Stay Warm & Eat Well:

Reducing Indoor Air Pollution from Cooking and Unvented Gas Appliances

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The Program

- Basic Combustion Primer – *Jeff*
- Unvented Gas Fireplaces - *Jeff*
- Pollutants from Cooking Burners - *Brett*
- Range Hood as Mitigation - *Brett*
- Questions and Discussion

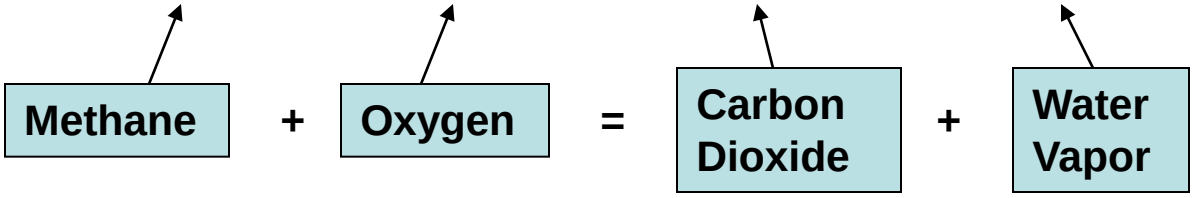
What is Combustion?

- Common fuels have molecules with carbon and hydrogen locked up together. Adding sufficient oxygen and heat leads to combustion
- Breaking down the carbon-hydrogen bonds turns chemical energy into heat energy.
- The carbon and hydrogen atoms are released to create new bonds.

Combustion

In a perfect world, burning a fuel (breaking the carbon-hydrogen bonds), will produce carbon dioxide, and water vapor:

$$CH_4 + 2O_2 = CO_2 + 2H_20$$



Plus a bunch of heat (about 24,000 BTUs/pound)

(Note: Natural gas is about 77% methane, and some other stuff)

Water Vapor

- 2 molecules of H_2O for each molecule of fuel
- Water is not a problems by itself, but . . .
- What is in this picture?

Carbon Dioxide

- The principal greenhouse gas (390 ppm)
- Part of our respiration process
- Not typically harmful at indoor levels (but issues at very high concentrations, > 3,500 ppm (Health Canada)
- Often used as a surrogate for IAQ. Levels above 1000 ppm may indicate IAQ problems in a building.

In a less than perfect world . .

- We can't count on complete, perfect combustion – where all of the carbon finds the oxygen it needs to form CO_2.
- The amount of oxygen must be right, the mixing of the fuel and the oxygen must be perfect, and the temperatures be correct.
- If not, "incomplete" combustion occurs, and . .

Incomplete Combustion

To little oxygen, and instead of . . .

- CO_2 (carbon dioxide), we get some . . .
- CO (carbon monoxide), and just plain . . .
- C (carbon in the form of soot)

When we burn fuel for heat, we want combustion to be as complete as possible.

But we don't live in a perfect world. All of our combustion appliances produce some CO

Carbon Monoxide

- Colorless, odorless gas
- Combines with hemoglobin in the blood
- Interferes with the blood's ability to deliver oxygen throughout the body
- Low concentration can cause headaches, fatigue, dizziness, nausea, chest pains
- High concentrations are fatal

Nitrogen Dioxide

- Nitrogen in the fuel and surrounding air also combines with oxygen at high temperatures, making NO and NO_2
- Nitrogen Dioxide is a colorless, odorless gas, the main ingredient of smog
- Irritates mucous membranes of eyes, nose, and throat
- High concentrations can cause shortness of breath, and may increase the risk of respiratory infections and emphysema

Formaldehyde (HCHO or CH_2O)

- Formaldehyde is a VOC
- Healthy Home issue because of its use in many building materials
- Can also be a byproduct of combustion
- Allergic reactions resulting in flu-like symptoms:
  - Eye, nose, and throat irritant
  - Coughing, wheezing, chest tightness
  - Headaches, nausea, diarrhea
- Possible carcinogen
- Sensitivities can vary

Particles

- There are traces of a lot of other things in natural gas
- In addition to carbon (soot), combustion will produce respirable particles of many kinds and sizes
- These particles can irritate the eyes, throat, sinuses, and lungs

(That's the Combustion Primer)

Combustion Product Concentrations from Unvented Gas Fireplaces

Unvented Gas Fireplaces

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

Field Tests

- Winters of 2006 and 2007 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)

Field Test Equipment

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 (ft^2)	Blower Door (ACH50)	Fireplace Age (Years)
Minimum	3	1200	5.6	0 (4 weeks)
Median	34	1960	11.4	4
Maximum	100	3000	26.3	15

Usage patterns were equally variable.

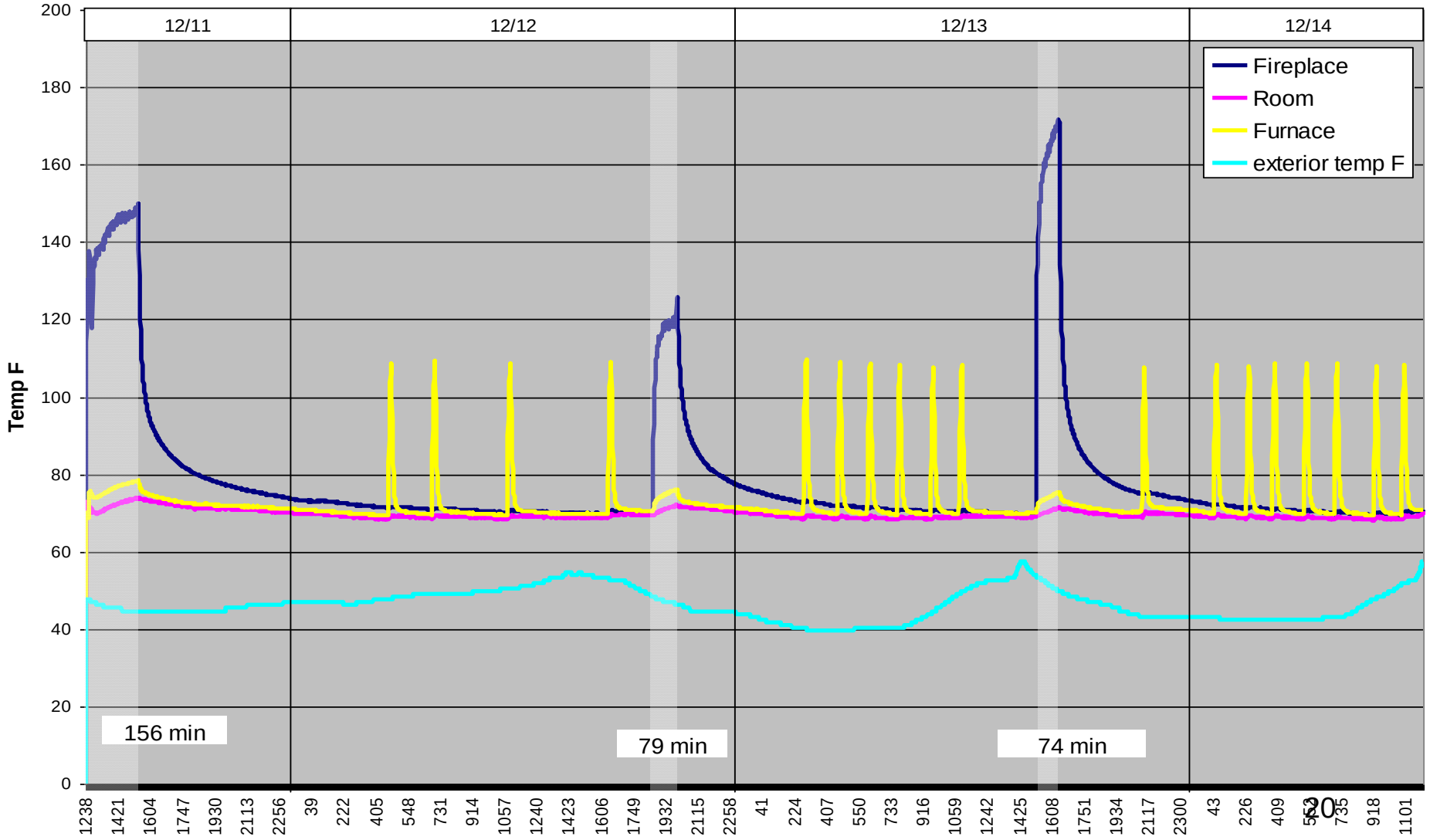
What does the data look like?

