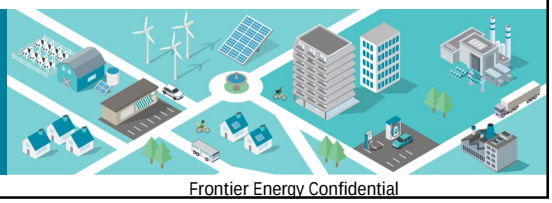
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IAQ Update: Field monitoring from LBNL and PSE on Indoor Air Pollutants and Kitchen Comfort

October 21st, 2026



Frontier Energy Confidential

FRONTIER energy

Food Service Tech Center

FrontierFSTC.com



Presentation by:
Richard Young
Director
ryoung@frontierenergy.com

Fossil fuel combustion creates pollutants.
Cooking equipment produces radiant heat.

What is the quantity of each?
What are the mitigation strategies?

Sneak Summary: Most IAQ and heat challenges can be mitigated with:

1. Better cooking equipment/cookline choices
2. Better kitchen ventilation design
3. Optimized & functioning kitchen ventilation

Intro

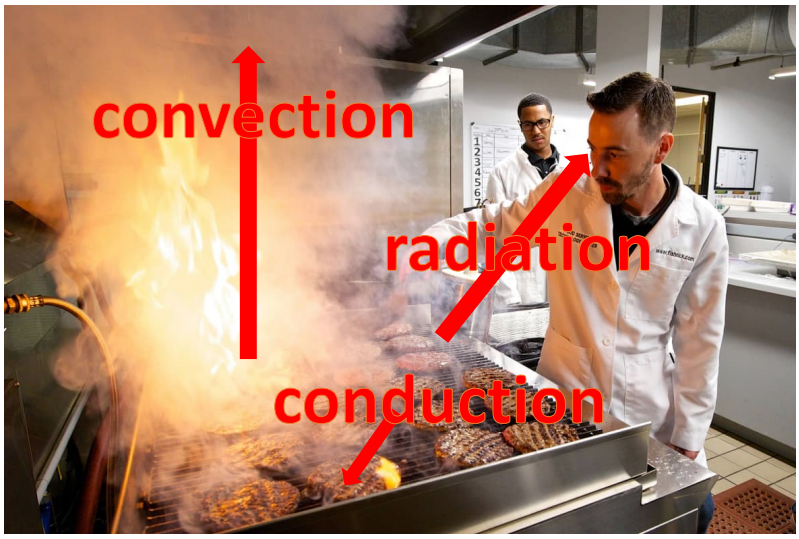
Some relevant basics before we get started....

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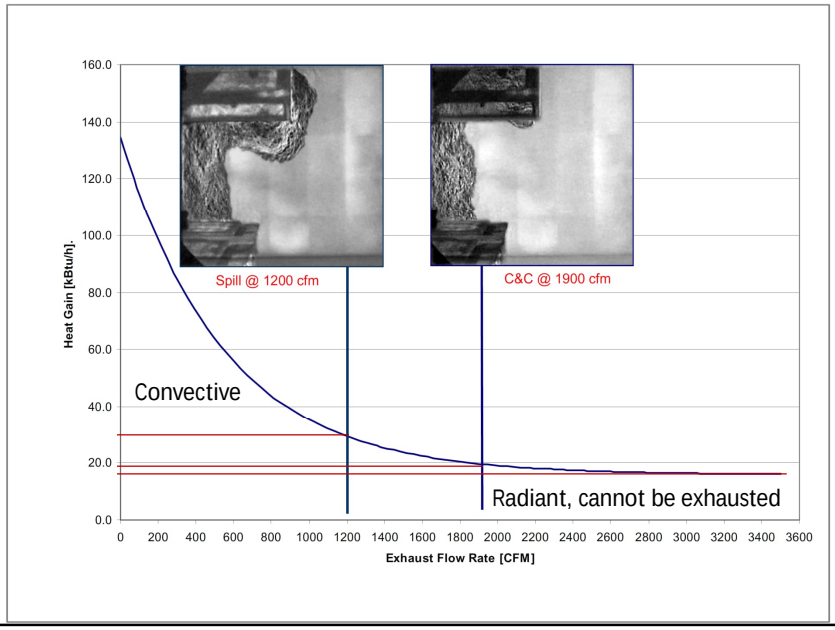
Food Service Tech Center

Commercial Kitchen Ventilation (CKV) Testing





Heat Gain Curve for Two 3ft Broilers



Not that big a difference between most electric and gas appliances but, big difference between appliance types

Table 5B Recommended Rates of Radiant Heat Gain from Hooded Electric During Idle (Ready-to-Cook) Conditions

