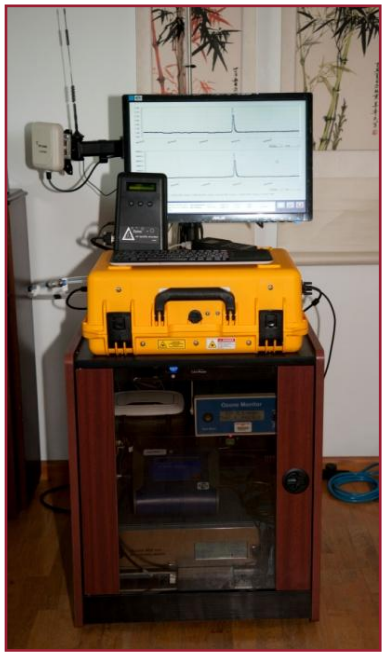
# Indoor Air Quality (IAQ) Measurements and Modeling of Homes during Periods of Intensive Wildfire Smoke

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# IAQ Measurements

| Outdoor Air | Outdoor Air | Indoor Air | | Ventilation | Weather (Airmar) |
|---|---|---|---|---|---|
| **H2: July 23 – Aug 20** | H2: July 23 – Aug 20 | H2: July 23 – Aug 18 | | H2: July 23 – Aug 20 | H2: July 23 – Aug 20 |
| | | | | | |
| **VOCs** | VOCs (PTR-MS) | VOCs (PTR-MS) | | Blower door test | Air temperature |
| **$CO_2/H_2O$** | $CO_2/H_2O$ (LiCOR 840A) | $CO_2/H_2O/CH_4$ (Los Gatos UGGA) | | $CO_2$ injection-decay (LiCOR 840A) | Dewpoint |
| **$O_3$** | $O_3$ (TECO 48) | $O_3$ (2B Tech. 205) | | Window/door position (smart home sensors) | Relative Humidity |
| **$NO/NO_2/NO_x$** | $NO/NO_2/NO_x$ (TECO 42C) | $NO/NO_2/NO_x$ (2B Tech. 405) | | | Barometric pressure |
| **$PM_{2.5}$** | $PM_{2.5}$ (DustTrak) | $PM_{2.5}$ (DustTrak) | | | Wind direction, true |
| **CO** | CO (Monitor Labs) | $CO/O_3/NO$* (Alphasense B4 series) | | | Wind direction, mag. |
| | | Particle counts (Dylos) | | | Wind speed. |
| | | Air Temperature (thermocouple) | | | |

| House | Year Built | Square Footage | Attached Garage | Floors | Occupants : Pets | Blower Door Results |
|---|---|---|---|---|---|---|
| **H2** | 1963 | 1,765 | Yes | 2 | 2 : 2 | 0.64 $hr^{-1}$ |

Rooftop weather station and air inlet

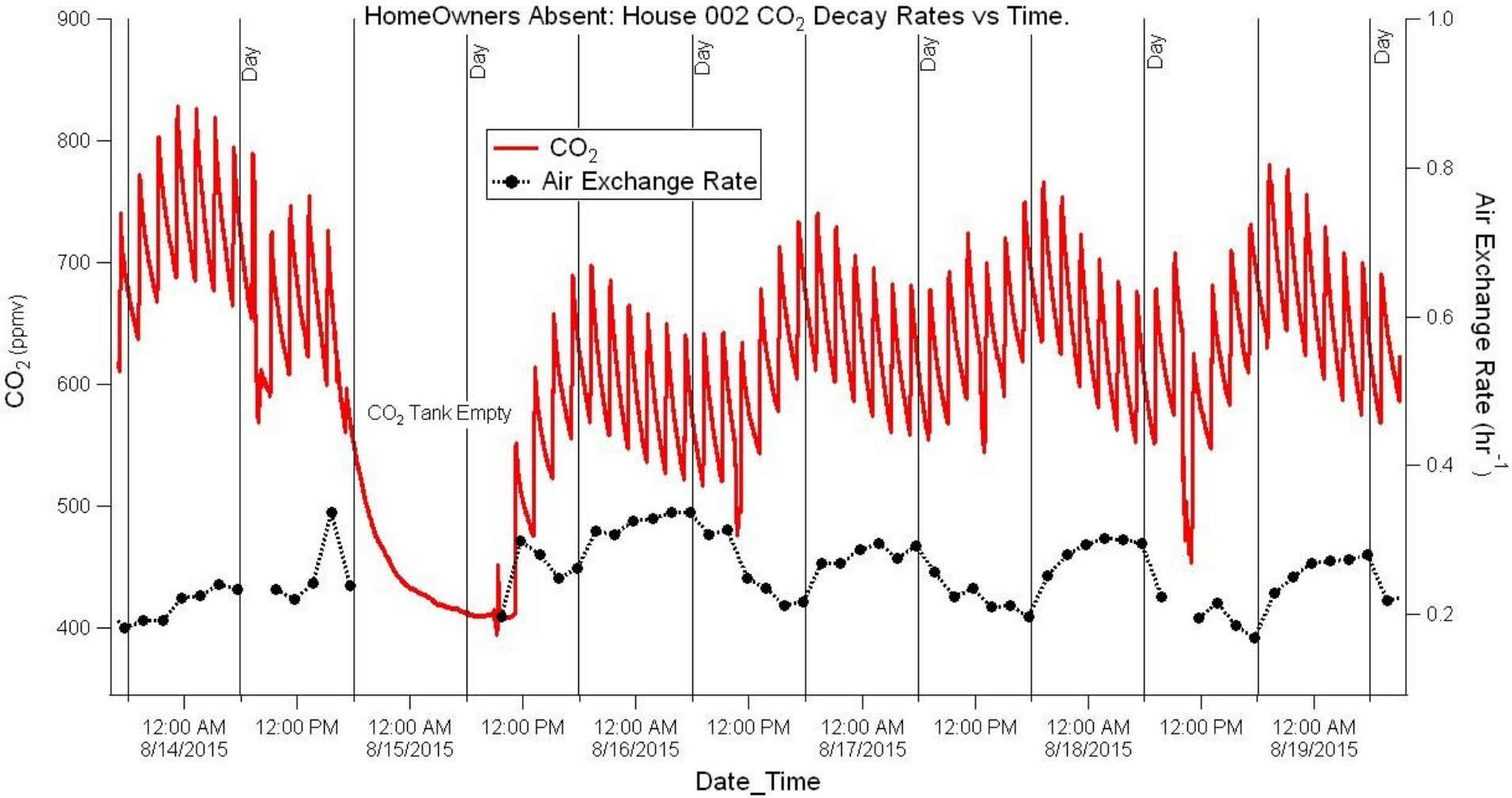
Indoor air sampling unit

Outdoor sampling unit with sample inlet from the roof


PTR-MS sampling from the roof and from the furnace air handling system (alternating)

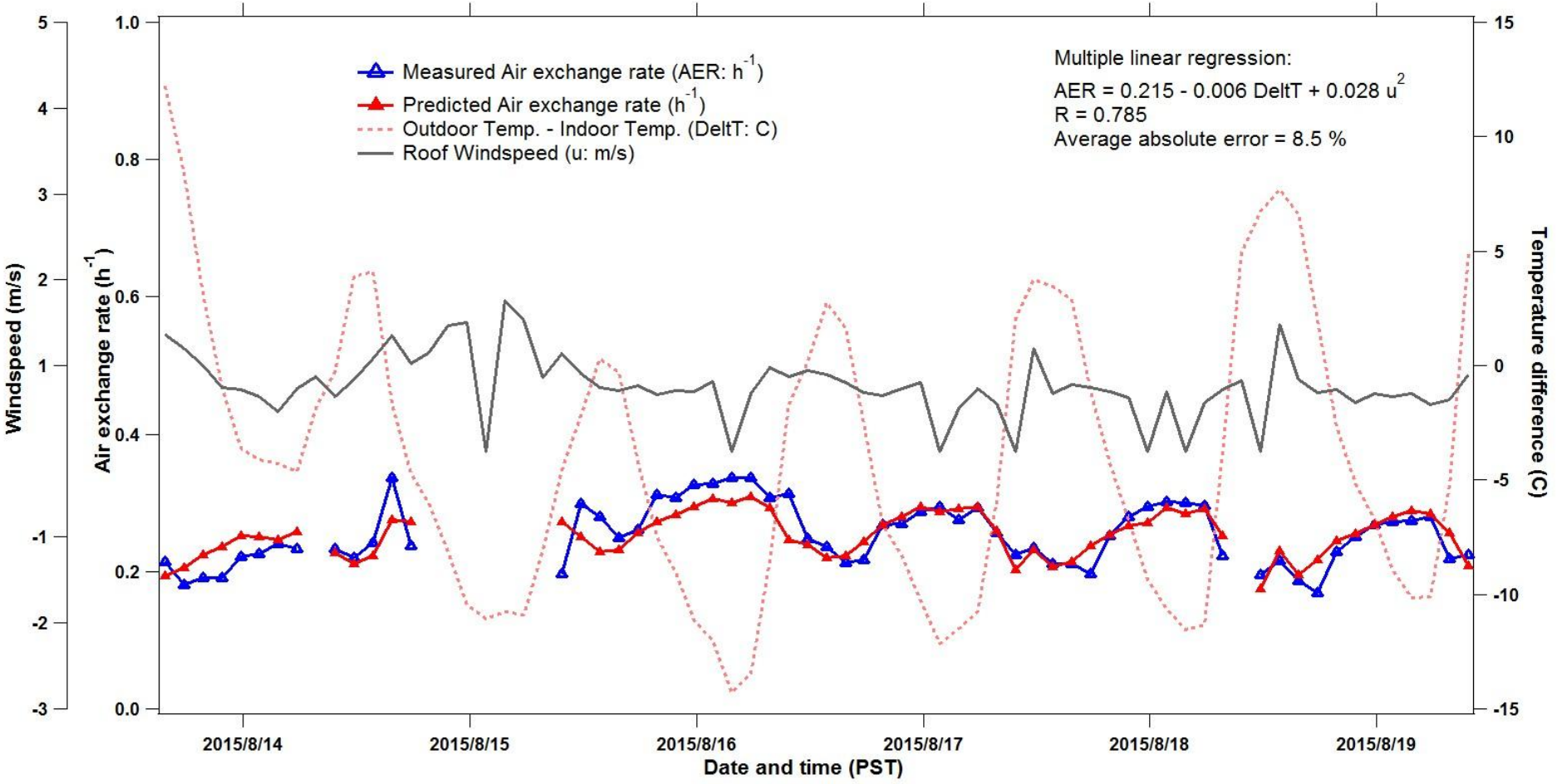
CO2 tracer injection and sampling from furnace air handling system