In this case:

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

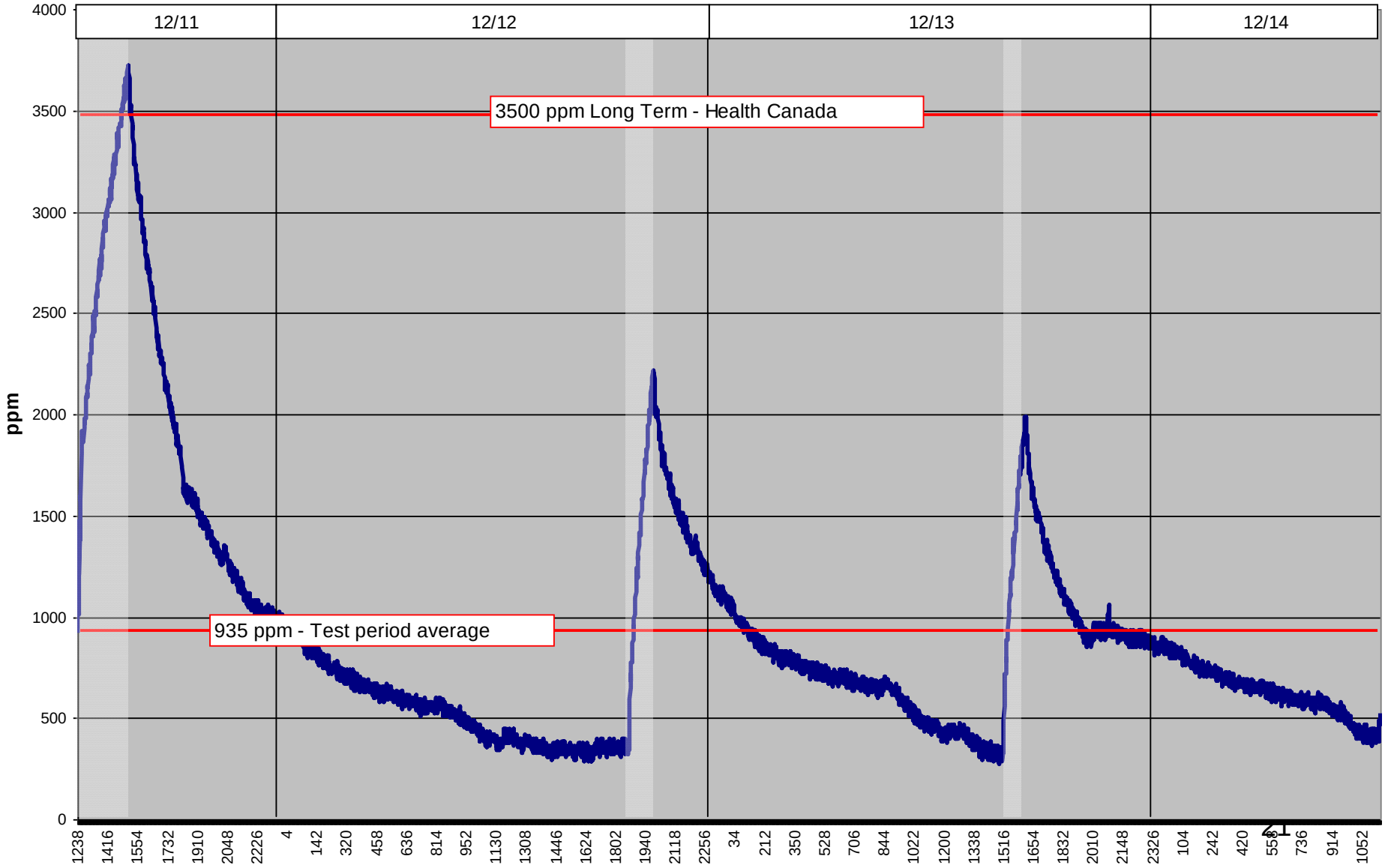
On/Off Timeline

Figure 1: Fireplace Use



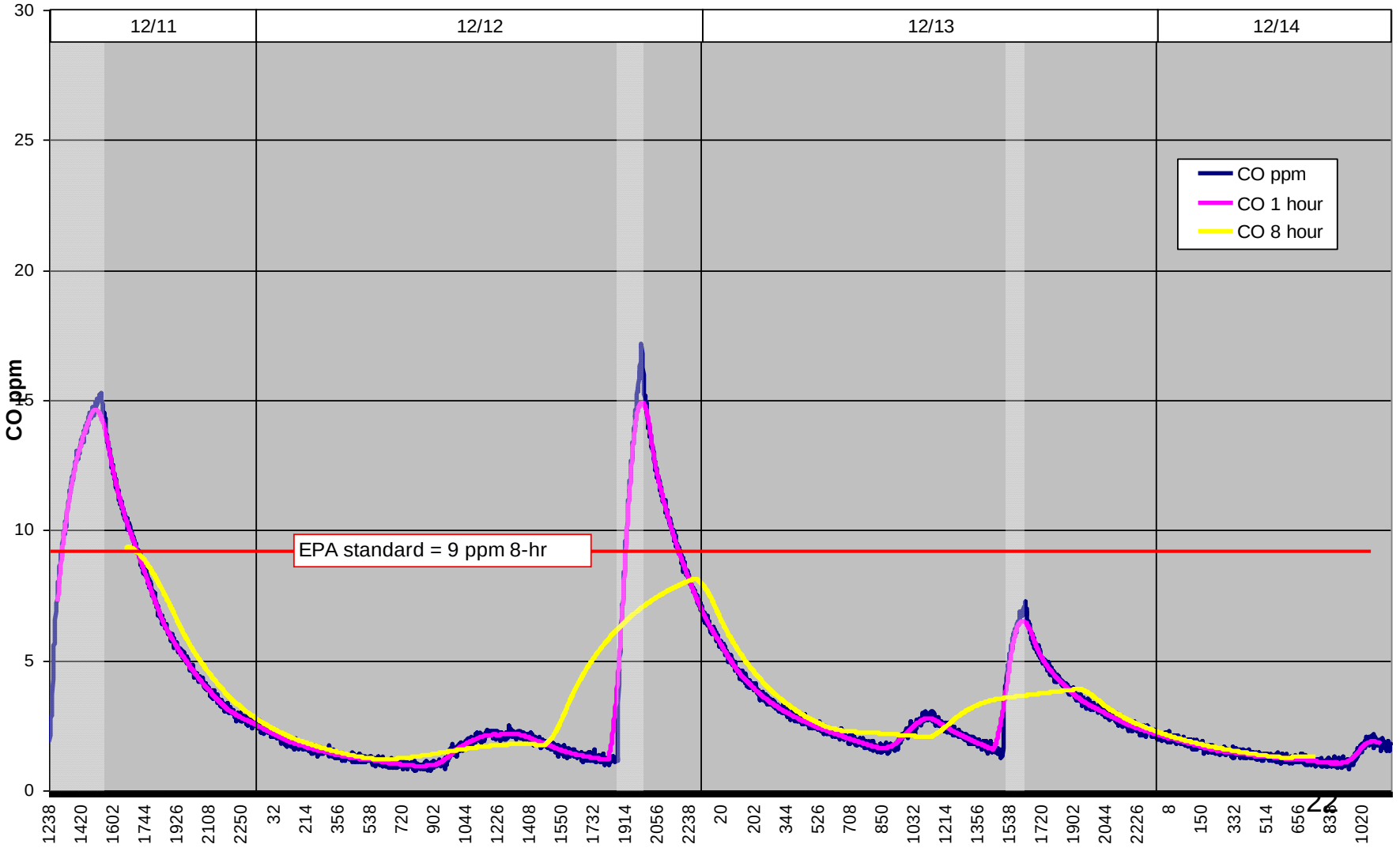
Carbon Dioxide Timeline

Figure 4: CO2 Concentration



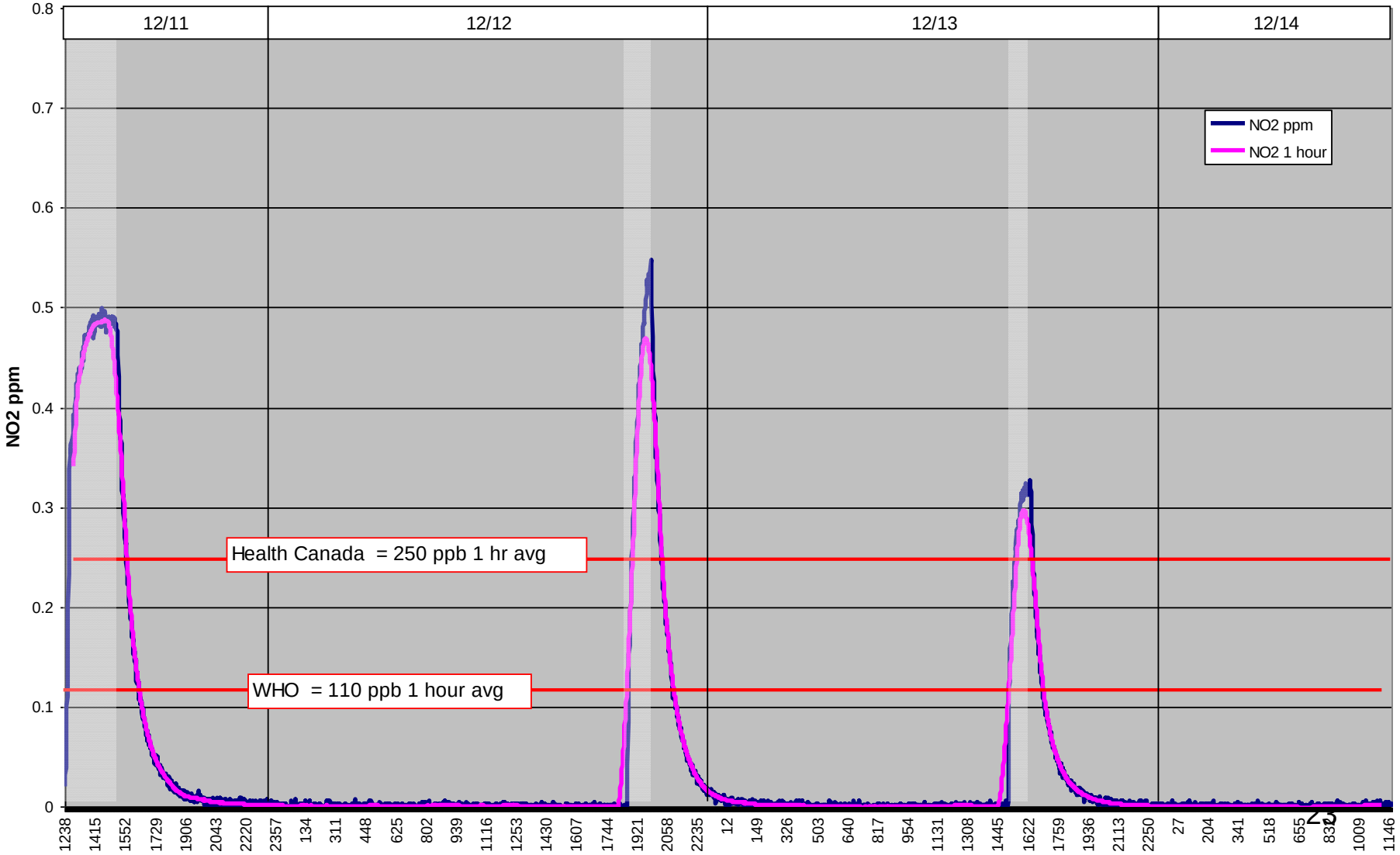
Carbon Monoxide Timeline

Figure 2: CO Concentration