	Energy Rate, Btu/h		Rate of Heat Gain, Btu/h	
Appliance	Rated	Standby	Sensible Radiant	U
Broiler: underfired 3 ft	36,900	30,900	10,800	
Cheesemelter*	12,300	11,900	4,600	
Fryer: kettle	99,000	1,800	500	
Fryer: open deep-fat, 1-vat	47,800	2,800	1,000	
Fryer: pressure	46,100	2,700	500	
Griddle: double sided 3 ft (clamshell down)*	72,400	6,900	1,400	
Griddle: double sided 3 ft (clamshell up)*	72,400	11,500	3,600	
Griddle: flat 3 ft	58,400	11,500	4,500	
Griddle-small 3 ft*	30,700	6,100	2,700	
Induction cooktop*	71,700	0	0	
Induction wok*	11,900	0	0	
Oven: combi: combi-mode*	56,000	5,500	800	
Oven: combi: convection mode	56,000	5,500	1,400	
Oven: convection full-size	41,300	6,700	1,500	
Oven: convection half-size*	18,800	3,700	500	
Pasta cooker*	75,100	8,500	0	
Range top: top off/oven on*	16,600	4,000	1,000	
Range top: 3 elements on/oven off	51,200	15,400	6,300	
Range top: 6 elements on/oven off	51,200	33,200	13,900	
Range top: 6 elements on/oven on	67,800	36,400	14,500	
Range: hot-top	54,000	51,300	11,800	
Rotisserie*	37,900	13,800	4,500	
Salamander*	23,900	23,300	7,000	
Steam kettle: large (60 gal) simmer lid down*	110,600	2,600	100	
Steam kettle: small (40 gal) simmer lid down*	73,700	1,800	300	
Steamer: compartment: atmospheric*	33,400	15,300	200	
Tilting skillet/braising pan	32,900	5,300	0	

Table 5C Recommended Rates of Radiant Heat Gain from Hooded Gas Appliances During Idle (Re

	Energy Rate, Btu/h		Rate of Heat Gain, Btu/h
Appliance	Rated	Standby	Sensible Radiant
Broiler: batch*	95,000	69,200	8,100
Broiler: chain (conveyor)	132,000	96,700	13,200
Broiler: overfired (upright)*	100,000	87,900	2,500
Broiler: underfired 3 ft	96,000	73,900	9,000
Fryer: doughnut	44,000	12,400	2,900
Fryer: open deep-fat, 1 vat	80,000	4,700	1,100
Fryer: pressure	80,000	9,000	800
Griddle: double sided 3 ft (clamshell down)*	108,200	8,000	1,800
Griddle: double sided 3 ft (clamshell up)*	108,200	14,700	4,900
Griddle: flat 3 ft	90,000	20,400	3,700
Oven: combi: combi-mode*	75,700	6,000	400
Oven: combi: convection mode	75,700	5,800	1,000
Oven: convection full-size	44,000	11,900	1,000
Oven: conveyor (pizza)	170,000	68,300	7,800
Oven: deck	105,000	20,500	3,500
Oven: rack mini-rotating*	56,300	4,500	1,100
Pasta cooker*	80,000	23,700	0
Range top: top off/oven on*	25,000	7,400	2,000
Range top: 3 burners on/oven off	120,000	60,100	7,100
Range top: 6 burners on/oven off	120,000	120,800	11,500
Range top: 6 burners on/oven on	145,000	122,900	13,600
Range: wok*	99,000	87,400	5,200
Rethermalizer*	90,000	23,300	11,500
Rice cooker*	35,000	500	300
Salamander*	35,000	33,300	5,300
Steam kettle: large (60 gal) simmer lid down*	145,000	5,400	0
Steam kettle: small (10 gal) simmer lid down*	52,000	3,300	300
Steam kettle: small (40 gal) simmer lid down	100,000	4,300	0
Steamer: compartment: atmospheric *	26,000	8,300	0
Tilting skillet/braising pan	104,000	10,400	400

Title 8 CCR Section 3396 – Indoor Heat Illness Prevention

- Some requirements of the standard:
  - Access to Water (c)
  - Access to Cool-Down Areas (d)
  - Implement control measure under certain conditions (e)
  - Acclimatization (g)
  - Employee and Supervisory Training (h)
  - Written Procedures Including Emergency Response (i)/(f)

Same as Outdoor except for Control Measures (e)

DIR State of California Department of Industrial Relations EST. 1927

CalOSHA Heat-Illness Regulation – Full Application

Entire regulation applies including subsection (e) – *Assessment and Control measures*

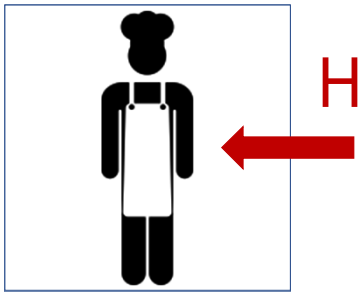
Temperature or Heat Index ≥ 87°F



CalOSHA Heat-Illness Regulation – Full Application

Entire regulation applies including subsection (e) – *Assessment and Control measures*

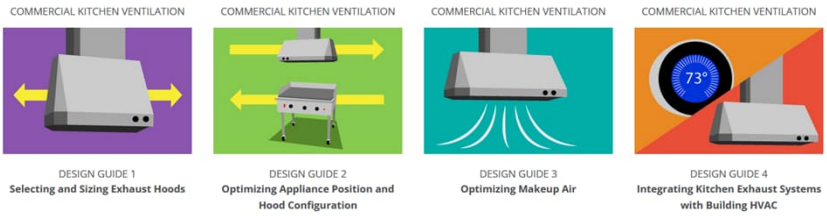
Temperature ≥ 82°F



High radiant heat area (+5°F)

