



Challenges to Provide Adequate Ventilation in Buildings

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**Presented at the 2018 Conference on Health,
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INDOOR AIR QUALITY

SCIENTIFIC FINDINGS RESOURCE BANK



Topics



Building Ventilation

Ventilation is the supply of outdoor air to a building. This section discusses how ventilation rates influence indoor air quality and occupant health and performance.



Dampness and Mold

Topics discussed include the causes of excess building dampness, the influence of dampness on indoor biological and organic chemical contaminants, and the effects of dampness and of dampness-related indoor contaminants on people's health.



Volatile Organic Compounds

Indoor volatile organic compounds, or VOCs, are carbon-containing organic chemicals emitted from a variety of sources. The implications of indoor VOCs for health are addressed.



Human Performance

This section discusses how the performance of office and school work is affected by indoor environmental conditions and by the features of buildings that influence indoor environmental conditions.



National-Level Opportunities

This section provides estimates at the national level of some of the benefits and costs of taking practical steps to improve indoor environmental conditions in U.S. buildings.



Air Cleaning

Indoor air cleaning is the process of intentionally removing pollutants from indoor air, or from the outdoor air as it enters a building. This section of the web site addresses the relationship of air cleaning to health and perceived air quality, focusing on application of air cleaning to buildings outside of the health care and industrial sectors.



Climate Change

Climate change will modify outdoor environmental conditions which, in turn, will modify indoor environmental quality (IEQ).



IAQ in Schools

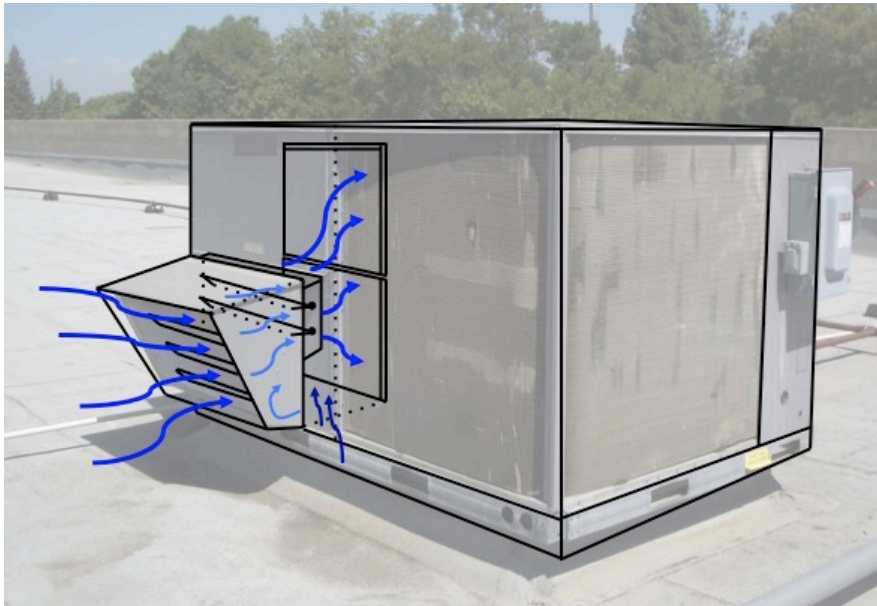
This section provides an overview of indoor air quality (IAQ) in schools and its influence on the health, performance, and absence of

iaqsicence.lbl.gov

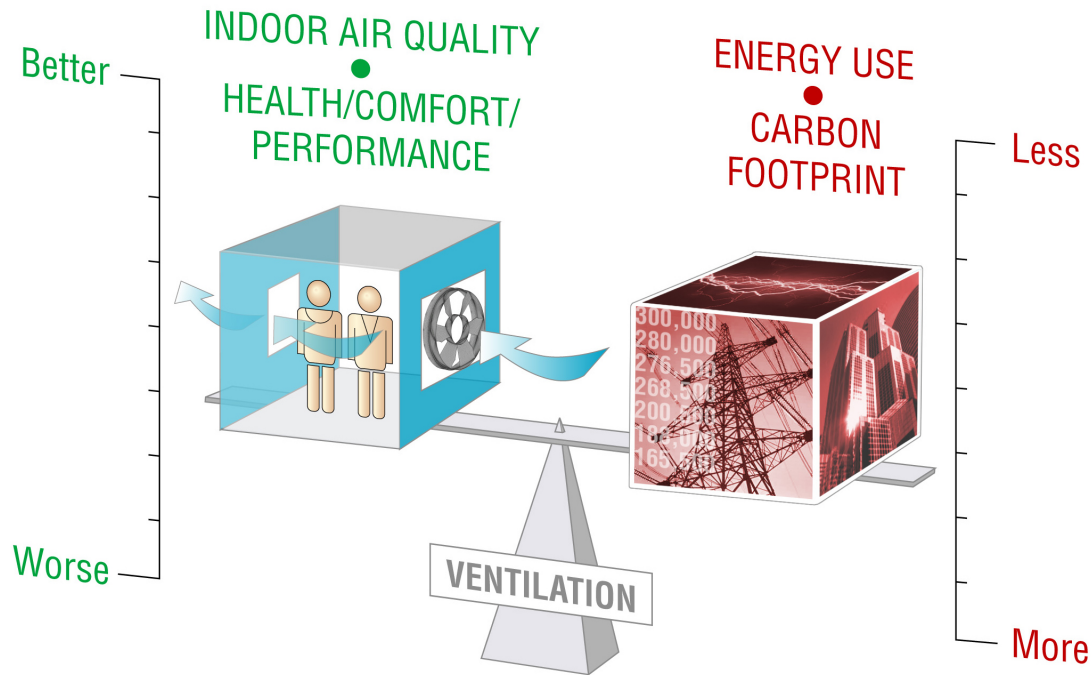
- A resource of scientific information about the effects of IAQ on people's health or work performance for health & building professionals, and general public.
- Critical reviews, summary findings of relevant key research papers, and new statistical analyses of available data.
- Updated periodically with funding support from the U.S. Environmental Protection Agency.

