Commercial Building Ventilation

Effects on People and Building Energy Use

Implications for Standards

Presentation to CIAQ
October 8, 2014

William Fisk

Indoor Environment Group

Lawrence Berkeley National Laboratory

May 14, 2014

Contributors

- Michael Apte
- Marcella Barrios
- Douglas Black
- Samuel Brunswick
- Rengie Chan
- Sebastian Cohn
- Molly Davies
- Spencer Dutton
- Ekterina Eliseeva
- Agnes Lobscheid
- Randy Maddalena
- Tom McKone
- Mark Mendell
- Anna Mirer
- Srinandini Parthasarathy
- Marion Russell
- Usha Satish
- Meera Sidheswaran
- Douglas Sullivan

Sponsors

California Energy Commission

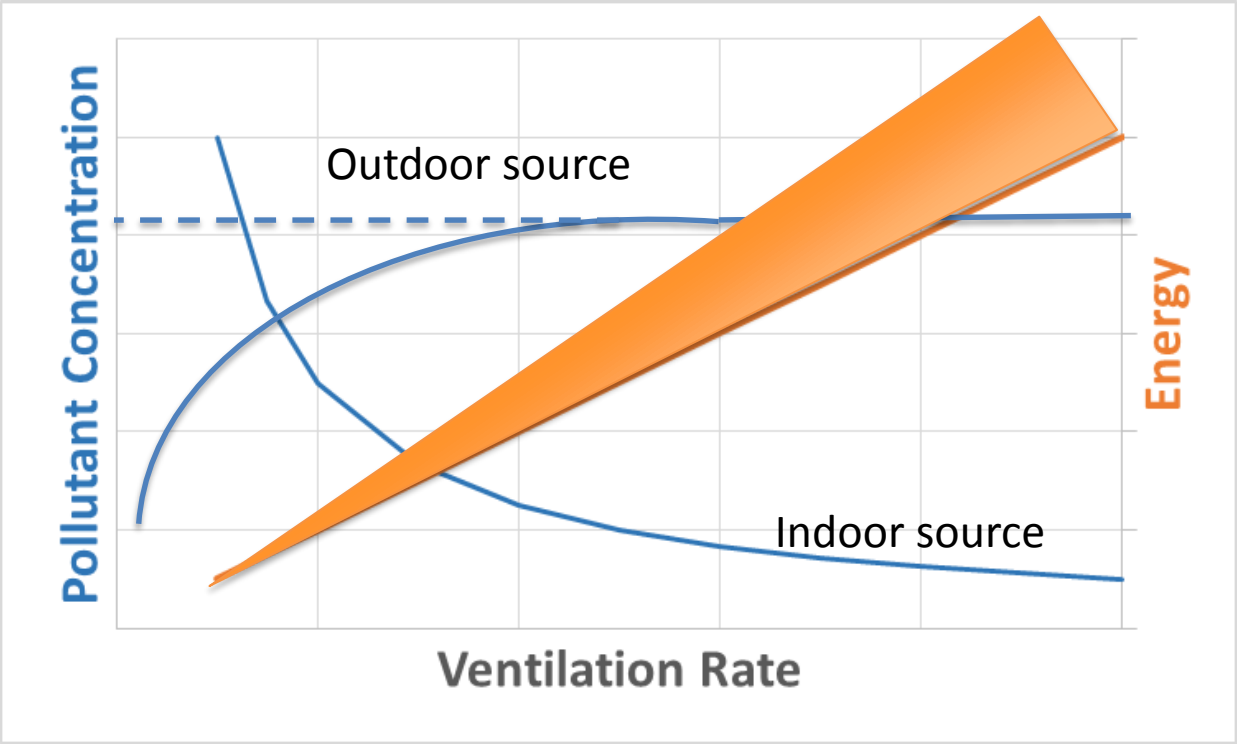
- Marla Mueller
- Brad Meister

U.S. EPA

- Greg Brunner

Also we have used data from studies by scientists from around the world

Context



QUESTION: What is the appropriate minimum ventilation rate (MVR)?

Other Important Factors:

- Indoor pollutant source strengths
- Outdoor air pollutant concentrations
- Filtration systems

Minimum Ventilation Rate (MVR) Standards

ASHRAE Standard 62.1

- MVR = A x (# people) + B x (floor area)
  - For offices, MVR = 8.5 L/s per person at default occupancy
  - At very high density, MVR approaches 2.5 L/s-person

California Title 24

- MVR = larger of 7.1 L/s per person and C x (floor area)
  - For offices at default occupancy MVR = 7 L/s per person
  - At high density MVR = 7 L/s-p

MVRs in current standards are traceable to decades old chamber studies of MVR needed to maintain 80% satisfaction with perceived air quality when people are the only source of pollutants

Research Questions

Chronic Health Effects

How do VRs affect risks of chronic health effects?

How do VRs affect indoor concentrations?

What are the key pollutants?

Acute Effects

How do VRs affect:

- Acute health symptoms ?
- Satisfaction with air quality?
- Absence rates?
- Respiratory infections?
- Work and school performance?

Energy

How do VRs affect:

- Energy use?
- Peak electricity demands?

Standards

How can VR standards take advantage of scientific data?

Prescriptive versus performance standards?

Should standards allow MVR to vary with weather?

VR = outdoor air ventilation rate

Key Indoor Pollutants in Offices & Schools

Considering Chronic Health Risks and Odors, and Effects of VRs on Concentrations

Existing Concentration Data

Pollutants above or near guidelines for health or odor?*

- **Particles**
- **~20 types of VOCs**

Models and Empirical Data

Are indoor concentrations highly affected by ventilation rate?