CaEnergyWise.com/design-guides

Four Design Guides cover Kitchen Ventilation
These are very useful for plan checkers



There are also classes that explain how to use these Guides

Lawrence Berkeley National Labs (LBNL) Field Results



Jiayu Li
Postdoctoral Researcher
CBE

CBE
CENTER FOR THE BUILT ENVIRONMENT
UC Berkeley

Indoor Environmental Quality and Ventilation in Commercial Kitchens

Rengie Chan
LBNL

Angelo Karas, Todd Bell
Frontier Energy

Stefano Schiavon
CBE

Project overview

Objective

- Document indoor environmental quality
- Assess the ventilation performance and energy-saving potentials

Methods

- Physical measurements
- Subjective feedback from kitchen staff
- Energy audit and ventilation assessments

Funding

- U.S. Department of Energy



Generated with AI | Adobe Stock

Completed measurements in 10 restaurants

Locations

- San Francisco Bay Area (Berkeley, Lafayette, Oakland, San Francisco)

Restaurant types

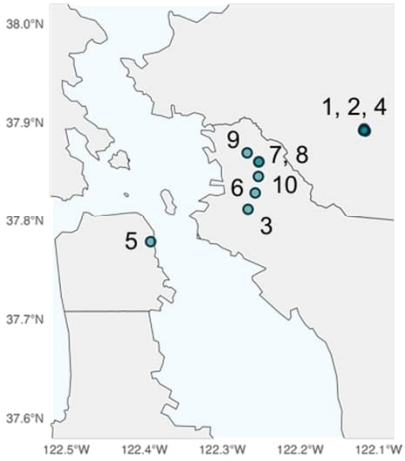
- Independent restaurants
- 6 fast casual; 4 full service
- Occupancy: 15 to 500 (median about 50)

Cooking locations

- 6 front; 3 back; 1 both front & back

Fuel types

- 8 Natural gas
- 2 Natural gas and firewood

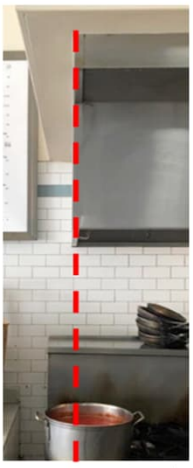


Kitchen locations (Map source: OpenStreetMap)

Assessment of exhaust hoods

- 18 hoods were evaluated in 10 kitchens
- 14 had airflow rate within the expected range per UL requirement
- Spillage or poor capture was observed in 6 out of 10 kitchens
- Unhooded cooking appliances


UL-listed hood with demand ventilation control


Range outside hood canopy


Unhooded double-stack convection ovens

Makeup air (MUA) and air conditioning systems

- Issues in MUA systems were identified in 9 of 10 kitchens
  - 1 kitchen has no MUA
  - Evaporative coolers in 7 kitchens either had no water feed or were in poor condition
  - 3 kitchens didn't have sufficient airflow supplied by MUA
- 5 of 10 kitchens had insufficient cooling capacity
- Dirty and crushed air filters



Evaporative cooler



Undersized ductless split system air handler



Dry evaporative media



Dirty and crushed air filters

Kitchen environment sampling

Indoor air quality

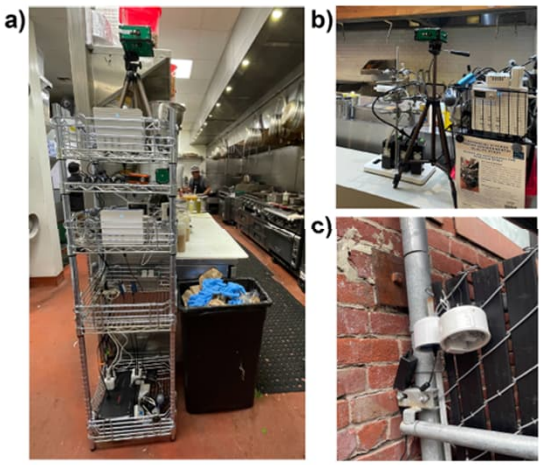
- Ultrafine particles (< 100 nm)
- PM2.5 (< 2.5 µm)
- NO_2 and CO
- Speciated VOCs and SVOCs

Thermal environment

- Air and mean radiant temperature
- Relative humidity
- Air velocity
- Radiant asymmetry

7-day sampling locations

- Indoor: near the main cooking activity on a multilayer shelving unit or in a stacked basket
- Outdoor: sheltered area near the kitchen



Setup of indoor instruments on a multi-layer shelving unit (a) or in a stacked basket (b) and outdoor instruments (c)

Indoor air quality – PM2.5

- Half of the kitchens had PM2.5 levels higher than the World Health Organization (WHO) guideline
- Cooking activities elevated the PM2.5 concentrations
- Poor ventilation and solid fuel burning potentially caused high levels of PM2.5 during cooking hours



Median and interdecile range of hourly PM2.5 concentrations under cooking (teal) and non-cooking (gray) conditions in 10 kitchens. Dots represent median values, and vertical bars represent the 10th to 90th percentile range.