Building Ventilation

Ventilation is the supply of outdoor air to a building.



Building Ventilation



Outdoor air ventilation rates affect building energy use, indoor air quality, health and performance of people.

Building Ventilation

Poor ventilation control is a common problem in many types of buildings.





ASHRAE STANDARD

Ventilation for Acceptable Indoor Air Quality

“Laboratory and field studies have shown that with sedentary persons about 15 cfm (7.5 L/s) per person of outdoor air will dilute odors from human bioeffluents to levels that will satisfy a substantial majority (about 80%) of unadapted persons (visitors) to a space.”

TABLE 6-1 MINIMUM VENTILATION RATES IN BREATHING ZONE

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values		
						Occupant Density (see Note 4)	Combined Outdoor Air Rate (see Note 5)	
	cfm/person	L/s·person	cfm/ft ²	L/s·m ²		#/1000 ft ² or #/100 m ²	cfm/person	L/s·person
Office Buildings								
Breakrooms	5	2.5	0.12	0.6		50	7	3.5
Main entry lobbies	5	2.5	0.06	0.3		10	11	5.5
Occupiable storage rooms for dry materials	5	2.5	0.06	0.3		2	35	17.5
Office space	5	2.5	0.06	0.3		5	17	8.5

A New Framework to Setting Ventilation Rate Standards

- Evidence-based = consider a range of human effects with demonstrated relationship to ventilation rates
- Proposed framework provides more comprehensive protection for occupants than prior standards

- Poor perceived IAQ

+

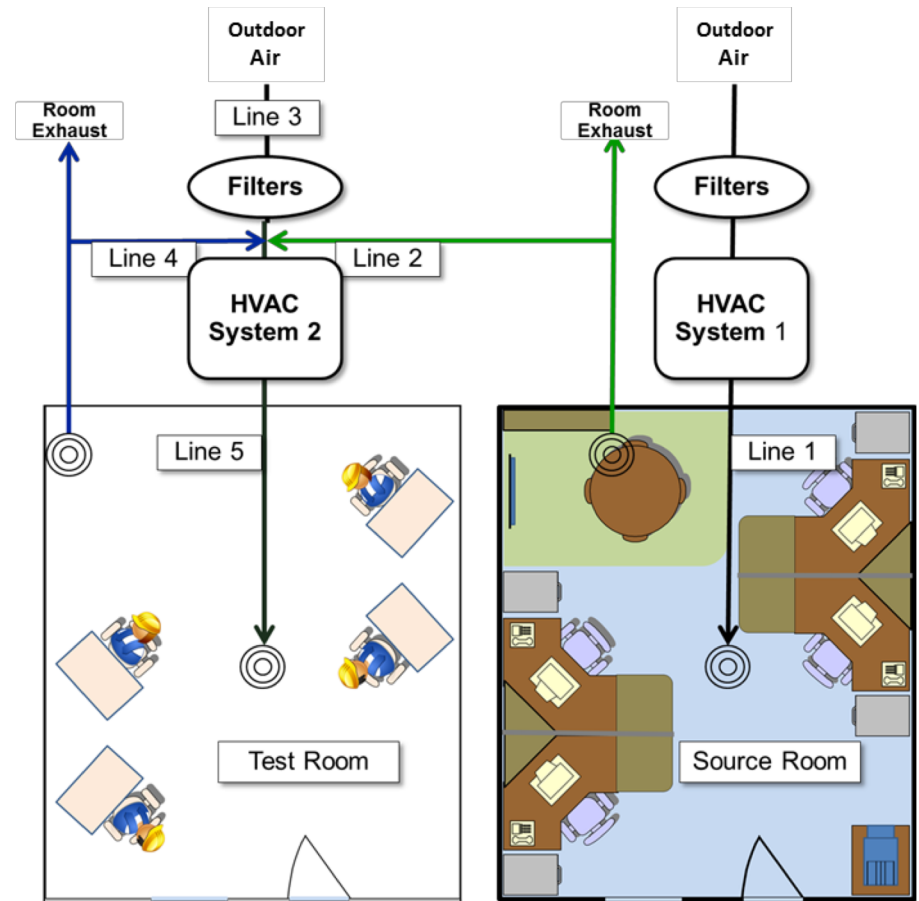
- Building-related symptoms
- Work performance
- Chronic health outcomes



