IEA Annex 86 Formaldehyde and Cooking Contaminants

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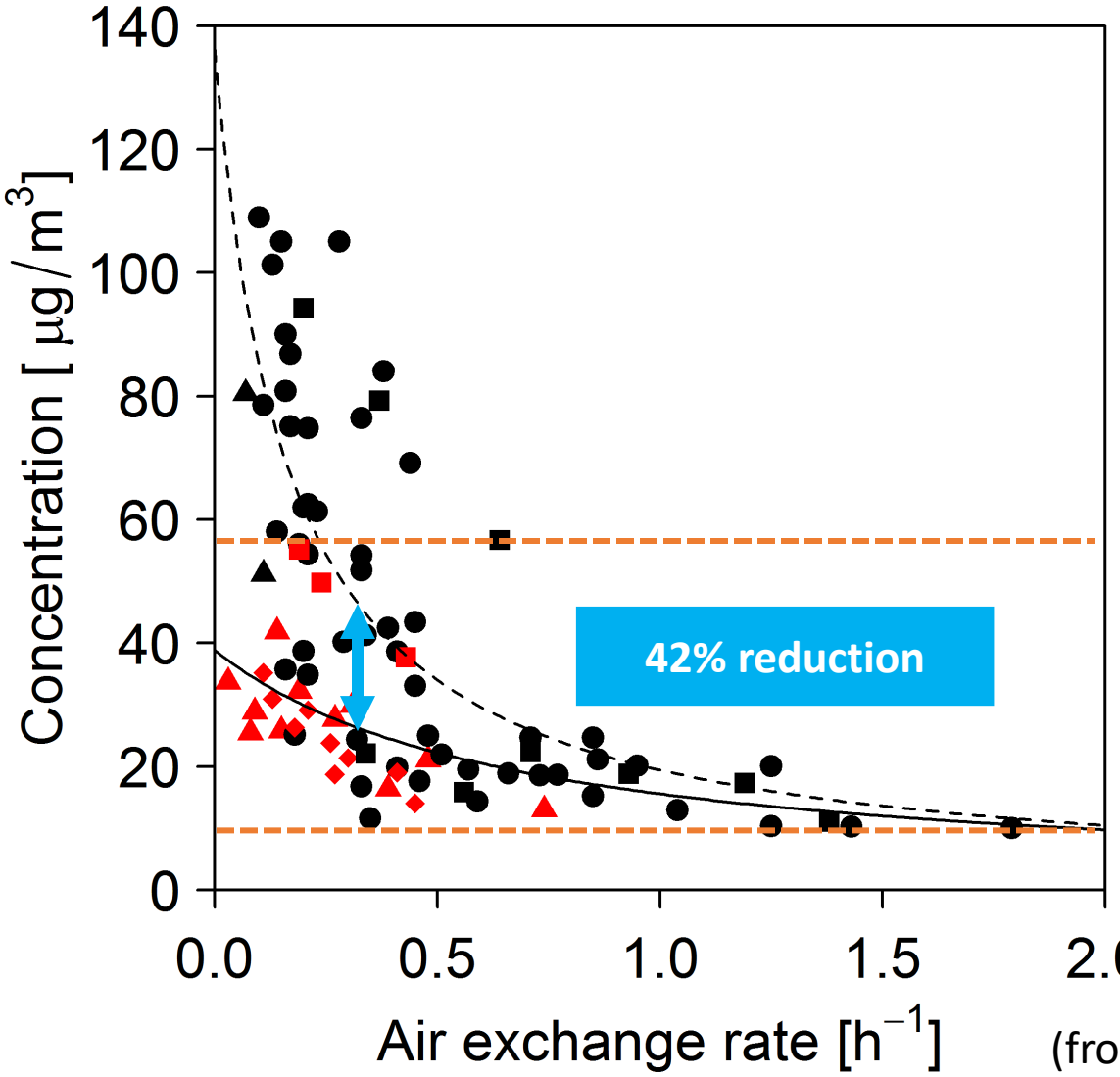
Formaldehyde Emissions

- Big challenge for sensing – no low-cost way to real-time sense for controls
- Its everywhere
- Many homes exceed standards
- Some standards are very low (almost no homes can meet them):
  - 9 μg/m^3 (California OEHHA reference exposure level)
- Hard to ventilate away – emission rates tend to increase with more ventilation – field studies show about 60% reduction c/w constant emission (Hult et al.)
- Emission rates depend on temperature and humidity
  - Andersen et al. measured an increase in temperature of 7 °C doubled the formaldehyde equilibrium concentration in a chamber and the change of 40% relative humidity also doubled the formaldehyde concentration
  - Salthammer et al. measured an increase of 6 μg/m^3 per °C increase in temperature and 2 μg/m^3 for every 1% increase in relative humidity
  - Poppendieck et al. found an almost a factor of 2.6 increase in VOCs for an 8 °C increase in temperature

