An overview of EPA indoor air quality project

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What is IAQ Project?

Integrated Measurements and Modeling Using US Smart Homes to Assess Climate Change Impacts on Indoor Air Quality

- Nine homes were measured: summer/winter; indoor/outdoor

- Complete suite of indoor/outdoor measurements
  - O_3, $PM_{2.5}$, CO, CO_2, NO_x, & VOCs
  - indoor temperatures, humidity, outdoor meteorology
  - 1 min average temporal resolution
  - CO_2 tracer air exchange rate measurements
  - occupant activity sensors

- Indoor VOC levels vs influencing factors (ACH, temperature…)

- The application of Proton Transfer Reaction Mass Spectrometer (PTR-MS): high time resolution VOC measurement.

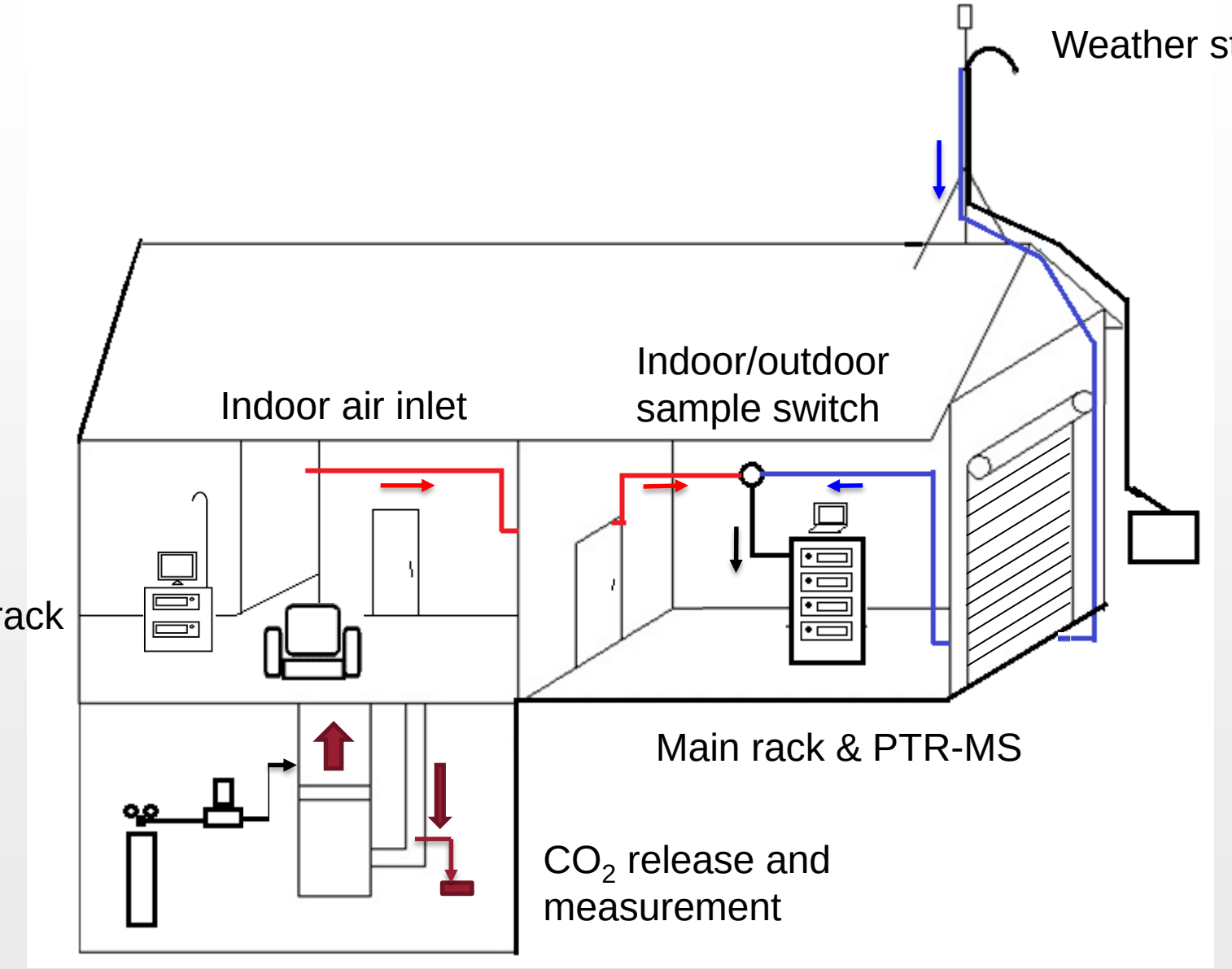
Characteristics of Test Houses

Home	Year Built	Occupants (adults / children)	Living space (ft^2)	Ventilation type*	Home Heating	Fireplace- Range**
H2	1963	2 / 0	1,765	CFA	G	G-E
H3	2011	2 / 1	2,640	CFA -HRV	E	P-P
H4	2000	2 / 3	4,032	CFA -FAI	G	G-G
H5	2010	2 / 0	3,152	CFA -HRV	G	G-E
H6	1958	2 / 0	1,804	**no CFA**	**Baseboard**	NA-E
H7	2010	1 / 0	1,051	CFA -FAI	G	NA-E
H8	2000	2 / 0	2,606	CFA -FAI	G	G-E
H9	1986	2 / 2	1,933	CFA	G / E	NA-E
H10	1972	2 / 1	2,116	**no CFA**	**Radiant ceiling**	NA-E