Work is funded by the California Energy Commission to develop scientific information for setting building ventilation standards that balance energy efficiency while maintaining acceptable IAQ.

Building Ventilation Impact on Occupant Outcomes and Decision Making

- In a laboratory study, the per-person and per-floor area ventilation rate was independently varied
- Study subjects were surveyed on perceived air quality (PAQ), sick building syndrome (SBS) symptoms, and decision-making performance (SMS)
- Collaboration with SUNY (Usha Satish, Psychiatry and Behavior Science)



Study Finding Strategic Management Simulation (SMS) tests showed highly statistically significant improvement in decision-making performance at higher ventilation rates.

Simple competencies

- Speed of response
- Activity
- Task orientation

Intermediate level capabilities

- Initiative
- Emergency responsiveness
- Use of information

Highly complex thought/action

- Breath of approach to problems
- Planning capacity
- Strategy

COMMERCIAL BUILDING VENTILATION EFFECTS ON INDOOR AIR QUALITY, HUMAN HEALTH AND PERFORMANCE, AND BUILDING ENERGY USE AND IMPLICATIONS FOR FUTURE VENTILATION STANDARDS

Prepared for: California Energy Commission
Prepared by: Lawrence Berkeley National Laboratory



JULY 2016
CEC-500-2016-048

Chan, et al. (2014). Contaminant levels, source strengths, and ventilation rates in California **retail stores**. *Indoor Air*.

Chan, et al. (2015). Modeling the effect of ventilation and filtration on **chronic health risks** in U.S. offices, schools, and retail stores. *Indoor Air*.

Dutton and Fisk (2014) **Energy and indoor air quality** implications of alternative minimum ventilation rates in California offices. *Building and Environment*.

Dutton, et al. (2014) Evaluation of the Indoor Air Quality Minimum **Ventilation Rate Procedure** for Use in California Retail Buildings. *Indoor Air*.

Mendell, et al. (2015) A longitudinal study of ventilation rates in California office buildings and self-reported occupant outcomes including **respiratory illness absence**. *Building and Environment*.

Sidheswaran, et al. (2013) **Formaldehyde emissions from ventilation filters** under different relative humidity conditions. *ES&T*.



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WESTERN COOLING EFFICIENCY CENTER



In our recent study of 104 California classrooms with single-zone HVAC replacements between 2013-2016, **65% of classrooms had evaluated CO₂** (above 1100 ppm), suggesting inadequate ventilation despite new HVAC equipment.

The ventilation problem in schools: literature review

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Abstract

Based on a review of literature published in refereed archival journals, ventilation rates in classrooms often fall far short of the minimum ventilation rates specified in standards. There is compelling evidence, from both cross-sectional and intervention studies, of an association of increased student performance with increased ventilation rates. There is evidence that reduced respiratory health effects and reduced student absence are associated with increased ventilation rates. Increasing ventilation rates in schools imposes energy costs and can increase heating, ventilating, and air-conditioning system capital costs. The net annual costs, ranging from a few dollars to about 10 dollars per person, are less than 0.1% of typical public spending on elementary and secondary education in the United States. Such expenditures seem like a small price to pay given the evidence of health and performance benefits.

KEYWORDS

carbon dioxide, costs, health, performance, schools, ventilation

Ventilation Rates and Student Performance & Health

8 of 11 studies reported statistically significant ($p < 0.05$) improvements in some measure(s) of student performance with increased ventilation rates or lower CO₂ concentrations.

8 of 11 studies report statistically significant ($p < 0.05$) improvements in some health symptom(s) with increased ventilation rates.

4 of 5 studies report statistically significant ($p < 0.05$) decreases in absence rates with more ventilation or lower CO₂ concentrations.