Homes Built With Low-Emitting Materials Have Lower Formaldehyde Concentrations



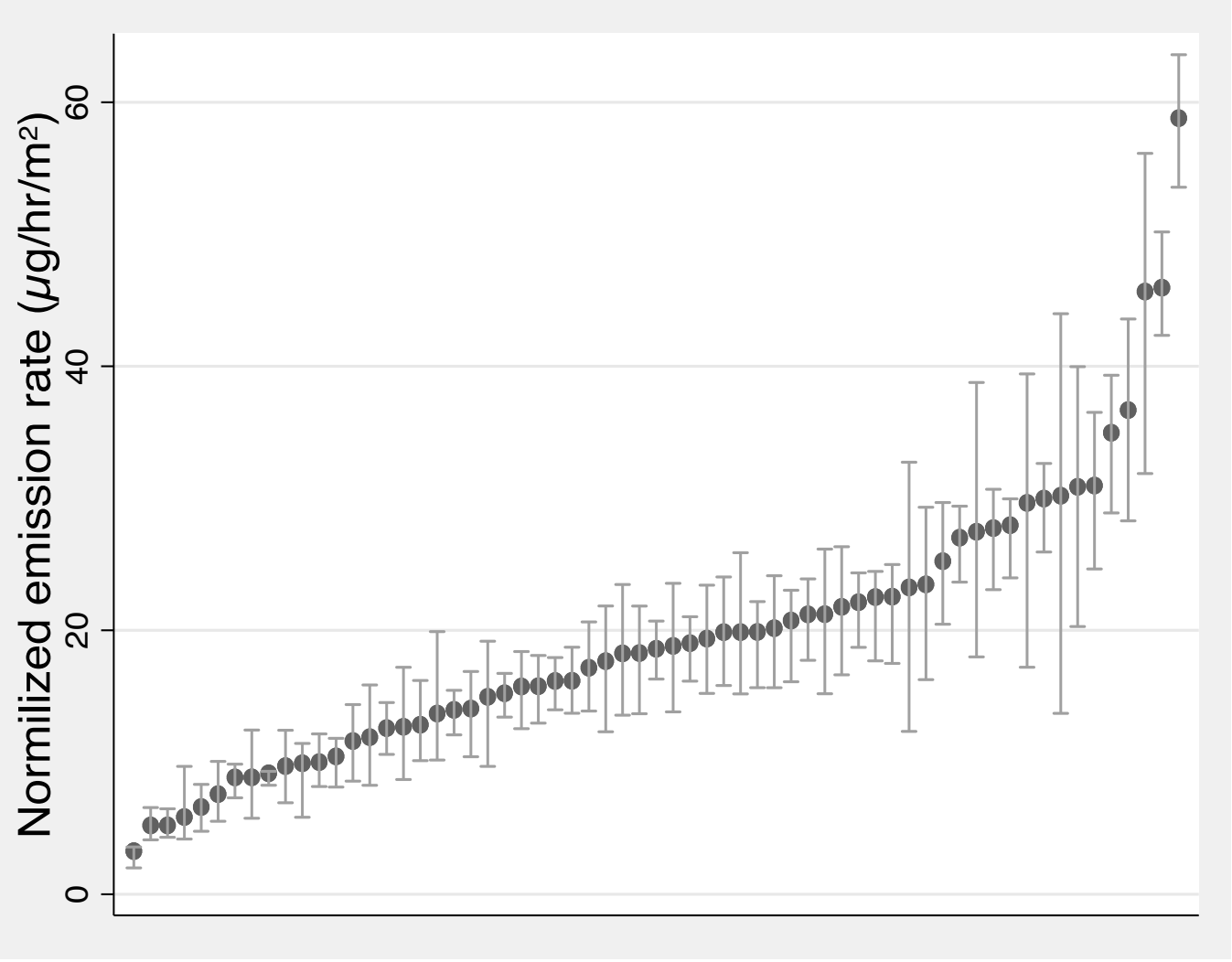
- **Conventional Materials**
- **Low-Emitting Materials**

CA Acute Exposure Limit

California OEHHA reference exposure level

(from Hult et al., 2015)

Formaldehyde emissions vary a lot



From 70 new California homes

Large variation, even when **normalized**

Data from paper in review at IJERPH

Zhao et al.

Formaldehyde emission modeling

$$\frac{E_t}{A_f} = \frac{C_{st} * (1 + A(T_t - 25))(1 + B(RH_t - 50))}{\frac{1}{a_t} + \frac{1}{kL}} * H$$