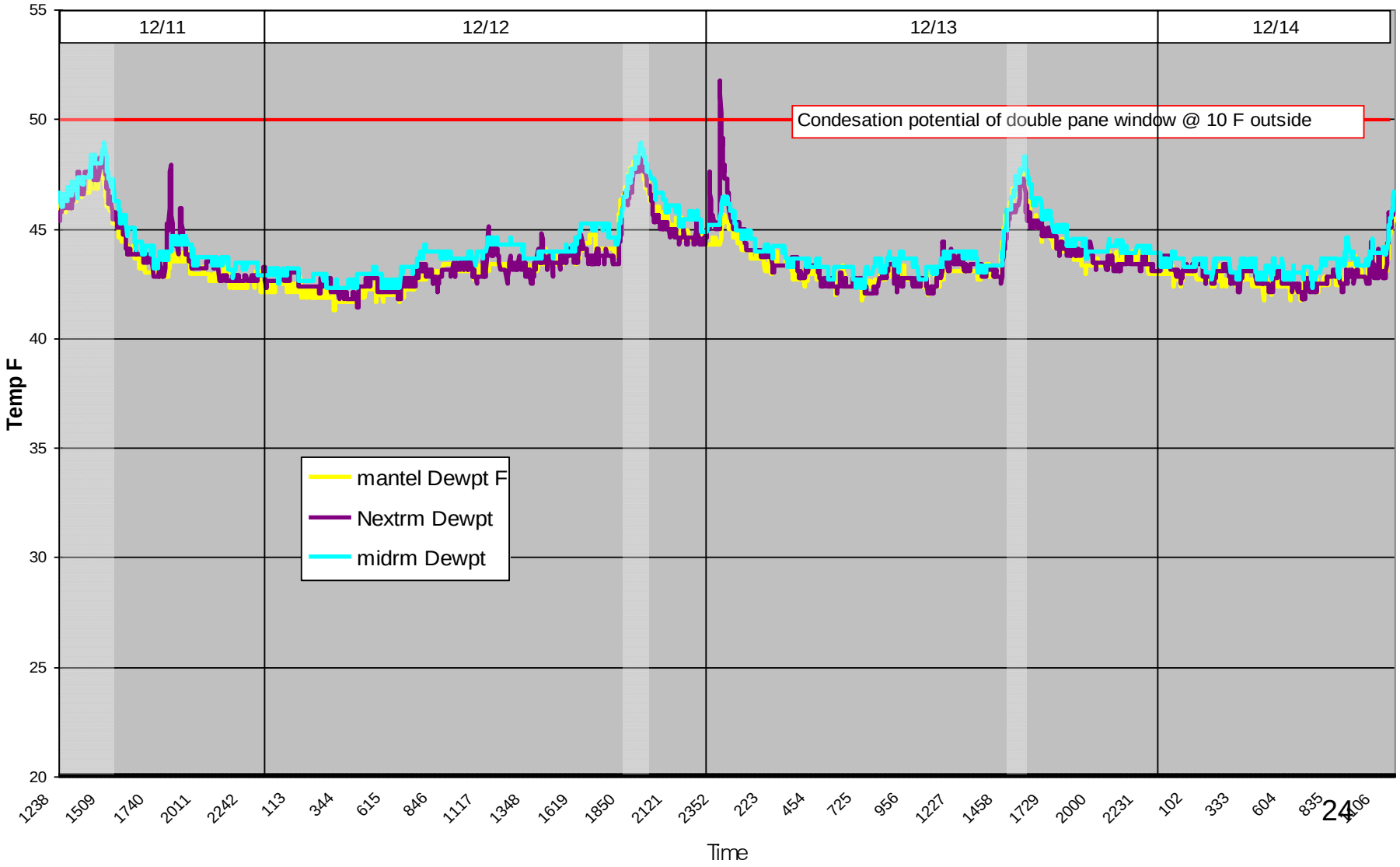
Nitrogen Dioxide Timeline

Figure 6: NO2 Concentration



Water Vapor Timeline

Figure 7: DewPoint Temp



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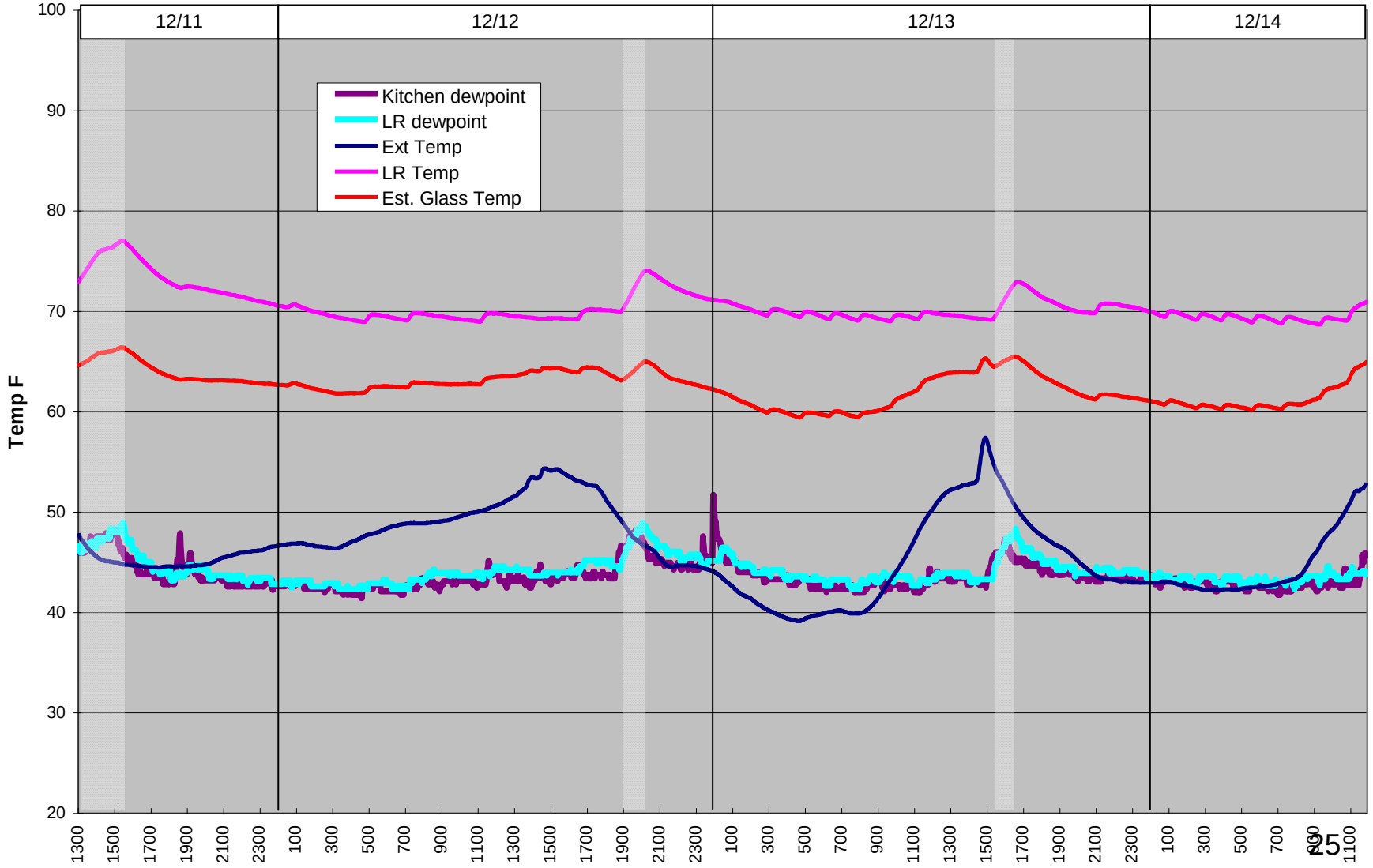
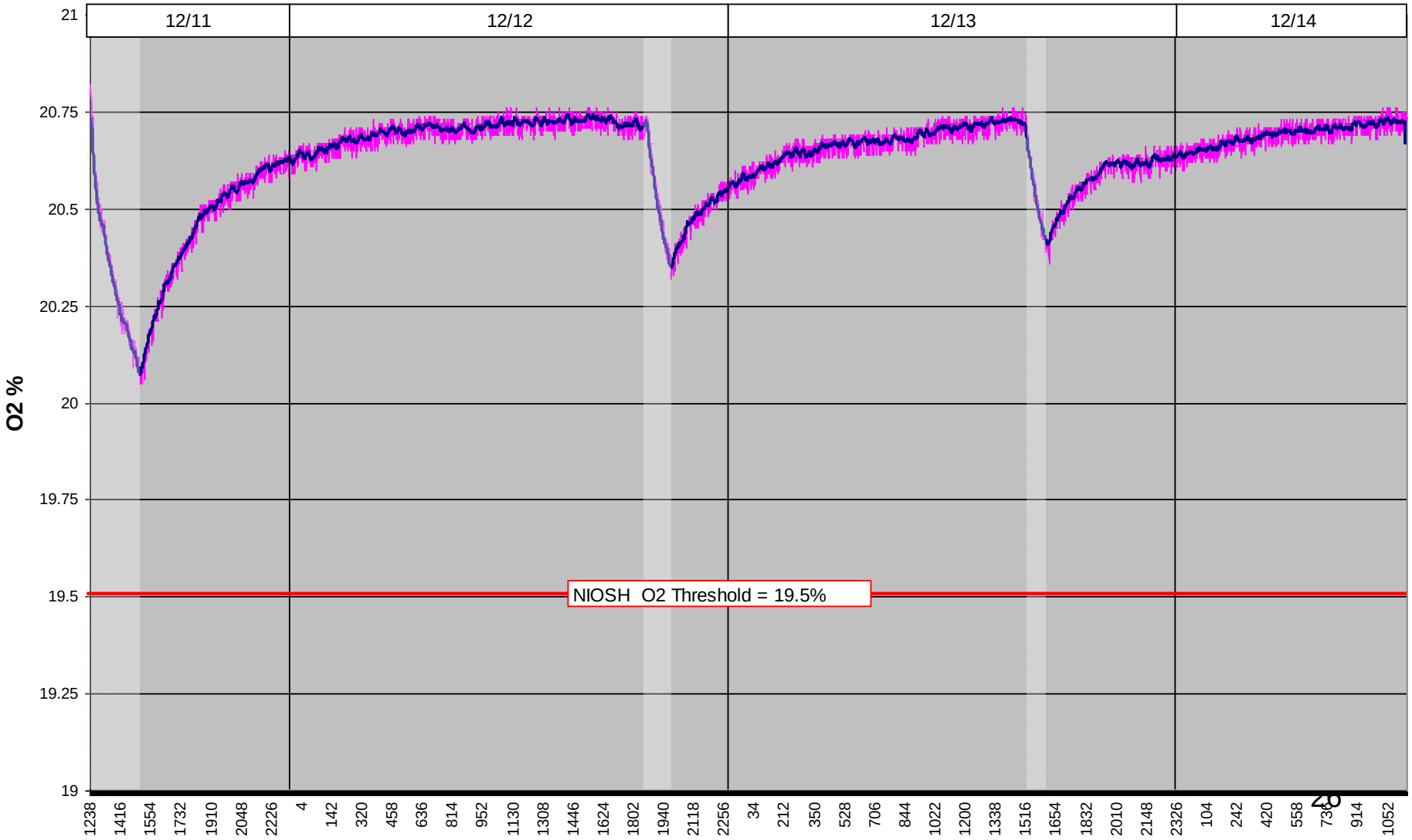
Water Vapor Timeline 2

Figure 6: DewPoint Temp



Oxygen Timeline

