California Energy Commission

CEC-Funded Indoor Air Quality Research to Measure Nitrogen Dioxide

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CARB's Workshop on Updating the Indoor Air Quality Guidelines for Nitrogen Dioxide

Human exposure to indoor nitrogen dioxide

- Sources: include **indoor fuel combustion** (gas stoves, ovens, water heaters).
- Impacts: Higher levels of NO_2 inside homes linked to **respiratory health effects.**
- **Precursor** to other pollutants such as ozone and fine particles.
- Ambient NO_2 is **regulated** by **health-based standards**.
- **No standards** agreed upon for NO_x in **indoor air,** but **guidelines exist.**

Nitrogen Dioxide	1-hour average (ppb)	Annual average (ppb)	24-hour average (ppb)	Long-term average (ppb)
NAAQS (Outdoor)	**100**	53	-	-
CAAQS (Outdoor)	180	**30**	-	-
CARB IAQ Guidelines (2005)	250	-	80	-
Canadian IAQ Guidelines (2015)	90	-	-	11
WHO AQ Guidelines (2021)	106	5	13	-

Source: U.S. EPA, CARB, Health Canada, WHO

Title 24 Part 6 and Indoor Air Quality

- **Authority for Indoor Air Quality**

  PRC 25402.8 Indoor air pollution; assessment of new building standards

  "When assessing new building standards for residential and nonresidential buildings relating to the conservation of energy, the commission shall include in its deliberations the impact that those standards would have on indoor air pollution problems."

- The Energy Code (Part 6) contains requirements to **improve indoor air quality**.
- Dwelling unit **mechanical ventilation** has been **required** in new homes since the 2008 California Title 24 BEES.
  - The standard also requires exhaust ventilation in each bathroom and **either a venting range hood or an exhaust fan in the kitchen.**

Source: Warren-Alquist Act 2023 Edition, 2025 Building Energy Efficiency Standards

Extensive CEC-funded Research Re: AQ& Health

- Wei, M et al (2022, in press) *Building Healthier and More Energy-Efficient Communities in Fresno and the Central Valley: Developing a holistic community action plan to improve access to clean energy technologies.* Forthcoming Final Report from EPC-17-035.
- Singer, BC et al (2021) *Effective Kitchen Ventilation for Healthy Zero Net Energy Homes with Natural Gas*. CEC-500-2021-005.
- Walker, I, B Less, S Dutton, D. Lorenzetti, M. Sohn (2020) *Smart Ventilation for Advanced California Homes*. CEC-500-2020-050.
- Chan et al (2020) *Ventilation and Indoor Air Quality in New California Homes with Gas Appliances and Mechanical Ventilation*. CEC-500-2020-023.
- Chan et al. (2019) *Measurement and control of ventilation rates in commercial buildings in California.* CEC-500-2019-056.
- Alexander, M et al. 2019. *Air Quality Implications of an Energy Scenario for California Using High Levels of Electrification*. CEC-500-2019-049.
- Singer, B (2017) *Emissions, indoor air quality impacts, and mitigation of air pollutants from natural gas appliances.* CEC-500-2017-034.
- Singer et al. (2013) *Natural Gas Variability in California: Environmental Impacts and Device Performance: Experimental Evaluation of Installed Cooking Exhaust Fan Performance*. CEC-500-2013-033.
- Fisk, WJ et al (2014). *Integrating Energy and IEQ Retrofits in Apartments*. CEC-500-2014-084.
- Fisk, WJ (2013) *Demand-controlled ventilation and classroom ventilation.* CEC-500-2013-057.
- Sherman, M (2013) *Residential energy savings from air tightness and ventilation excellence (RESAVE).* CEC-500-2014-014.
- Walker, I (2013) *Energy implications of in-line filtration in California.* CEC-500-2013-081.
- Webster, T (2013) *A Prototype toolkit for evaluating indoor environmental quality in commercial buildings.* CEC-500-2013-141.
- Apte, MG (2012) *Improving ventilation & saving energy: final report on indoor environmental quality & energy monitoring in sixteen relocatable classrooms.* CEC-500-2012-075.
- Bennett et al. (2011) *Indoor environmental quality and heating, ventilating, and air conditioning survey of small and medium size commercial buildings: field study.* CEC-500-2011-043.
- Levin, H, Phillips, T (2011) *Indoor environmental quality research roadmap 2012-2030: energy-related priorities.* CEC-500-2015-012.
- Apte, MG (2010) *Predicted indoor air quality and energy consumption for big box stores in California.* CEC-500-2014-034.
- Offermann, F (2009) *Ventilation and Indoor Air Quality in New Homes.* CEC-500-2009-085.
- Lapsa, MV (2008) *Market analysis for healthy air HVAC systems in California.* CEC-500-2007-031.
- Linden et al. (2008) *Simplified models for particulate dispersion in buildings*. CEC-500-2007-098.
- Walker, IS, Sherman, MK (2008) *Evaluation of existing technologies for meeting residential ventilation requirements.* CEC-500-2007-051.
- Frey, D, Smith, V (2007) *Advanced HVAC systems for improving the indoor environmental quality and energy performance of California K-12 schools.* CEC-500-2007-006.
- Singer, B (2007) *Natural Gas Variability in California: Environmental Impacts and Device Performance.* CEC-500-2006-110.
- Gadgil, A (2006) *Indoor-outdoor air leakage of apartments and commercial buildings.* CEC-500-2006-111.

