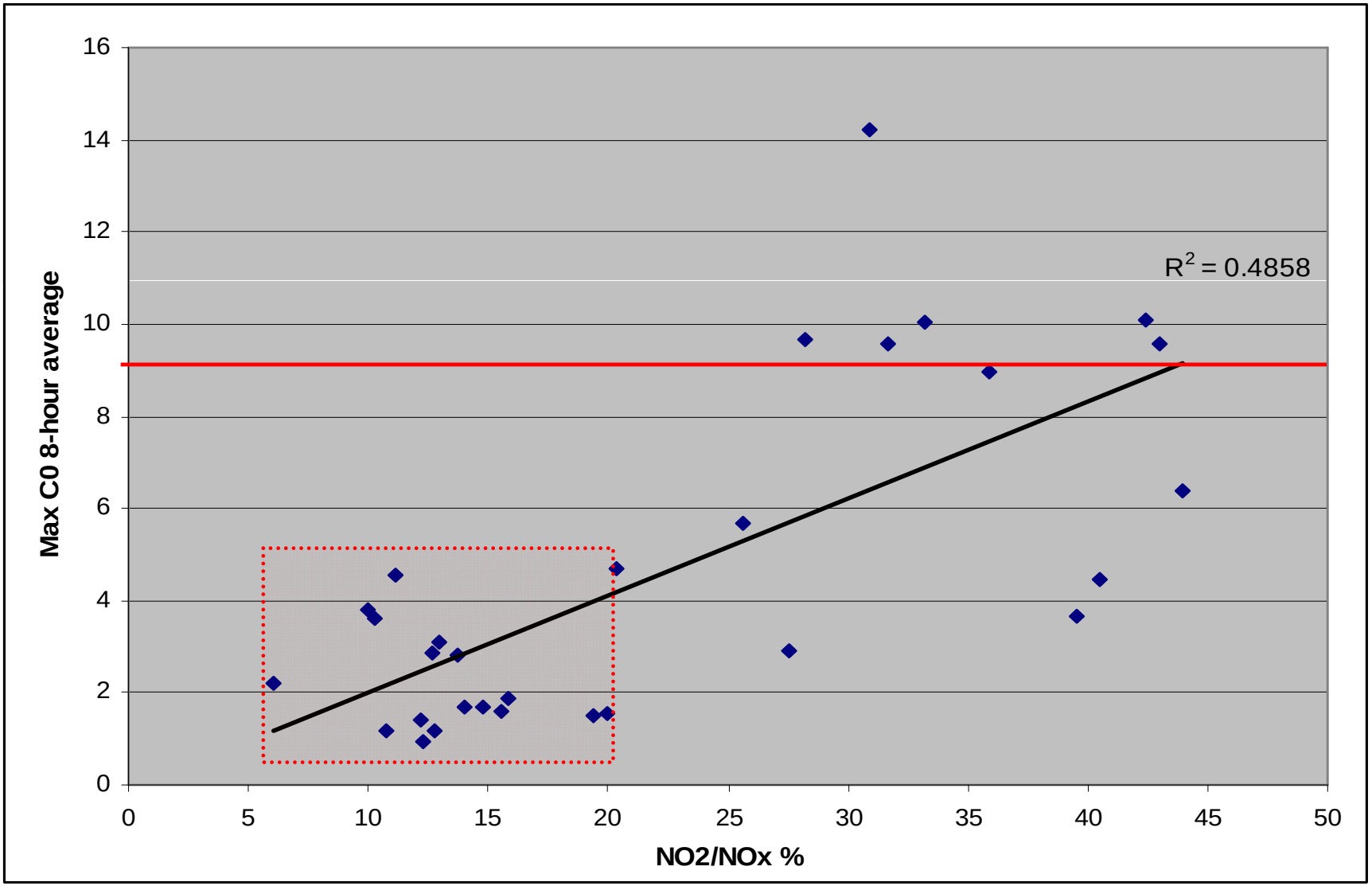
# Relationship between gases

- All gas accumulation rates were highly correlated, EXCEPT for CO.
- Suggests that all gases but CO are purely from basic combustion
- CO has other contributors

# CO vs. $NO_x$

- Common belief:
  - Cooler flame leads to higher CO, lower $NO_x$
  - Hotter flame leads to lower CO, higher $NO_x$
- Does not consider additional contributors to CO production
- Does not necessarily mean $NO_2$

# CO vs $NO/NO_2$ Ratio



# A Few N = 1 Examples

- What about an old leaky house?
- 26.3 ACH50
- 2 year old fireplace
- Constant cycling on thermostat