# $CO_2$ Decay Rates & Air Exchange Rates



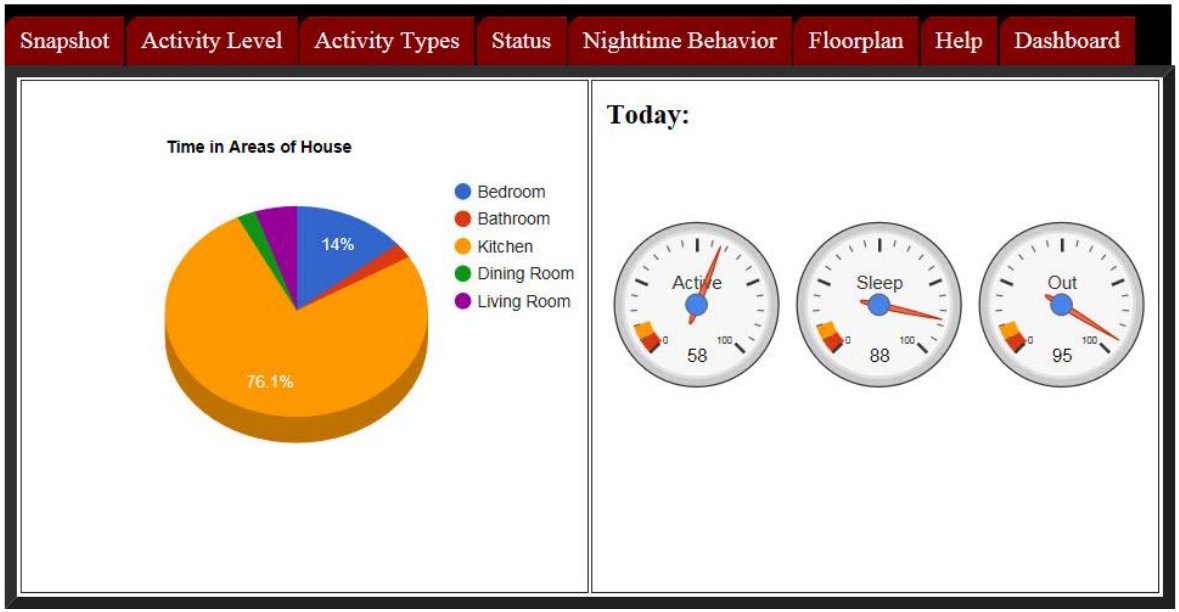

| | Home Owners Absent (61 points) | Home Owners Present (15 points) |
|---|---|---|
| Average | 0.25 ± 0.04 $hr^{-1}$ | 0.65 ± 0.18 $hr^{-1}$ |
| Range | 0.17 – 0.34 $hr^{-1}$ | 0.37 – 0.96 $hr^{-1}$ |

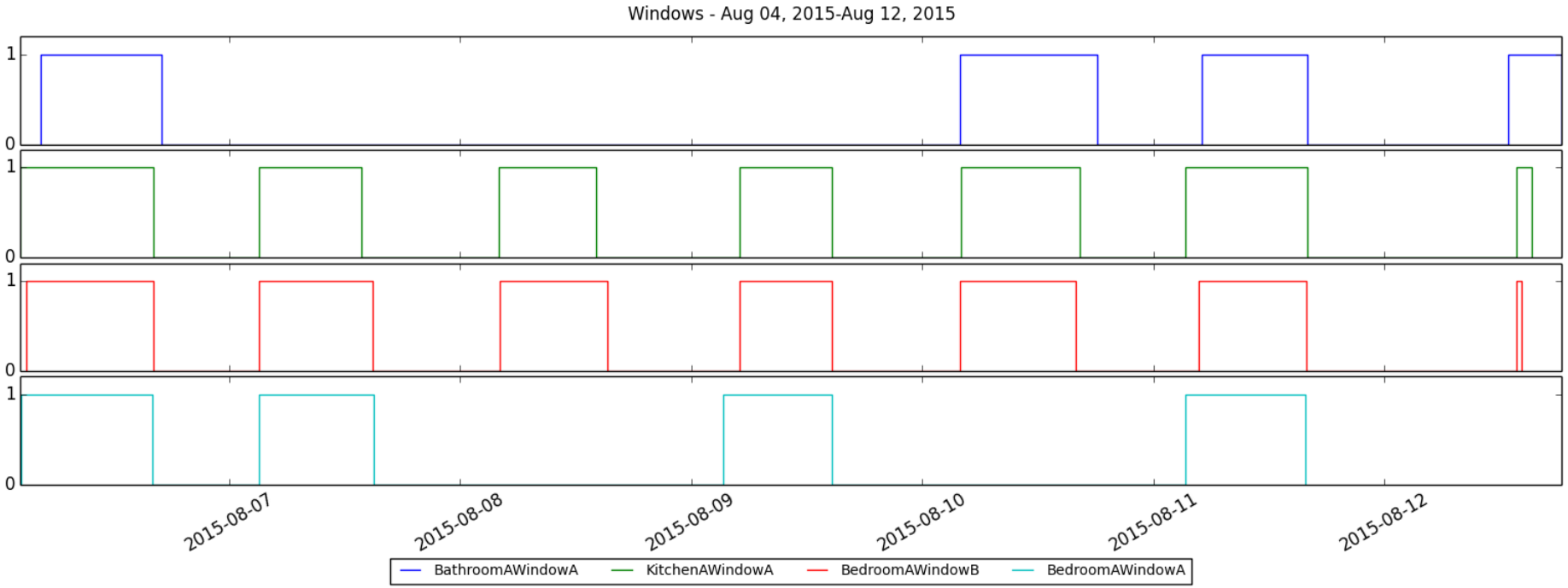
# Air Exchange Regression Model
# $AE = a + b\Delta T + cU^2$