Figure 5: Oxygen Concentration



Field Tests Results

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

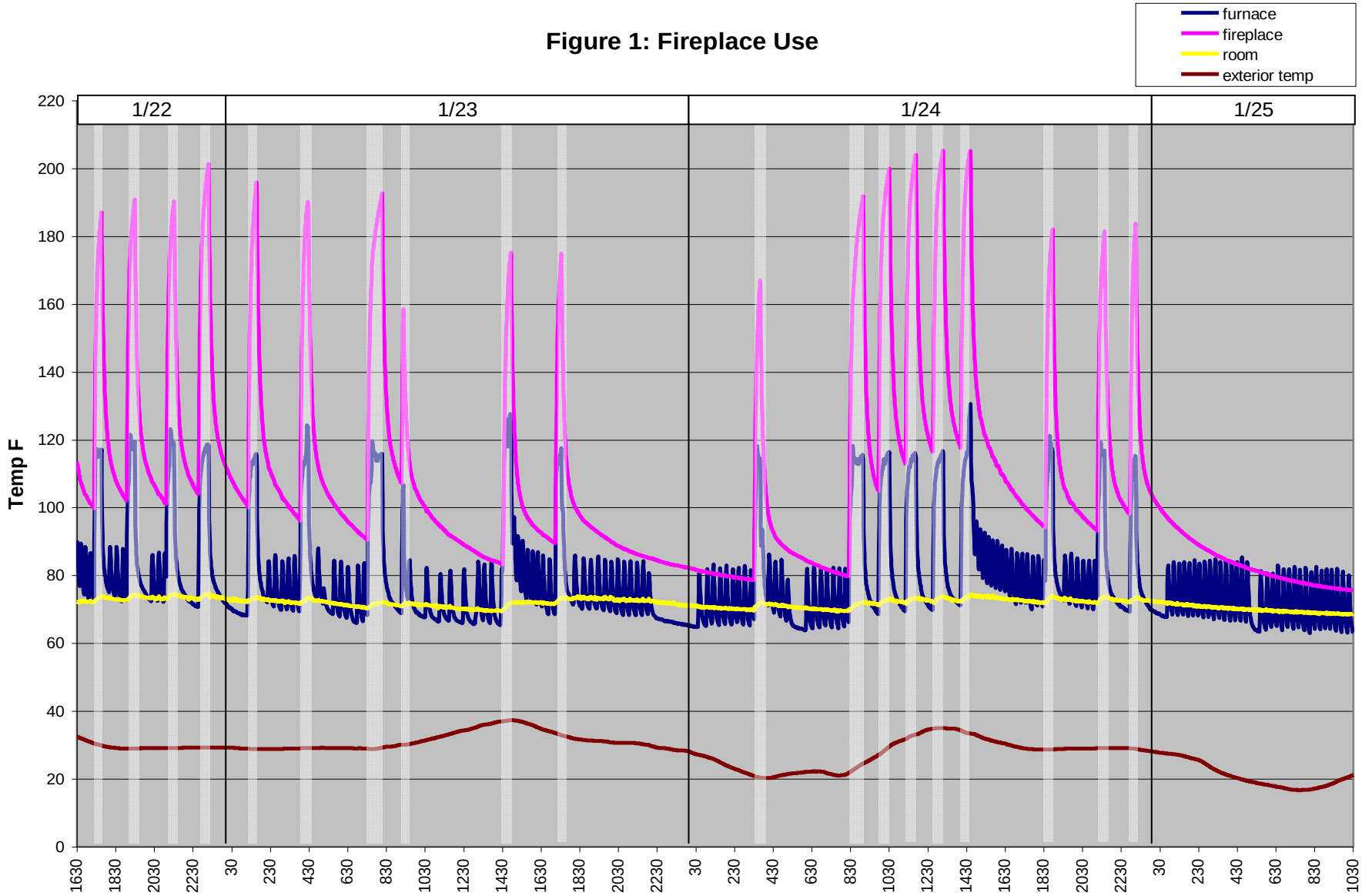
A Few Case Studies

- Variability of house, use pattern, fireplace was huge
- Each house had a story to tell
- Many lessons to be learned from the case studies beyond the n = 30 results