Indoor air quality – Ultrafine particles

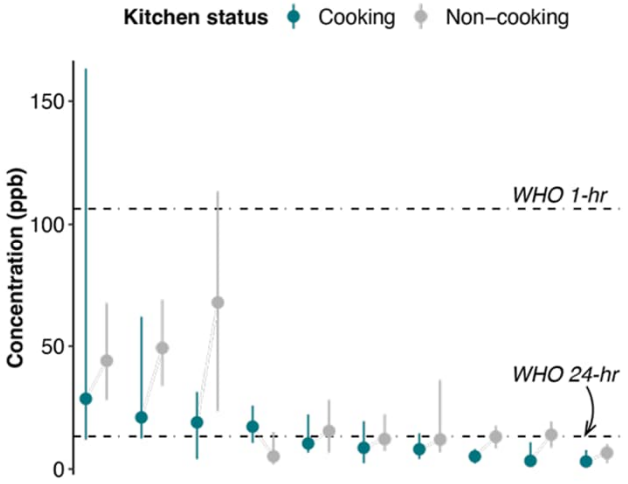
- All kitchens had ultrafine particle concentrations higher than the WHO guideline
- The levels during cooking hours were up to 20 times higher than non-cooking



Hourly ultrafine particle concentrations under cooking and non-cooking conditions in 10 kitchens.

Indoor air quality – NO2

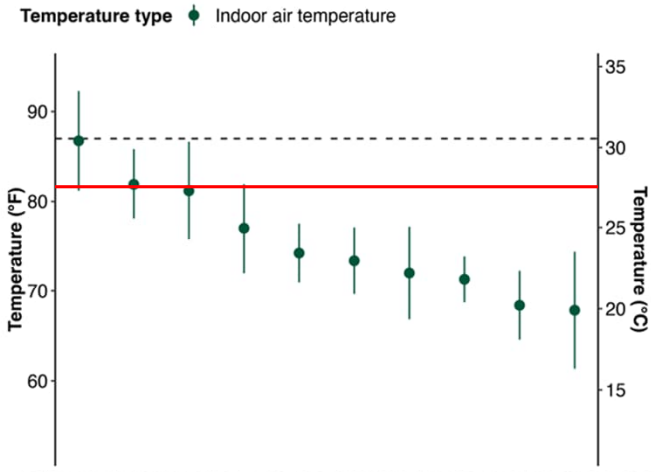
- Non-cooking NO2 concentrations higher than those during cooking hours
- In 8 kitchens, the non-cooking NO2 levels exceeded or approached the WHO 24-hr guideline



Hourly NO2 concentrations under cooking and non-cooking conditions in 10 kitchens.

Thermal environment

- High heat stress
  - Indoor air temperature > 70 °F
  - PMV > 2
- Indoor temperature higher than outdoors
  - Large cooling potentials through ventilation
- High and asymmetry radiant heat
  - 5/10 kitchens are high radiant spaces [Air and radiant temperature differences > 5 °F]
  - Difference between radiant temperatures from coolest and hottest walls was up to 25 °F



The horizontal dashed line indicates the air temperature thresholds that are subject to the provision of the Heat Illness Prevention Guidance (Cal/OSHA, 2024).

Summary

- **High indoor air pollution**

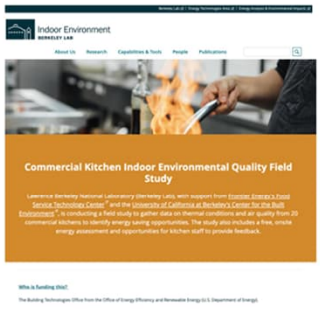
  During cooking hours, PM2.5 frequently and ultrafine particles consistently exceeded WHO guidelines. NO2 levels were higher during non-cooking hours.
- **Elevated heat stress**

  Kitchens experienced high indoor temperatures and radiant heat, potentially impacting worker comfort and health.
- **Inadequately maintained ventilation system**

  Most kitchens lacked adequate make-up air, contributing to poor capture of cooking pollutants and high heat stress.
- **Energy efficiency opportunities**

  Some energy-efficient equipment was found, and further adoption could reduce energy costs and emissions.