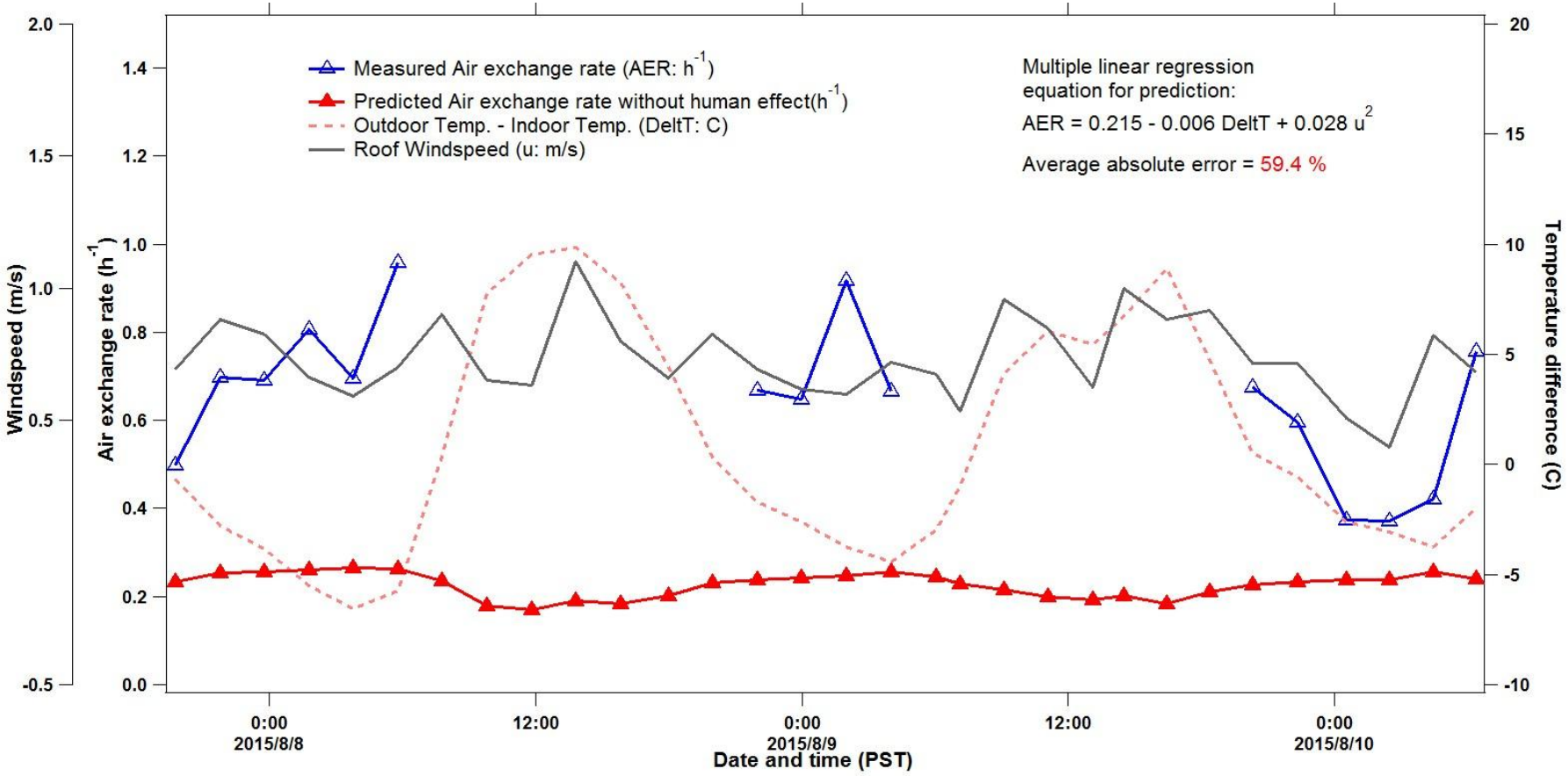

Owner absent, no open windows or doors

# Smart Home Sensors for Occupant Behavior



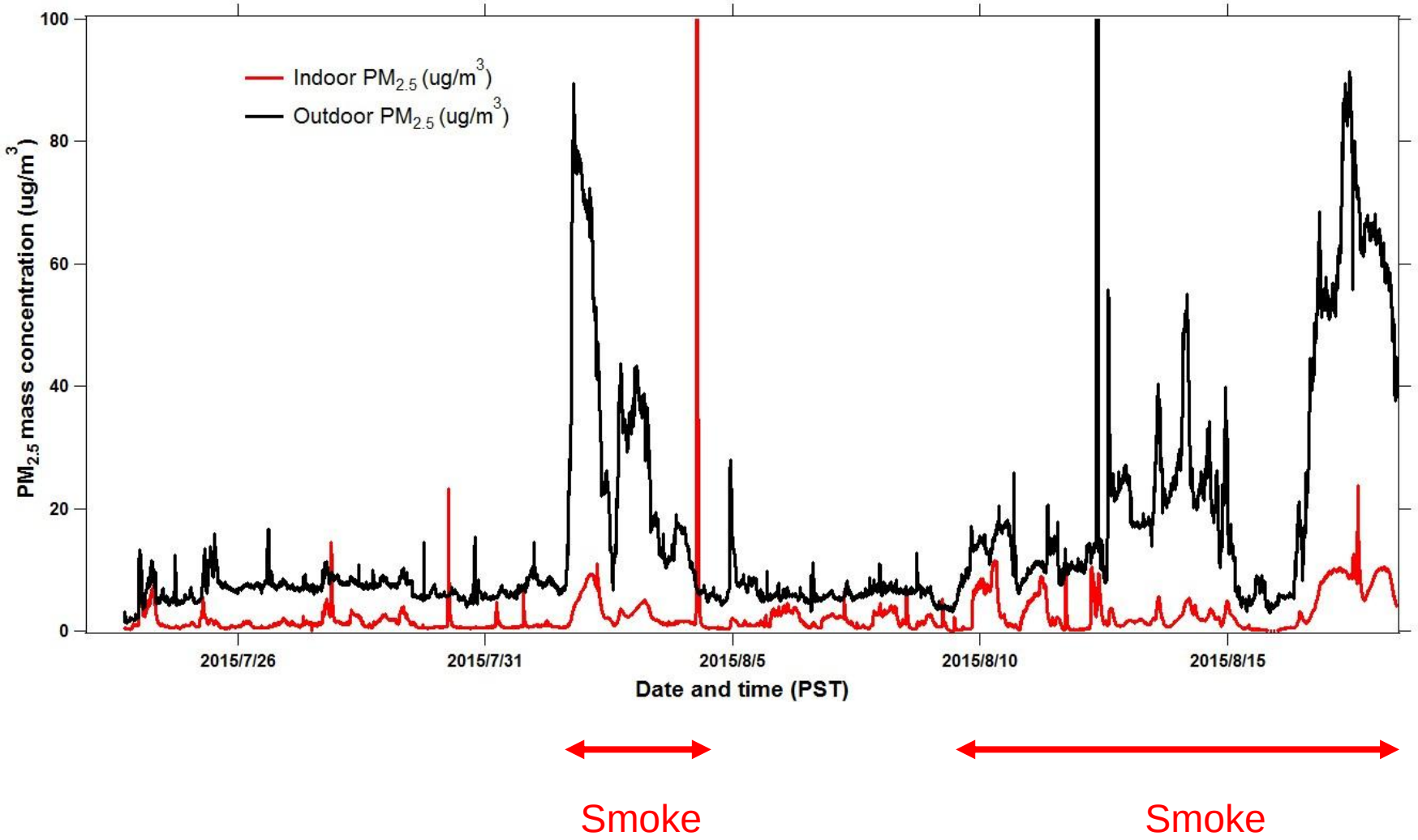



# Air Exchange Regression Model
# $AE = a + b\Delta T + cU^2$

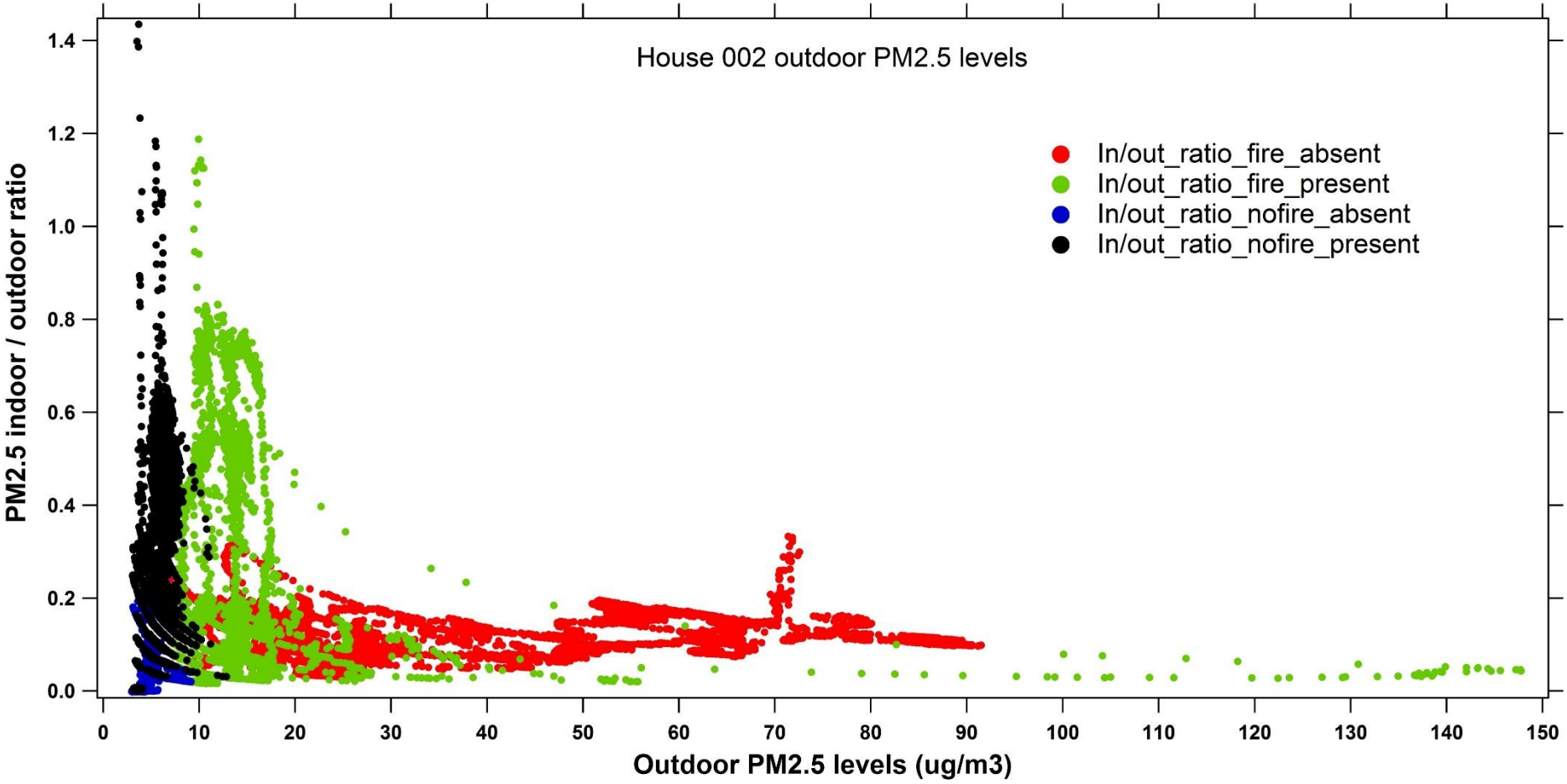



Owner present, variable open windows or doors