Case Study Site 26

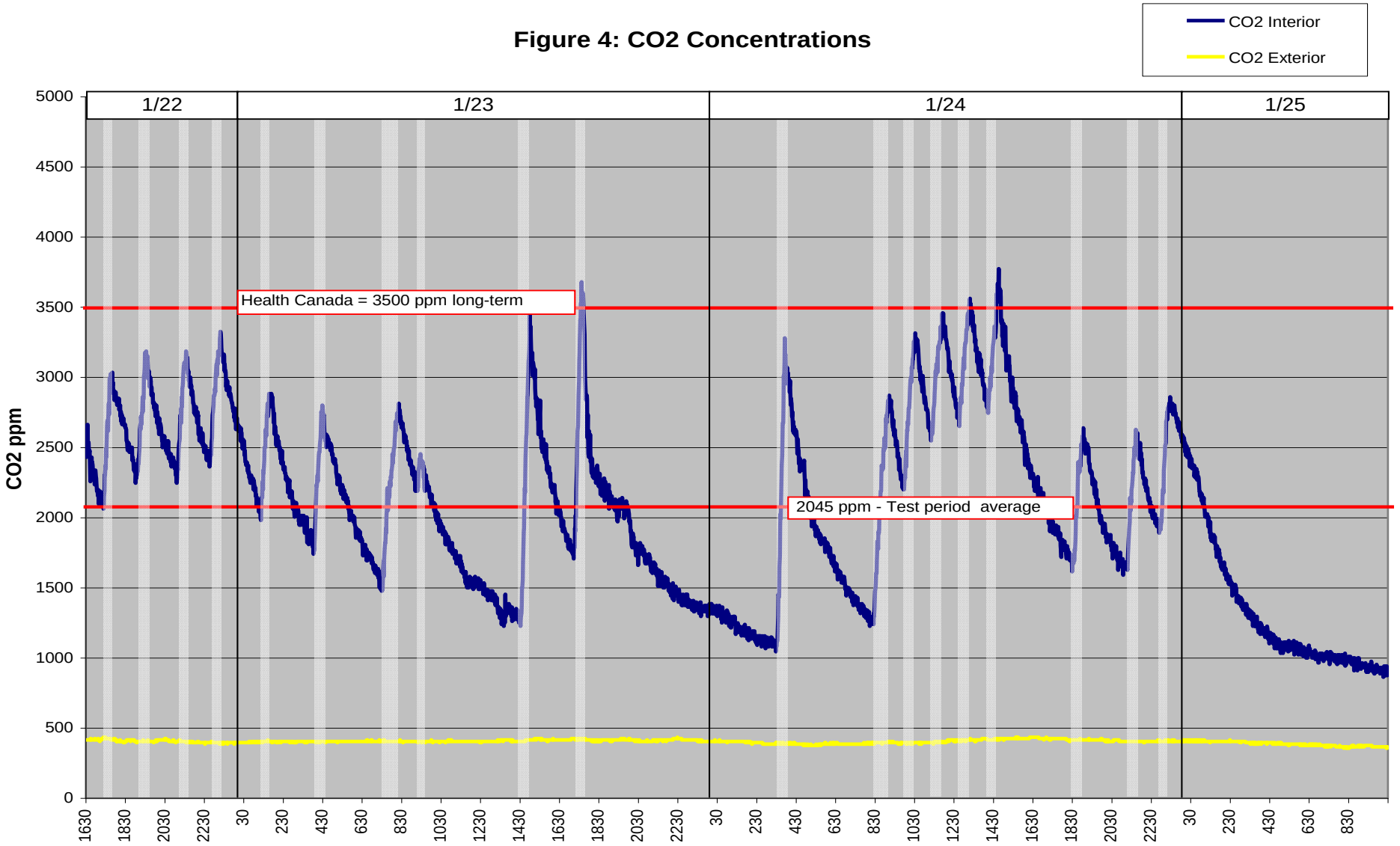
- 12.5 ACH50
- 15 year old fireplace
- Cycling on thermostat
- Installed in tight basement

Figure 1: Fireplace Use



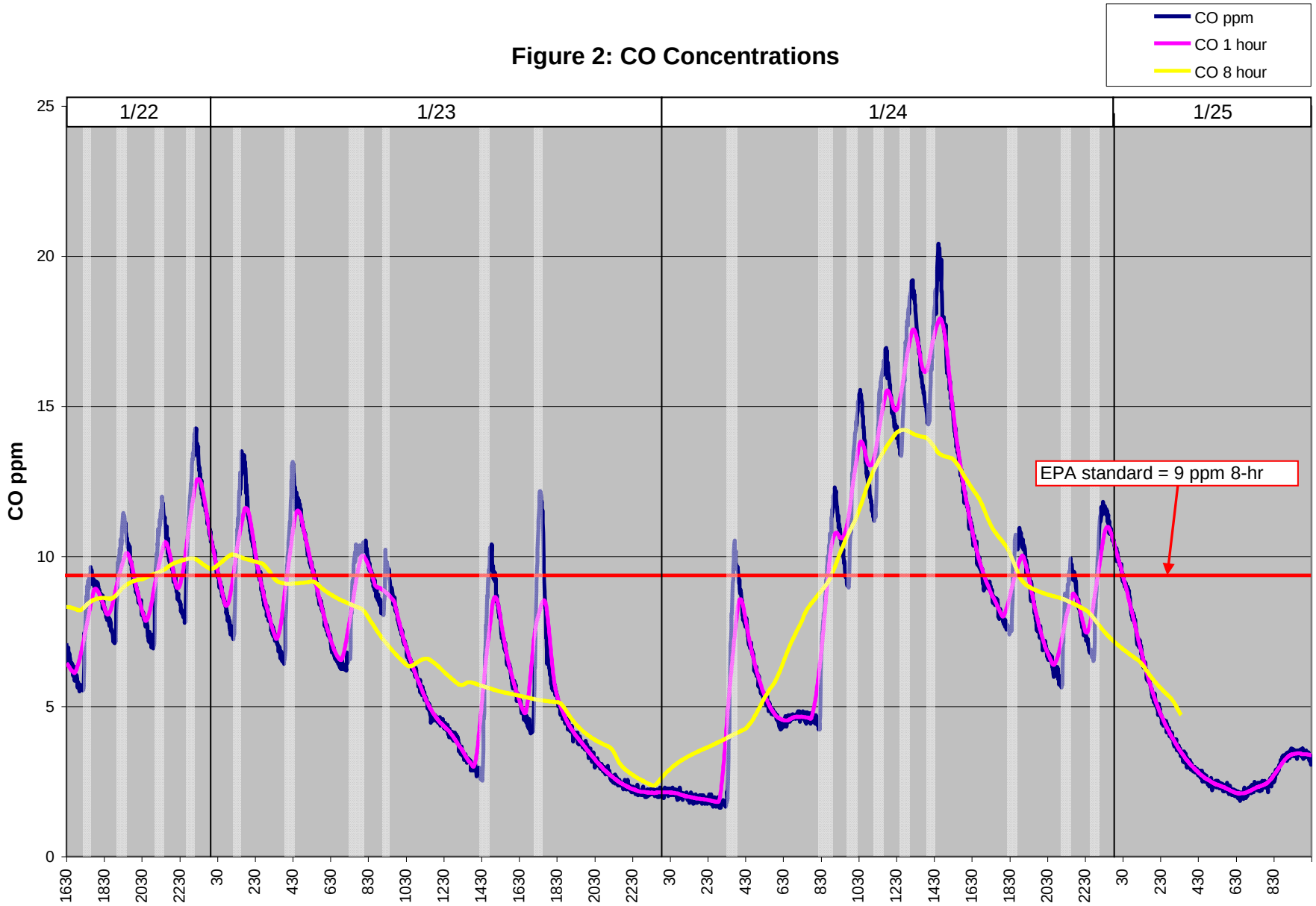
Primary vs. Secondary Heat?