Project webpage



Please join the breakout session on

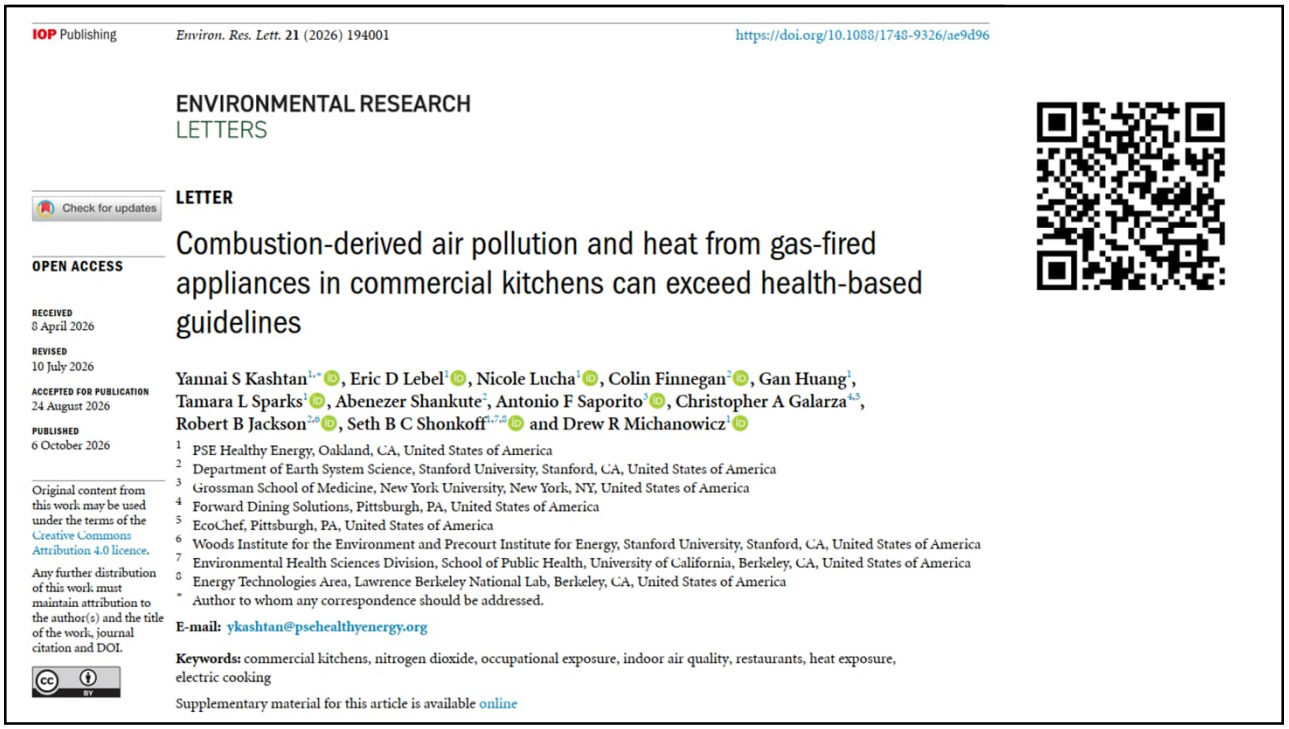
Indoor Environmental Quality in Less-Studied Building Types

Email: jiayu.li@berkerley.edu

15

Center for the Built Environment | April 2025

Physicians, Scientists, and Engineers for Healthy Energy (PSE Energy) Field Results



IOP Publishing Environ. Res. Lett. 21 (2026) 194001 https://doi.org/10.1088/1748-9326/ae9d96

ENVIRONMENTAL RESEARCH
LETTERS

LETTER

Combustion-derived air pollution and heat from gas-fired appliances in commercial kitchens can exceed health-based guidelines

Yannai S Kashtan[1,*], Eric D Lebel[1], Nicole Lucha[1], Colin Finnegan[2], Gan Huang[1], Tamara L Sparks[1], Abenezer Shankute[2], Antonio F Saporito[3], Christopher A Galarza[4,5], Robert B Jackson[2,6], Seth B C Shonkoff[1,7,8] and Drew R Michanowicz[1]

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Keywords: commercial kitchens, nitrogen dioxide, occupational exposure, indoor air quality, restaurants, heat exposure, electric cooking

Supplementary material for this article is available online

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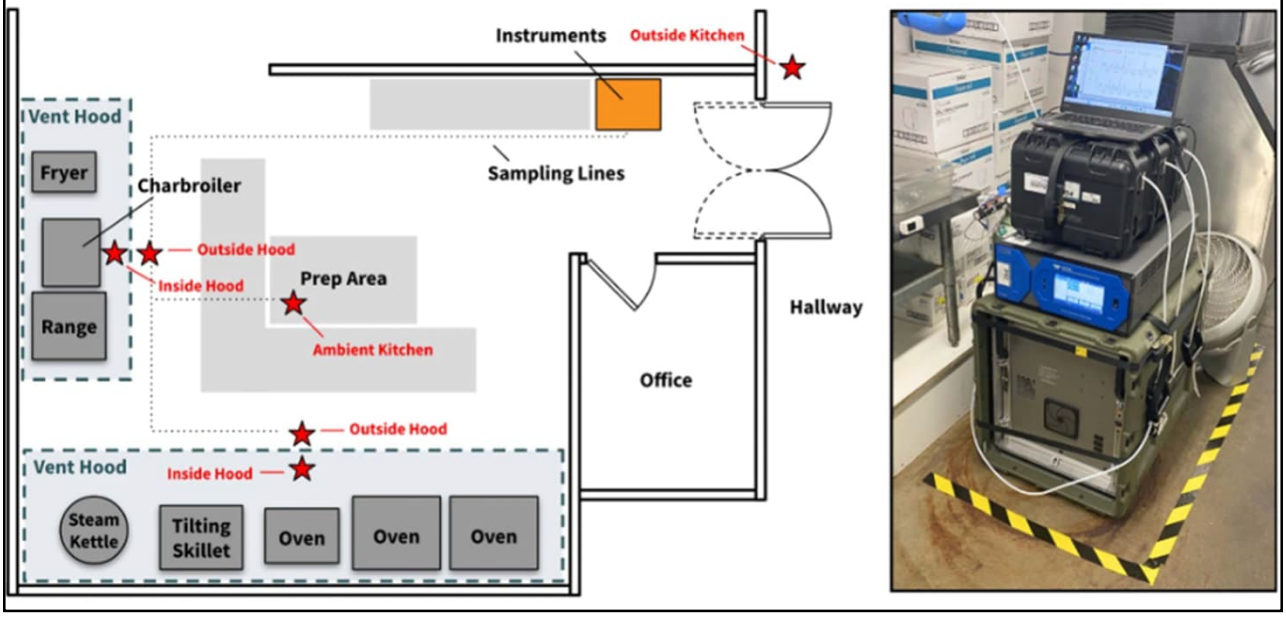
Kitchen characteristics and sample design