**Figure 1: Fireplace Use**

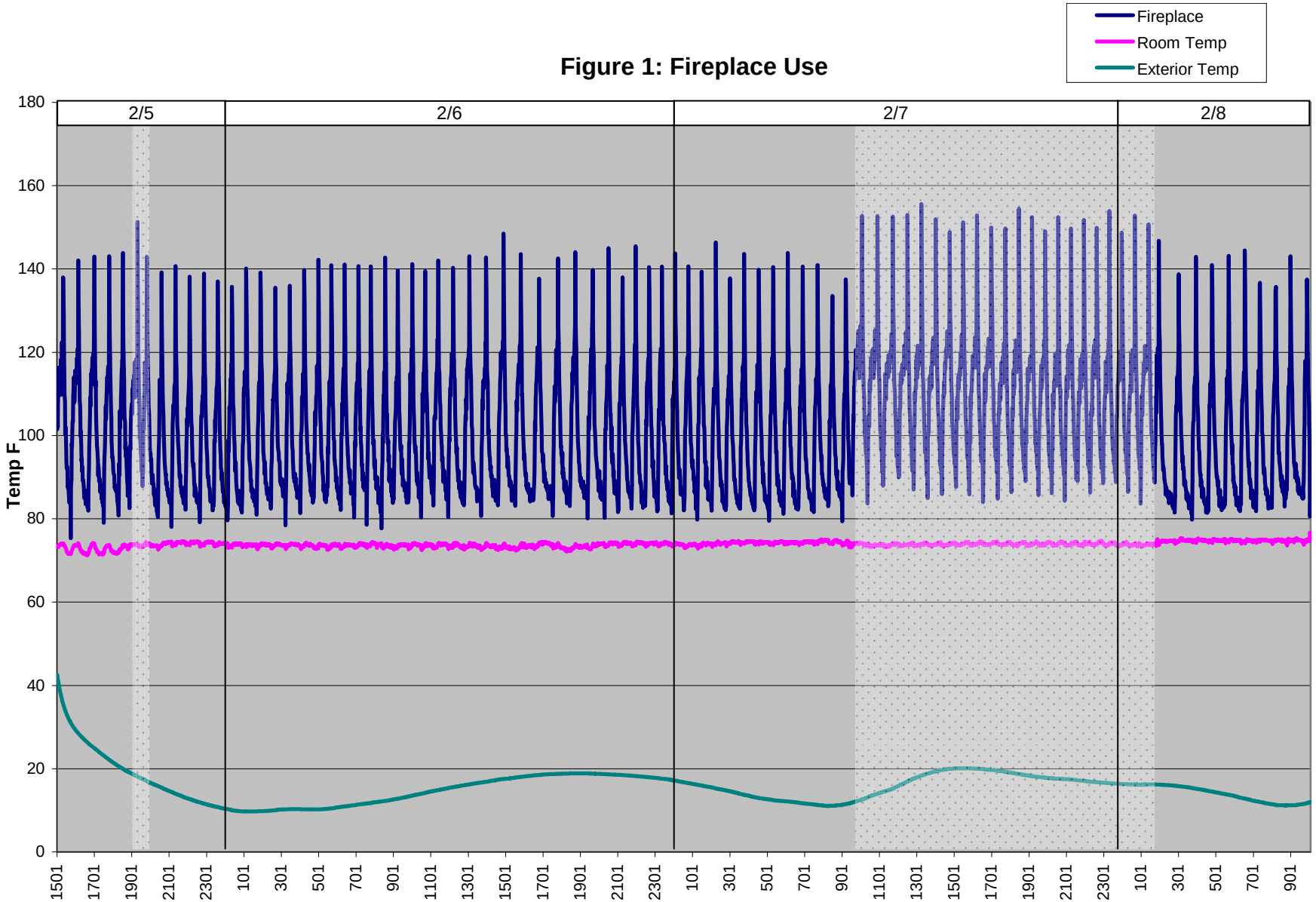