Yes

- **Several VOCs**

No

- **Particles**
- **SVOCs**

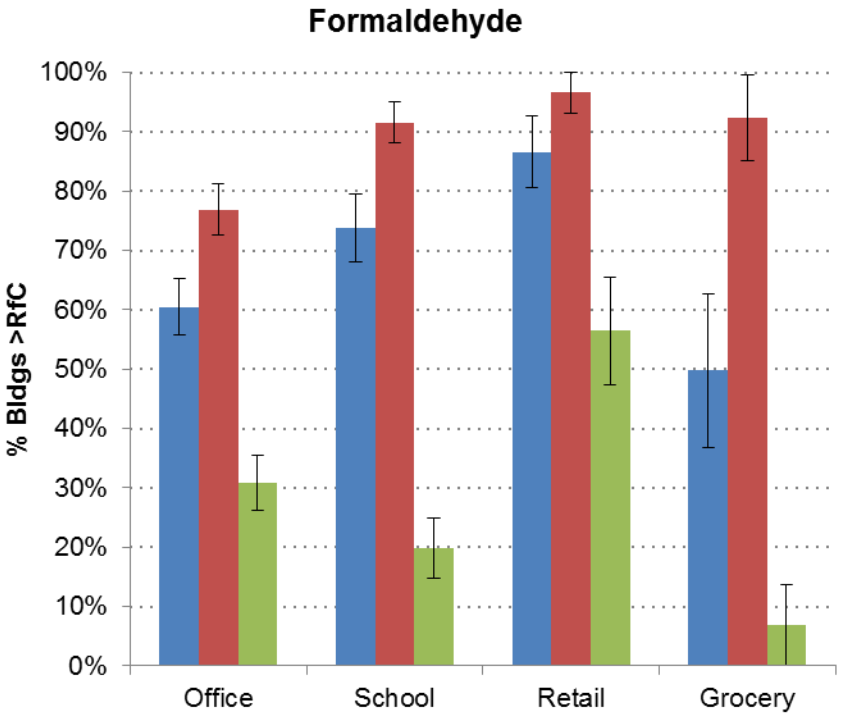
Risk Analysis

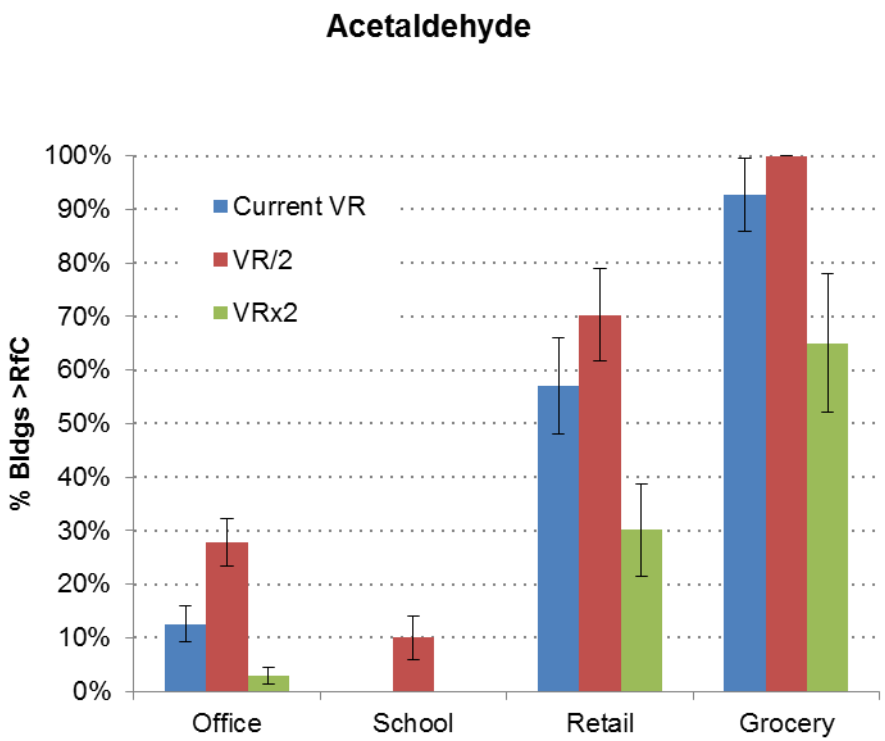
Poses highest chronic risks*

- **Formaldehyde**
- **Acetaldehyde**
- **Tetrachloroethene**
- **m,p xylene**
- **Napthalene**
- **etc.**

***varies with building type**

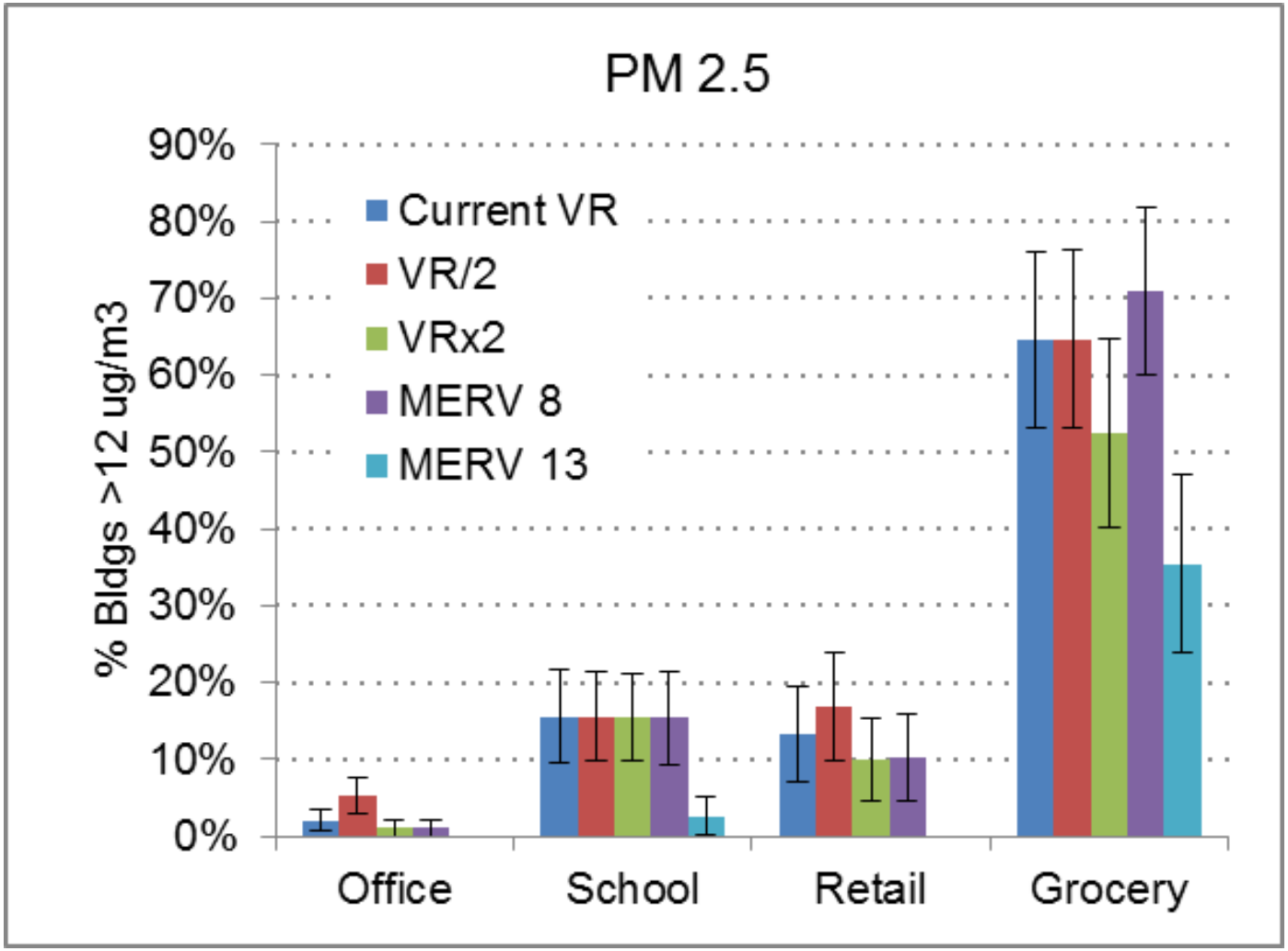
Percent of Buildings with Concentrations Exceeding Most Stringent Guidelines at Different Ventilation Rates (VRs)*





*related to chronic health effects

Percent of Buildings with PM2.5 Exceeding the 12 µg m^{-3} Ambient Standard at Different Ventilation Rates (VRs) and Filter Efficiencies