Figure 4: CO2 Concentrations



Most houses averaged 1000 to 2000 ppm of CO2

Figure 2: CO Concentrations

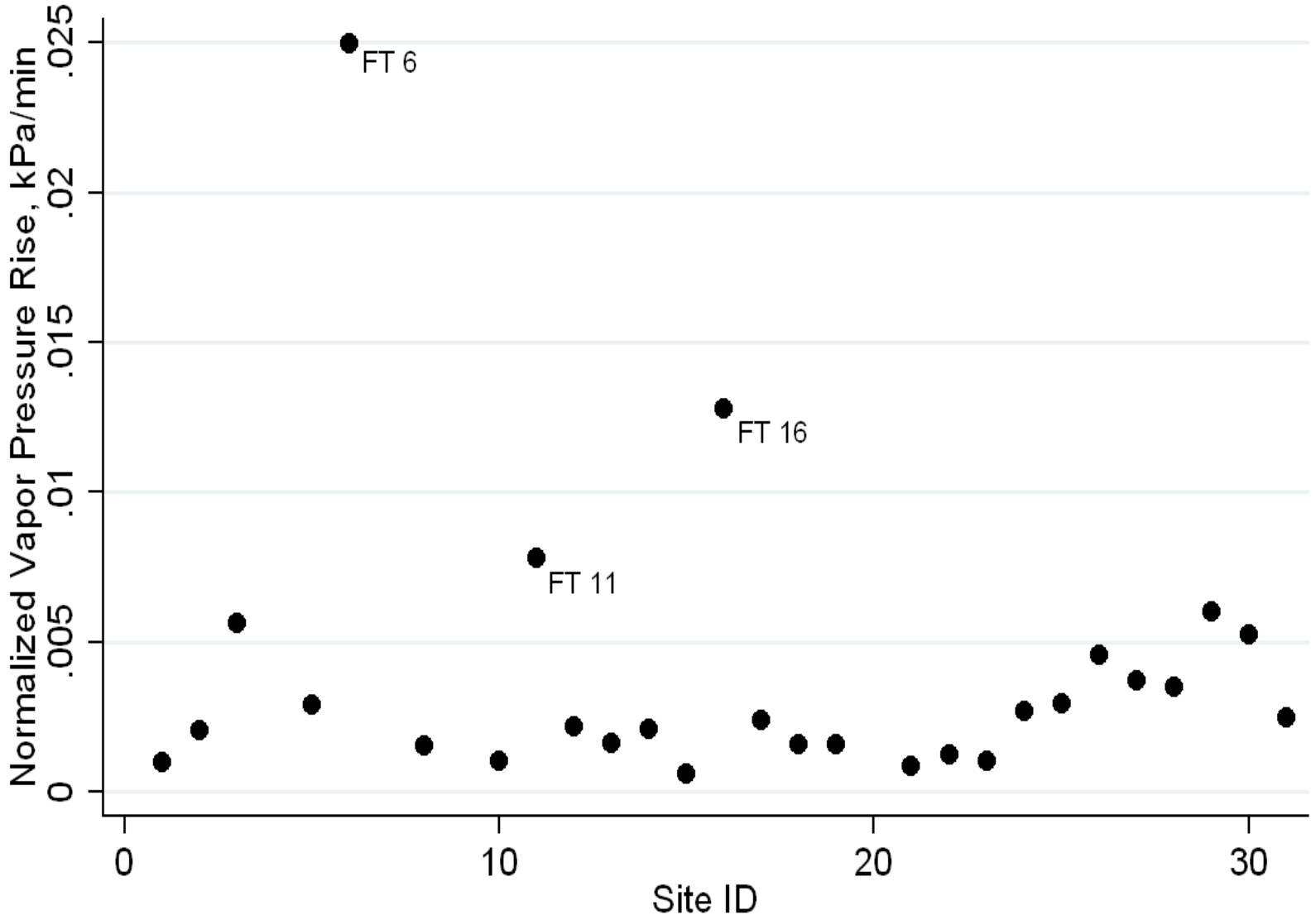


Insulation vs. ACH – the “stair step” scenario

Sunrooms & Porches

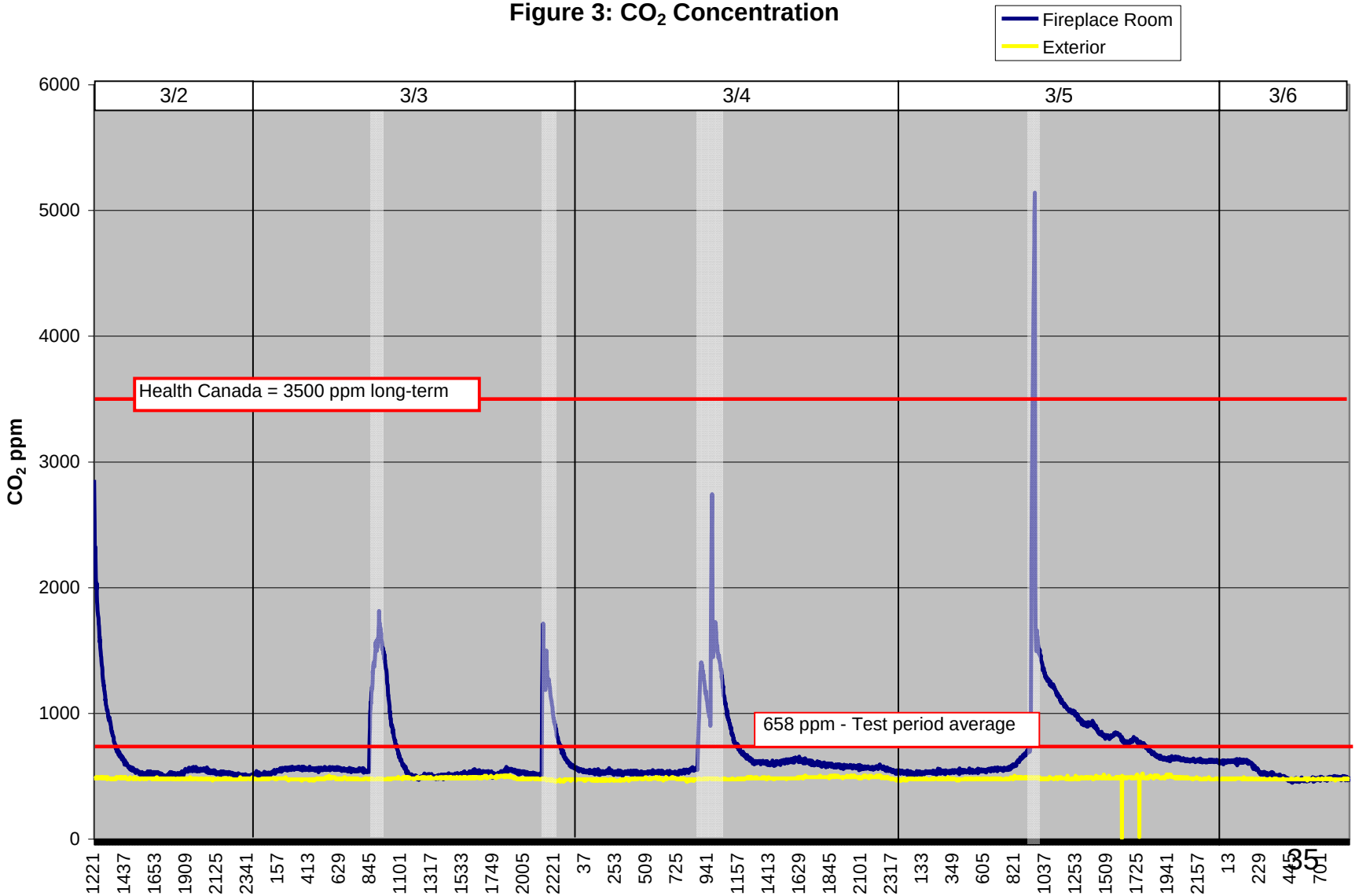
- Beware of little spaces!
- Heat loss vs. ACH
- Gas accumulation