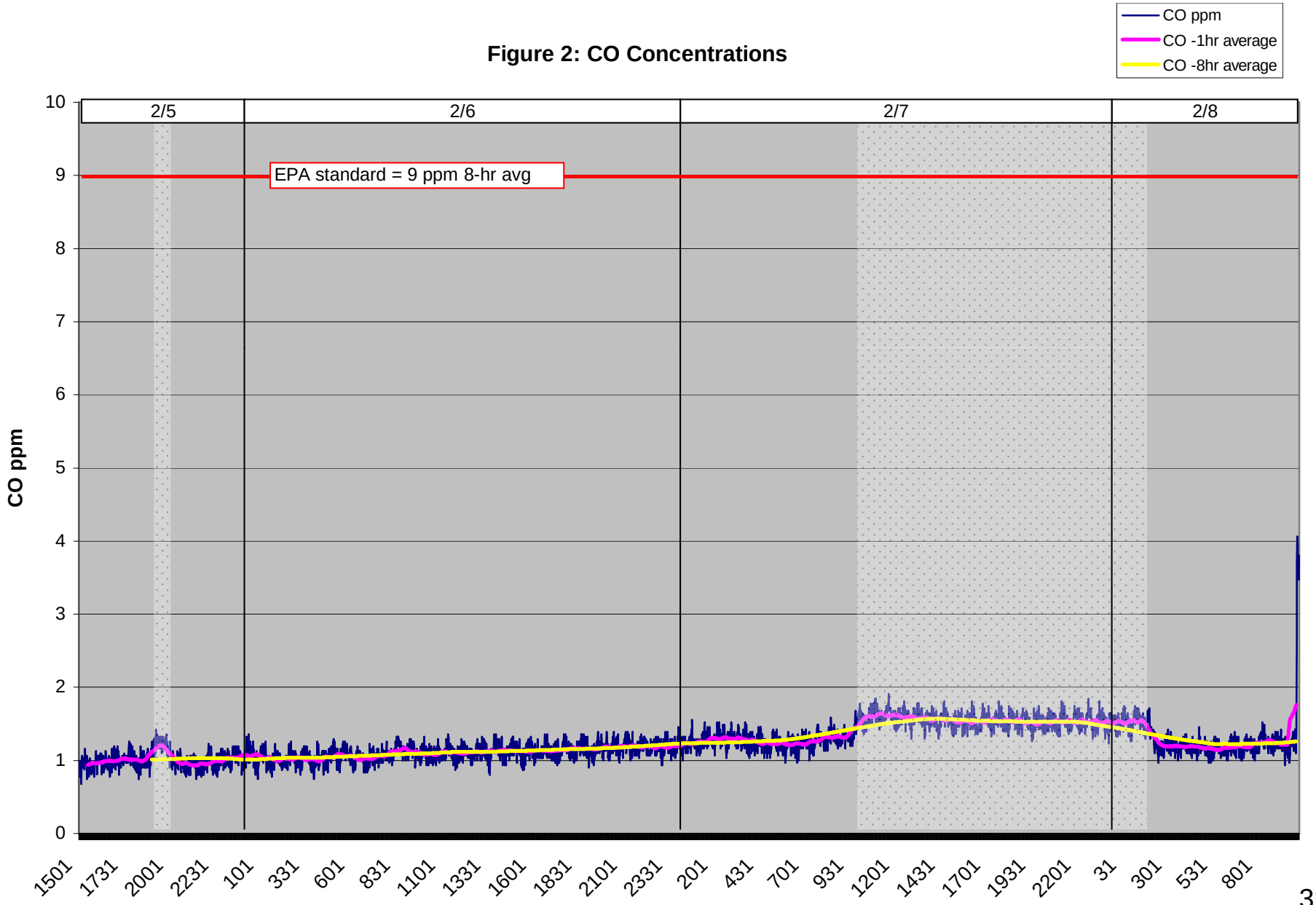
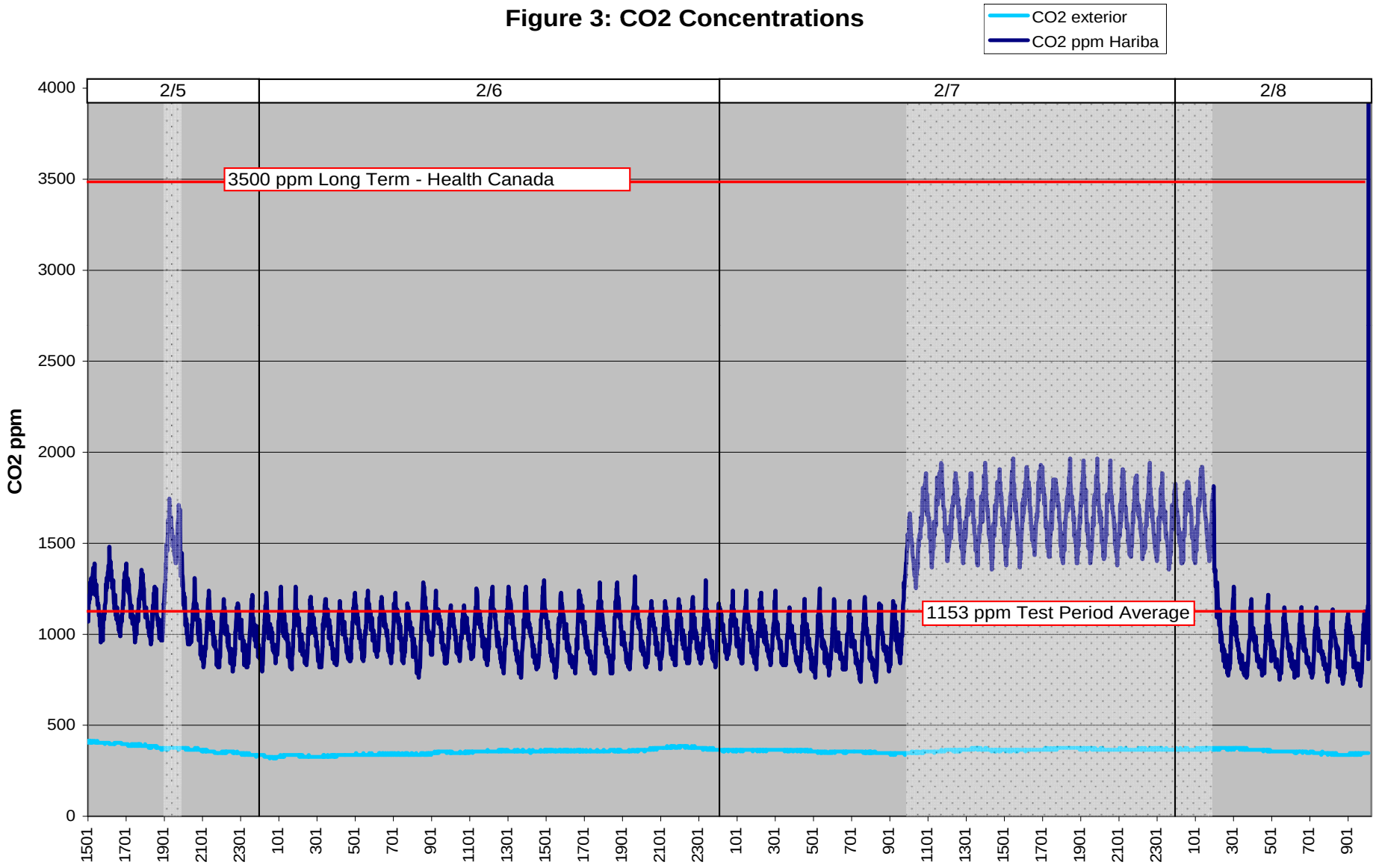