*CFA=central forced air system, HRV=heat recovery ventilator, FAI=fresh air intake

**G = gas, E = electric, P = propane, NA = none

Experimental Design

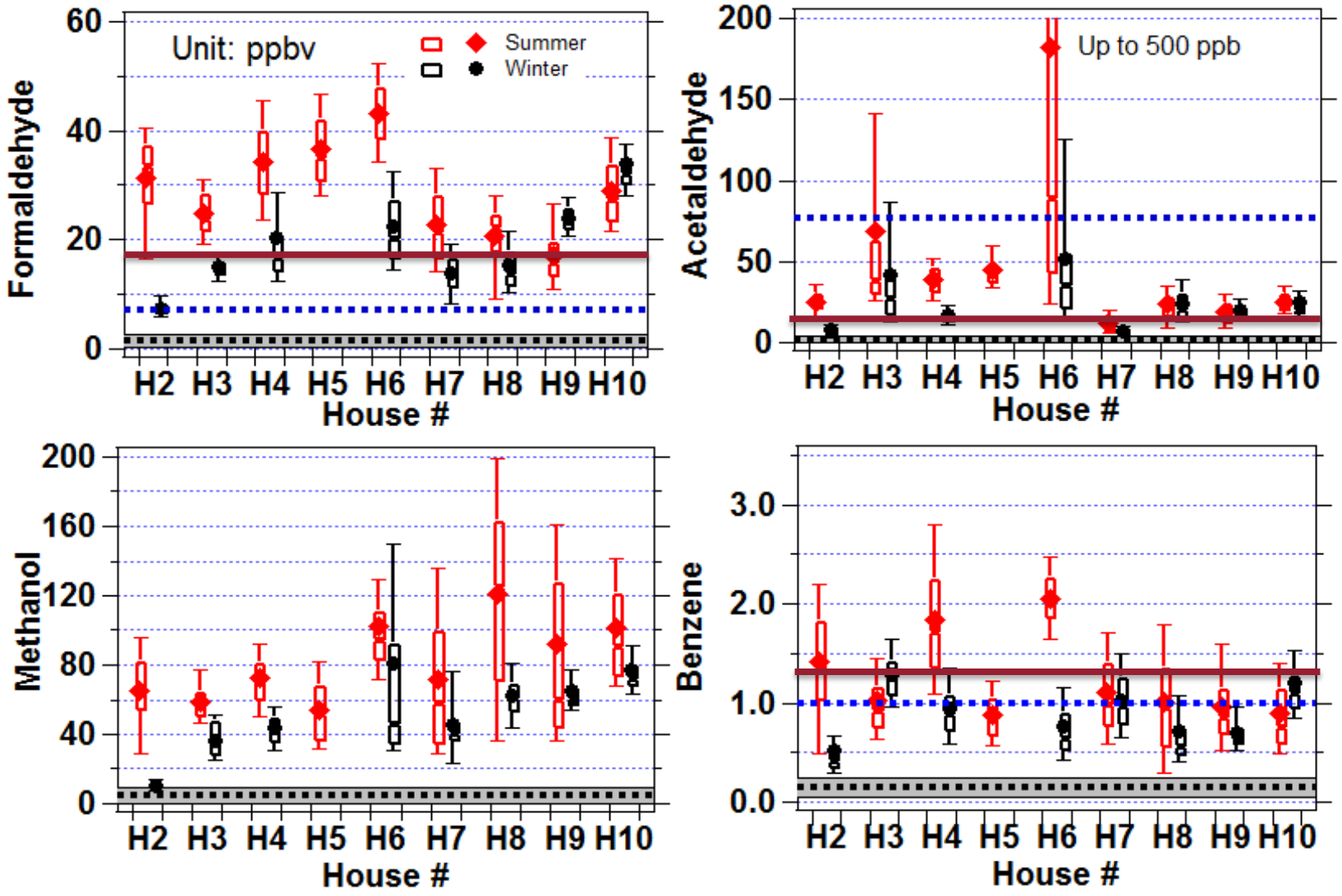


Indoor sample line

Outdoor sample line

Field Pictures

Air Toxic VOC Levels in Houses



RIOPA data

RIOPA study: Relationships of Indoor, Outdoor, and Personal Air; 234 houses were measured across US.