Gas Accumulation Rate



Gas Accumulation Rate

Figure 3: CO_2 Concentration



Case Study Site 20

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

Figure 1: Fireplace Use

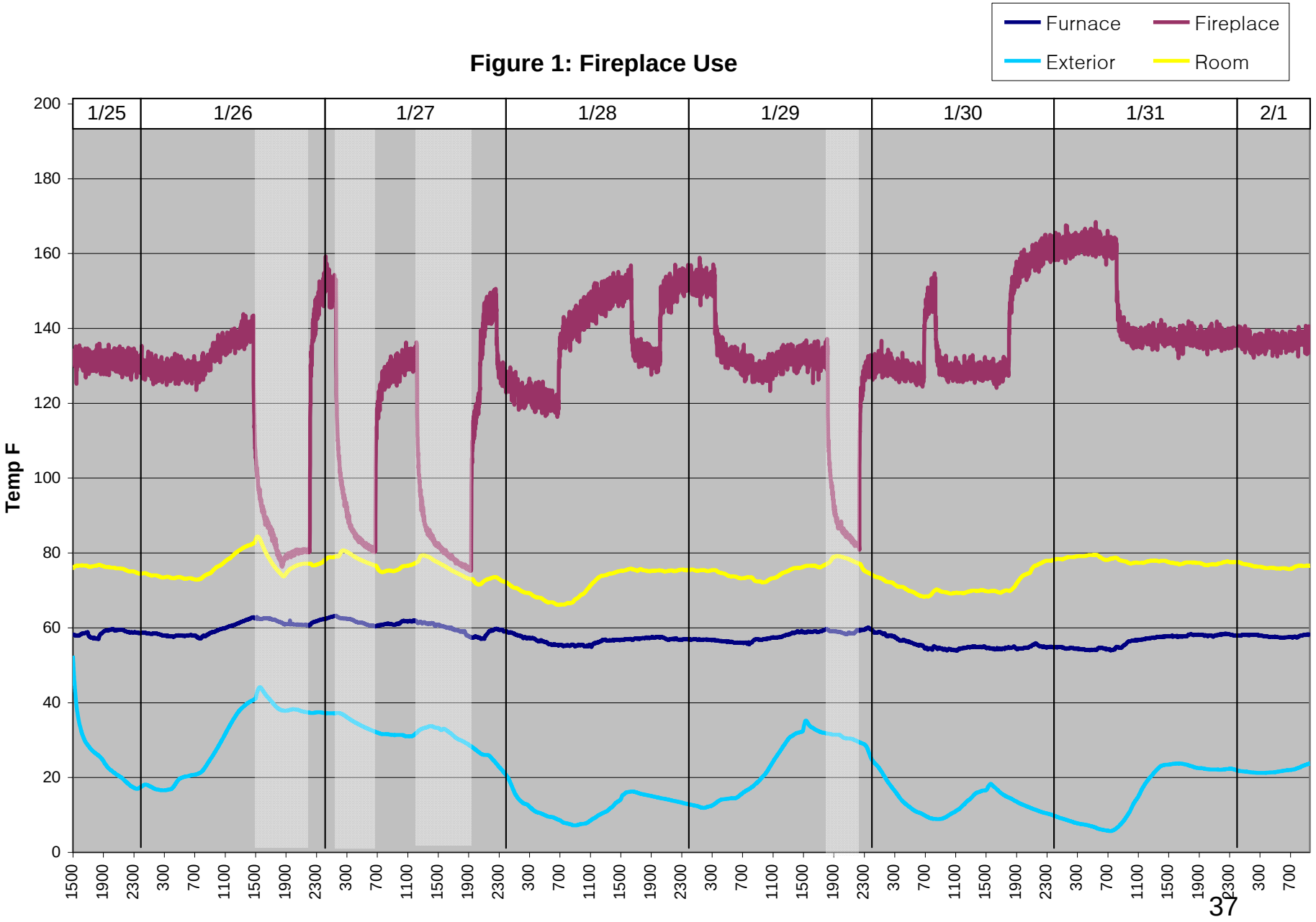


Figure 2: CO Concentrations

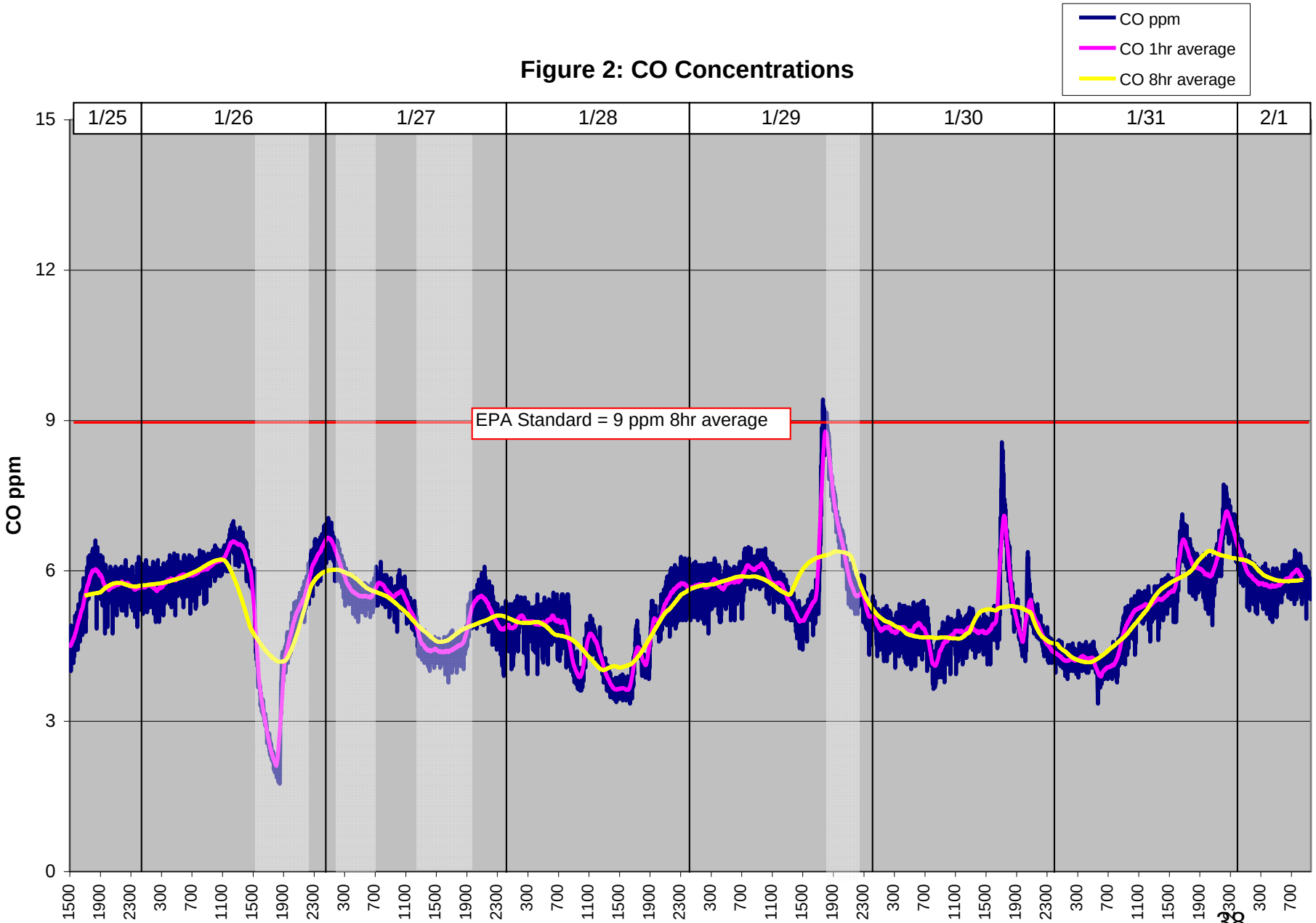


Figure 4: CO2 Concentrations

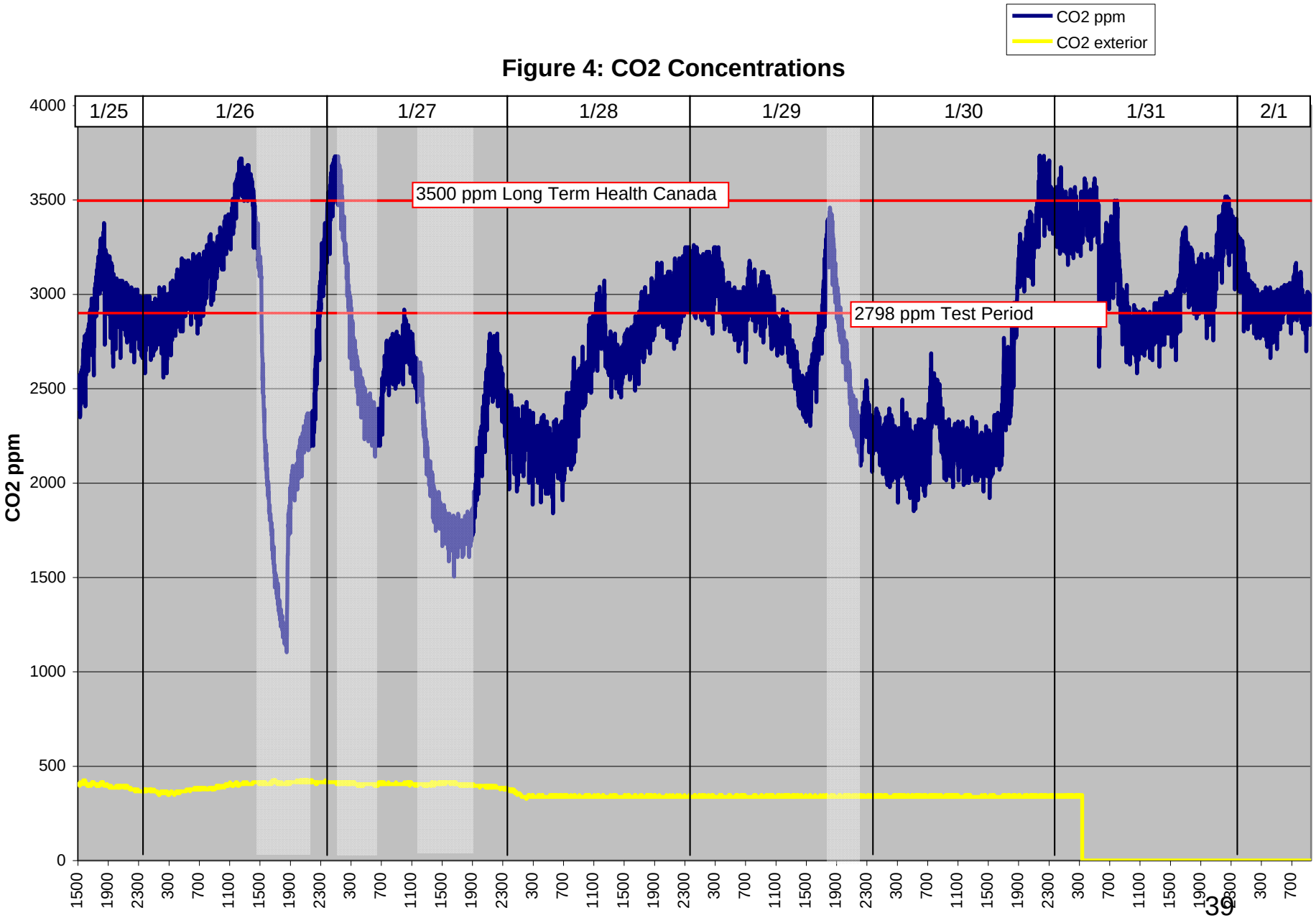


Figure 6: NO2 Concentrations

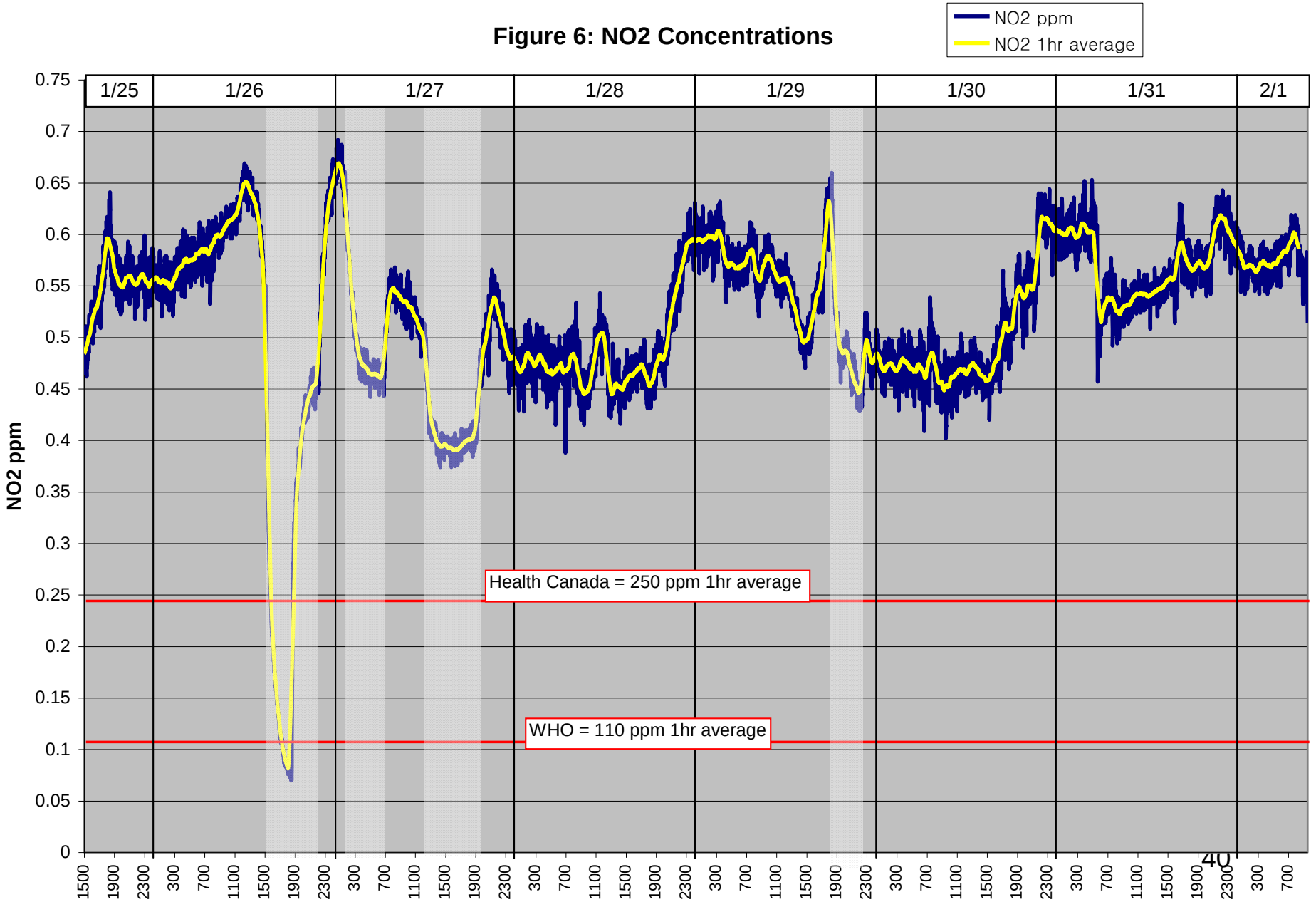
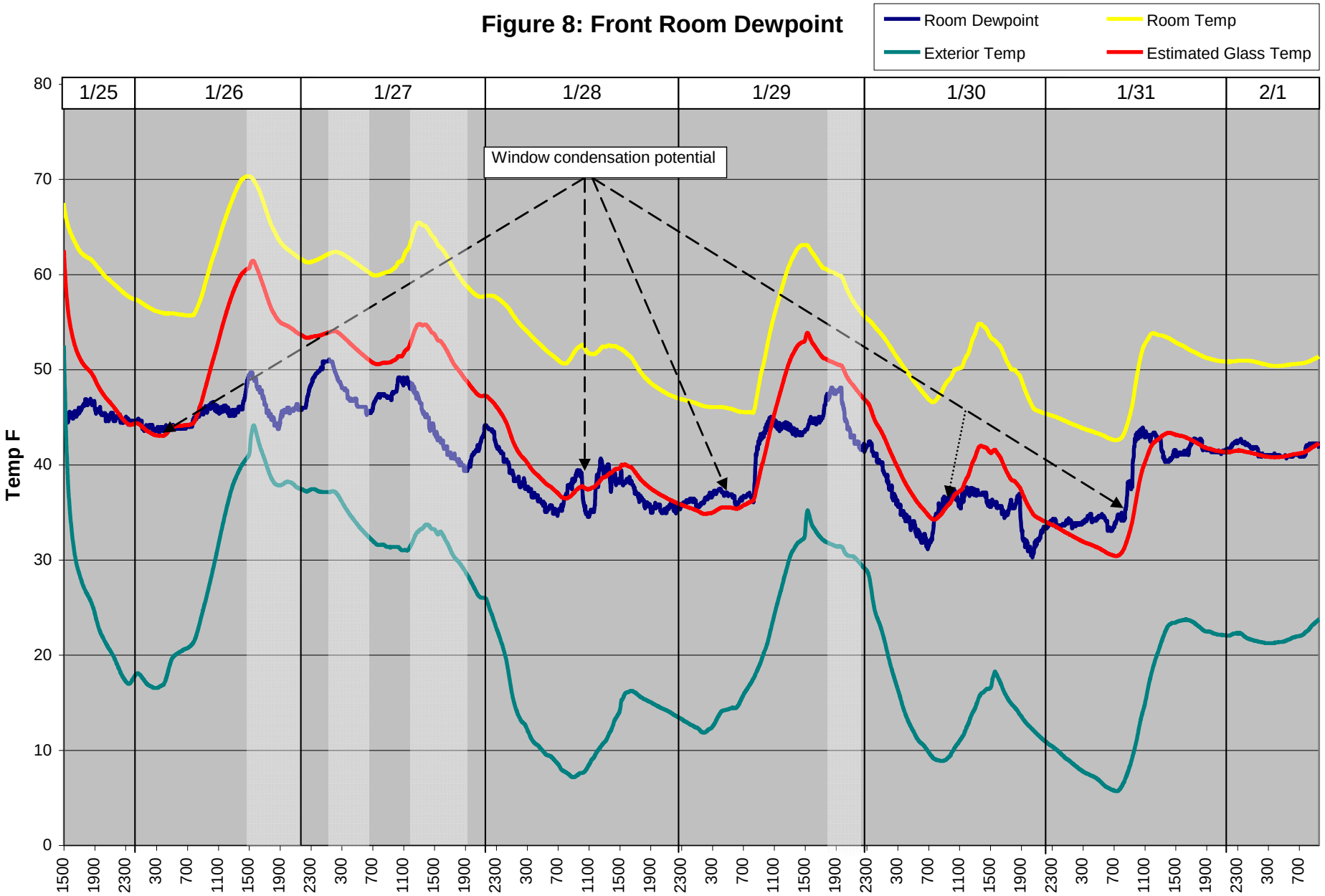


Figure 8: Front Room Dewpoint



Condensation Issue – Point source heat cautionary tale

Conclusions

- **CO was an occasional problem** - 20% of homes exceeded the 8-hour avg. threshold for CO, typically during extended fireplace use. None of the homes exceeded the 1-hour avg. threshold of 35 ppm.
- **NO_2 was most problematic** combustion product 80% exceeded the 110 ppb threshold.
- **Oxygen depletion was rare**, and never triggered a fireplace oxygen depletion sensor. One house fell below the 19.5% threshold.
- **Water vapor** was not a big problem

Conclusions

- **Primary vs. Secondary heating**. This is an elusive distinction. Some occupants turned down the thermostat to the furnace. In many cases, proximity to fireplace overrode the furnace thermostat.
- When operating, the **fireplace usually acts as primary** – furnace does not operate
- There is no guarantee (or safeguard) preventing users from following **manufacturers** installation and use **recommendations**.

Recommendations

- There is no way to reduce combustion gases from unvented fireplaces, except

KEEP THEM OUT OF HOMES

- Particularly true in households with people having respiratory illness and issues - high NO_2 concentrations
- Stick with vented heating appliances
- A healthy home distributes heat evenly around the house

Acknowledgment

- Funding provided by U.S. Department of Housing and Urban Development – Office of Healthy Homes and Lead Hazard Control
- Several Graduate Students
- 30 families who put up with the noise

Let's Talk Cooking

Figure 3:CO Concentration - Kitchen