Et - emission rate

Af – floor area

Tt – temperature

RHt – Relative Humidity

at - air exchange rate

1/kL – deposition term

H= Ceiling Height

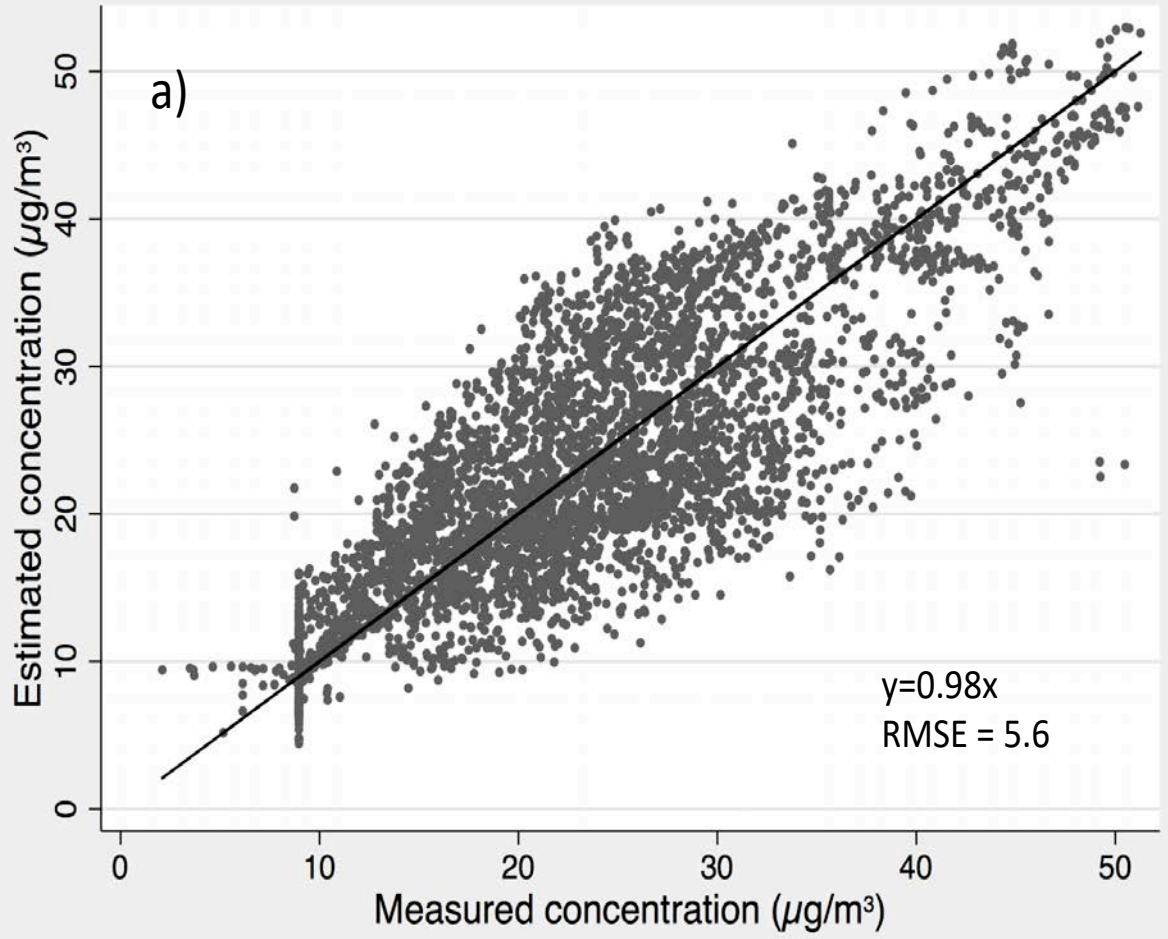
Unknowns:

A, B, Cst (concentration at reference condition (25 C, 50% RH))

Formaldehyde emission modeling

Method		1-hour average	8-hour running average	Range from previous studies
Coefficient estimates	A (1/°C)	0.088	0.086	0.05-0.15
	B (1/RH%)	0.036	0.047	0.005-0.038
	Cst (µg/m^3)	72.9	70.8	41-118