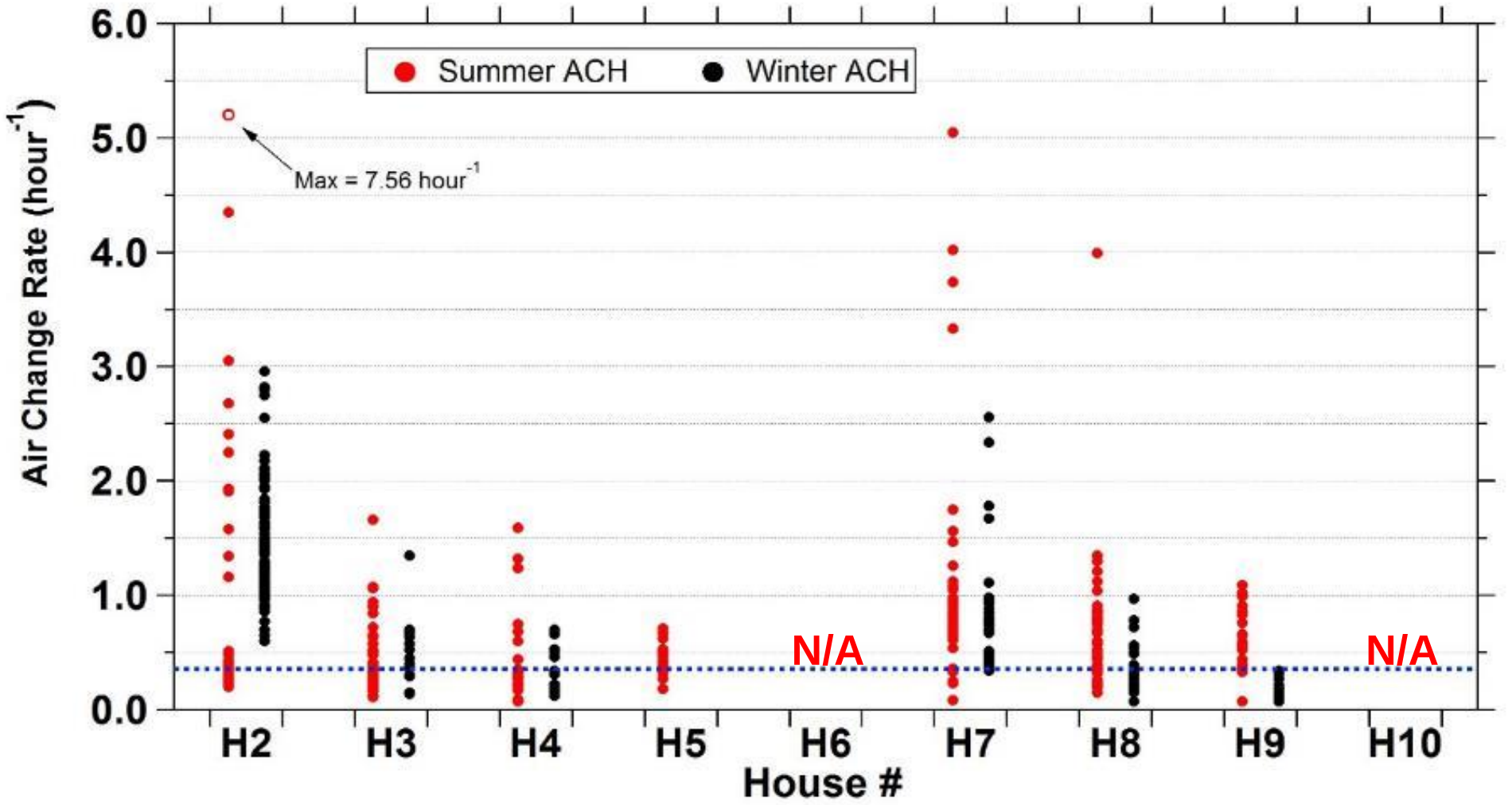
(Liu, 2006)

Reference exposure level

A concentration at or below which no adverse non-cancer health effects are anticipated for the specified exposure duration. (Chronic)

(OEHHA, 2016)