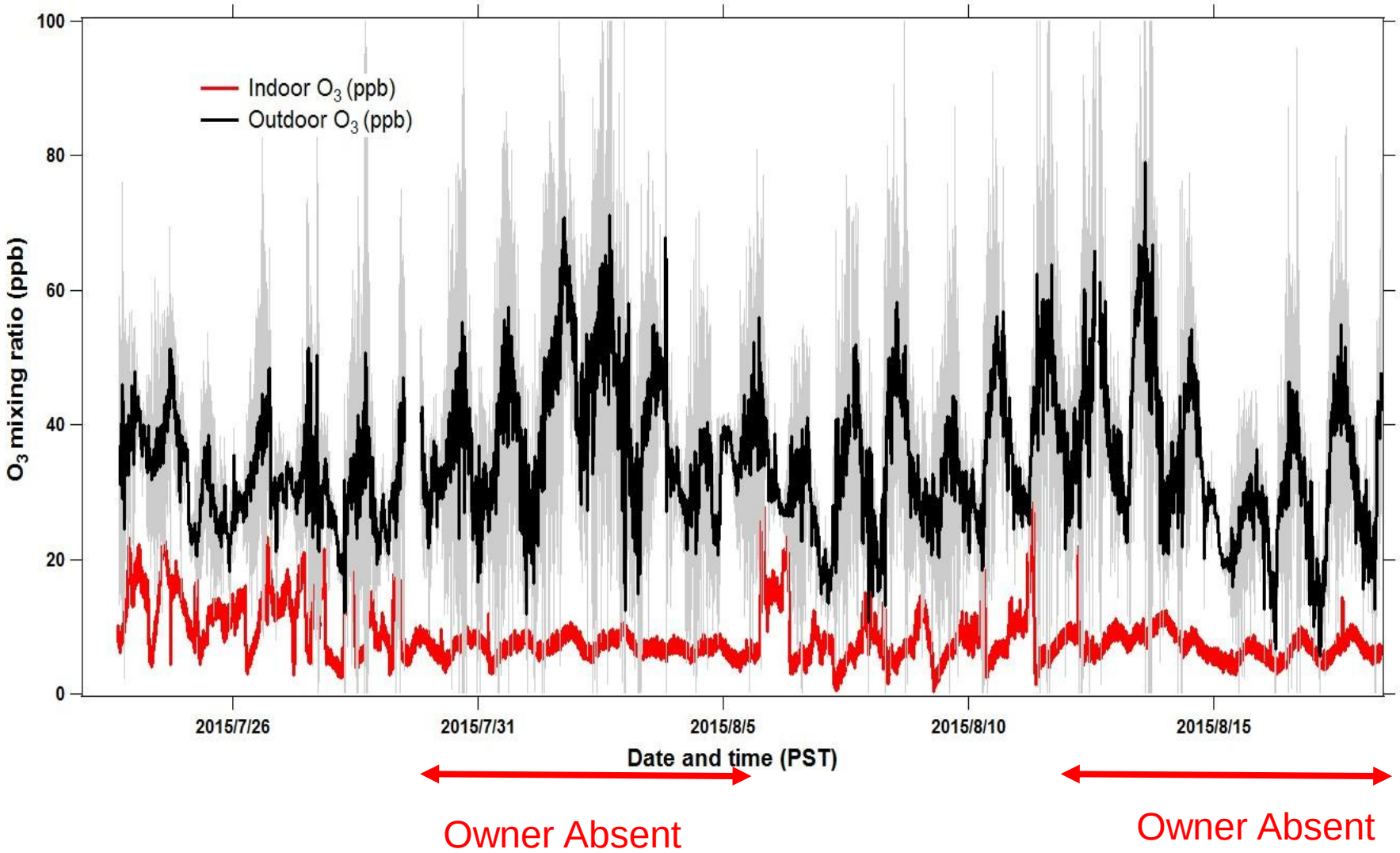
# PM2.5 Indoors and Outdoors



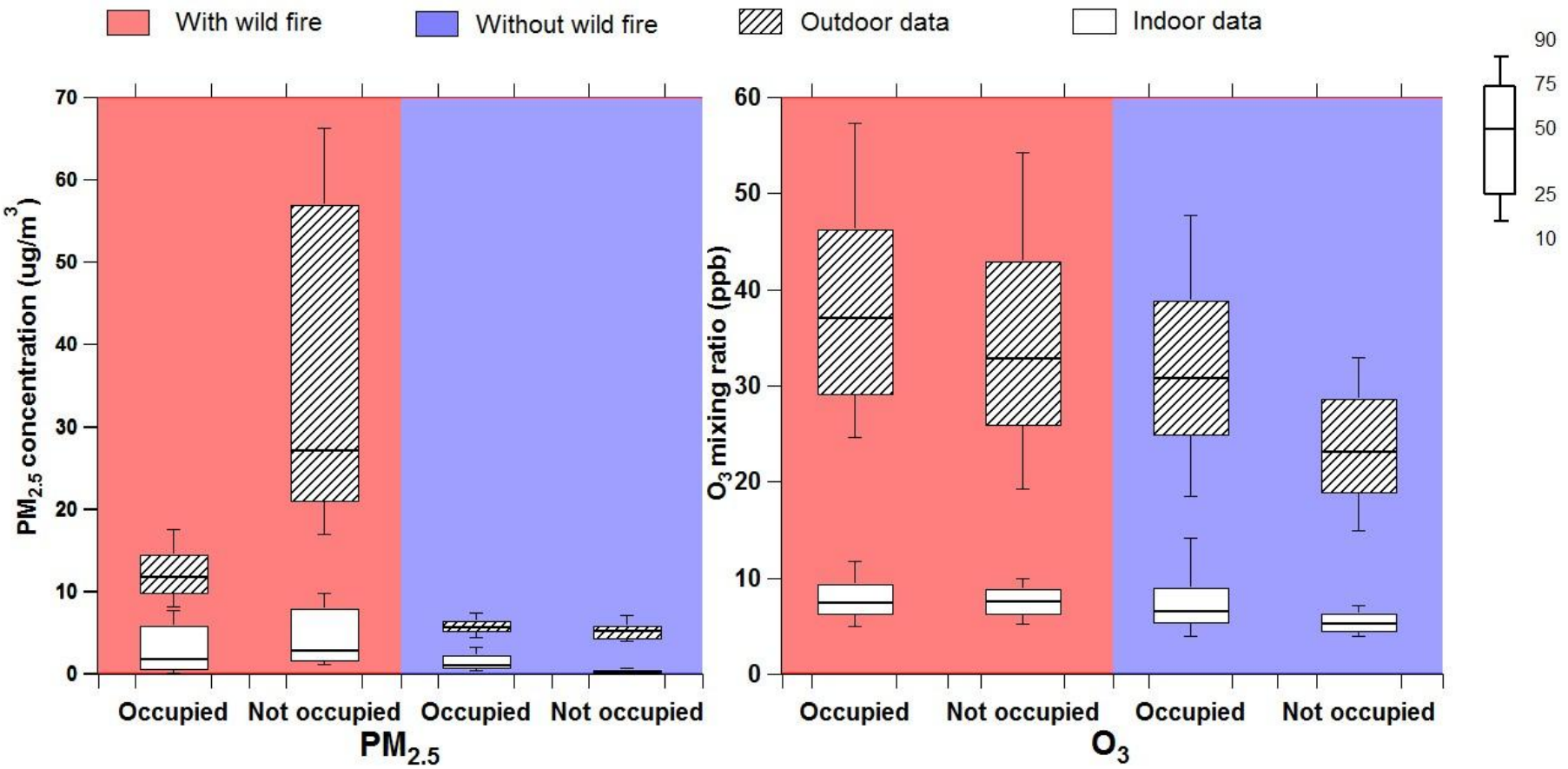
# PM2.5 Penetration Indoors



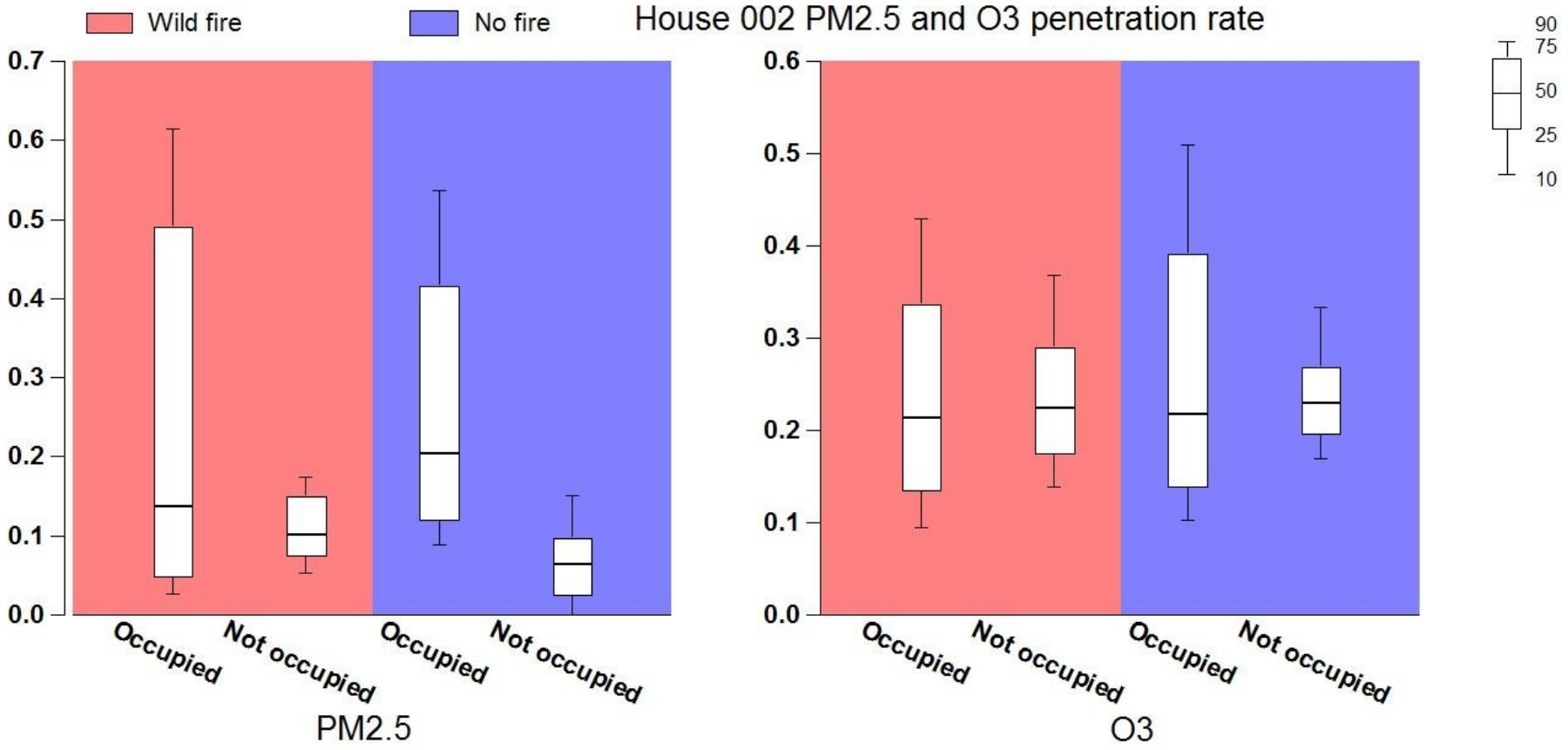
# Ozone Indoors and Outdoors



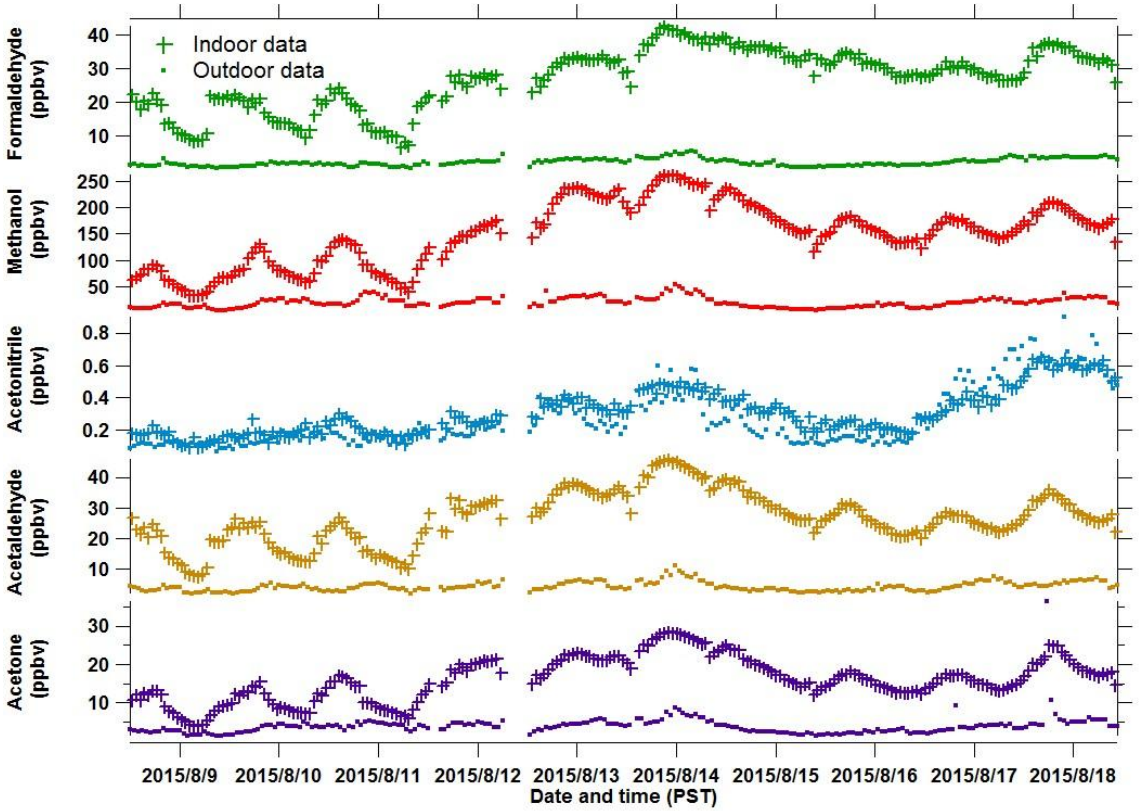
# Whisker Plots of Indoor and Outdoor $PM_{2.5}$ and $O_3$