**Figure 2: CO Concentrations**



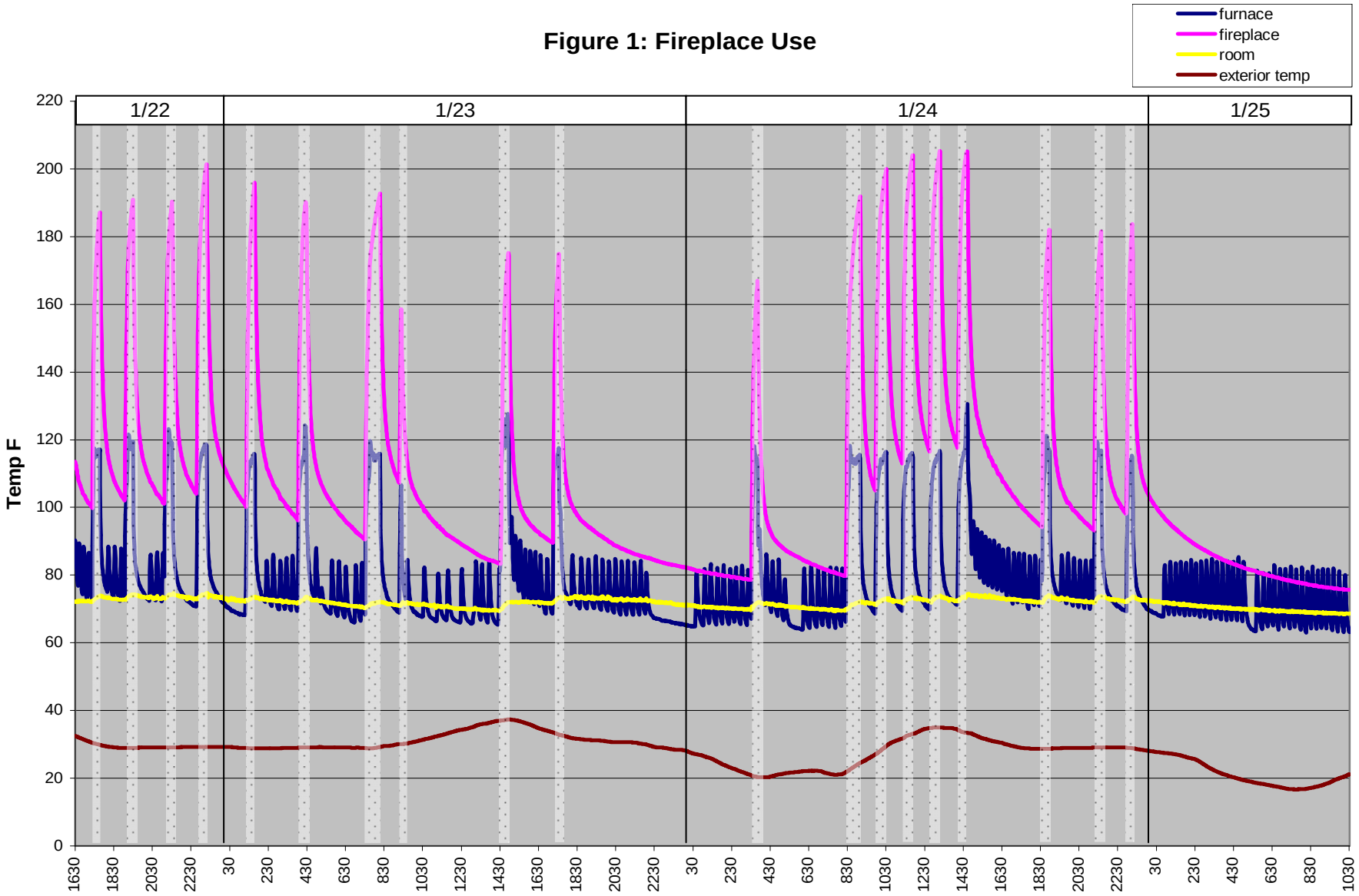
## Figure 3: CO2 Concentrations



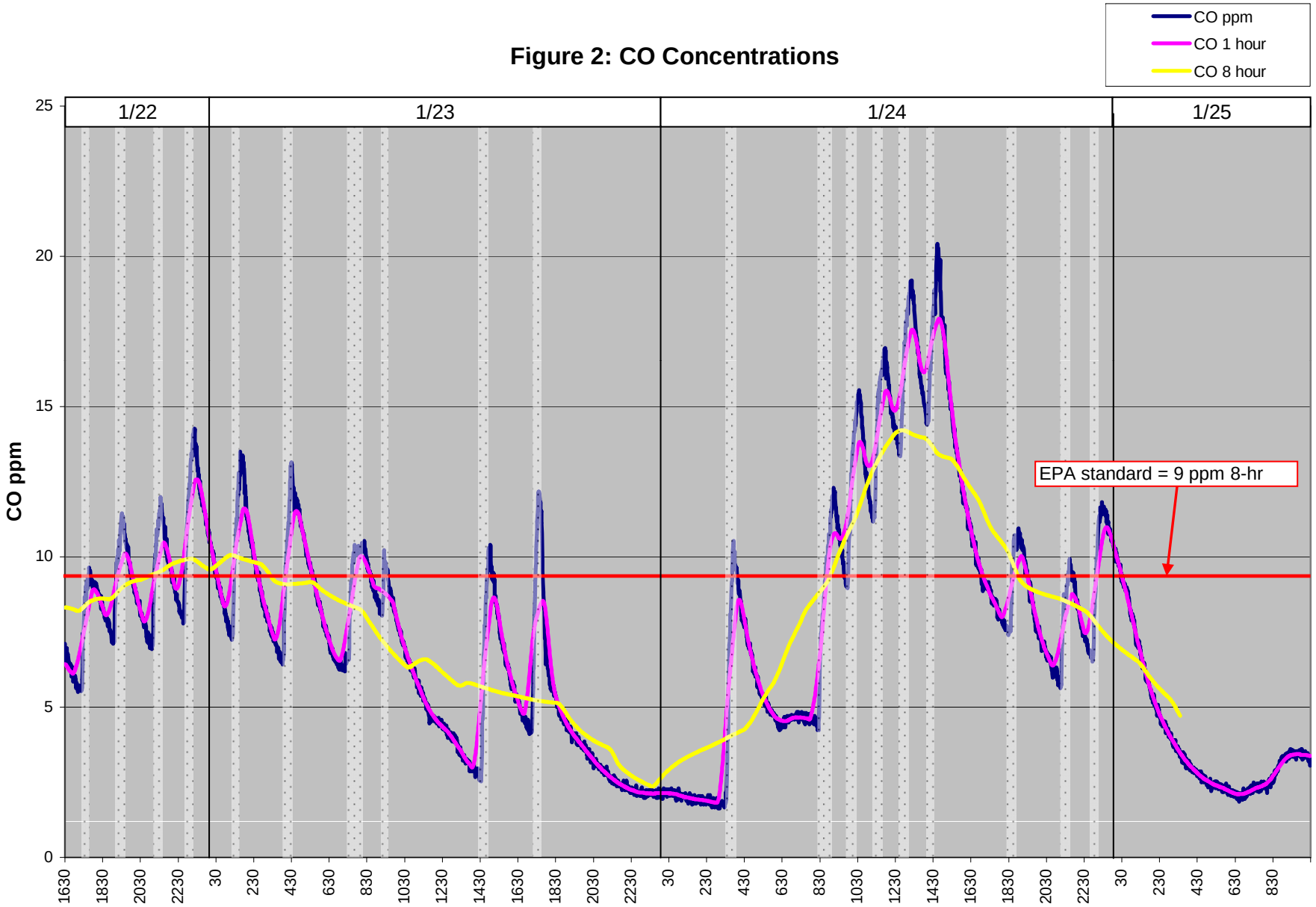
# House Example #3 – Site 26