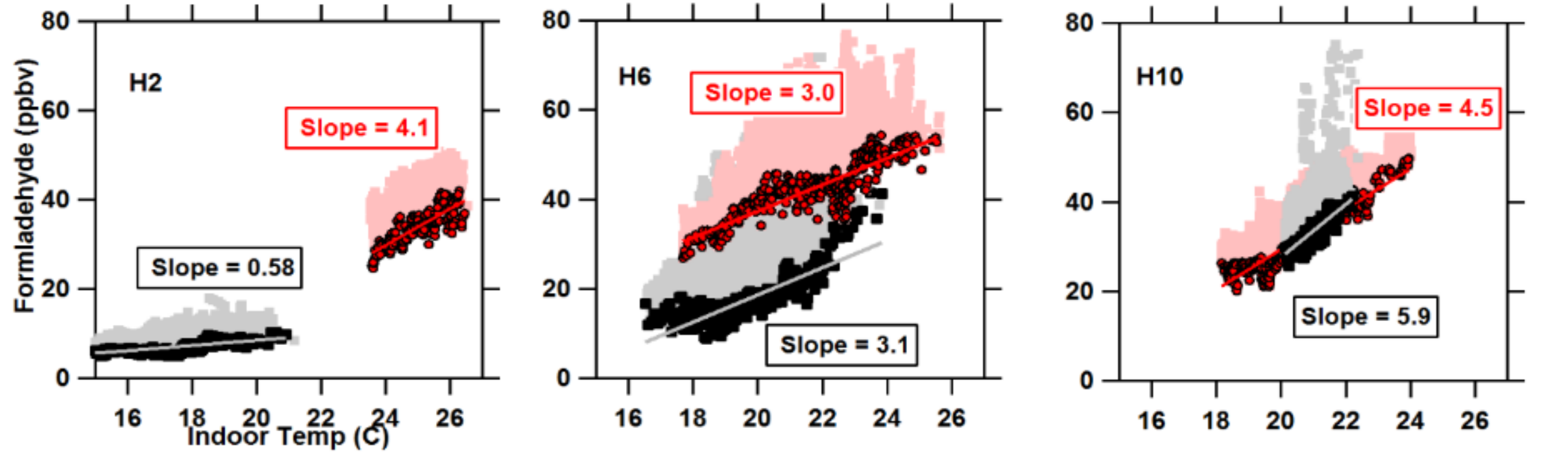
Measured Air Change Rate in Houses



Ventilation requirements for residential dwellings are covered by ASHRAE standard 62.2 that recommends **0.35 hr^{-1}**

Average ACH ~ 0.6 hr^{-1}

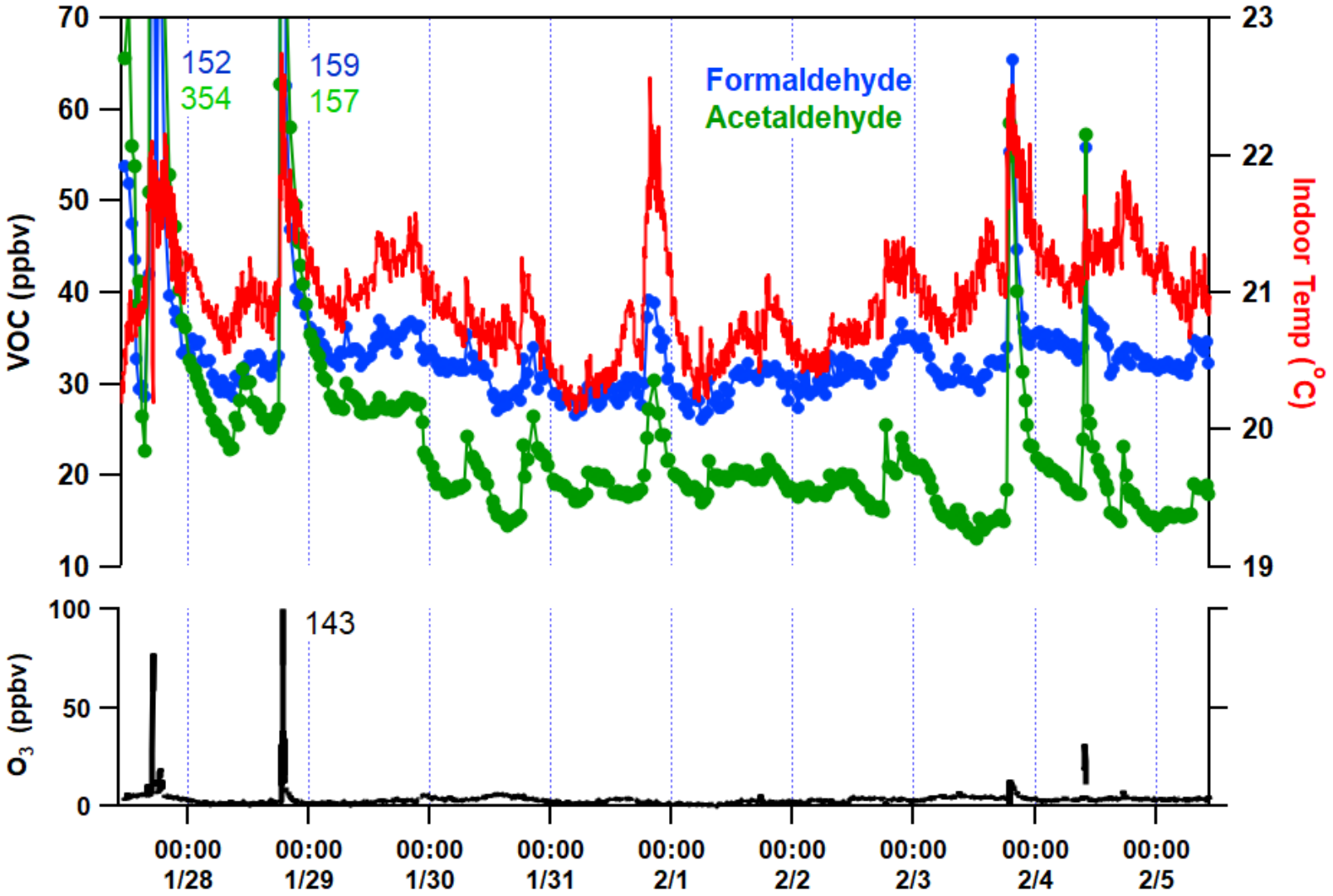
Formaldehyde Levels vs. Indoor Temperature