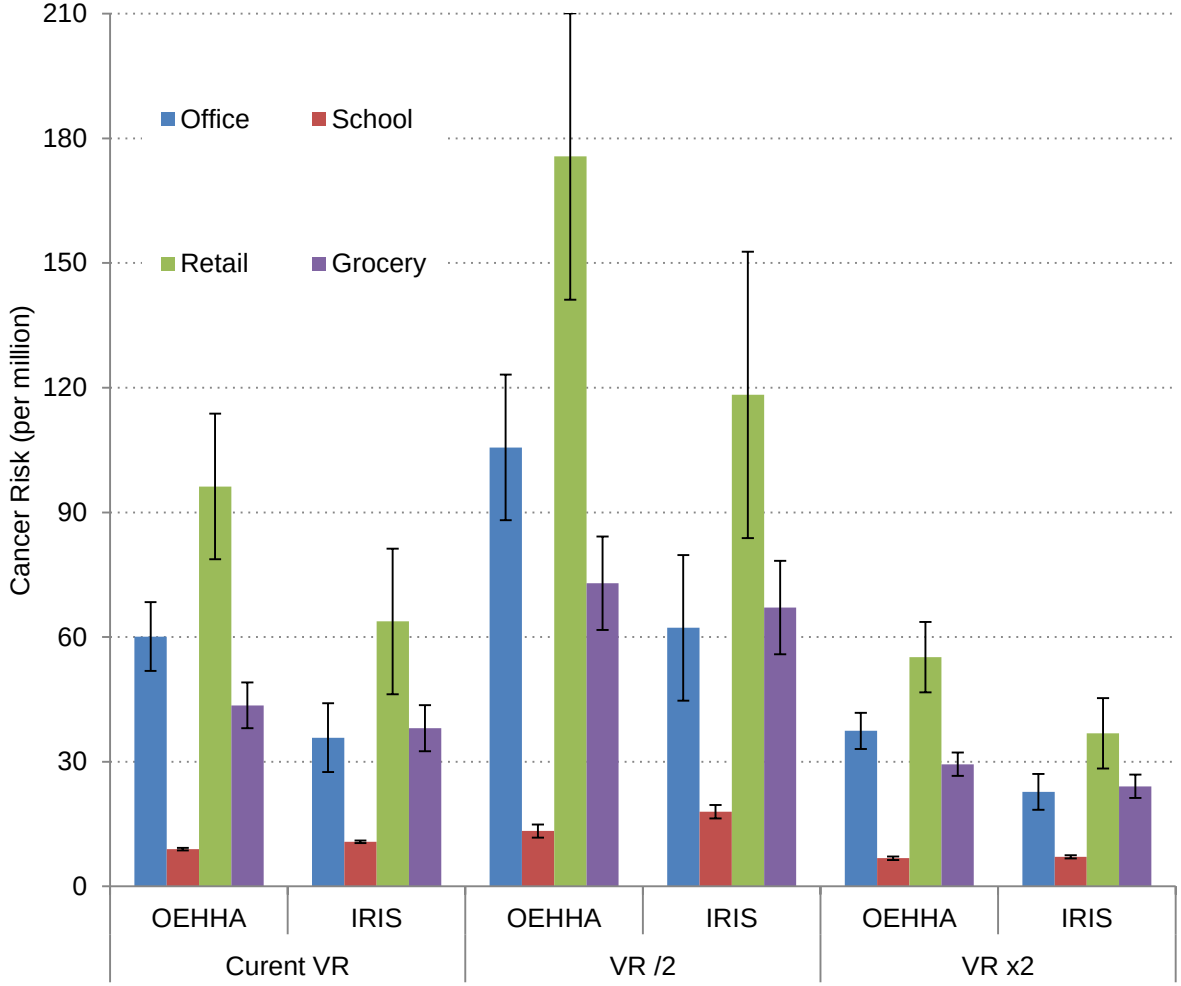


KEY FINDINGS

Small effect of VR and larger effect of filter efficiency

Higher PM in Grocery Stores, Probably from Cooking

How Ventilation Rates (VRs) Affects Lifetime Cancer Health Risks from VOCs



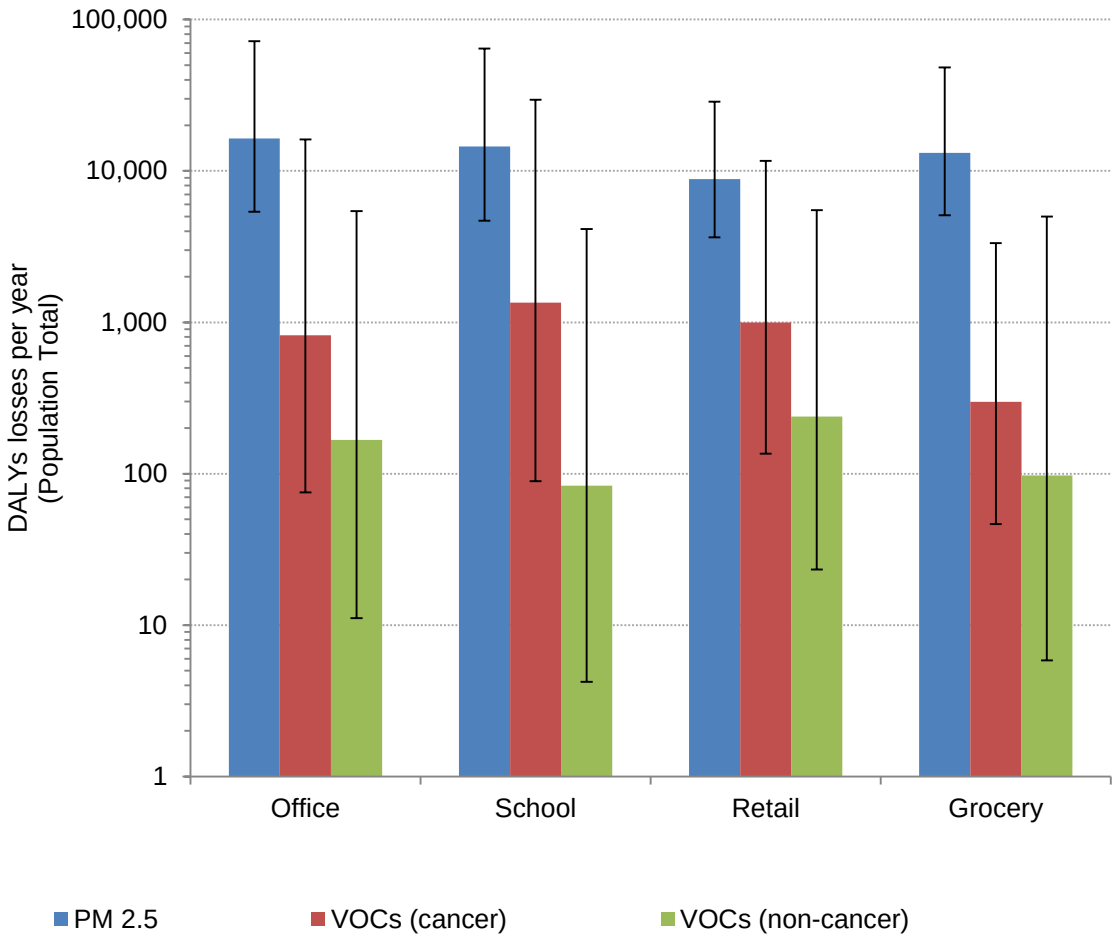
KEY FINDINGS

Risks are moderate, and smaller than from VOC exposures in homes

Doubling VRs does not much reduce risks; halving VR has a larger effect

For VOCs, cancer risks of formaldehyde dominate

Total Health Burden in Disability Adjusted Life Years (DALYs) at Existing Ventilation Rates