Steps for HVAC Replacement (and where ventilation goes wrong)

Design and Equipment Selection

Equipment must be capable of providing ventilation rates for high occupant density classrooms

Installation

Ventilation equipment must installed correctly and accurately connected to control system

Commissioning and Acceptance Testing

*Ventilation system settings must be configured
Control system must be programmed correctly*

Maintenance and Operation

*Filters must be changed regularly
Teachers need instruction on system operation*

Installation Considerations for Ventilation

School starts
next week!



- Ventilation Equipment must
 - Be installed, powered, and connected correctly to control system
 - Have the correct damper settings programmed
 - Have the correct thermostat or EMCS settings

Commissioning and Acceptance Testing Ventilation

- **Title 24, Part 6 §120.5(a) Required Nonresidential Mechanical System Acceptance**
 - **NA 7.5.1 Outdoor Air**
 - **NA 7.5.2 Constant-volume, single-zone, AC and HPs**
 - **Also: Duct leakage (<15%), Economizers, Demand Control Ventilation Systems**

STATE OF CALIFORNIA OUTDOOR AIR ACCEPTANCE CEC-NRCA-MCH-02-A (Revised 07/16)	
CERTIFICATE OF ACCEPTANCE	
Outdoor Air Acceptance	
Project Name:	Enforcement Agency:
Project Address:	City:
System Name or Identification/Tag:	System Location:
<p><i>Note: Submit one Certificate of Acceptance for each system that must demonstrate compliance.</i></p>	

STATE OF CALIFORNIA CONSTANT VOLUME, SINGLE ZONE, UNITARY AIR CONDITIONER AND HEAT PUMP SYSTEMS CEC-NRCA-MCH-03-A (Revised 07/16)	
CERTIFICATE OF ACCEPTANCE	
Constant Volume, Single Zone, Unitary (Packaged and Split) Air Conditioning System	
Project Name:	Enforcement Agency:
Project Address:	City:
System Name or Identification/Tag:	System Location:
<p><i>Note: Submit one Certificate of Acceptance for each system that must demonstrate compliance.</i></p>	

Commissioning and Acceptance Testing Ventilation

- Highlights of acceptance testing
 - **MEASURE** Outdoor air rate for each unit and confirm it's within $\pm 10\%$ of design
 - Confirm control system is programmed correctly
 - Ventilation, heating, and cooling are all functioning
 - Teachers know when heating or cooling is broken. Teachers perceptions of IAQ do not correlate to measured data.
Teachers can not detect broken ventilation systems.



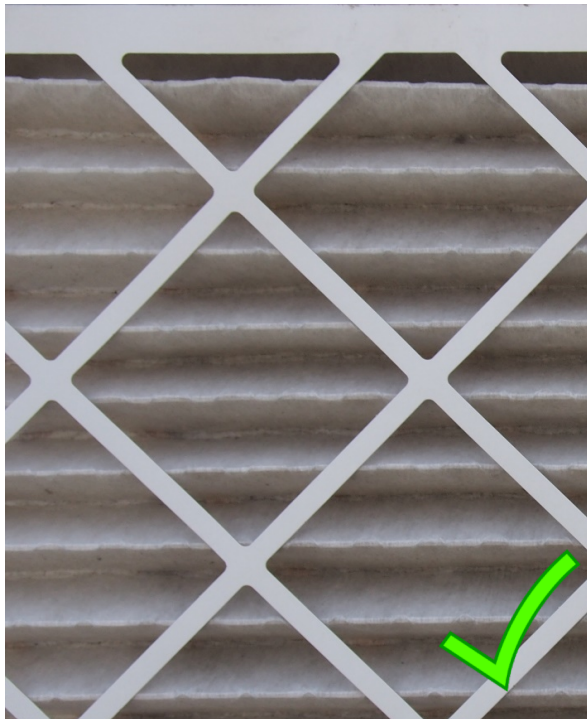
Flow capture hood to measure outdoor air rate

Educating Teachers

- One-third of teachers surveyed said that HVAC noise interfered with learning environment.
 - Some teachers work very hard to get the district to shut off their fans
 - Consider fan noise ratings in HVAC purchases
- Educate teachers on the importance of running the fan during occupied hours.
 - Report fans that are not running
 - Use the “override” outside of scheduled hours to provide ventilation, even when temperature is okay
- UC Davis to create educational materials to share with teachers

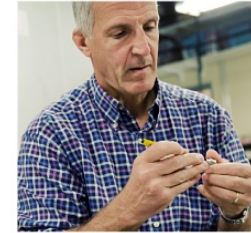
Maintenance/Filters

- Dirty filters reduce may airflow and ventilation rates and reduce system operating efficiencies



Ensuring Proper Installation and Commissioning of HVAC Systems for Energy Efficiency and Indoor Air Quality

- Request acceptance test reports from contractor (especially if your contract specified Title 24 compliance)
- Perform your own outdoor air measurements (flow hood)
- Spot check classroom CO₂ levels using inexpensive sensors (\$200-\$300 each). Log a classroom's CO₂ concentration for a few days. "OK" classrooms should peak at less than 1100 PPM.