- The slope can be a useful simple predictor of the influence of indoor air temperature on formaldehyde levels.

- High ACH (probably due to unintended natural ventilation) led to quite low formaldehyde measured in H2 winter. Colder indoor temperature contributed to low emission rate.

Radiant ceiling heating as VOC source

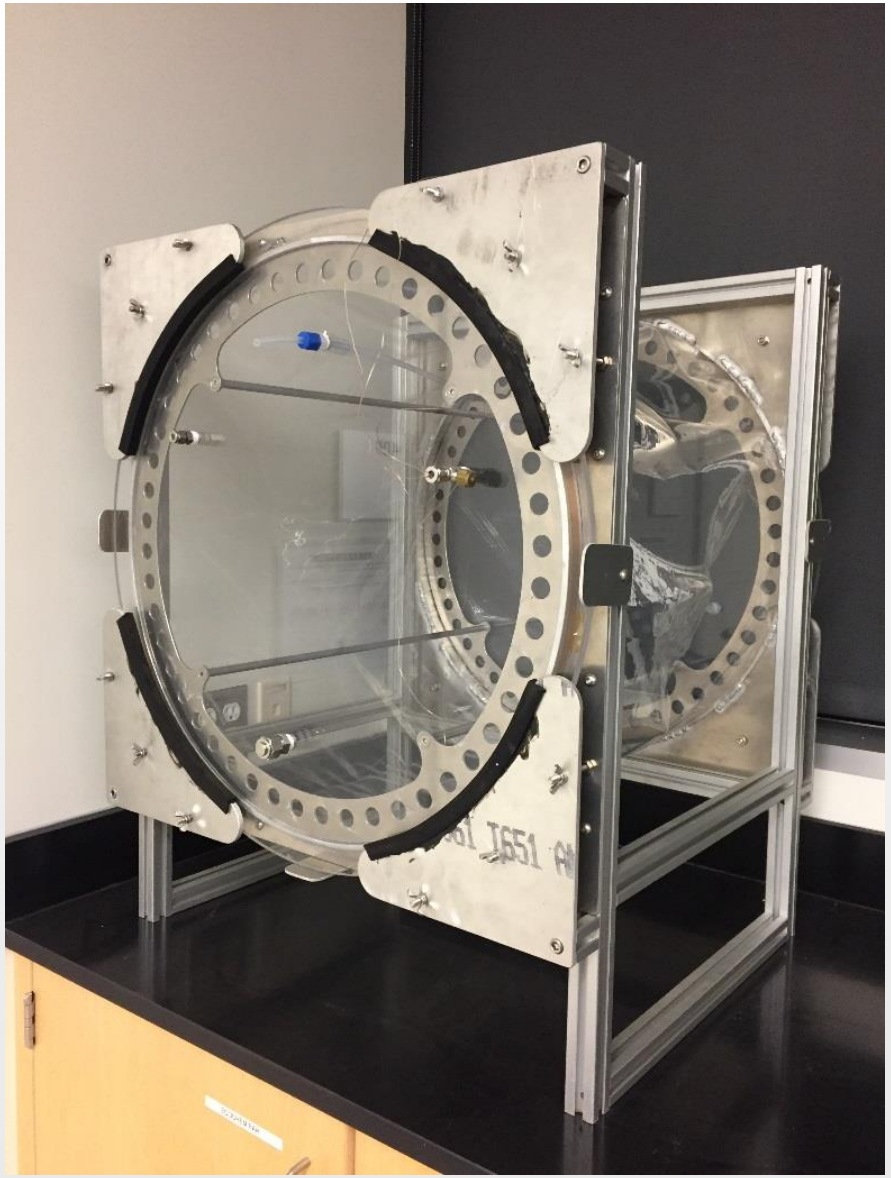


H10 winter

- Extreme high levels of acetaldehyde (up to 354 ppbv) and formaldehyde (up to 159 ppbv) were measured when indoor temp. showed peaks.
- High O_3 levels (up to 143 ppbv) were captured during the events.