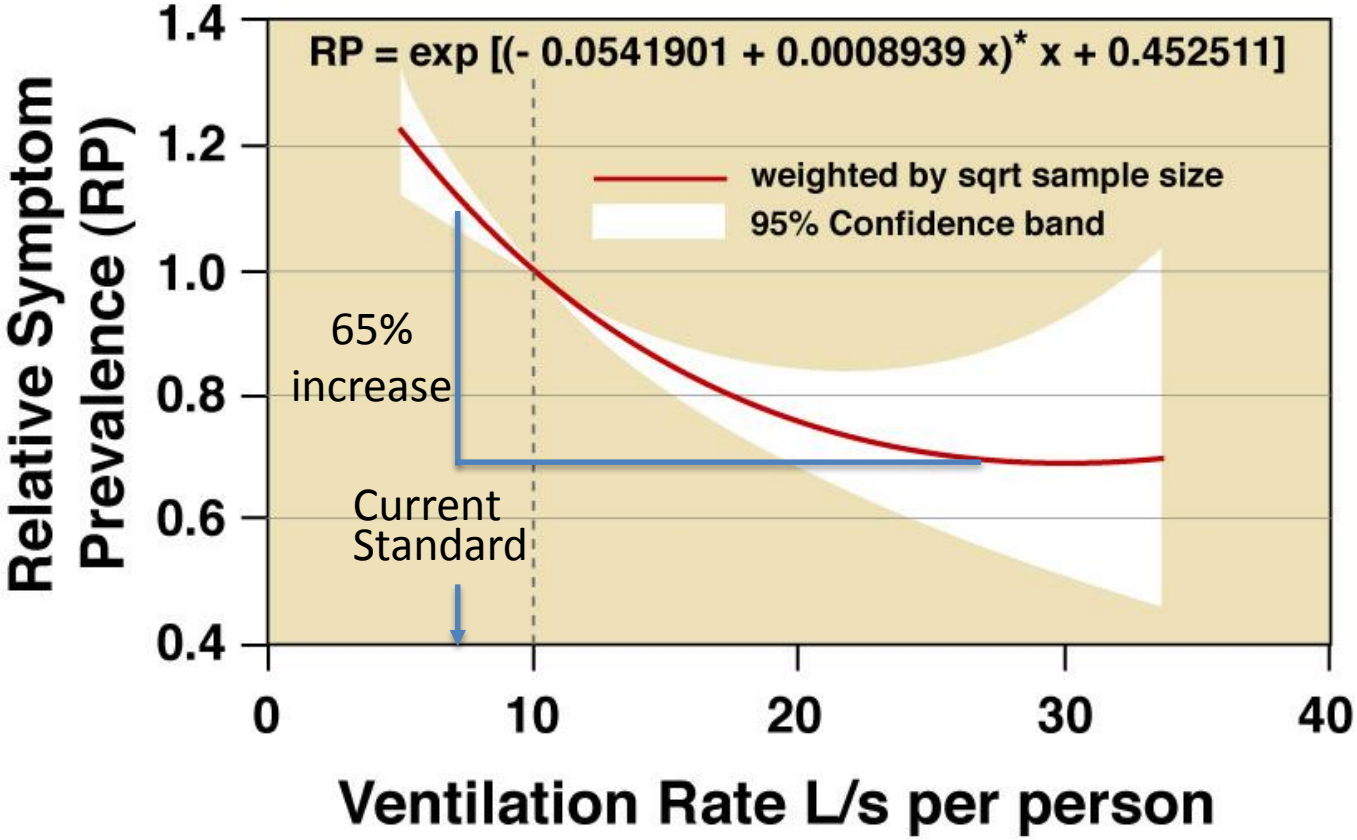
KEY FINDINGS

Risks from particles dominate, but are little affected by VR

For VOCs, cancer risks of formaldehyde dominate

Relationship of Ventilation Rates in Offices with Building Related (SBS) Health Symptoms

Statistical Analyses of 8 Studies with 43 data Points



Data

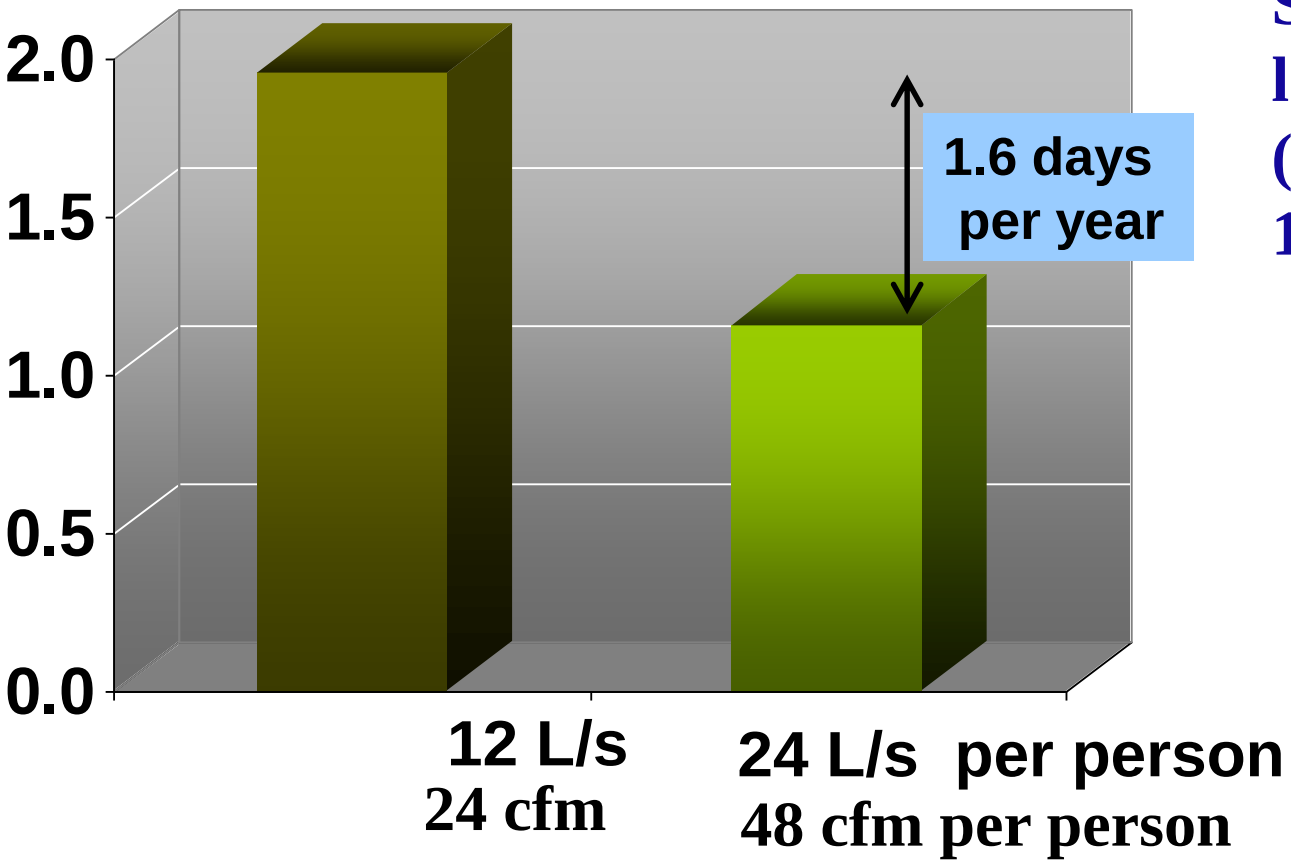
Slopes: ΔPrevalence/ΔVR and Midpoint VR

Fit Equation to Slope vs. VR data

Integrate to obtain Prevalence vs. VR

Ventilation and Short Term Sick Leave in Offices

$$\% \text{ Change} = [1 - 0.66^{(\Delta VR/12)}] \times 100\%$$



Short term sick leave rate = 2% (4.8 days/yr) at 12 L/s per person

CA –supported study performed by LBNL did not find a relationship, but VRs were high

Source: 40 building study of Milton et al. (2000) Indoor Air Journal

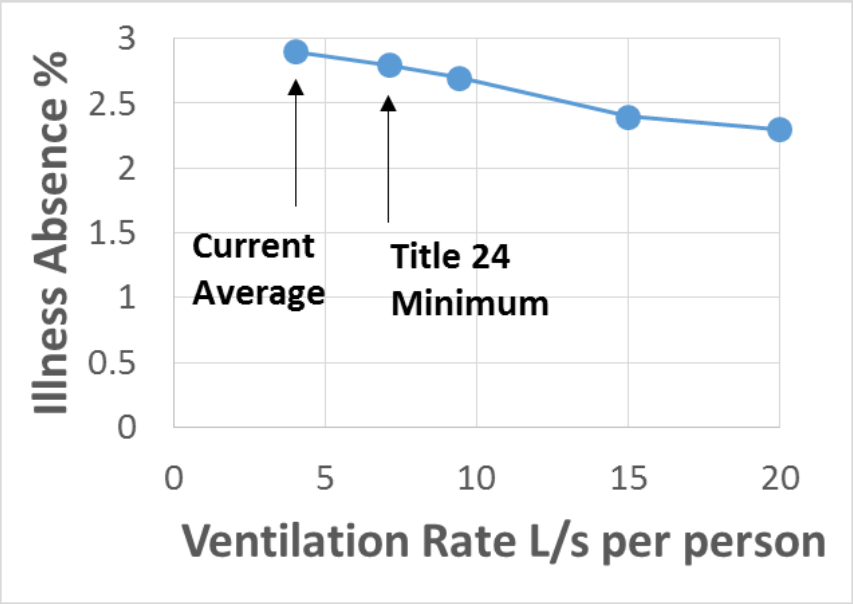
Reductions in Illness Absence in CA Classrooms With Increased VR (160 classrooms, 2 years)