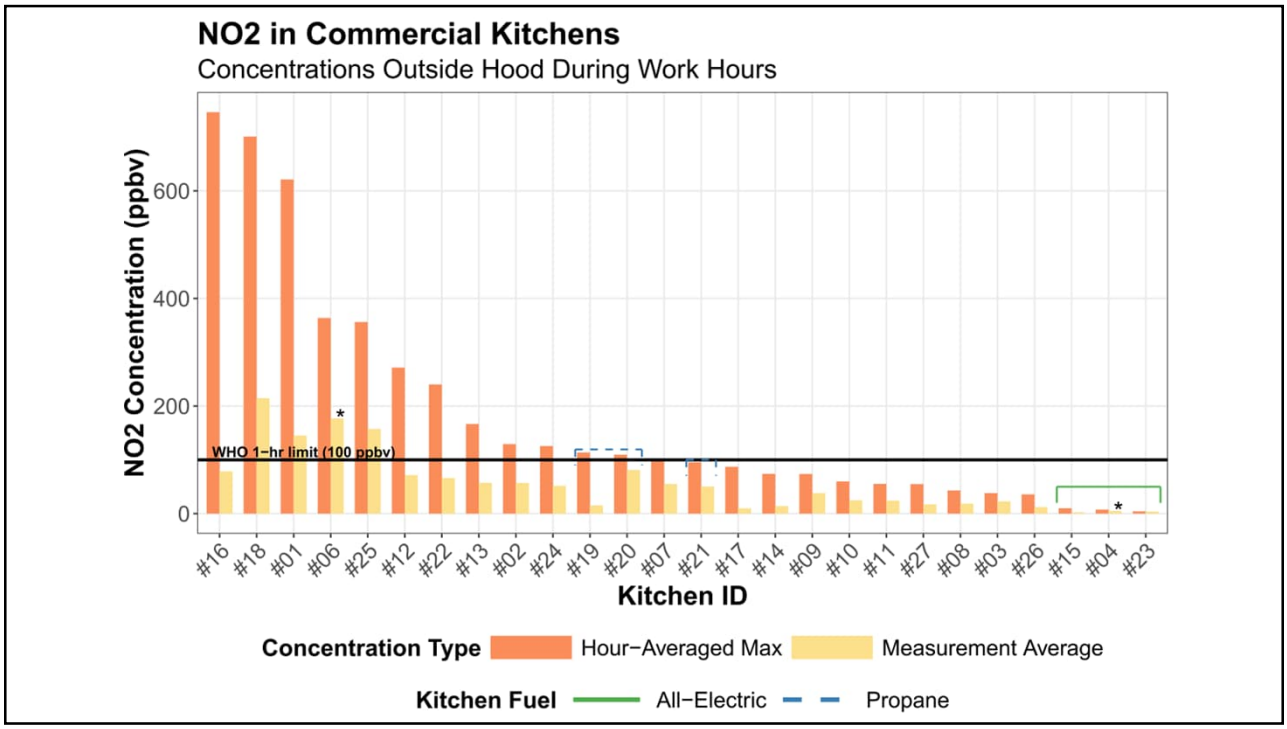
- 27 kitchens, three states (NY, CA, PA)
- Varied in cuisine, size, layout, appliances, CKV, and intensity
- 24 kitchens featured gas or propane
- 3 kitchens were fully electric
- Sampled in diverse commercial and institutional including
  - full-service restaurants (e.g. fine dining and casual),
  - specialty restaurants (e.g. pizza and Chinese cuisine),
  - catering facilities, and
  - institutional (senior living, university, and K–8 schools).