Radiant ceiling heating as VOC source

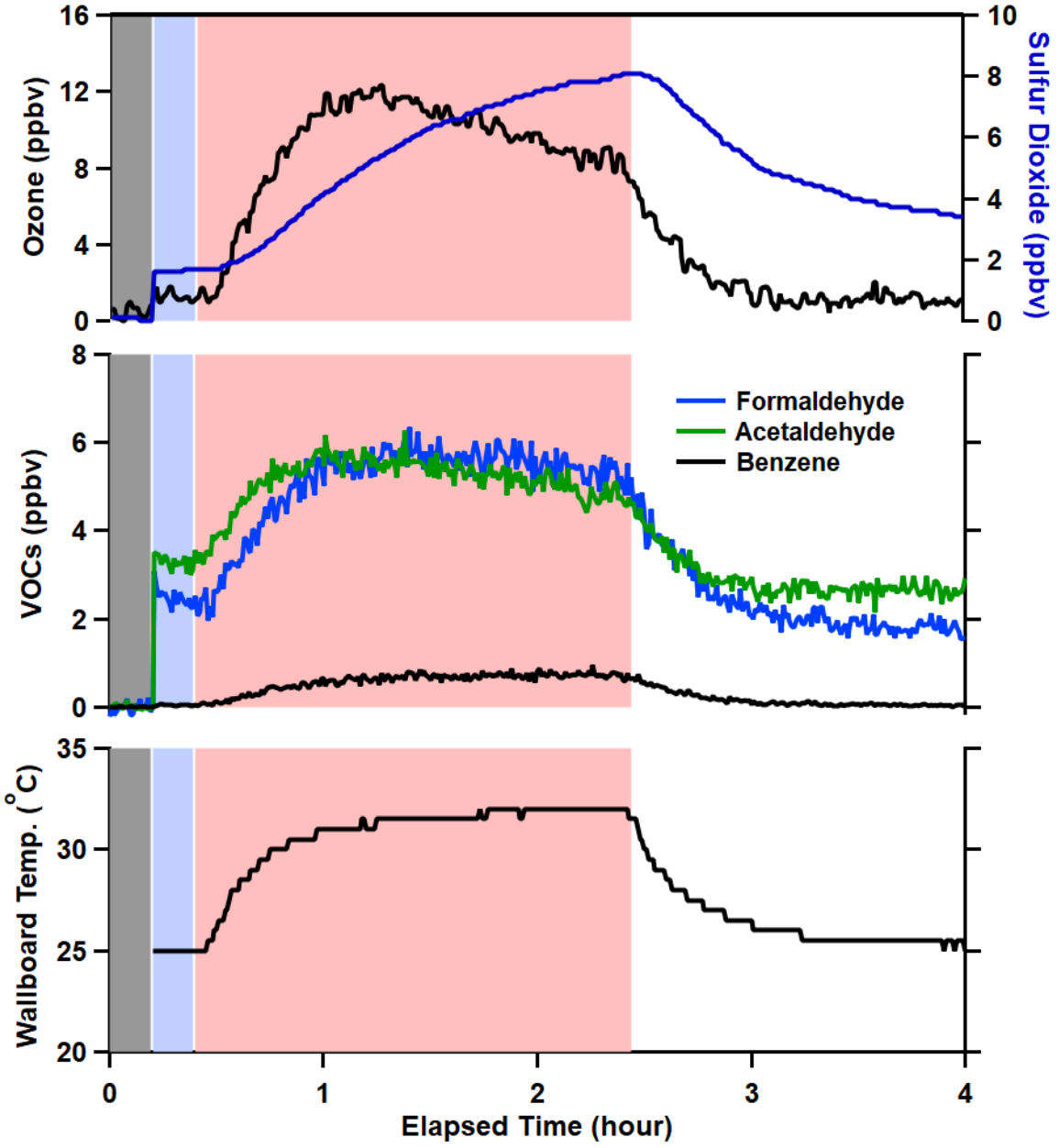
Chamber test of wallboard for radiant ceiling heating