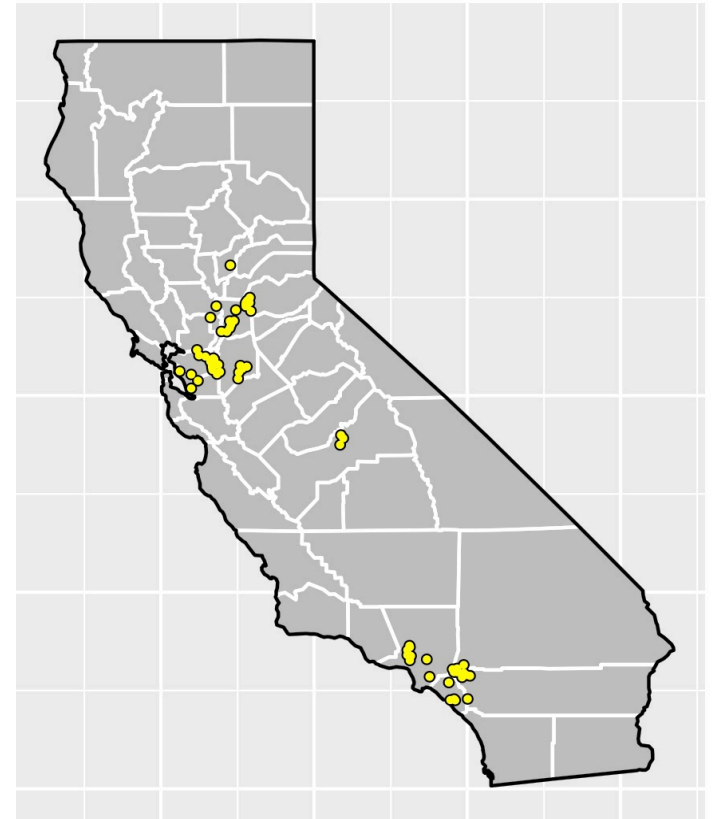


Healthy Efficient New Gas Homes (HENGH)



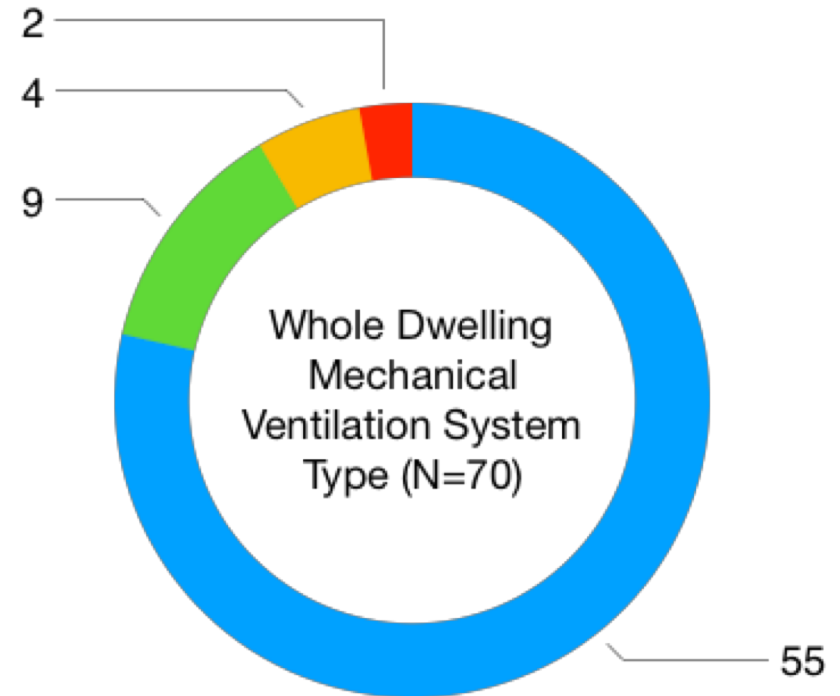
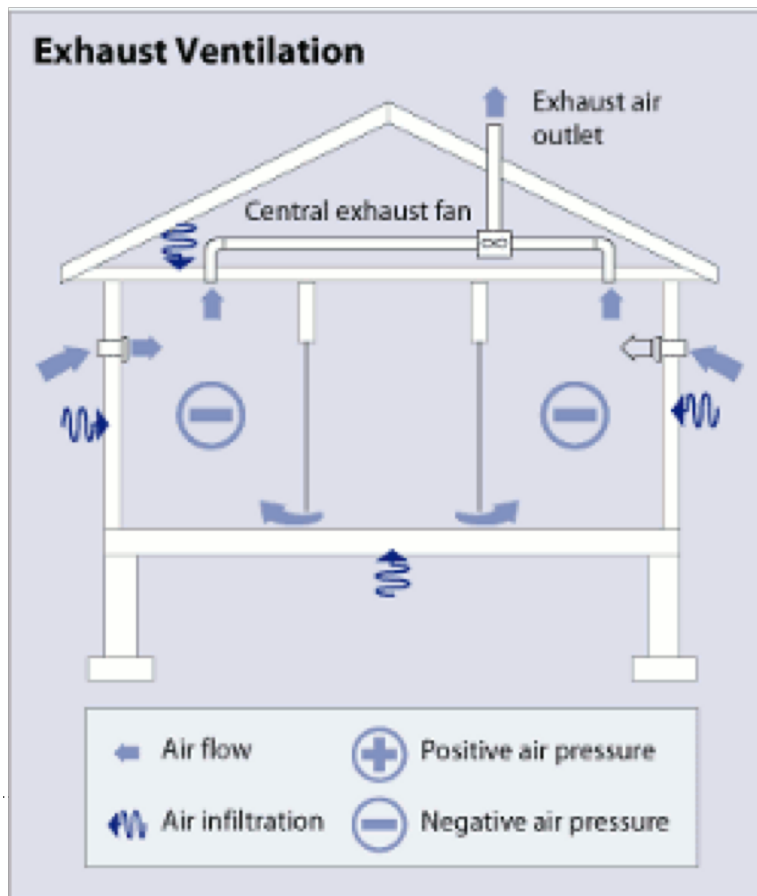
Field Study (2016–2018) of 70 New Homes