Formaldehyde emission modeling

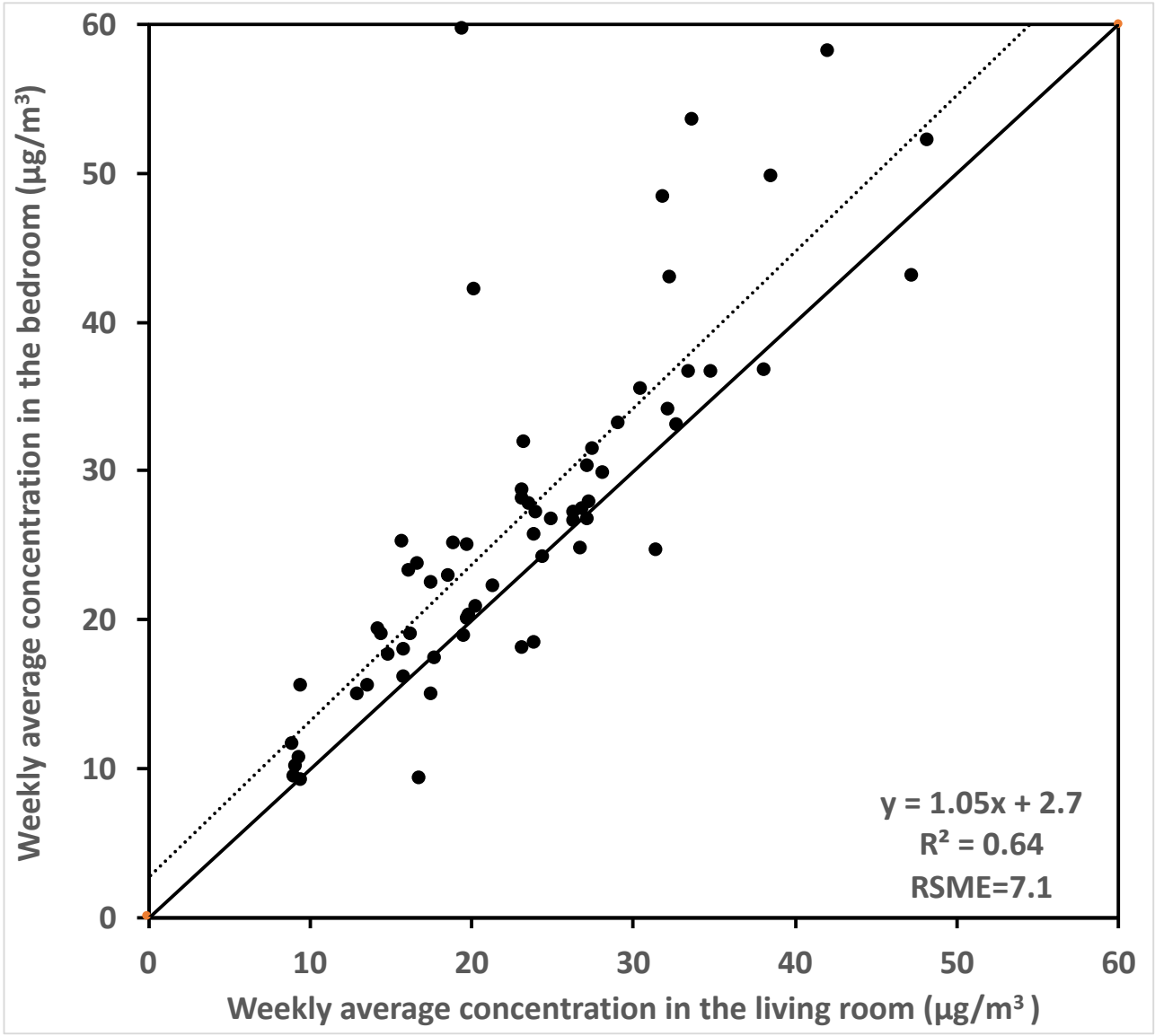


Using average A, B, Cst across all homes applied to individual homes

Formaldehyde: room-to-room variability

63 test houses measured for a week

Small differences (5%) on average



Cooking Contaminants

Gas

CO_2 & H_2O

Particles, NO_2 (and NO), CO, Formaldehyde,

Electric

Ultrafine particles

Food

Particles, Formaldehyde, Acetaldehyde, Acrolein,

H_2O, Odors

Cooking

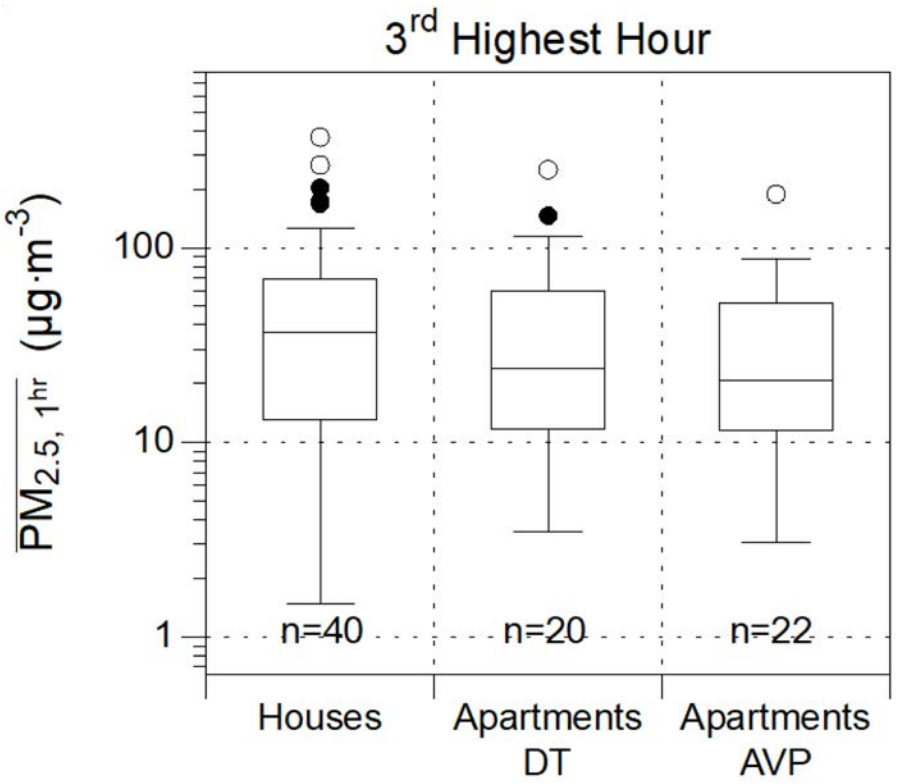
A ***hot*** issue in the US:

- Gas cooking emissions used as rationale for making homes all electric for decarbonization (see publications by Rocky Mountain Institute and others)
- US Consumer Product Safety commission new working group
- California Energy Commission – different kitchen venting requirements gas vs. electric (proposed)

Cooking Fuel	Floor Area (ft^2)	Capture Efficiency	Airflow (cfm)	Airflow (m^3/h)
Electricity	>1500 ft^2	0.50	110	190
	1000 - 1500 ft^2	0.50	110	190
	750 - 1000 ft^2	0.55	130	220
	<750 ft^2	0.65	160	270
Gas	>1500 ft^2	0.70	180	300
	1000 - 1500 ft^2	0.80	250	420
	750 - 1000 ft^2	0.85	280	480
	<750 ft^2	0.85	280	480

Cooking Contaminants

- Latest US Data: Houses and Apartments cooking with gas
- NO_2 1 hour limit EPA 100 ppb, WHO 110 ppb



DT = lab instrument
AVP = consumer instrument

Zhao et al. 2021

Cooking Contaminants

2 recent CA studies (one week sampling): 20 apartments and 40 homes

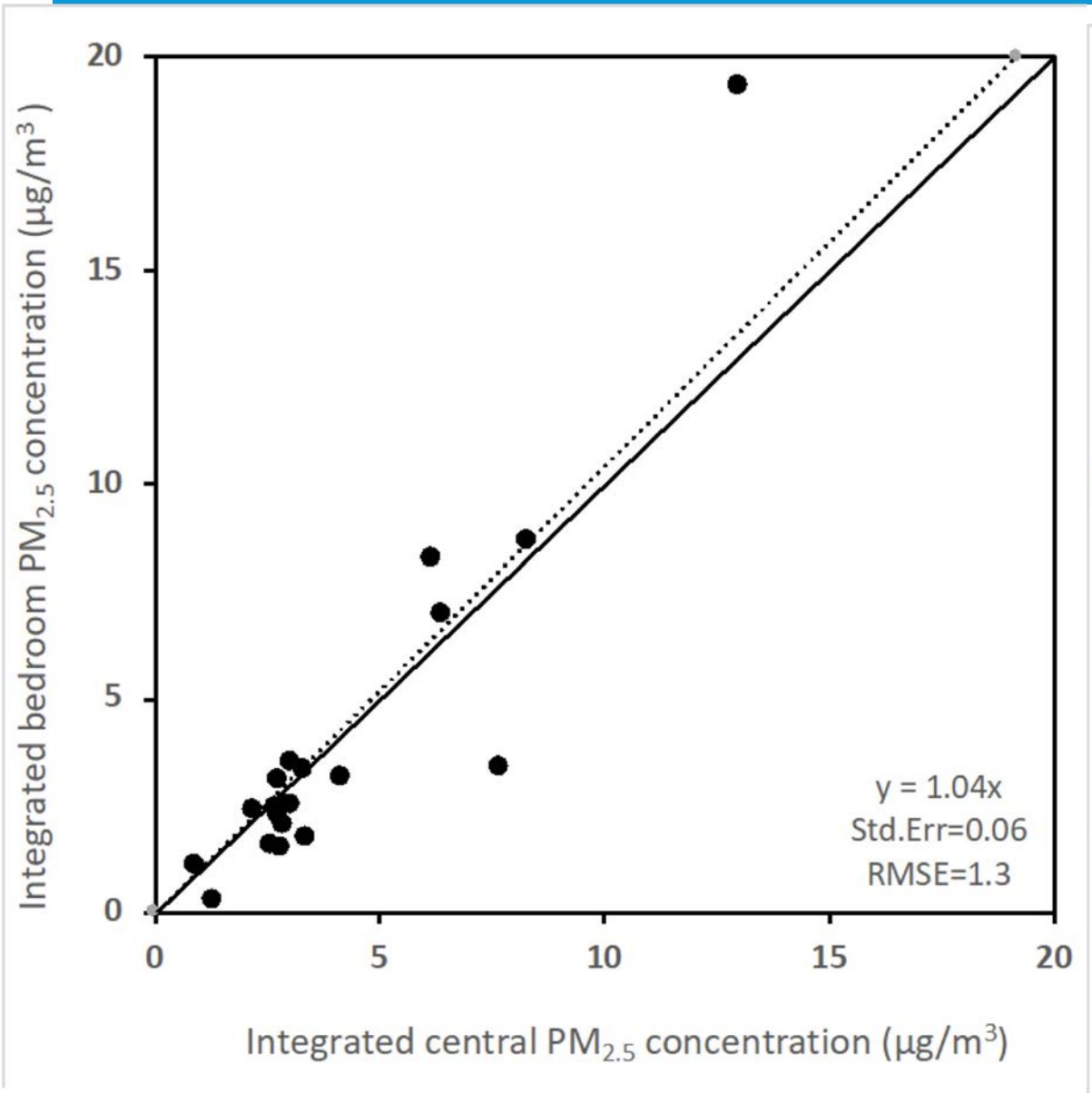
Particles:

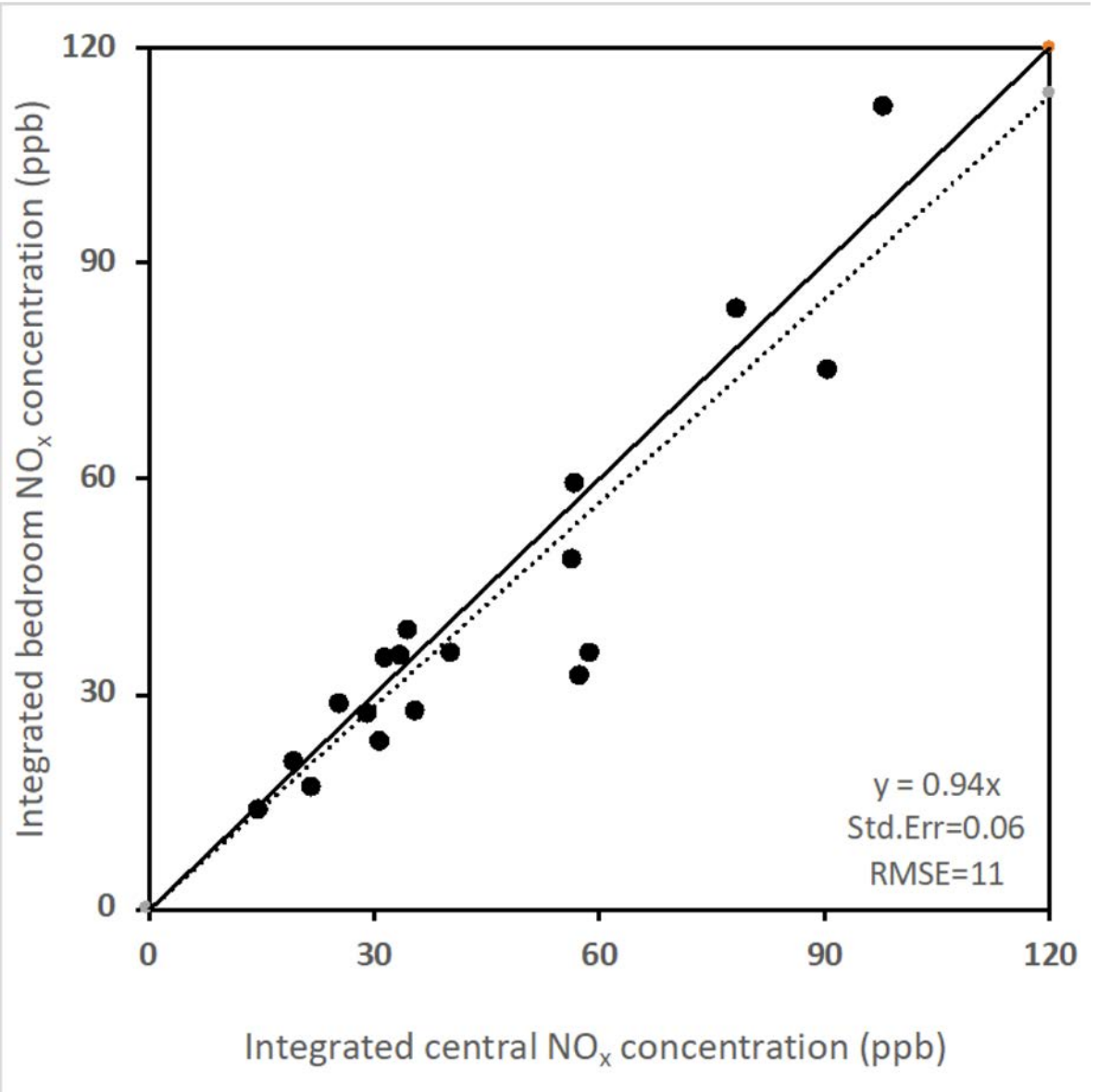
- about 20% of both above annual PM2.5 outdoor exposure limit of 12 µg/m^3 (USEPA)
- About 20% of both above 24 hour limit of 25 ug/m^3 (WHO)

NO_2

- 20 apts: 19 ppb
- 40 homes: NO_2 8 ppb
- None exceeded US EPA Annual AAQS of 53 ppb.
- 3 Apartments exceeded CA AAQS of 30 ppb
- For NO_2 avoiding 1 – hour 100 ppb requires good kitchen exhaust

Spacial Variation – not just a kitchen issue





Other Cooking Thoughts…

What about pans?

- Some indication that non-stick = less particles?

What about kitchen venting?