Results of Multivariate Analyses, per 1 L/s-person Increase

District	Estimated reduction (%)	*95% CL*	n (classroom days)
South Coast	**-1.2***	*-2.0, -0.3*	13,363 - 14,664
Bay Area	**-1.5**	*-4.9, 2.0*	5,252 - 6,106
Central Valley	**-1.0**	*-3.6, 2.0*	9.781 - 10,438
All	**-1.6***	*-2.9, -0.4*	28,396 - 31,208

*statistically significant

Implications

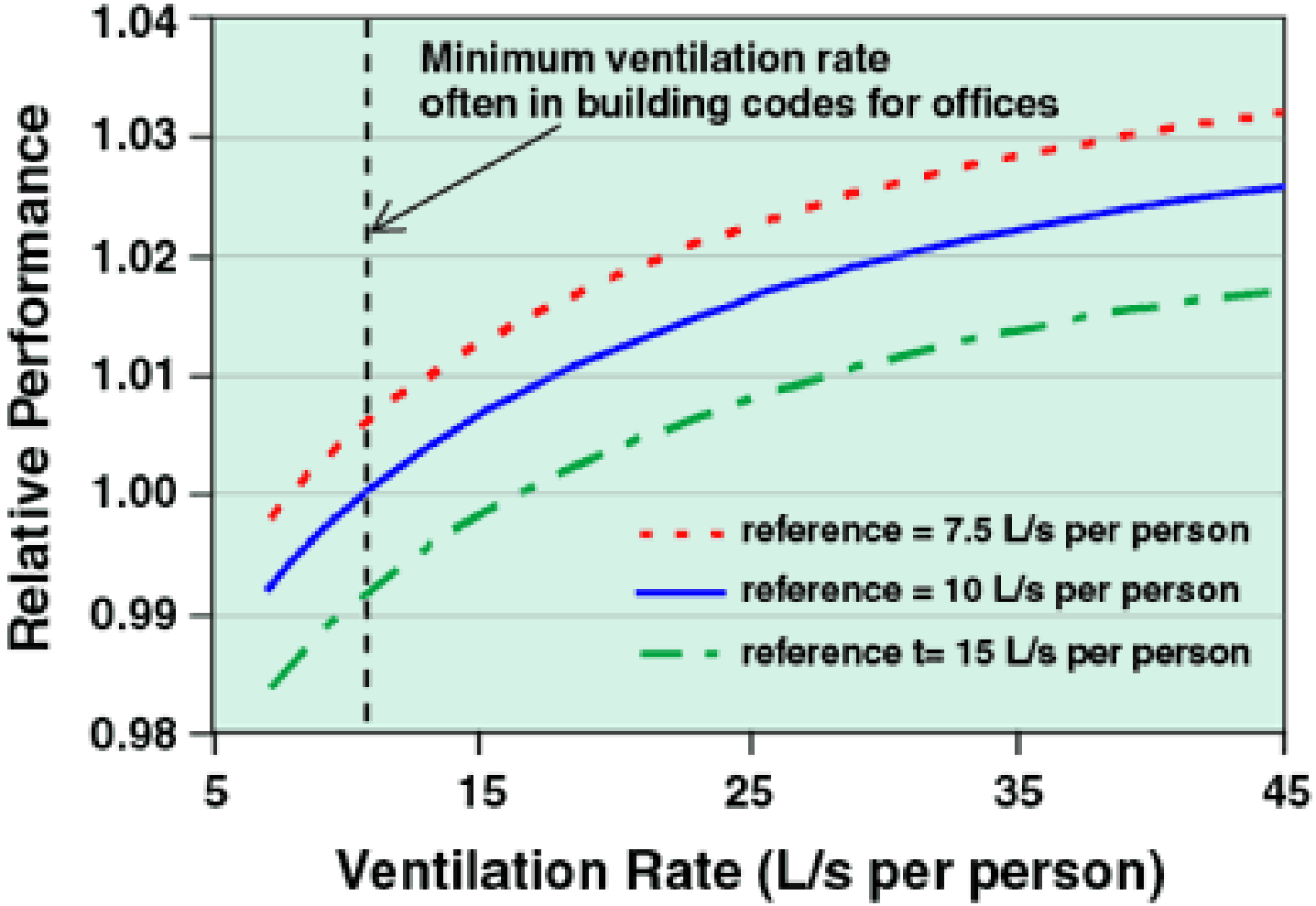


Two additional classroom studies also show that absence increases with decreased VR

If Average VR in CA is Increased to Current Standard

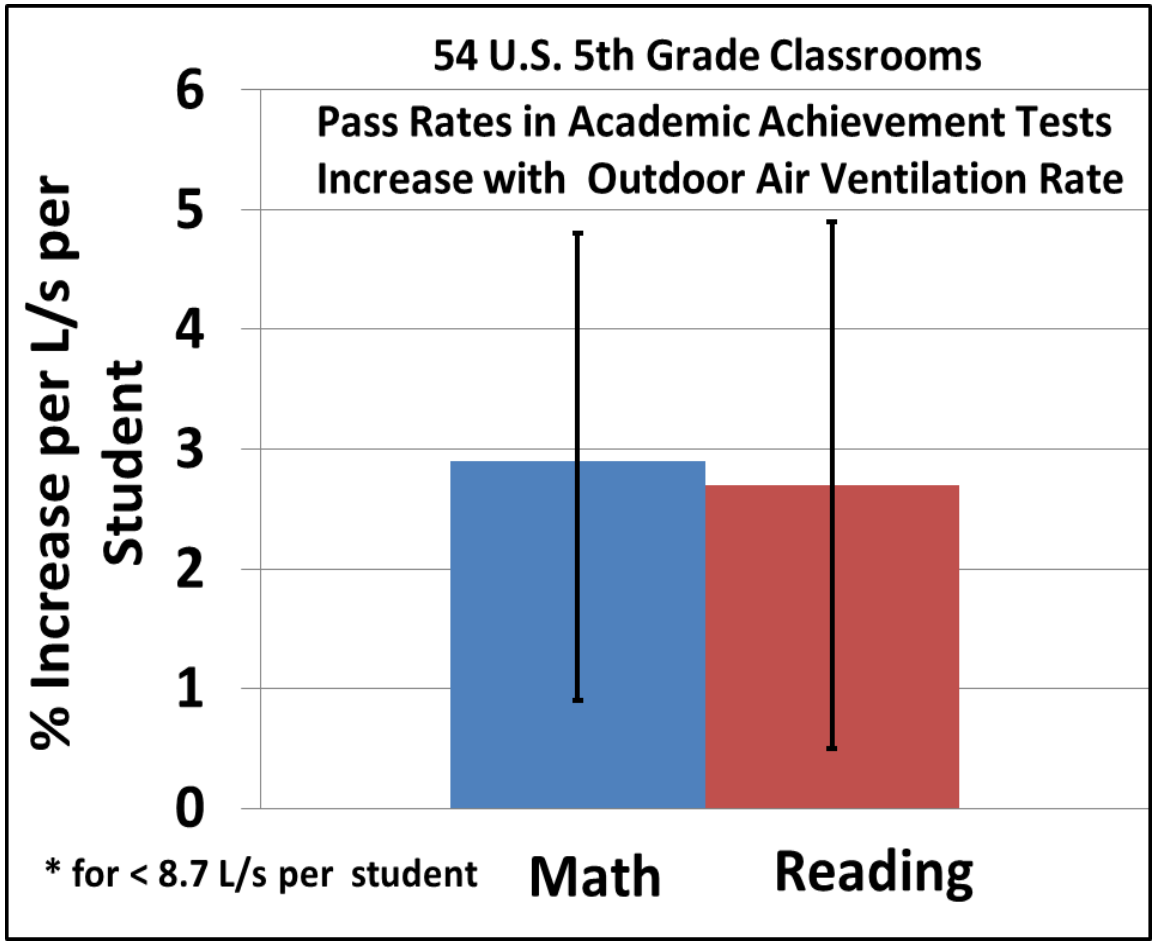
- $6.2 million annual energy cost increase (rough est.)
- $33 million increased revenue to school districts
- $80 million reduced care giver costs