- All homes have mechanical ventilation
 - Whole house ventilation [ON]
 - Bathroom exhaust fan
 - Kitchen range hood exhaust to outside
- Indoor air quality, occupant activities and ventilation use monitored for one week in each home



Mechanical Ventilation Systems

In most cases, the measured airflow of exhaust system exceeded the required whole-house ventilation need.



- Exhaust - Continuous
- Exhaust - Intermittent
- Supply - Continuous
- Supply - Intermittent

But, only **1 in 4** homes with whole-house ventilation system running as found.

Whole-house ventilation system controller label present in 12 of 70 homes.



Indoor Air Quality Results

Comparisons of formaldehyde, PM_{2.5}, and NO₂ with a prior study of new homes in California suggest that contaminant levels are lower than measured from about 10 years ago.

Mean Indoor Concentration	HENGH (2016-2018)	California New Home Study (2007-2008)*
Formaldehyde	19.8 ppb	36.3 ppb
PM _{2.5}	8.3 µg/m ³	13.3 µg/m ³
NO ₂	6.1 ppb	5.4 ppb

*Almost all homes (98%) use electric ranges for cooking.

Formaldehyde Emission Standards

California Environmental Protection Agency | AIR RESOURCES BOARD

FREQUENTLY ASKED QUESTIONS FOR CONSUMERS

REDUCING FORMALDEHYDE EMISSIONS FROM

Composite Wood Products

The [ATCM to control formaldehyde emissions](#) from composite wood products became effective January 1, 2009.

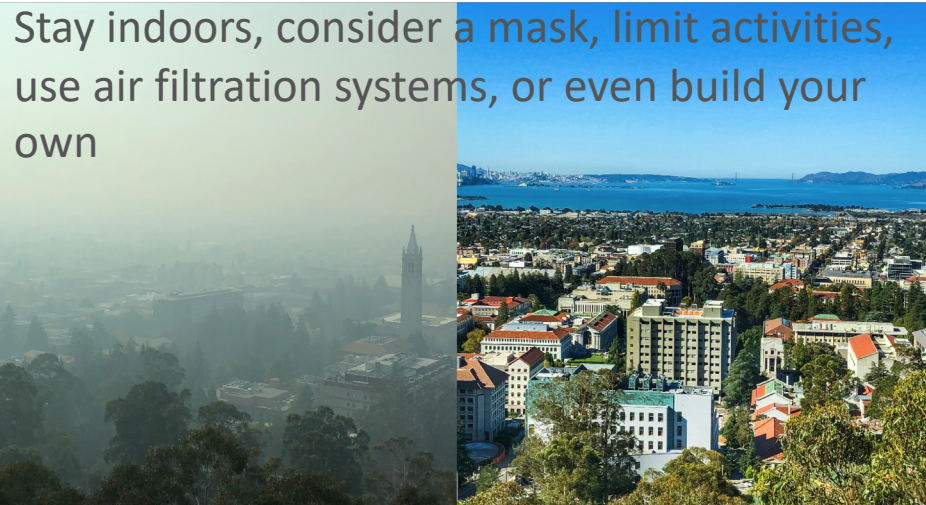


<https://www.arb.ca.gov/toxics/compwood/compwood.htm>

Adequate Ventilation in Buildings

- Ventilation standards to provide comprehensive protection for occupants
 - Work performance
- Implementation
 - Test and verify
 - User focus
- Emerging challenges
 - E.g., CA wildfires