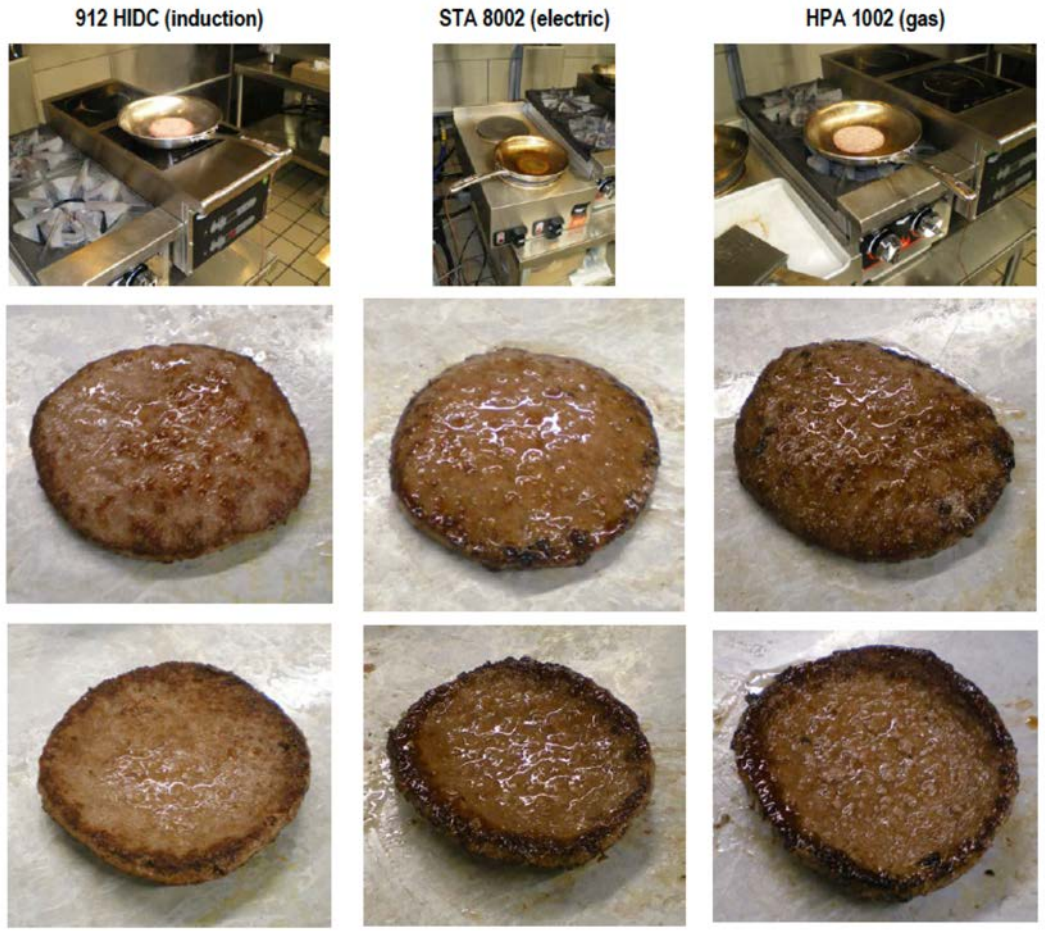
- Range hoods can be very effective
- New IEC ratings coming soon

Commercial kitchens

- Big interest in induction cooking

Induction cooking

- New LBNL California Energy Commission Study: Childhood Asthma & Cooking
- More energy efficient:
  - Recent commercial kitchen study: induction is 88% efficient, electric 74% and gas 42% for heating water
  - For sauteeing, the energy use is 113 Wh induction, 225 Wh resistance and 487 Wh (converted from 1608 Btu) for gas - a much bigger advantage for induction.