Highlights from Early CEC-Funded Energy-Related Air Quality Research

Highlights of Recent Air Quality Research

Ongoing Work and Future Research

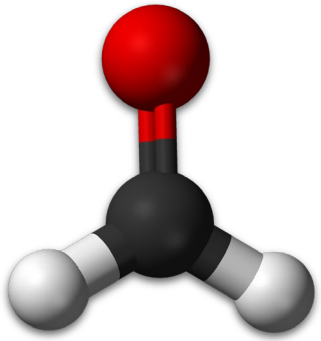
Conclusions

Early Field Study of Air Quality in New Homes

Measured indoor [NO_2] was below the 150 µg/m^3 (80 ppb) indoor NO_2 guideline (CARB 2005) in most homes (n=29).

Established need for mechanical ventilation in tightly sealed new homes.

Field data **informed CEC's 2008 Building Energy Efficiency Standards**.



High concentrations of formaldehyde and other VOCs that exceeded recommended guidelines.

Source: Offermann, F. 2009. *Ventilation and Indoor Air Quality in New Homes.* CEC-500-2009-085. http://web.archive.org/web/20170128040253/http://www.energy.ca.gov/2009publications/CEC-500-2009-085/CEC-500-2009-085.PDF

Residential Energy Savings from Air Tightness and Ventilation

Unvented natural gas cooking significantly affects occupant exposures on **acute and chronic exposure time frames**.

When a **range hood** was used, the % of homes exceeding health-based thresholds for **NO_2 was reduced from 52% to 15%.**

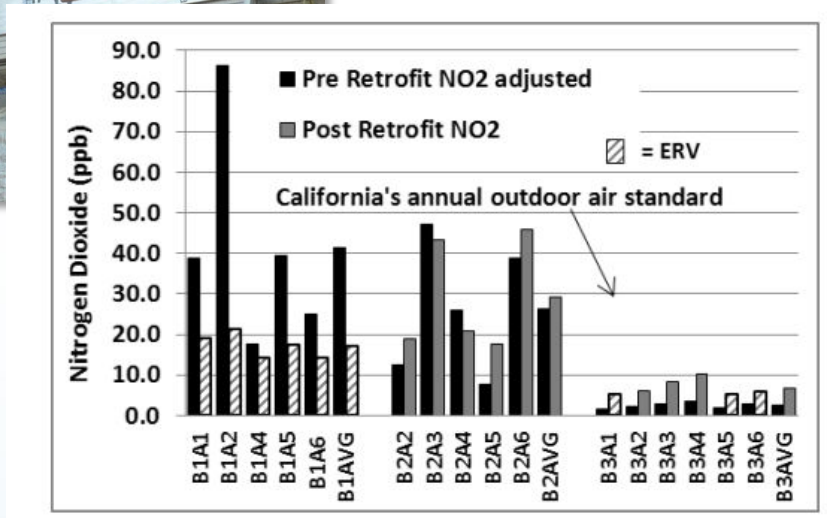
Health impacts of indoor air pollution in California estimated to be $15B-$40B/year.