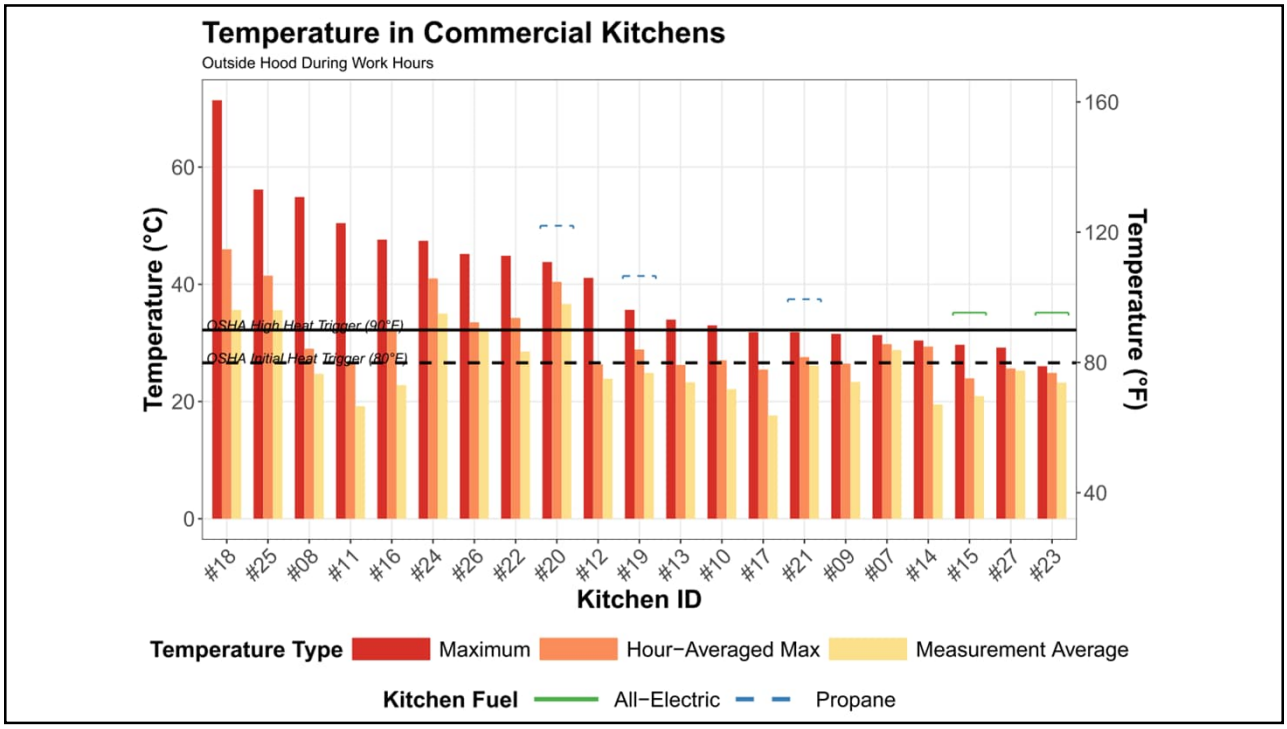
Sample design

- Durations ranged from 10 to 162 h per kitchen,
- Multiple meal services and overnight periods
- Focused on gas-phase pollutants attributable to gas combustion (e.g. NO2, CO, CO2, CH4, and benzene)
- Measured temperature in multiple locations and relative humidity in a central location