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

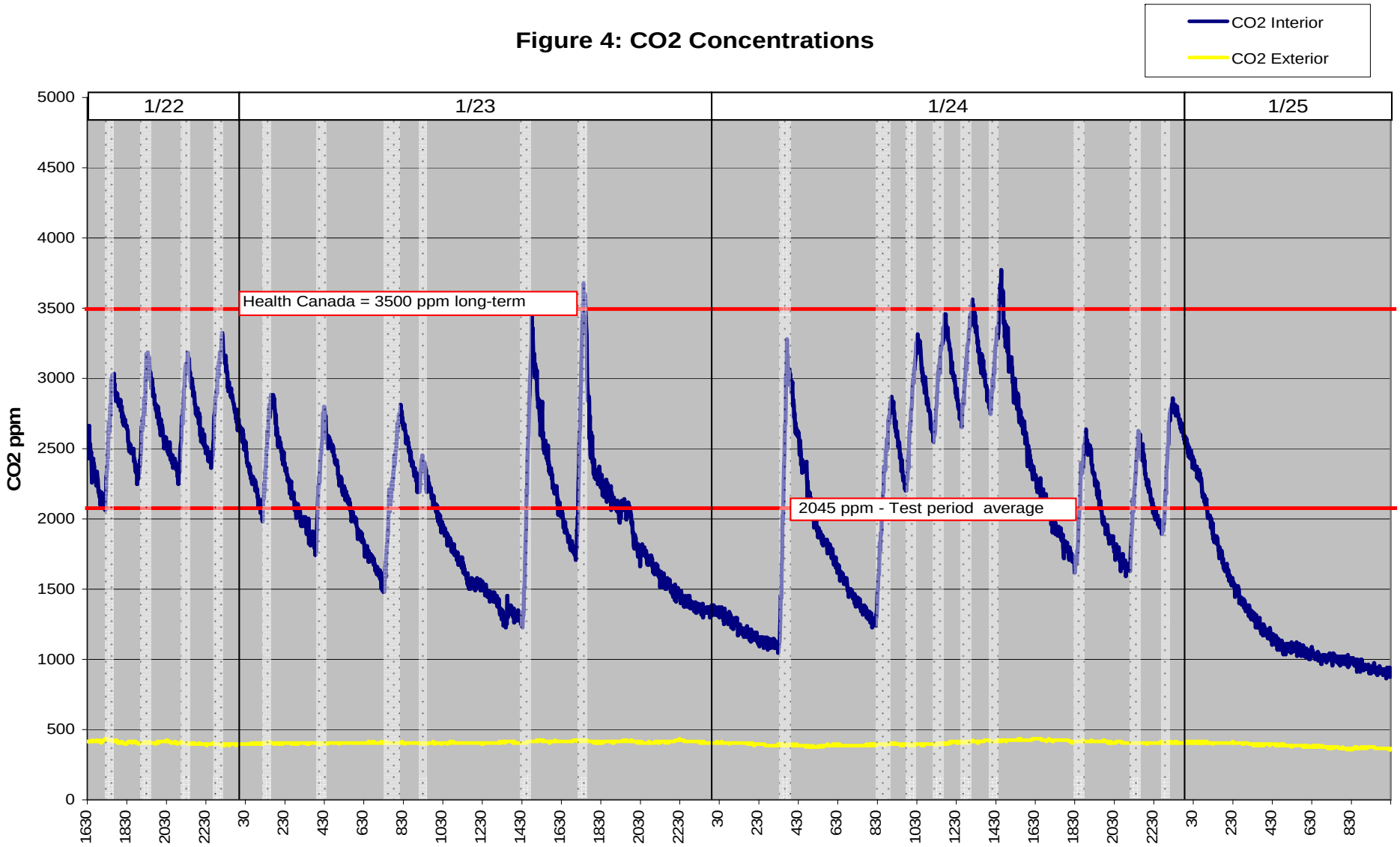
## Figure 1: Fireplace Use



## Figure 2: CO Concentrations



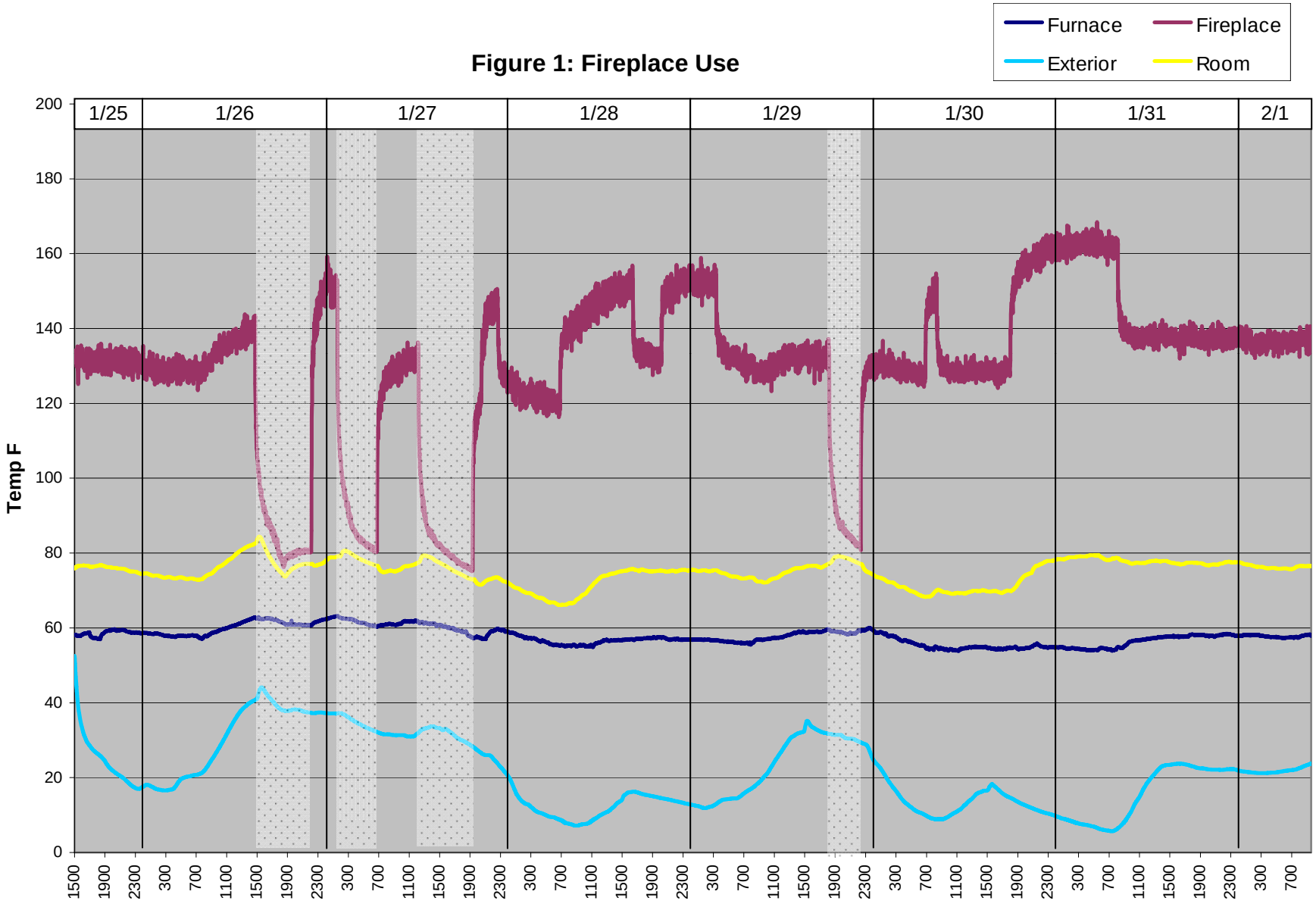
## Figure 4: CO2 Concentrations



# House Example #4 – Site 20

- 9.2 ACH50
- 2 year old fireplace
- Runs continuously – used as primary heat
- Week-long test