Radiant ceiling heating as VOC source

Chamber test of wallboard for radiant ceiling heating

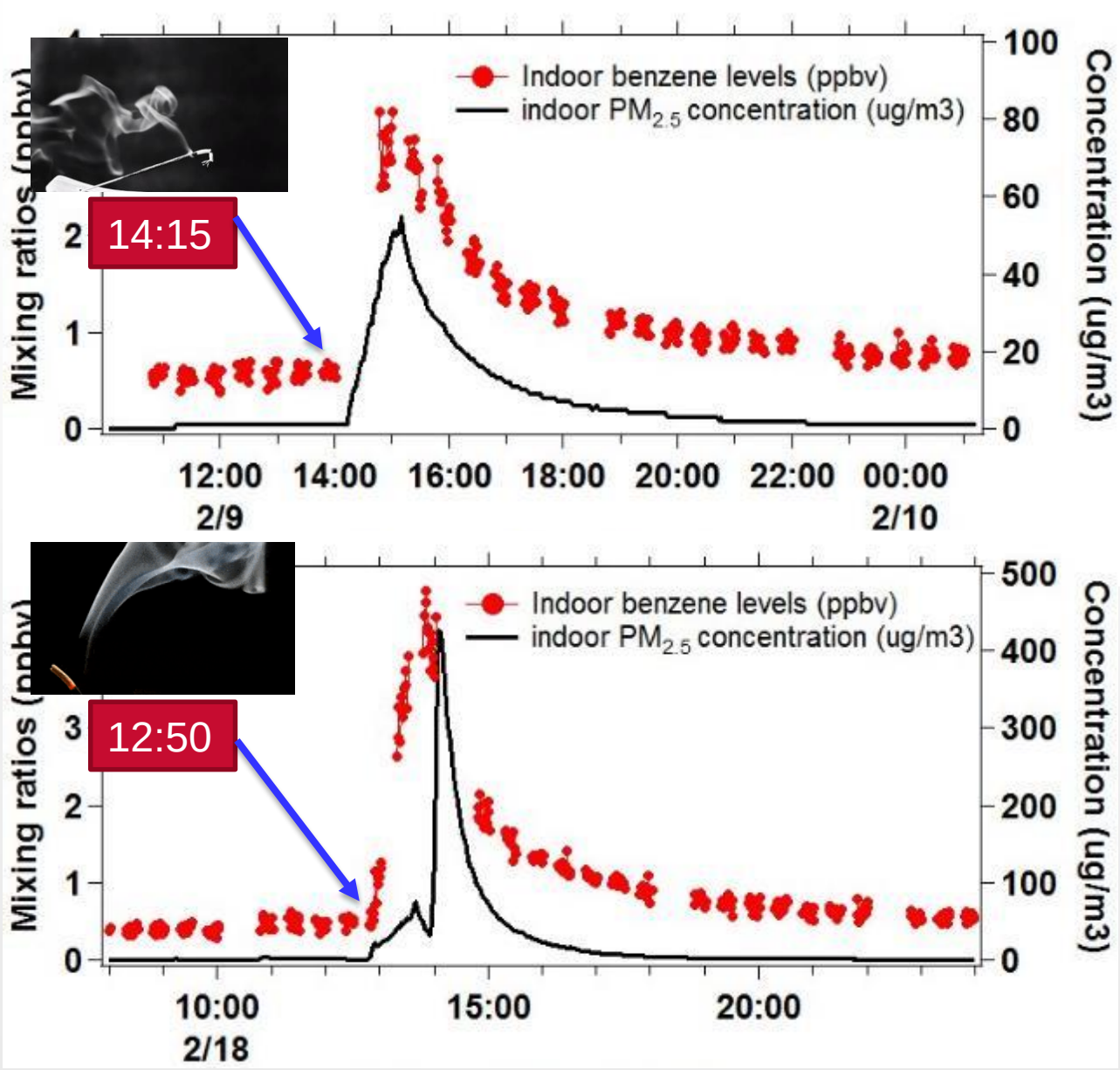
- With wallboard temperature increased from 25 ^{o}C to 31 ^{o}C, emission factor of formaldehyde increased from 26.4 to 62 µg m^{-2} hr^{-1}, acetaldehyde from 52.7 to 89.9 µg m^{-2} hr^{-1}, benzene from 1.2 to 20.2 µg m^{-2} hr^{-1}.
- Response of O_3 was measured as well.
  - *Hg ??* 0.04 ppbv Hg test gas mixtures yielded a 20 ppbv O_3 response (EPA 1999)



Chemical use is a source of **Benzene**

H8 winter

- The use of incense stick increased the benzene levels by a factor of 7 to 9. $PM_{2.5}$ levels increased up to 400 ug m^{-3}.
- Reference exposure level of benzene is 1 ppbv. NAAQS for $PM_{2.5}$ is 35 ug m^{-3} in 24 hours.