Q&A: How to Protect Yourself and Your Family From Wildfire Smoke NOVEMBER 14, 2018



<https://newscenter.lbl.gov/2018/11/14/qa-how-to-protect-yourself-and-your-family-from-wildfire-smoke/>



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<https://iaqscience.lbl.gov/>

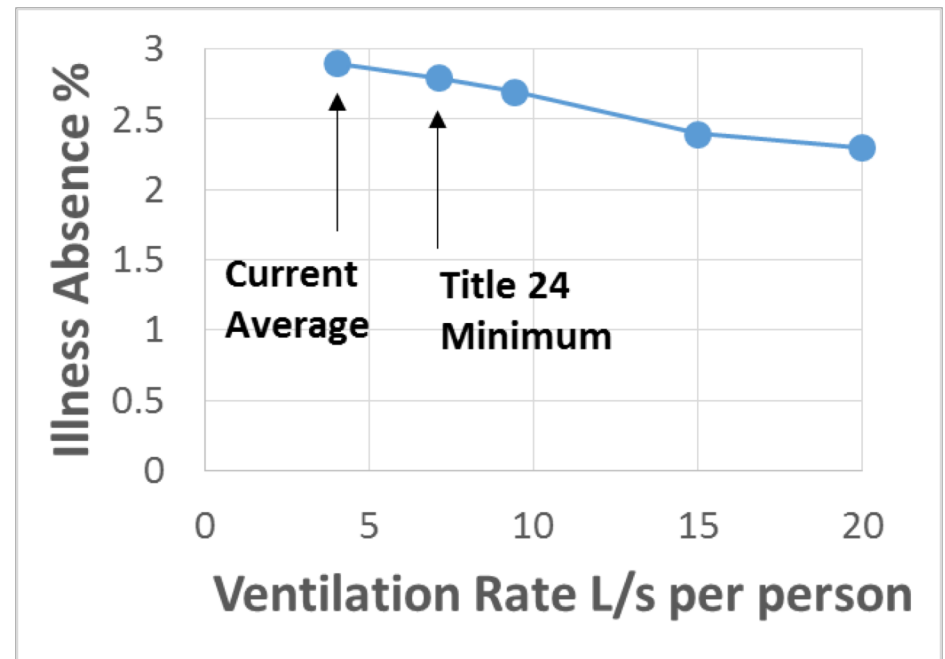
Research Scientist, Deputy Group Leader

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**Presented at the 2018 Conference on Health,
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Two-Year Study of Illness Absence in 162 California Elementary School Classrooms

- Study included 28 schools in three districts: South Coast, Bay Area, Central Valley
- Data collected on daily illness absence count, demographic data, and CO₂ levels
- Ventilation effects on long-term susceptibility to infections???



Economic Benefits of Bringing California Classroom Ventilation Rates

If 4 L/s per person (current average) was raised to 7 L/s per person (code requirement)