Commissioning of ventilation systems is critical to ensure ventilation require-ments are met.

Source: *Sherman, M et al. 2013. Residential Energy Savings from Air-Tightness and Ventilation Excellence (RESAVE). CEC-500-2014-014.*

Integrating Energy & Indoor Environmental Quality Retrofits in Apartments

NO_2 concentrations



- From the sample (n=16 apartments), in the apartments with gas stoves (5), the **average indoor concentration of NO_2** decreased 58% after the **retrofits** including:
  - replacement of the stove to eliminate the pilot lights,
  - addition of range hoods that vented to outdoors, and
  - increases in apartment ventilation rates.

***Source**: Fisk, W.J. et al. 2014 Integrating Energy and IEQ Retrofits in Apartments. CEC-500-2014-084.*

Indoor Air Quality Impacts from Natural Gas Appliances

Time-averaged **NO_x and NO_2 concentrations were higher** in homes with **natural gas** versus **electric cooking** and increased with the amount of gas cooking (n=352).

Moderate cooking burner use produced NO_2 concentrations that **exceeded the 1-hour outdoor air quality standard** in many homes.

In households that cooked 4 hours or more with gas, reported use of kitchen exhaust was associated with lower pollutant concentrations.

Controlled experiments on advanced technology water heaters showed an increase in NO_X emissions with increasing Wobbe number.

***Source**: Singer, B.C. et al. 2017. Emissions, Indoor Air Quality Impacts, and Mitigation of Air Pollutants from Natural Gas Appliances. CEC-500-2017-034.*

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Air Quality in New California Homes with Gas Appliances and Mechanical Ventilation

Measured NO_2 concentrations (n=67) were well below the NAAQS standards

Ventilation systems often mislabeled and not used as intended.

When T24 equipment was used properly, most new homes met air flow requirements.

Source: *Chan, WR et al. 2020. Ventilation and Indoor Air Quality in New California Homes with Gas Appliances and Mechanical Ventilation. CEC-500-2020-023.* https://www.energy.ca.gov/sites/default/files/2021-05/CEC-500-2020-023.pdf

Direct Support for 2022 Building Energy Efficiency Standards (BEES)

Using gas cooking burners produced **high short-term** and **weekly time-averaged NO_2 in apartments than homes**; in a substantial minority of apartments, concentrations may exceed health-based limits.

Provided health-protective (NO_2 and $PM_{2.5}$) "capture efficiency" framework for BEES.

Table 150.0-G Kitchen Range Hood Airflow Rates (cfm) and ASTM E3087 Capture Efficiency (CE) Ratings According to Dwelling Unit Floor Area and Kitchen Range Fuel Type

Dwelling Unit Floor Area (ft^2)	Hood Over Electric Range	Hood Over Natural Gas Range
>1500	50% CE or 110 cfm	70% CE or 180 cfm
>1000 - 1500	50% CE or 110 cfm	80% CE or 250 cfm
750 - 1000	55% CE or 130 cfm	85% CE or 280 cfm
<750	65% CE or 160 cfm	85% CE or 280 cfm

Source: 2022 BEES

If high-capture hoods are installed and used more consistently, benefits could exceed $200M.

***Source**: Singer, BC (2021) Effective Kitchen Ventilation for Healthy Zero Net Energy Homes with Natural Gas. CEC-500-2021-005.*
https://www.energy.ca.gov/publications/2021/effective-kitchen-ventilation-healthy-zero-net-energy-homes-natural-gas

Residential Electrification Transition Findings

Concentrations of NO_2 in several homes exceed health-based thresholds.