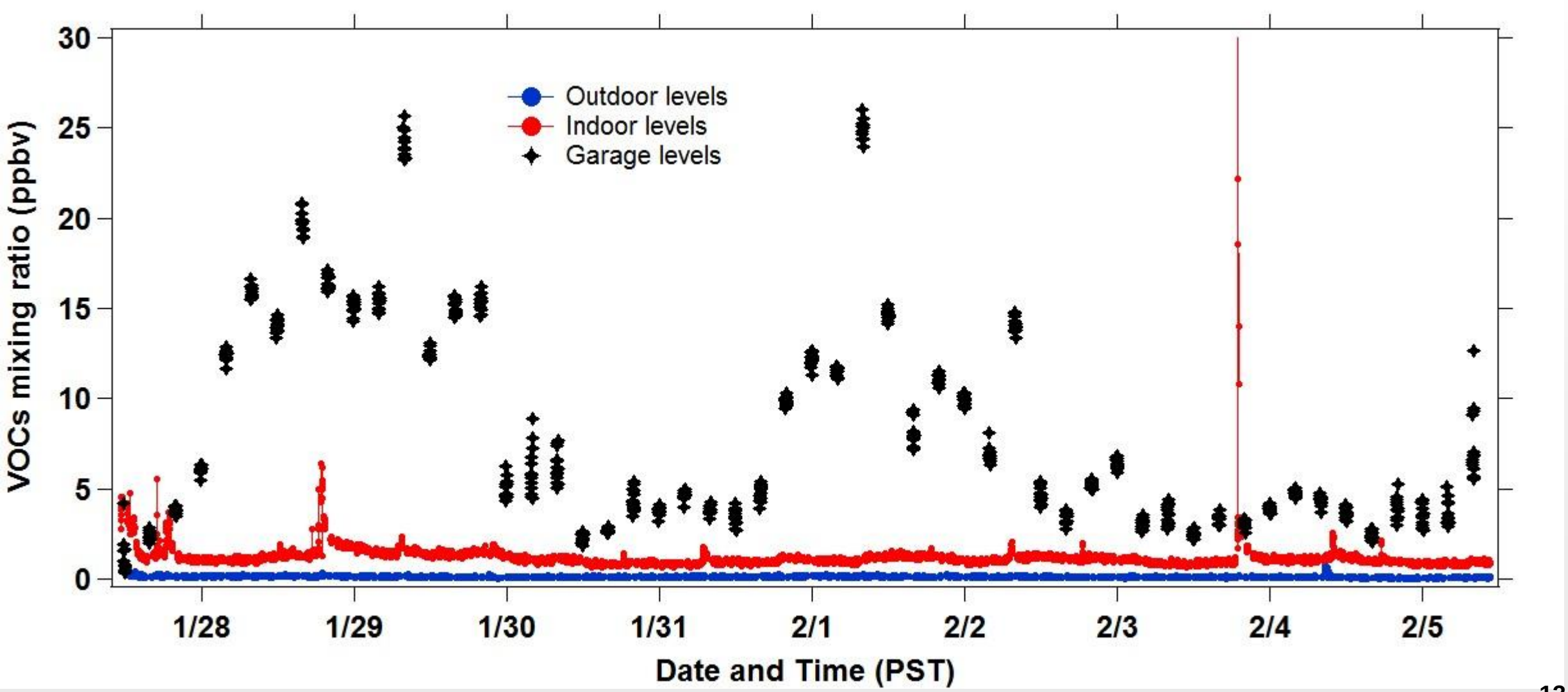


Gif courtesy of https://rudescience.tumblr.com/post/117360256373/burning-incense-sticks-in-asian-countries-where

https://gfycat.com/gifs/search/incense

Garage is a source of indoor **Benzene**

H10 winter **benzene** measurement



Garage is a source of indoor **Benzene**

H10 winter **benzene** measurement

Whole House Emission Factors of VOCs

Emission Factor: emission rate normalized to floor area, in **μg m^{-2} hr^{-1}**.

	Emission Factor	CNHS n=108	Site built n=7	Manufactured n=7
Formaldehyde	**90 ± 10**	**29**	**31**	**45**
Methanol	**51 ± 8**	**-**	**-**	**-**
Acetaldehyde	**76 ± 11**	**14**	**25**	**17**
Toluene	**5.5 ± 1.0**	**3.4**	**26**	**3.9**
Styrene	**4.1 ± 0.6**	**0.5**	**8.3**	**4.1**
Benzene	**2.3 ± 0.4**	**0.2[a]**	**-**	**-**
C_2-Benzene	**14.7 ± 1.7**	**1.1[a]**	**9.5[b]**	**3.2[b]**
Monoterpene	**11.7 ± 1.6**	**5.5[a,c]**	**183.3[c]**	**213.1[c]**

- Calculation was based on the measurement made under 24 ± 0.5 °C, ACH = 0.49 hr^{-1}.

[a] Median.
[b] Sum of o/m/p-Xylene.
[c] Sum of α/β-Pinene, d-limonene, and 3-Carene.

(Poppendieck, 2015)
(Offermann, 2011)
(Hodgson, 2000)

Conclusions

- Indoor VOC levels were much higher than the outdoor levels and for formaldehyde, levels were much greater than the REL.
- Averaged ACH of all the nine homes were ~ 0.6 hr^{-1}, higher than the recommended 0.35 hr^{-1}.
- Building materials, chemical use, radiant heating materials, and gasoline from attached garages can be significant indoor VOC sources.
- Whole house emission factors of VOCs were documented.

Thanks!