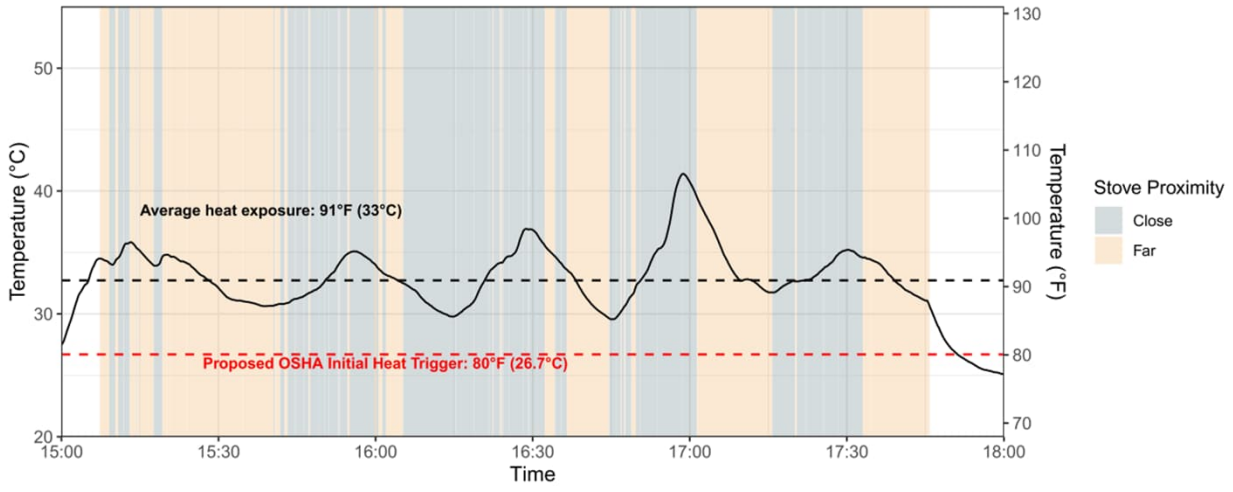
= Sampling Locations

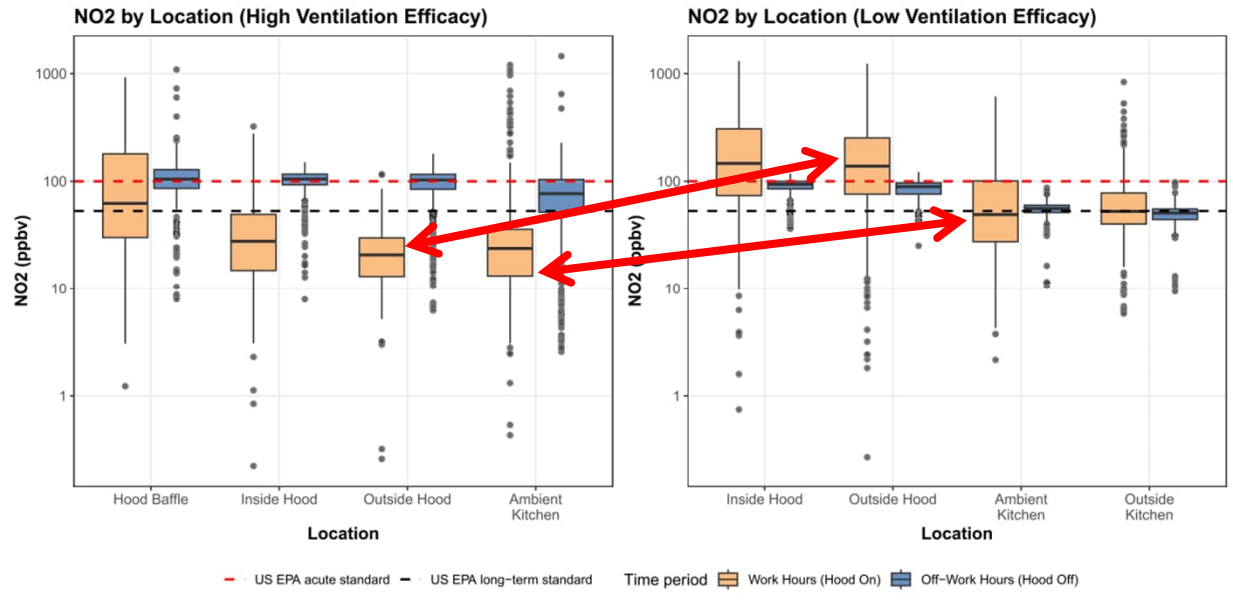



NO2 in Commercial Kitchens
Concentrations Outside Hood During Work Hours
NO2 Concentration (ppbv)
600
400
200
0
WHO 1−hr limit (100 ppbv)
*
*
#16 #18 #01 #06 #25 #12 #22 #13 #02 #24 #19 #20 #07 #21 #17 #14 #09 #10 #11 #27 #08 #03 #26 #15 #04 #23
Kitchen ID
Concentration Type
Hour−Averaged Max
Measurement Average
Kitchen Fuel
All−Electric
Propane


Temperature in Commercial Kitchens
Outside Hood During Work Hours
Temperature (°C)
60
40
20
0
160
120
80
40
Temperature (°F)
OSHA High Heat Trigger (90°F)
OSHA Initial Heat Trigger (80°F)
#18 #25 #08 #11 #16 #24 #26 #22 #20 #12 #19 #13 #10 #17 #21 #09 #07 #14 #15 #27 #23
Kitchen ID
Temperature Type
Maximum
Hour−Averaged Max
Measurement Average
Kitchen Fuel
All−Electric
Propane

Personal temperature monitoring of Chef working on gas range top. Close is less then 1 ft and Far is more than 1 ft



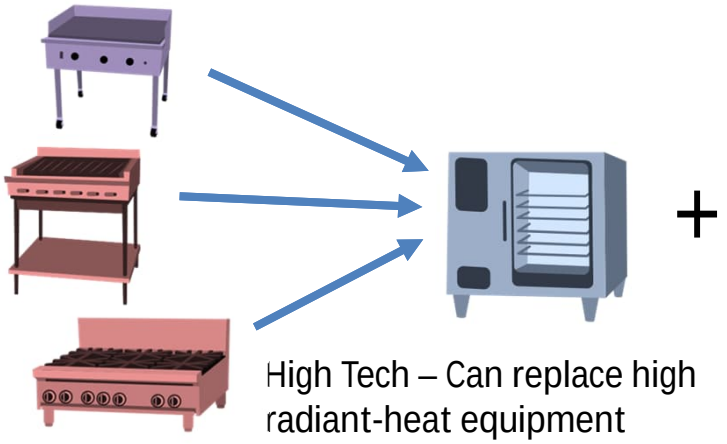


Summary

Three realities:

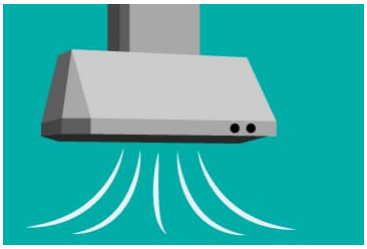
1. Kitchens are hotter than they should be
2. NO2 levels can be higher than WHO
3. Most kitchens have poor CKV

Kitchen discomfort and poor IAQ can be mitigated with high-tech equipment and better CKV



High Tech – Can replace high radiant-heat equipment

+



caenergywise.com/design-guides/

The Frontier Energy Food Service Tech Center has 40 years of experience researching energy and performance, solving real-world problems, and creating CFS resources.

Please take advantage of that experience!

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Thank you!

Richard Young
Director
RYoung@frontierenergy.com

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