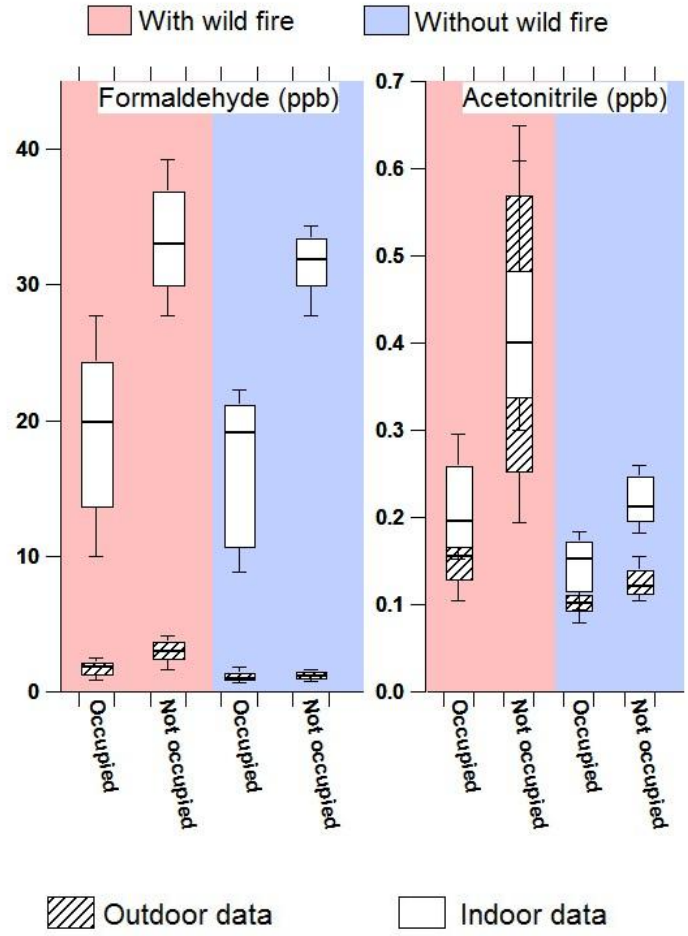


# Penetration rate of $PM_{2.5}$ and $O_3$

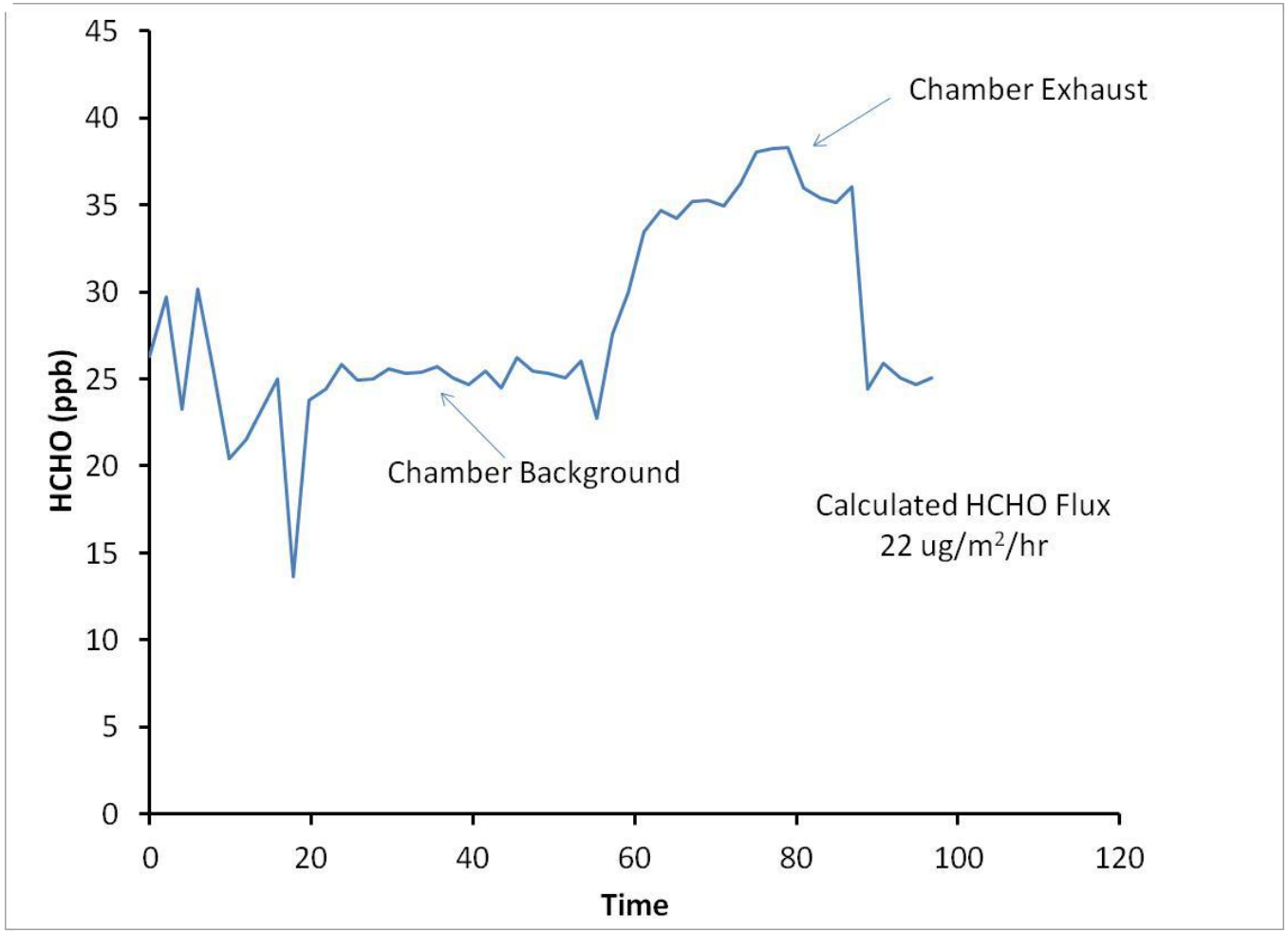


# VOCs Indoors and Outdoors

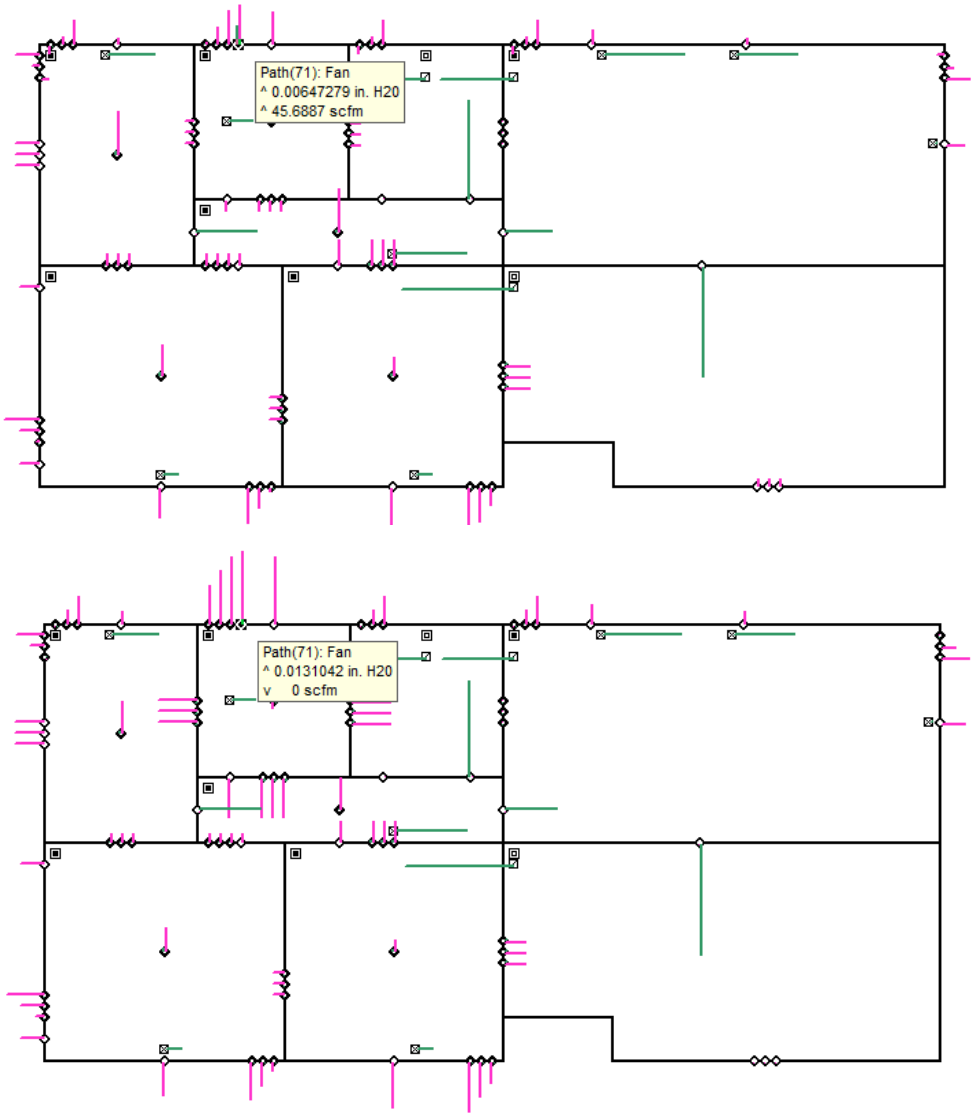


# Carpet Emission Measurements
# Dynamic Flux Chamber with PTR-MS

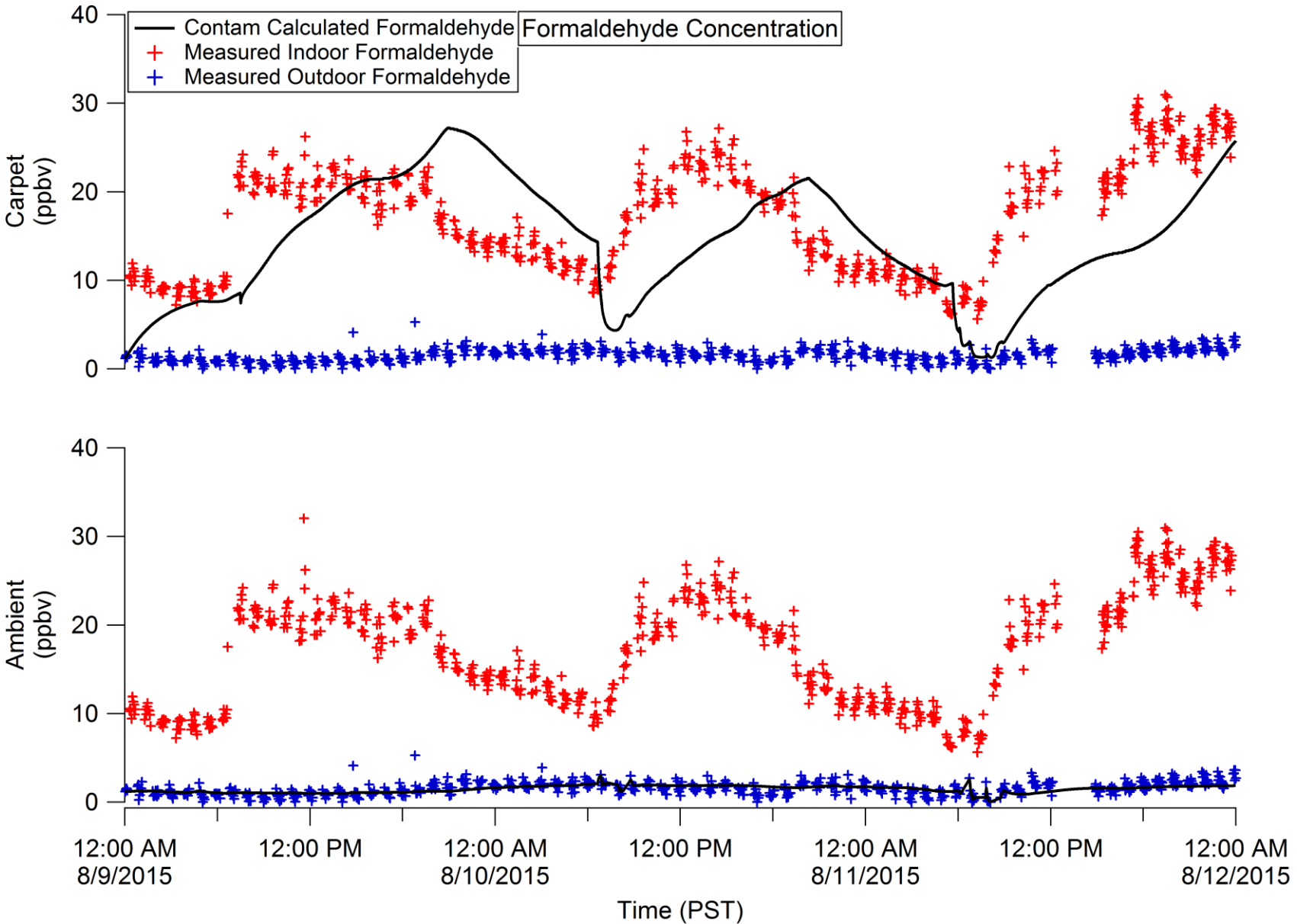


# CONTAM IAQ Model
# Flow Paths
# House 2




- Magenta lines represent pressure on that element, green lines represent air flow
- (Top) Normal ventilation conditions;
- (Bottom) bathroom ventilation fan operating
  - Air is drawn out of the house and the pressure on the whole house changes, most drastically near the fan.