Benefits

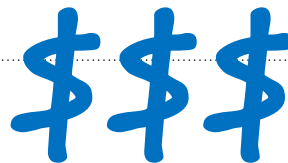
Costs

\$33 million
increase in school district revenue

\$80 million
reduction in care-giver costs



\$6 million
increase in energy cost



IAQ Monitoring

PM2.5



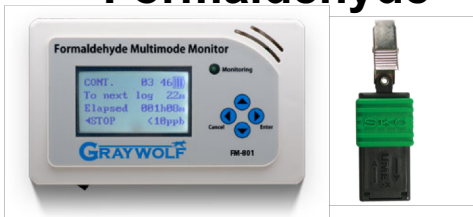
CO₂
T, RH



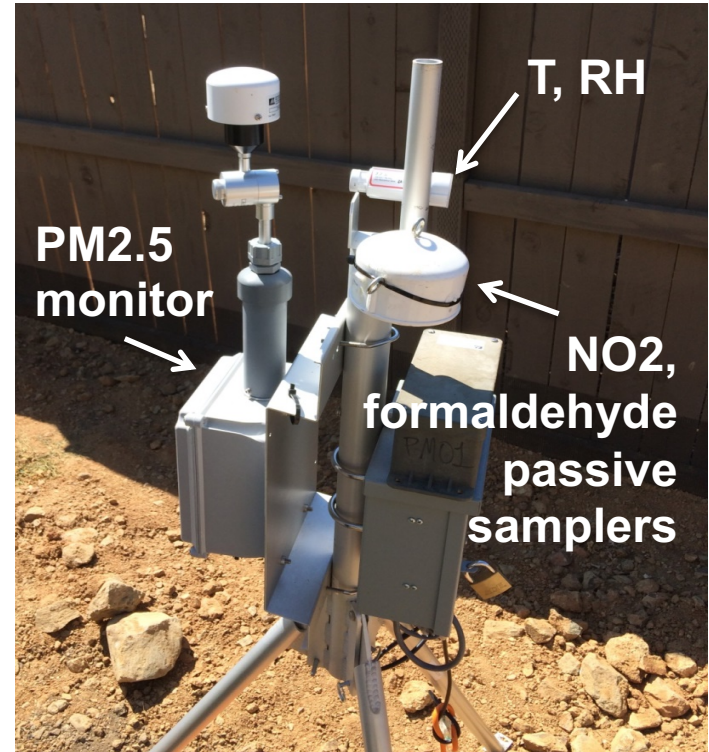
NO₂



Formaldehyde



Concurrent Outdoor Monitoring



Diagnostic Testing

Envelope and Duct Leakage



Exhaust Fan Airflow



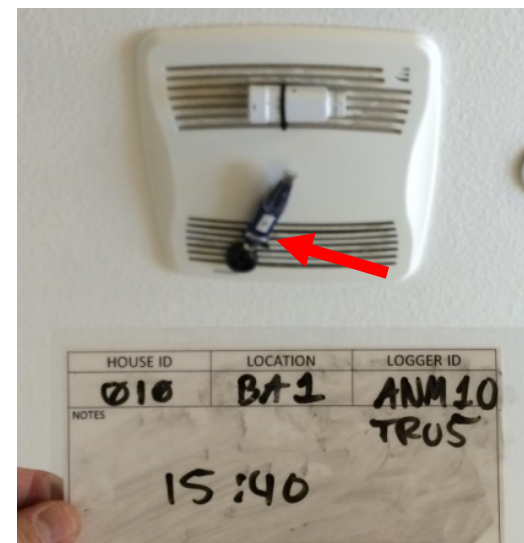
Range Hood Airflow



Activity Monitoring



**Range hood
use**



**Exhaust fan
use**

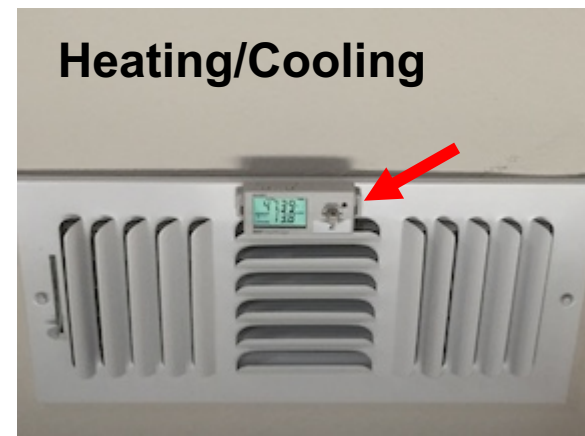
Cooking (cooktop, oven)

Activity Monitoring

External door use
(patio, garage)



Heating/Cooling



Clothes dryer



Occupant Survey and Activity Log

B. Air Quality In and Around Your Home

7. To what extent are you satisfied or dissatisfied with the indoor air quality in your home?

Very Dissatisfied					Neutral					Very Satisfied
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

8. How would you rate the outdoor air quality near where you live?

Very Poor					Neutral				Excellent
<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

9. How would you rate your home in protecting you from outdoor air pollution?

Very Ineffective					Neutral				Very Effective
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Healthy Efficient New California Homes Study Occupancy and Indoor Activities Data Log

Instructions: Please fill out this data log each day, or on the following day.

Please enter your estimates. If you are unsure, provide your best guess.
Do not list activities of any people.

Code number for home 13

Day 1: Date 11-30-16

Date completed 11-30-16

	Midnight to 7am	7am to 11am	11am to 1pm	1pm to 5pm	5pm to 9pm	9pm to Midnight
Number of people in home	2	4	4	2	2	2
Cooktop use Number of minutes	0	30	0	0	.45	0
Oven use Number of minutes	0	0	0	0	0	0
BBQ/outdoor grill Number of minutes	0	0	0	0	0	0
Vacuuming Number of minutes	0	0	0	.25	0	0
Window Use Number of minutes	0	0	0	0	45min	0
Other notable indoor/outdoor events	3 air cleaners 24/7			carpet & floor clean		0

* For example, use of fireplace, candle, air freshener, air cleaner, humidifier, unusual outdoor air quality (wood smoke, wildfire), and so on.