**Figure 1: Fireplace Use**



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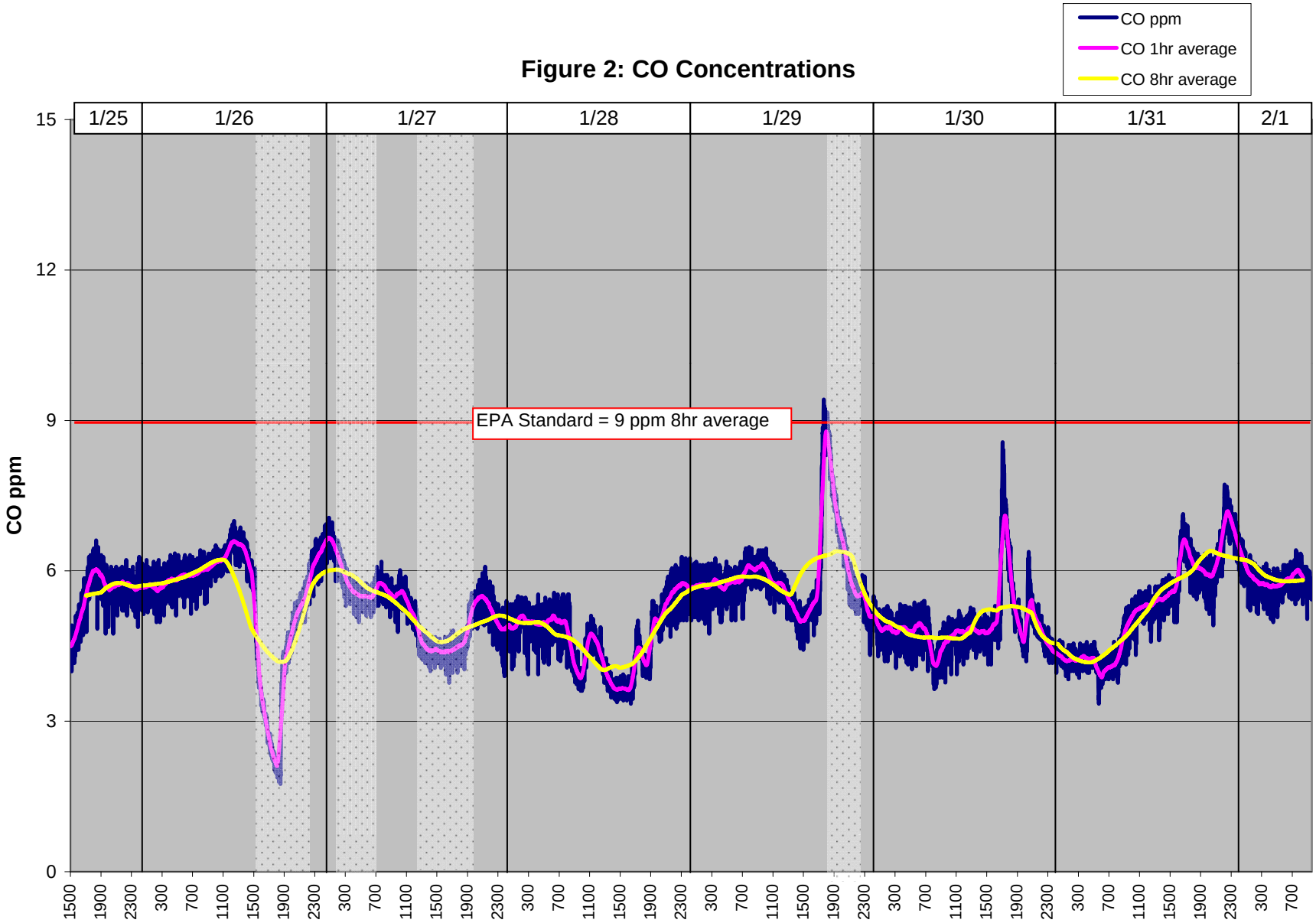