# CONTAM Model Results for Formaldehyde with and without a carpet source



# Summary

- Initial successful indoor air quality measurements
- Wildfire smoke produces significant outdoor PM levels, but penetration factors and indoor deposition for PM and O3 reduce indoor levels.
- In-house sources of most VOCs produce higher levels than infiltration of outside air even with wildfire smoke present (except for acetonitrile)
- Air exchange rates can be measured via $CO_2$ tracer method and modeled with a simple regression model (for periods with doors and windows closed)
- CONTAM produces relatively good results, but doesn't yet correctly capture concentration phase shifts

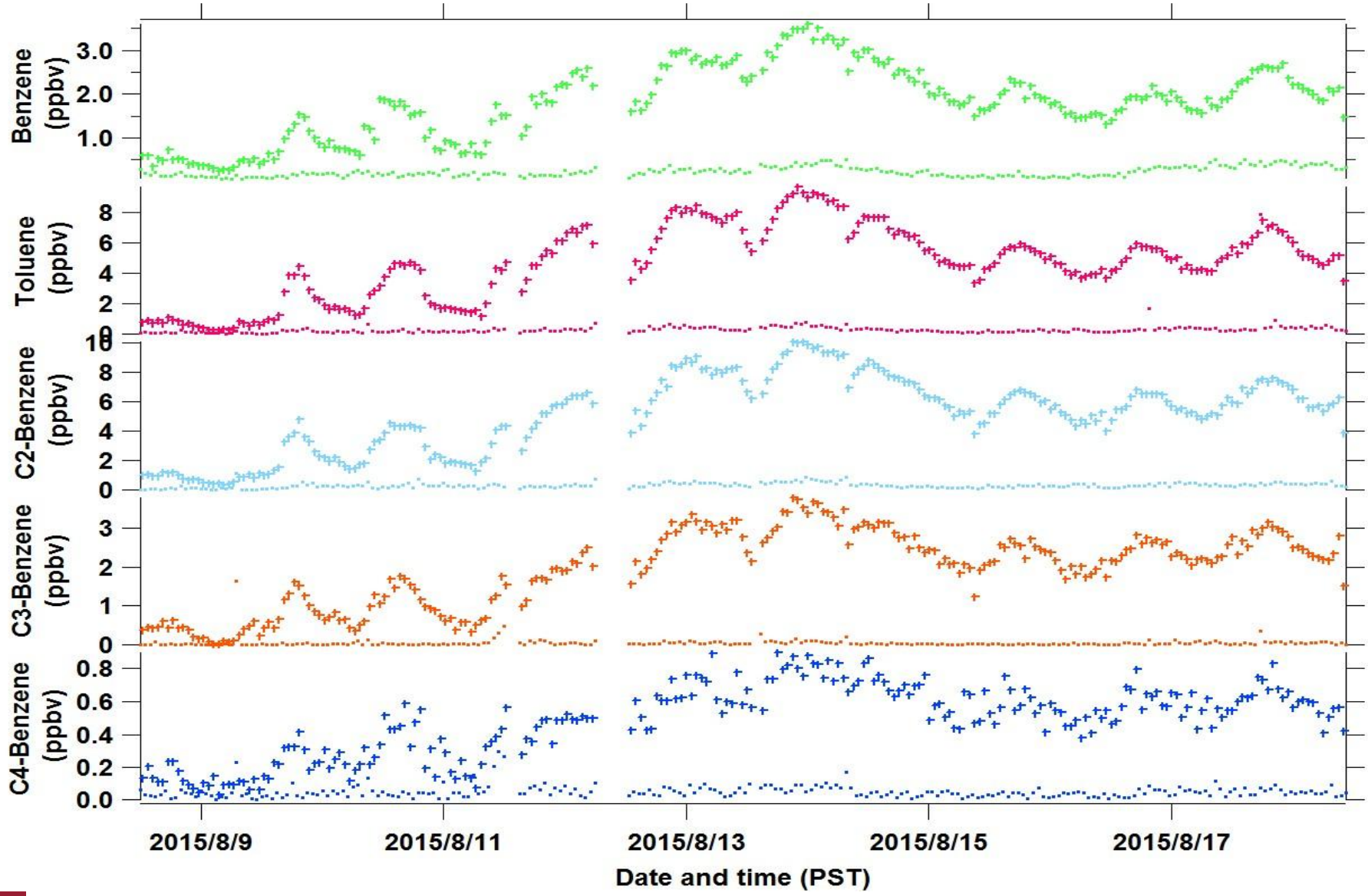
# Project Components

- **IAQ Measurements and Analysis**
  - SmartHomes Measurements
    - Structural, materials, and pollutant source characterization
    - Occupant behavior and energy consumption
    - Ventilation and meteorology
    - IAQ levels—key pollutants—summer and winter
  - Analysis
    - Create comprehensive observational data base
    - Linked analysis of observation data base
- IAQ Model evaluation—CONTAM
  - Evaluation of ventilation rates
  - Evaluation of IAQ pollutant levels
  - Documentation of model bias and uncertainties
  - Potential improvements to the model
- IAQ Modeling and Climate Change in the US
  - NIST US housing stock model runs
  - Multiple climate realizations
  - Development of technological scenarios—new materials, new structures, new sources
- Overall synthesis and analysis

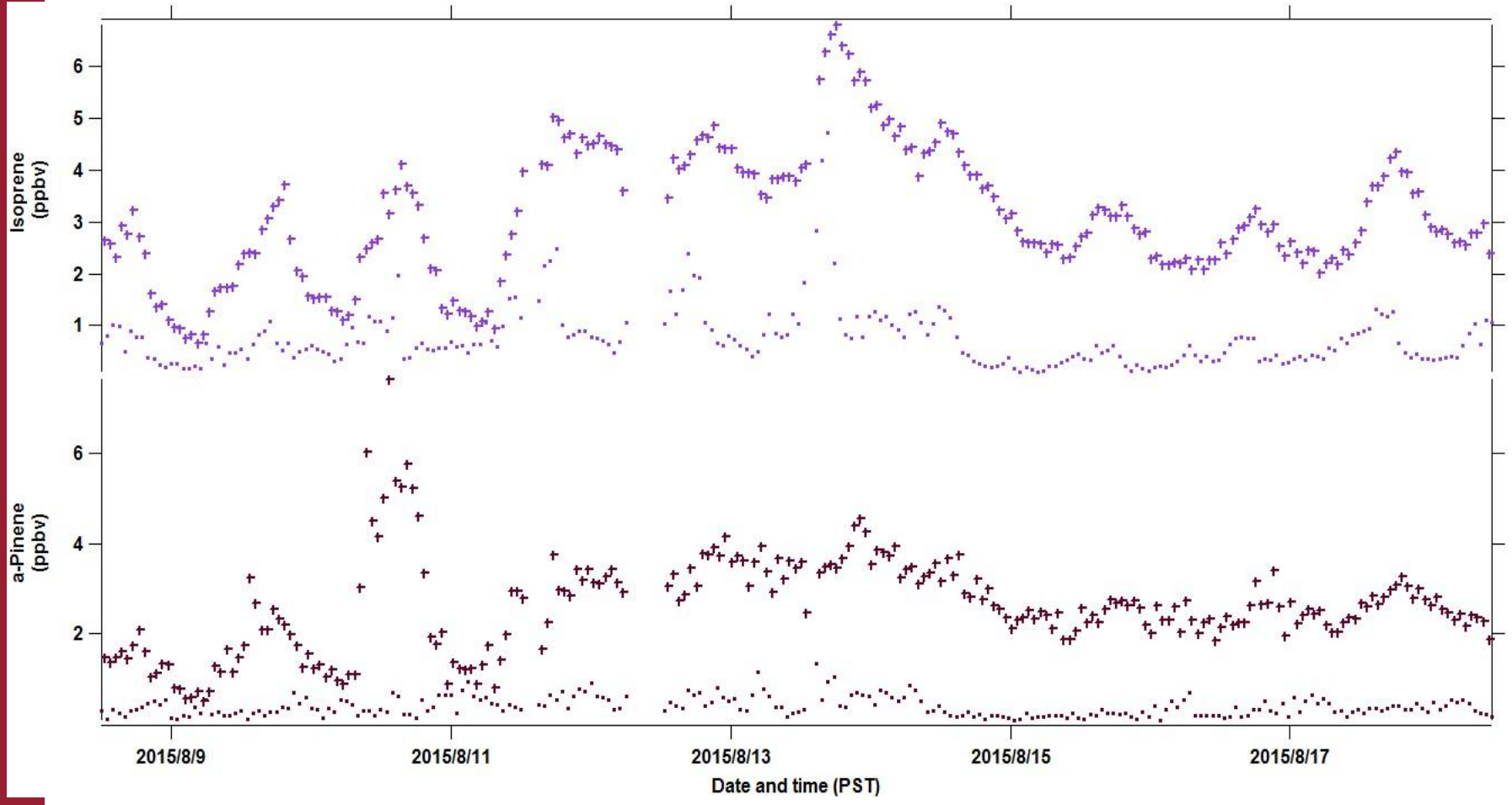
# IAQ Measurements
# Summer, 2015
# Houses 2 and 3

| House | Year Built | Square Footage | Volume Conditioned : Unconditioned | Attached Garage | Floors | Number of Occupants : Pets | Blower Door Results* |
|---|---|---|---|---|---|---|---|
| **H2** | 1963 | 1,765 | 13,614 : 4,308 cu ft | Yes | 2 | 2 : 2 | 0.64 $hr^{-1}$ |
| **H3** | 2011 | 3,440 | 33,598 : 3,663 cu ft | Yes | 2 | 4 : 2 | 0.45 $hr^{-1}$ |