Higher VRs Improve Office Work Performance
Regression Analysis of 10 Studies



Regression Analyses 10 studies, 24 points, Seppanen et al. 2006

Increased Ventilation (VRs) Rates in US Schools Improves Performance on Academic Achievement Tests



Source:
Haverinen-Shaughnessy et al. *Indoor Air*, 2011. 21(2): 121-131

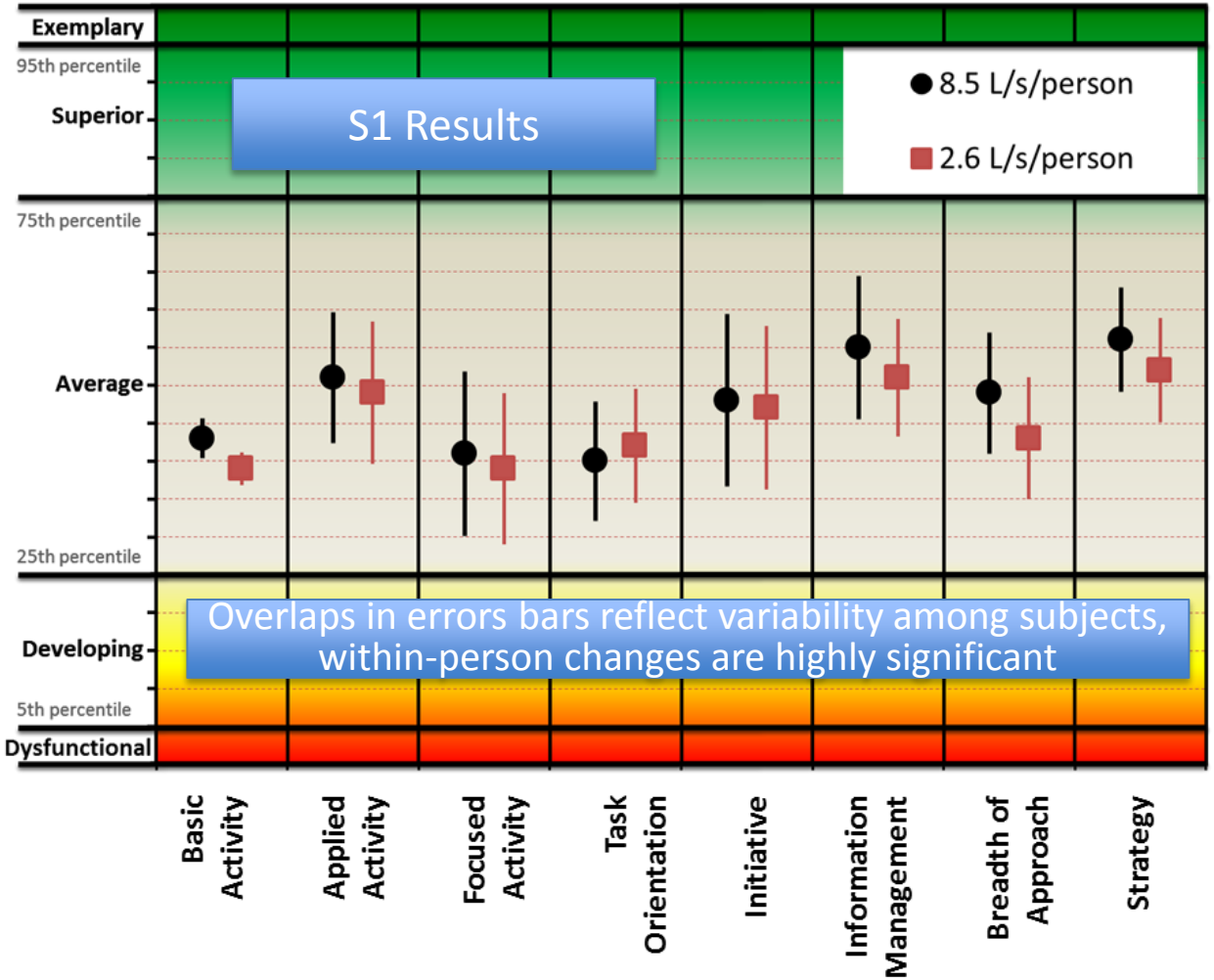
CEC and USGBC-Supported Study

- 160 CA Classrooms
- Higher scores associated with higher ventilation rates
- Many classrooms had VRs far less that specified in T24
- Paper pending

Effect of VRs on Decision Making

Two Controlled Exposure Studies

- S1: Vary VR per person in low-pollution space
- S2 Vary VR per floor area, with constant high VR per person



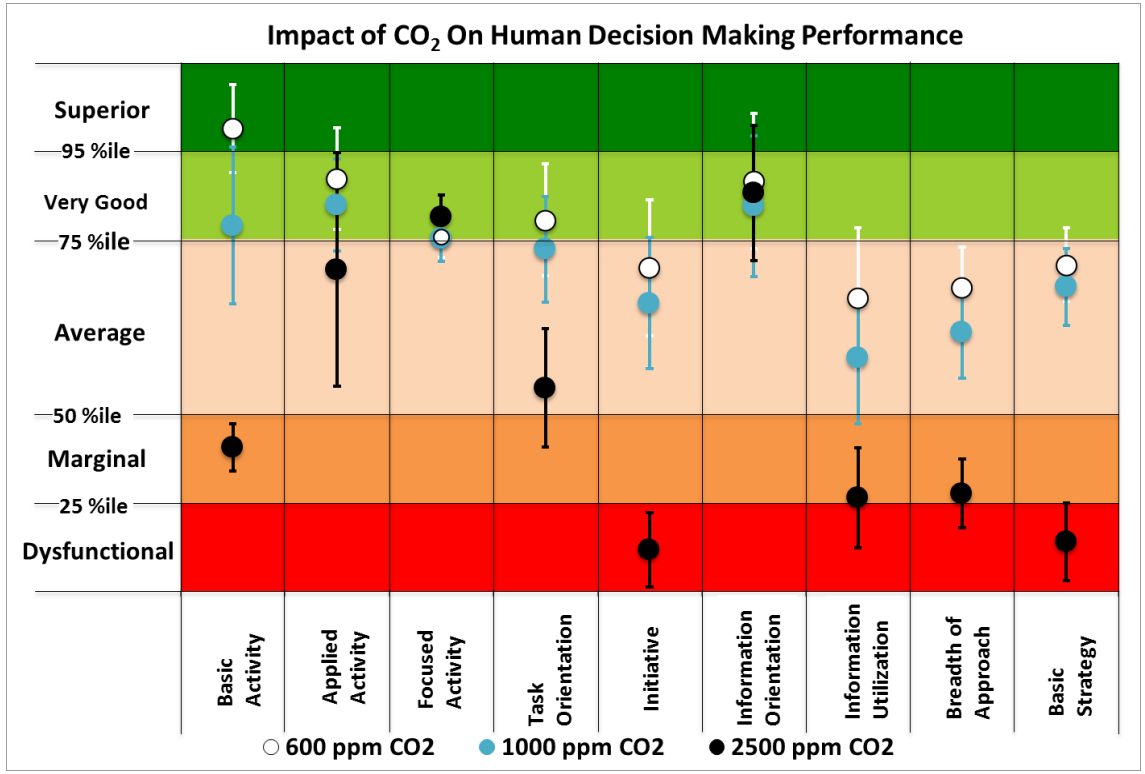
Results:

- Lower VR per person, lower VR per floor area independently and statistically-significantly decreased most metrics of decision making performance

Direct Effects of CO_2 on Decision Making

Controlled Exposure Studies

- Vary CO_2, other factors constant



Error bars reflect variability among subjects, within-subject changes are highly statistically significant

Higher CO_2, with all other factors constant, was associated with statistically significant degradation in decision making

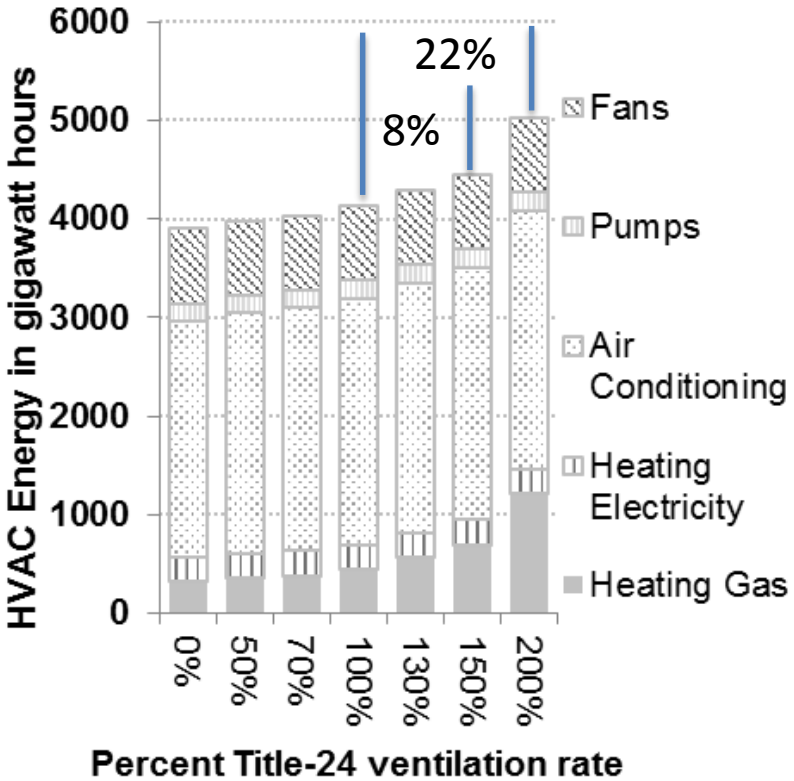
- Moderate effects at 1000 ppm vs. 600 ppm
- Large effects at 2500 ppm vs. 600 ppm
- So far, only assessed effects with 3.5 h exposure periods

Modeled Annual Economic Impacts of Different Minimum VRs (MVRs) in US Offices ($ US Billions)

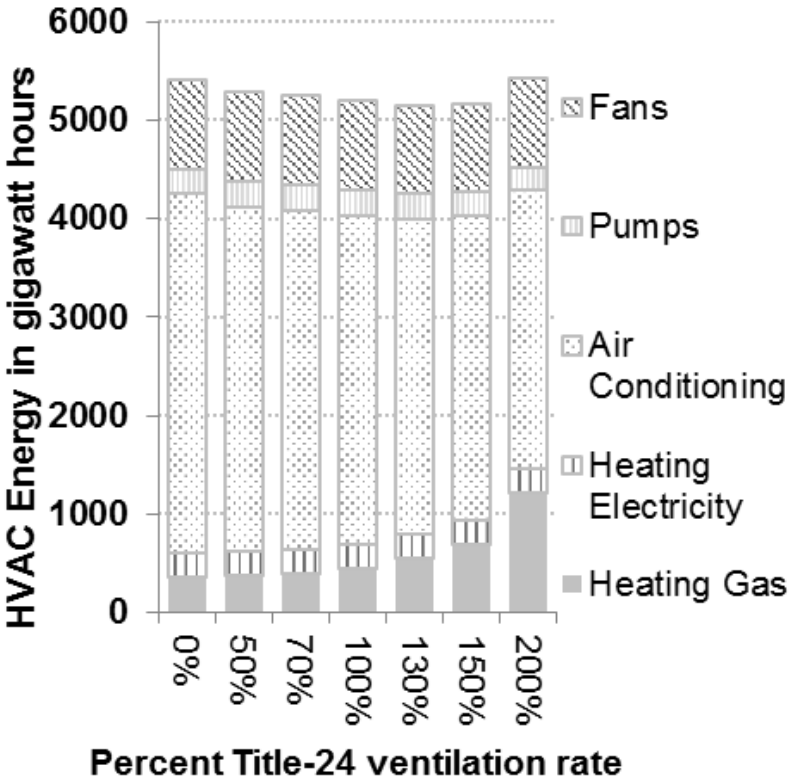
	Scenario 1 MVR 8 to 10 L/s-p	Scenario 2 MVR 8 to 15 L/s-p	Scenario 3 Economizers in all Buildings
Performance	$10.1 B	$28 B	$24.2 B
SBS	$0.09 B	$0.26 B	$0.2 B
Absence	$2.9 B	$9.4 B	$8.6 B
Energy	-$0.04 B	-$0.13 B	$0.22 B
Equipment	--	--	-$0.28 B*
Total	$13 B	$37.5 B	$33 B

*annual maintenance costs similar in magnitude to annualized capital cost

How Minimum VRs Affect HVAC Energy in California Offices



Buildings with Economizers
All Climates and Building Sizes



Buildings without Economizers
All Climates and Building Sizes

From Modeling of Full US Commercial Buildings Stock: Mechanical Ventilation Increases Total Building Energy Use by 6.5% (Benne et al. 2009 NREL/ TP-550-41955)

Proposed Process for Improving Standards for Minimum Ventilation Rates

1. Specify the use of more energy efficient and effective options to control IAQ when proven and practical
   - Don’t try to control particles with ventilation, use filters
2. Select thresholds for acceptable worsening in adverse outcomes (e.g., health symptoms) as MVRs are decreased from high value
   - Current outcomes: chronic health effects, acute symptoms, poor perceived air quality, reduced performance
3. Use scientific data (such as shown) to estimate MVRs needed to meet each threshold, estimate associated costs
4. Select highest MVR or, if judged too costly, perform a cost-benefit analysis and apply risk management process
5. Decisions made by committee of stakeholders, but with technical support from experts

Evaluation of ASHRAE 62.1 Indoor Air Quality Procedure (IAQP)