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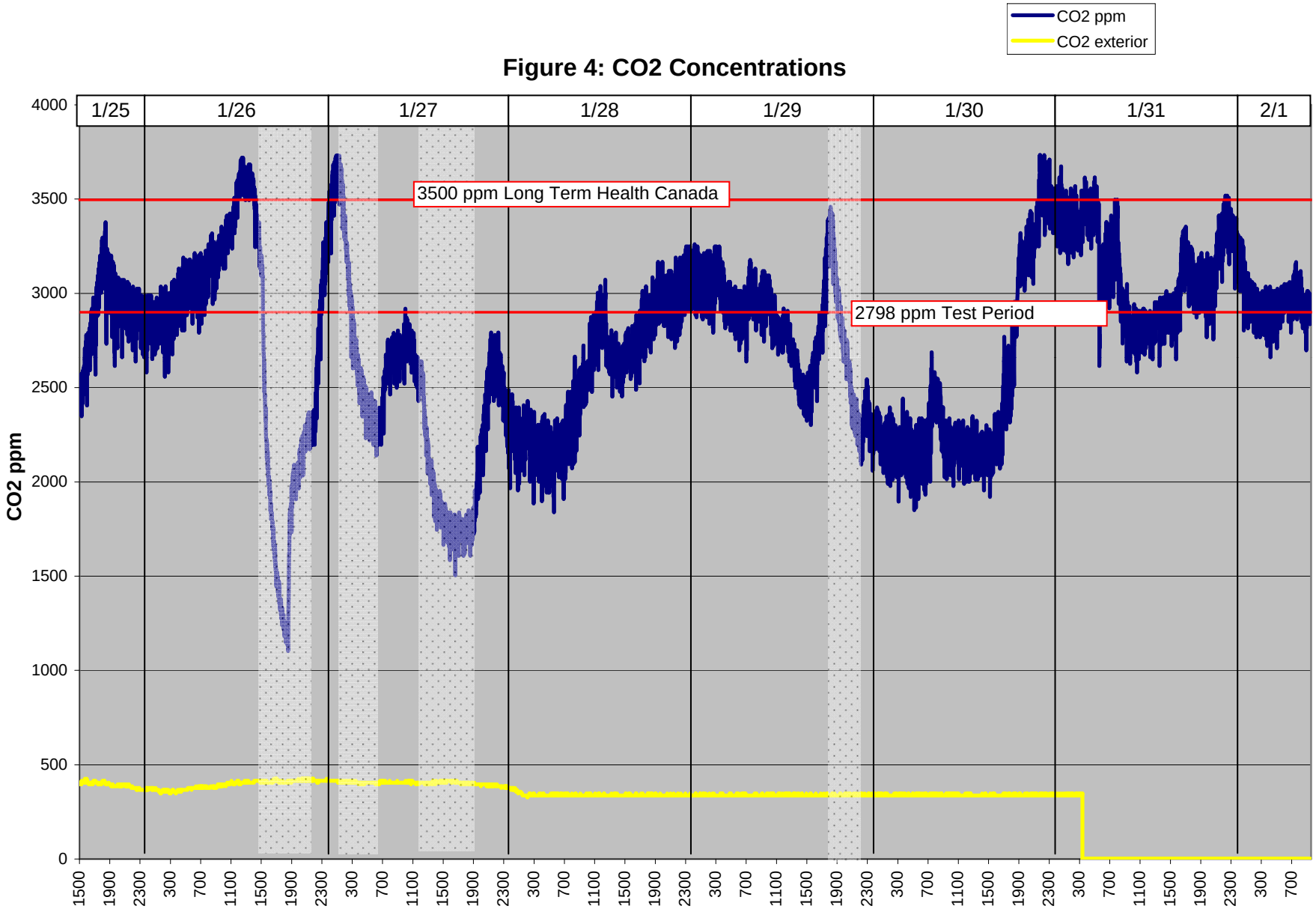
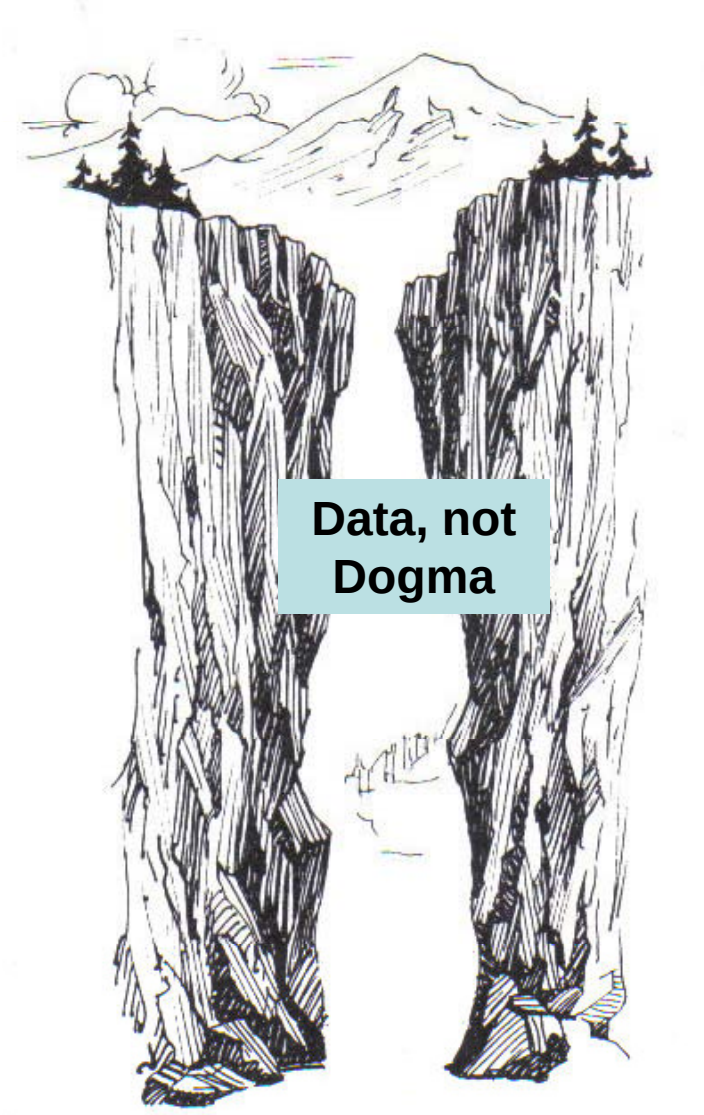


# Bridging the Chasm




Thanks for listening in.

Jeffrey Gordon

jrgordon@illinois.edu

Full Report available at:

http://brc.arch.uiuc.edu/billrose/FinalReport.pdf

http://brc.arch.uiuc.edu/billrose/Apps_all.pdf