Residential electrification can significantly improve local air quality.

***Source**: Fournier, E.D. et al. (2022, forthcoming). Using Big Data to Holistically Assess Benefits from Building Energy System Transition Pathways in Disadvantaged Communities.* Final Report from EPC-17-050.

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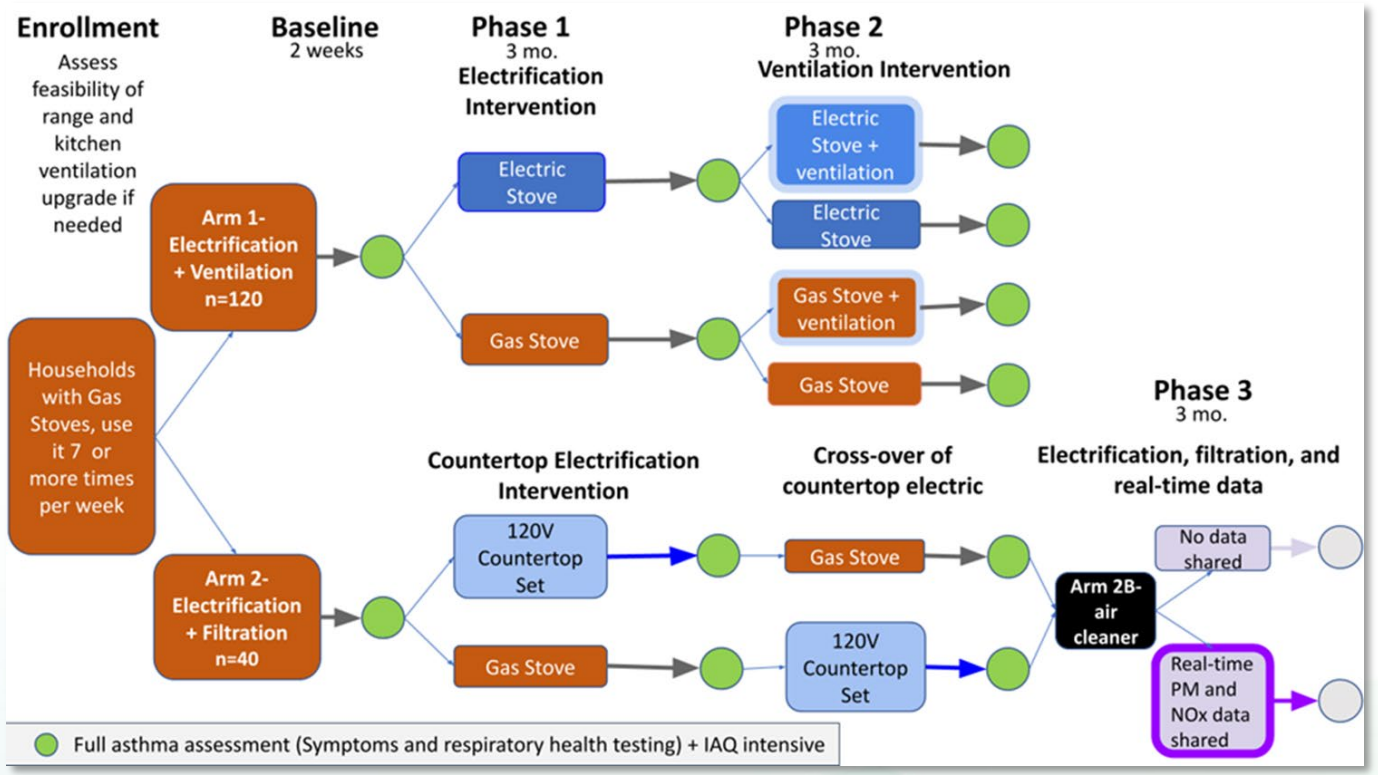
Cooking Electrification and Ventilation Improvements for Children's Asthma (CEVICA) Study

- **Purpose**: Investigate impact of kitchen electrification on children with asthma in under-resourced communities in California.
- **Objectives**:
  - Quantify the separate and synergistic benefits of multiple kitchen electrification interventions.
  - Quantify the exposure reduction and asthma control benefits.
  - Develop recommendations to accelerate residential kitchen electrification.