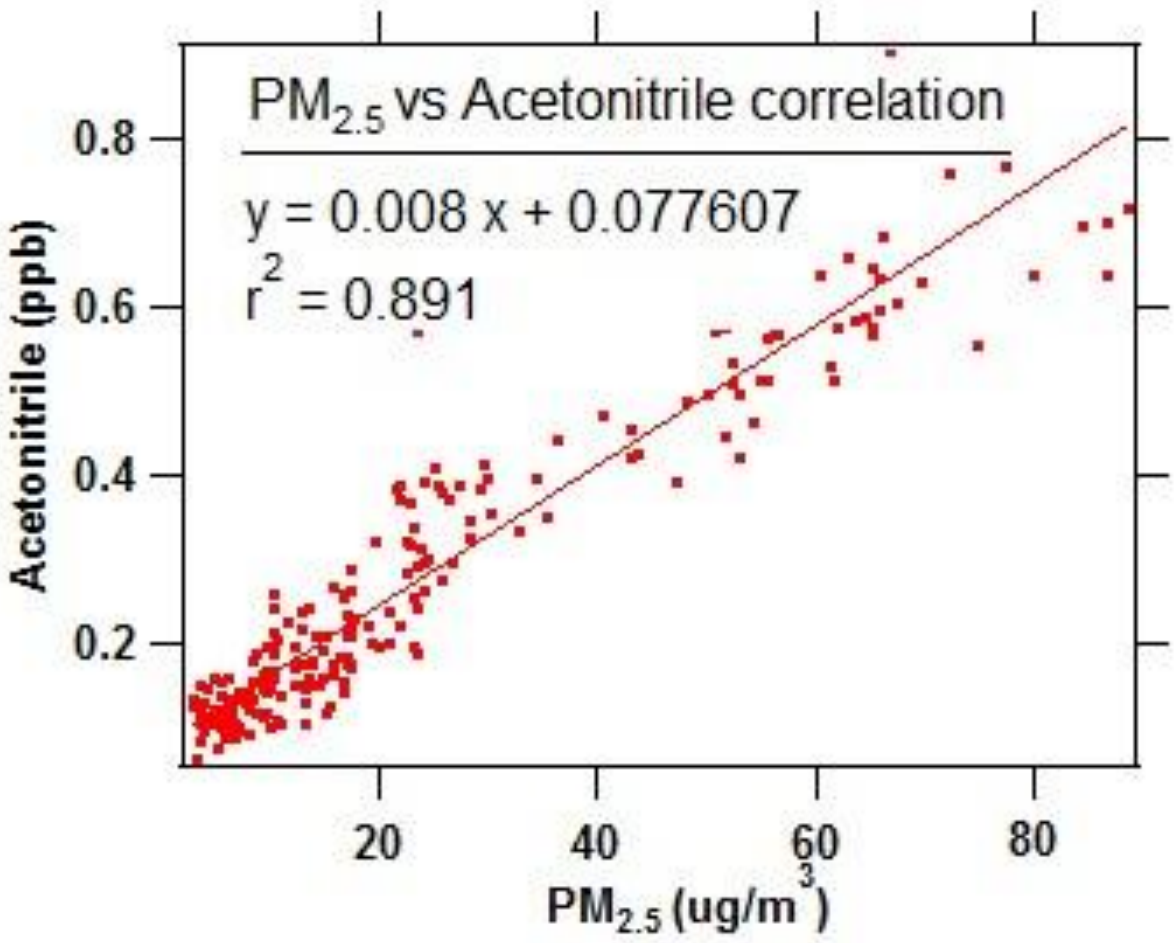
# VOCs


Benzene (ppbv)
3.0
2.0
1.0
Toluene (ppbv)
8
6
4
2
0
C2-Benzene (ppbv)
10
8
6
4
2
0
C3-Benzene (ppbv)
3
2
1
0
C4-Benzene (ppbv)
0.8
0.6
0.4
0.2
0.0
2015/8/9
2015/8/11
2015/8/13
2015/8/15
2015/8/17
Date and time (PST)

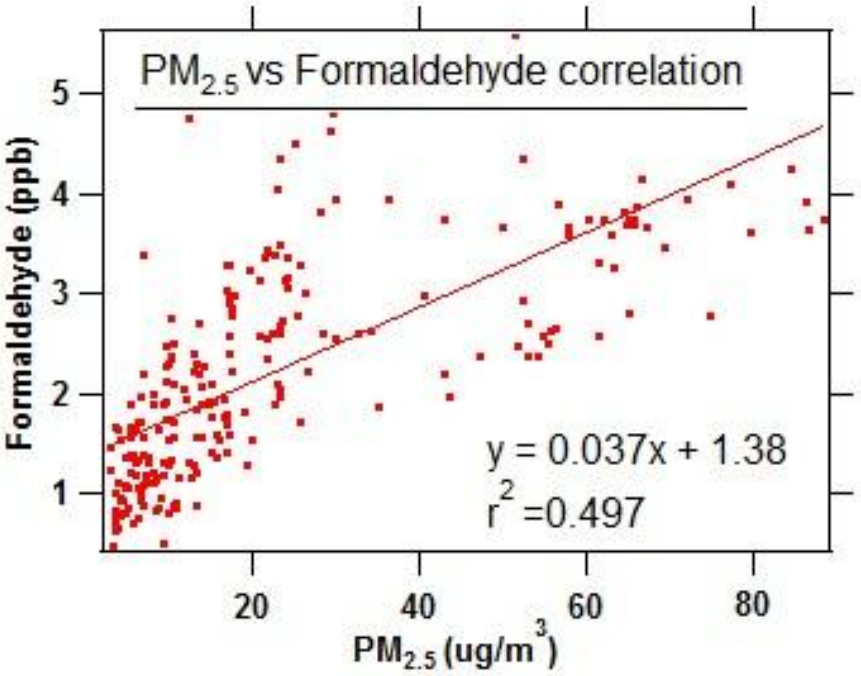
# VOCs

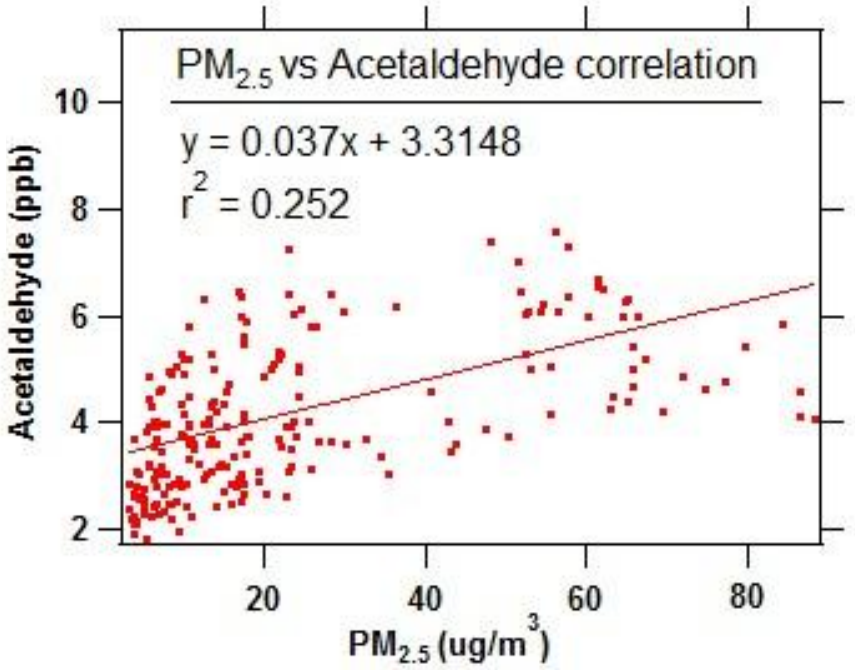

Isoprene (ppbv)
6
5
4
3
2
1
a-Pinene (ppbv)
6
4
2
2015/8/9
2015/8/11
2015/8/13
2015/8/15
2015/8/17
Date and time (PST)