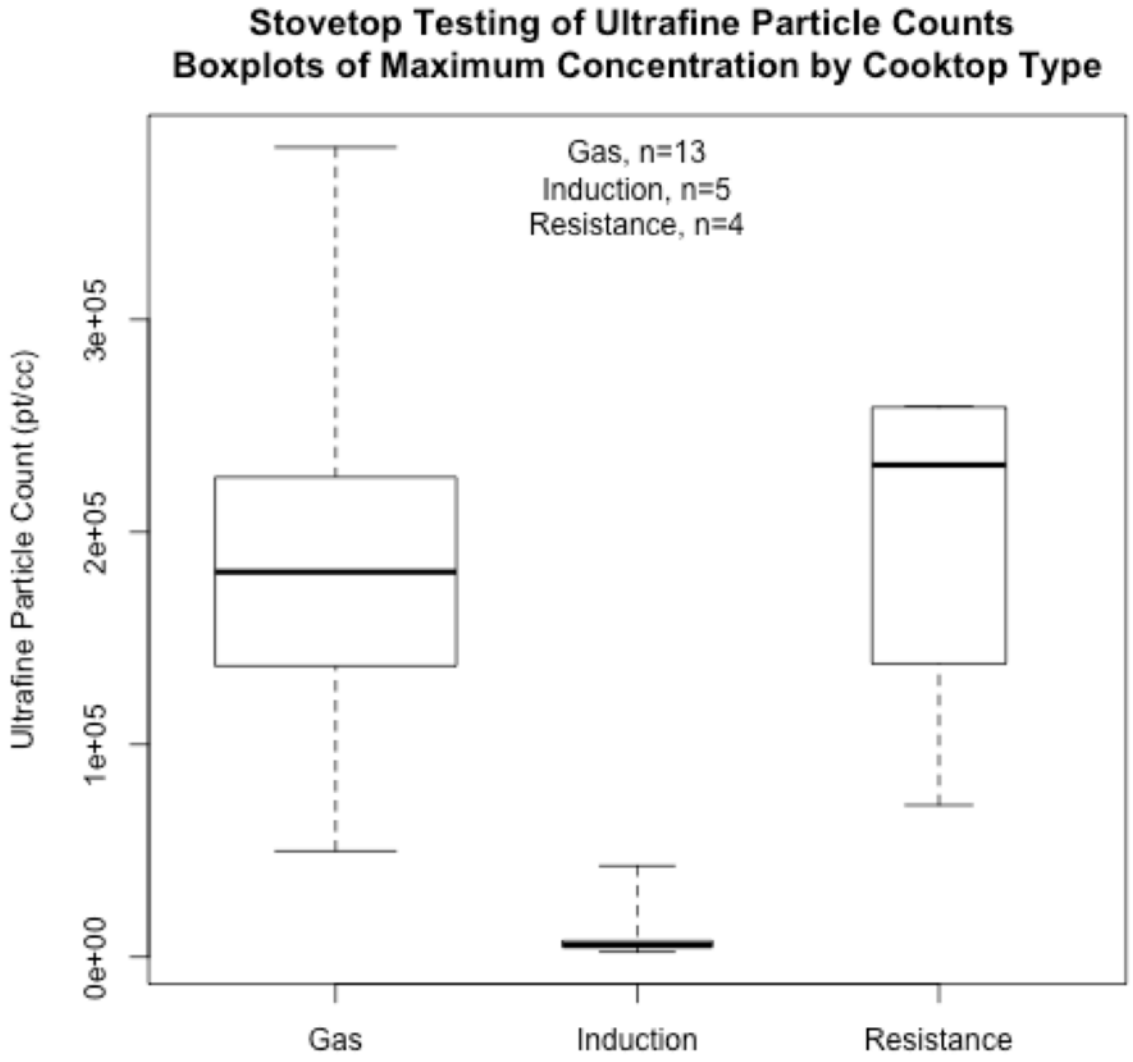
Fisher-Nickel 2013

Induction Cooking

Less ultrafines (sub-micron) c/w gas and resistance elements

But…. Small sample size

New laboratory testing planned with scripted cooking



Less (2012)

References

- Hult, E.L.; Willem, H.; Price, P.N.; Hotchi, T.; Russell, M.L.; Singer, B.C. Formaldehyde and Acetaldehyde Exposure Mitigation in US Residences: In-Home Measurements of Ventilation Control and Source Control. Indoor Air 2015, 25, 523–535.
- Andersen, I.B.; Lundqvist, G.R.; Mølhave, L. Indoor Air Pollution Due to Chipboard Used as a Construction Material. Atmospheric Environment (1967) 1975, 9, 1121–1127.
- Poppendieck, D.G.; Ng, L.C.; Persily, A.K.; Hodgson, A.T. Long Term Air Quality Monitoring in a Net-Zero Energy Residence Designed with Low Emitting Interior Products. Building and Environment 2015, 94, 33–42.
- Salthammer, T.; Fuhrmann, F.; Kaufhold, S.; Meyer, B.; Schwarz, A. Effects of Climatic Parameters on Formaldehyde Concentrations in Indoor Air. Indoor Air 1995, 5, 120–128.
- Zhao, H., Walker, I. , Sohn, M. and Less, B. 2022. A Time-Varying Model for Predicting Formaldehyde Emission Rates in Homes. International Journal of Environmental Research and Public Health (submitted)
- Zhao, H., Chan, W., Cohn, S., Delp, W., Walker, I. and Singer, B. 2021. Indoor Air Quality in New and renovated Low-Income Apartments with Mechanical Ventilation and Natural Gas Cooking in California. Indoor Air, 31(3). DOI: 10.1111/ina.12764
- Dennekamp, M., Howarth, S., Dick, C., Cherrie, J., Donaldson, K. and Seaton, A., 2001. Ultrafine particles and nitrogen oxides generated by gas and electric cooking. Occup Environ Med 2001; 58: 511-516
- Less, B. (2012). *Indoor Air Quality in 24 California Residences Designed as High Performance Green Homes*. University of California, Berkeley, Berkeley, CA. Retrieved from http://escholarship.org/uc/item/25x5j8w6
- Fisher-Nickel. 2013. Vollrath HIDC/HIMC Induction Range Comparison Appliance Test Report, Food Service Technology Center Report # 501311088-R0. San Ramon, CA.