Schematic showing CEVICA study design (EPC-21-033, LBNL).

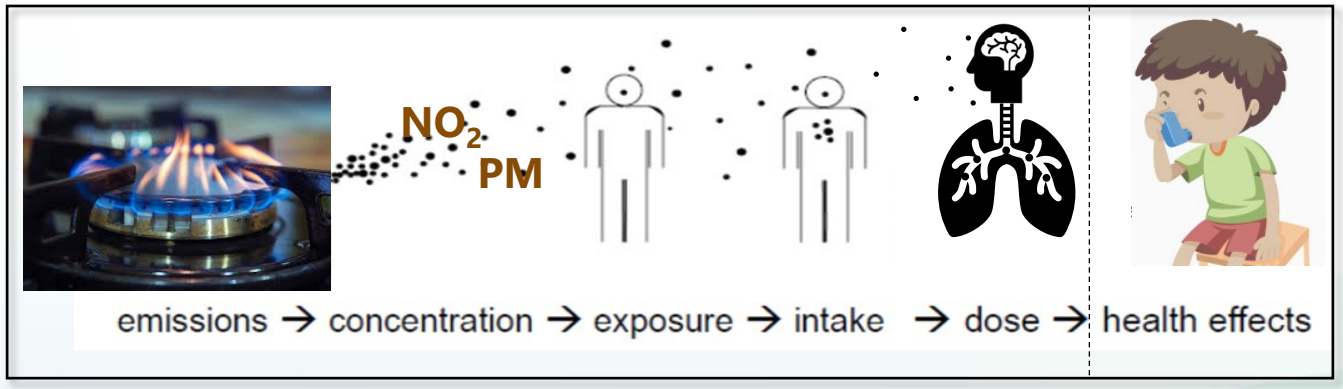


Source: *Agreement EPC-21-033, LBNL*

Quantify Exposures to Indoor Pollutants in Multifamily Homes

- **With Gas R&D Funding, we will advance our understanding of:**
  - Quantification of exposures to pollutants from gas cooking appliances.
  - An empirical basis for exposure assessment in multifamily units cooking with gas or alternatives.
  - Understanding of potential health impacts of cooking-generated PM in MF homes that burn gas vs electricity.

Emissions to health effects framework



Staff Workshop: Quantify Indoor Air Pollutants in Multifamily Homes that Cook with Gas Stoves or Alternatives

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Title 24 BEES and Air Quality Guidelines

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Conclusions

- Consistent findings that many homes with **unvented gas ranges** frequently **exceed** health-based ambient **standards for NO_2.**

- Existing **Title 24 BEES requirements for mechanical ventilation** keep NO_2 concentrations **well below NAAQS for larger homes.**

- Use of **pollutant-based capture efficiencies** for kitchen range hood (at multiple tiers of home size) in the 2022 Title 24 BEES requirements:
  - protects **residents' health**, especially in the most "vulnerable" homes.
  - can avoid extraneous **energy costs** (e.g., for larger homes).

- Challenges:
  - Old building stock
  - Operational deficiencies with mechanical ventilation systems in low-income homes

Further Research Needs

- More research is needed to:
  - **characterize emissions** from **cooking activities** regardless of fuel type.
  - estimate **health-related monetized impacts** of clean energy interventions that eliminate sources of NO_2 and other emissions.
  - develop **ventilation and control strategies** that are **effectively used by California residents**.
  - evaluate optimum ventilation rate by pollutant type (NO_2, PM) and housing type to maximize health benefits and lower energy costs.

THANK YOU

QUESTIONS?

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