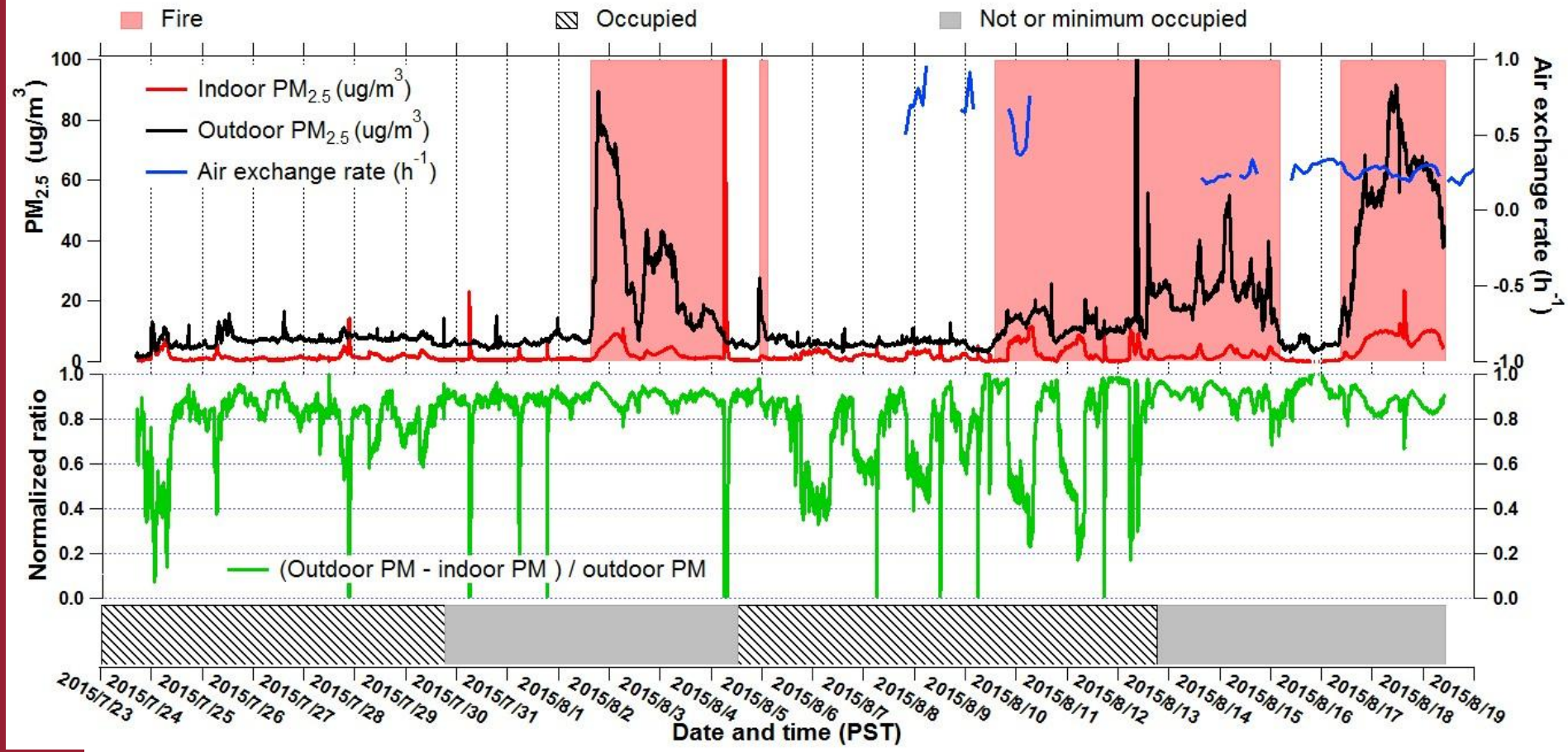
# Correlation



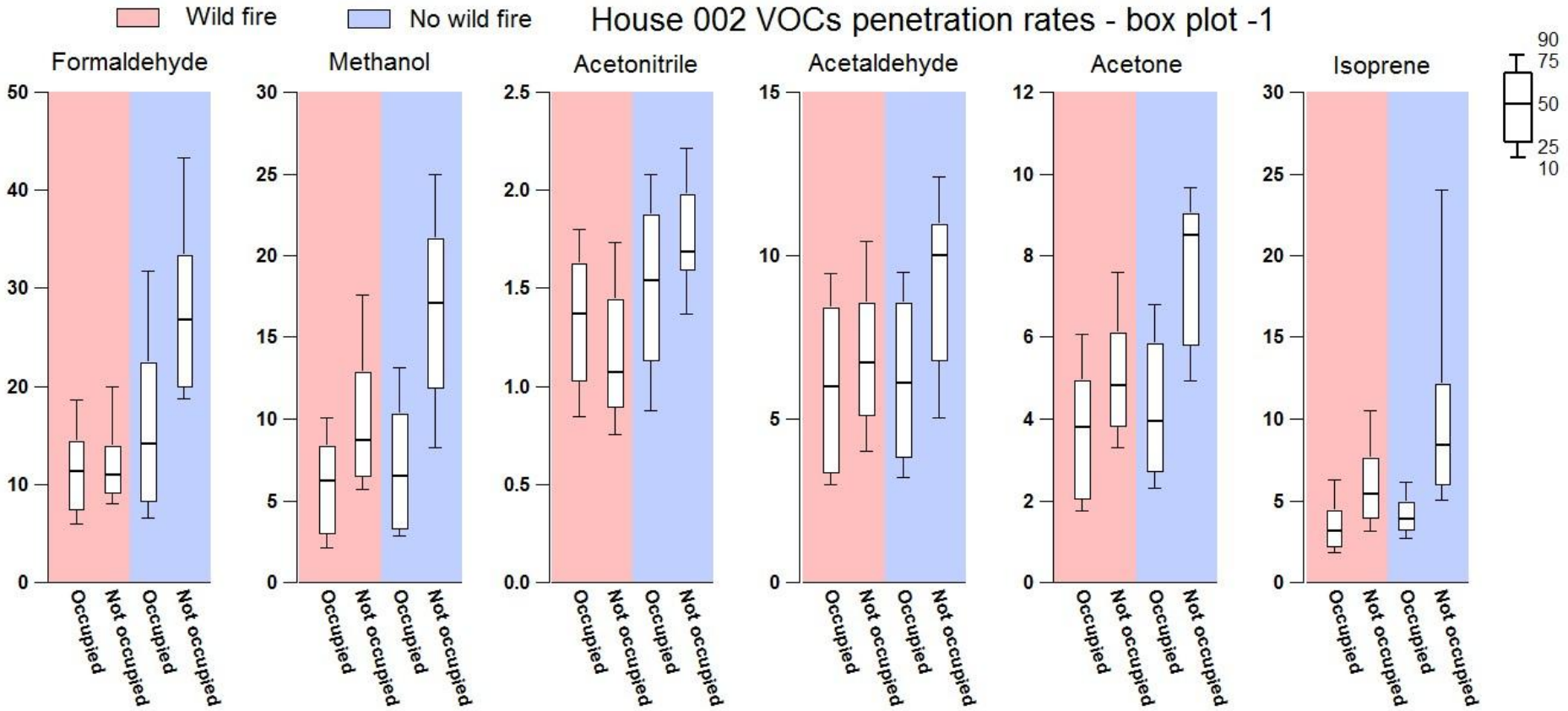
# Correlation



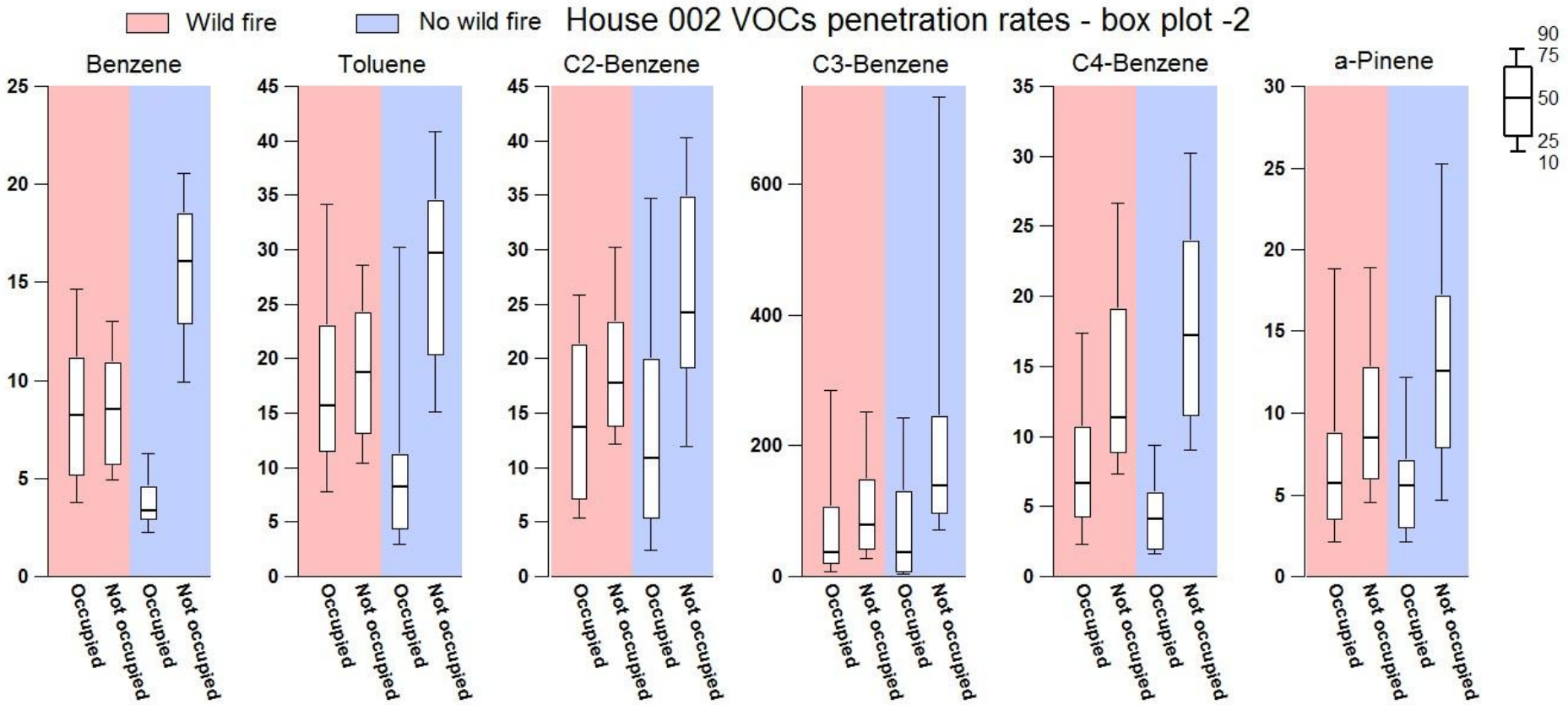




Fire
Occupied
Not or minimum occupied
Indoor PM2.5 (ug/m3)
Outdoor PM2.5 (ug/m3)
Air exchange rate (h-1)
PM2.5 (ug/m3)
Air exchange rate (h-1)
Normalized ratio
(Outdoor PM - indoor PM ) / outdoor PM
Date and time (PST)

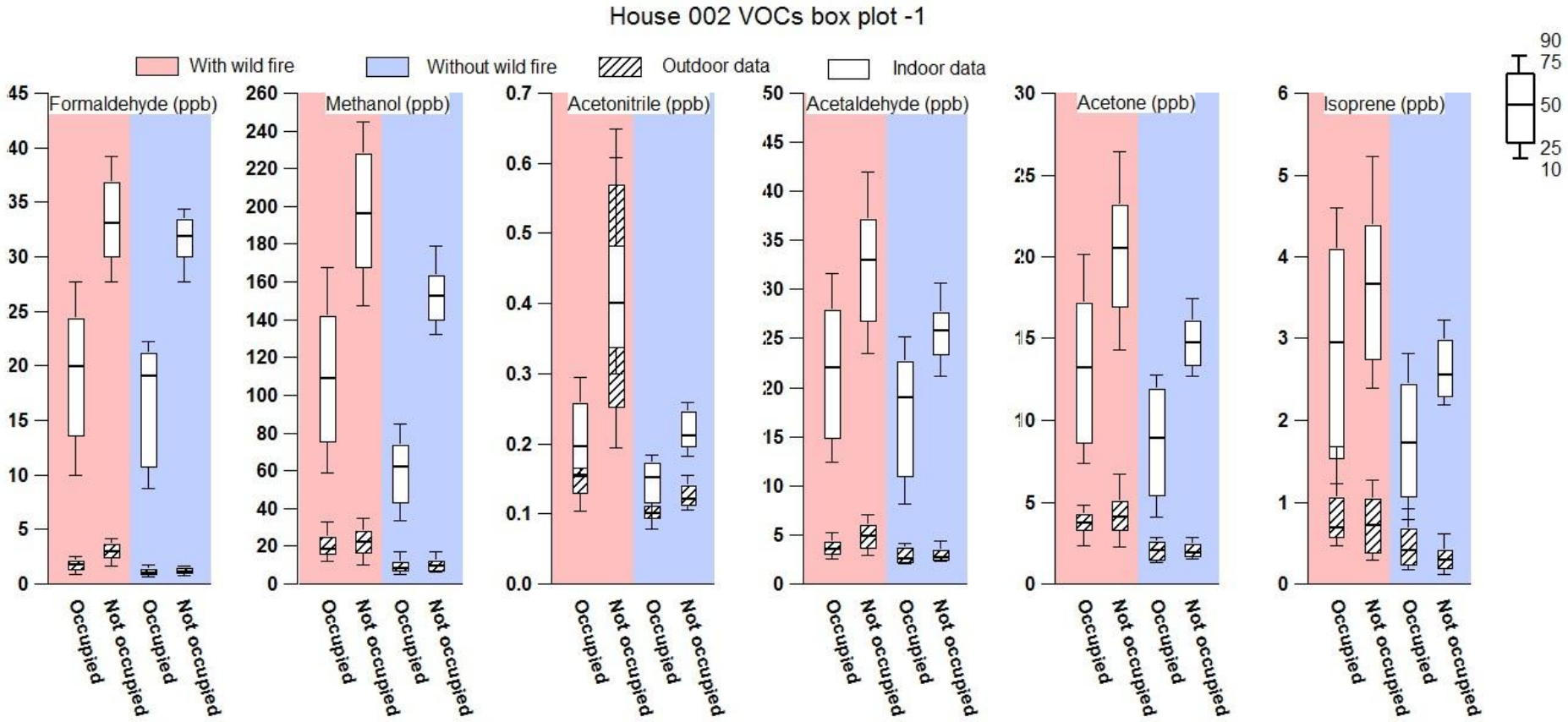
# Penetration rate of VOCs -1



# Penetration rate of VOCs -2



# VOCs concentration box plot -1



# VOCs concentration box plot -2