IAQP Process

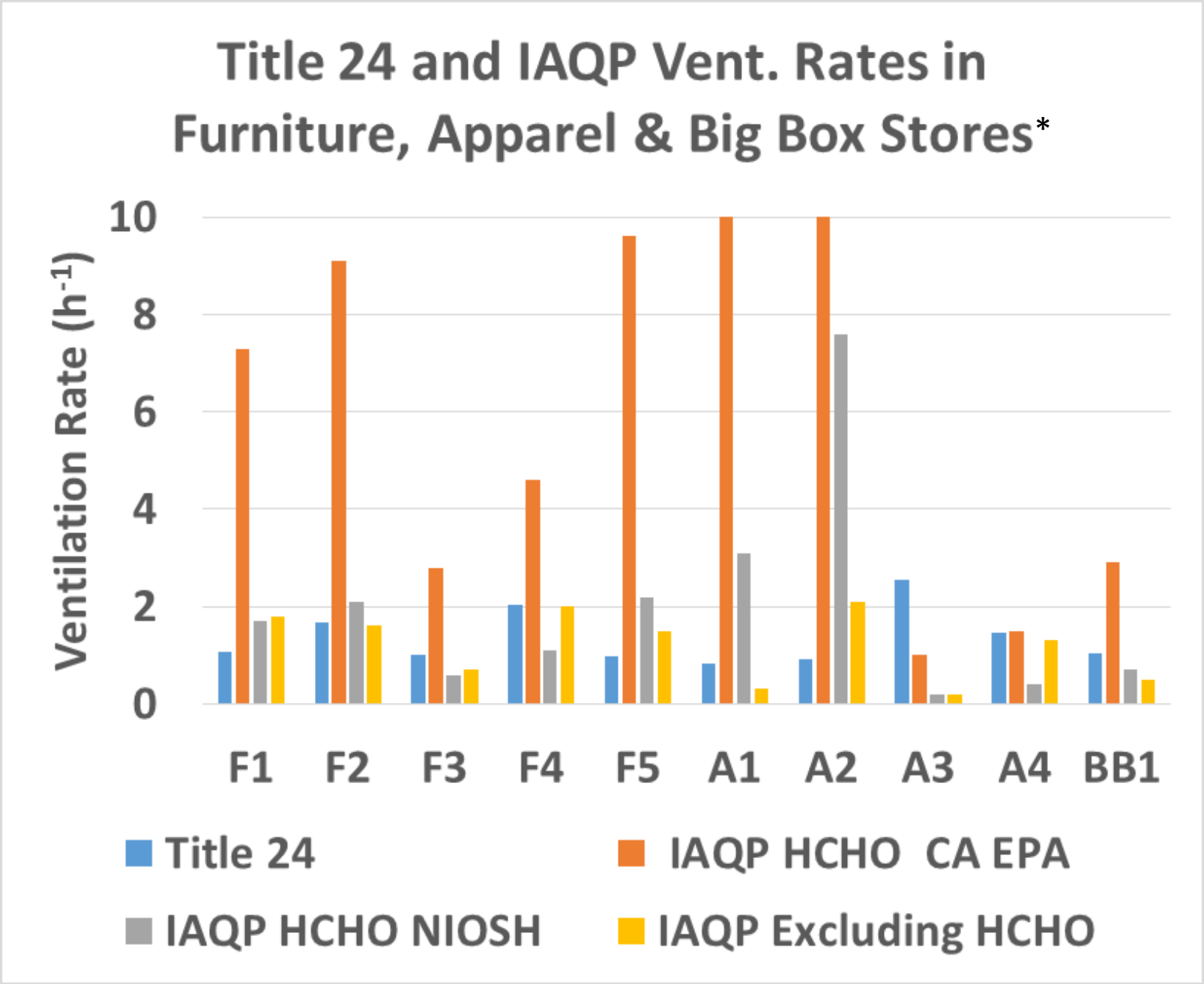
1. Identify contaminants of concern (could ignore most risky contaminants)
2. Select concentration limits for contaminants (from any cognizant authority)
3. Model (requires emissions data) or measure indoor pollutant levels as a function of ventilation rate and select ventilation rate that maintains concentrations of contaminants of concern below limits
4. After building is occupied, assess subjective acceptability of IAQ, increase VR as needed to meet acceptability target (up to user to select methods, criteria)

PROs

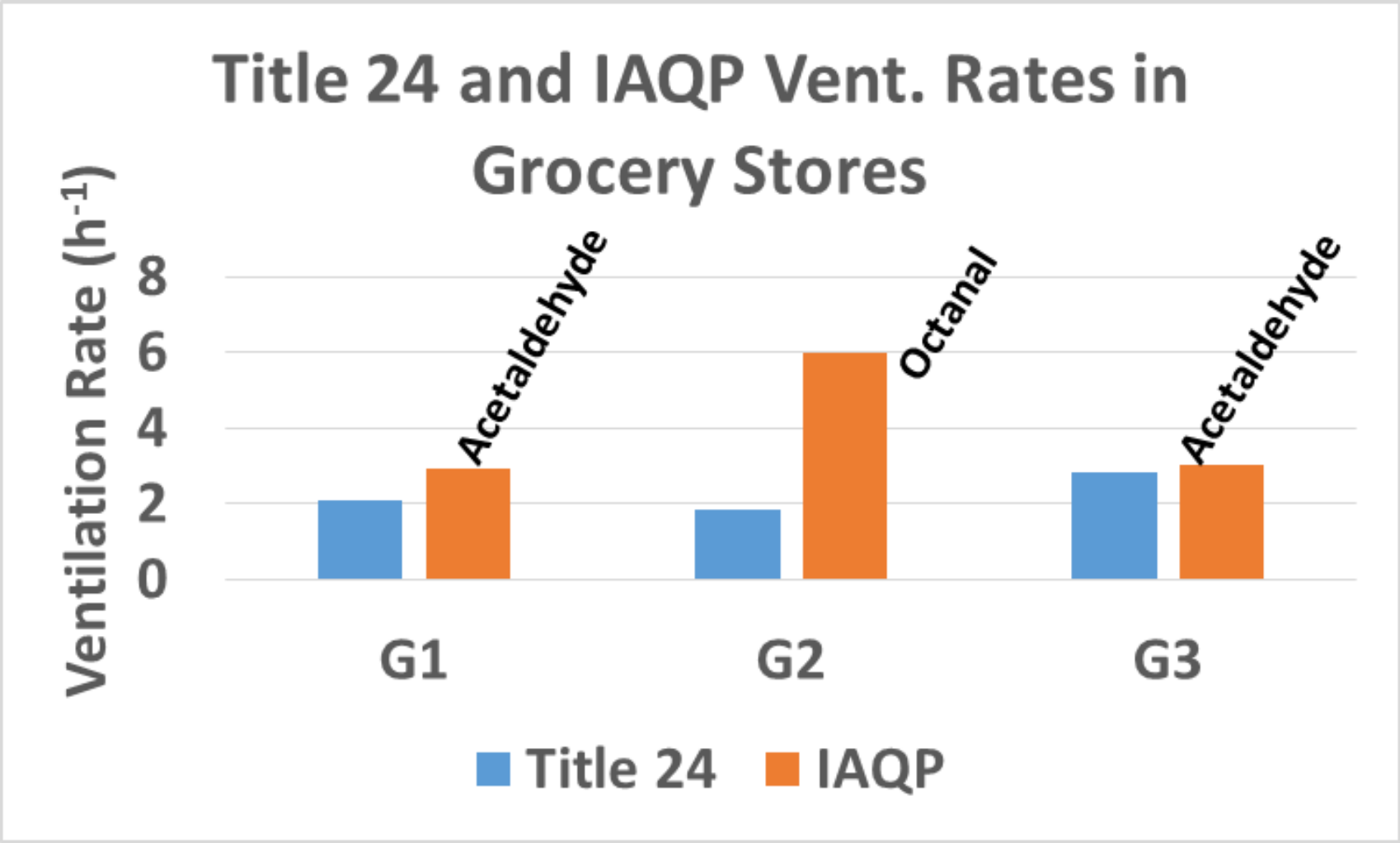
- Provides an incentive for development and deployment of technologies and practices that save energy and improve IAQ

CONs

- Many practitioners consider IAQP impractical
- Details up to the user who may not have sufficient expertise
- Misuse possible
- Sources of contaminants may change after IAQP is implemented
- Risky to reduce HVAC equipment capacity during design
  - Requires post-design subjective assessment and if goal not met, equipment could be undersized



*IAQP Rates with no changes in pollutant sources and no gas phase air cleaning



*IAQP Rates with no changes in pollutant sources and no gas phase air cleaning

Title 24 and IAQP Ventilation Rates

Without Pollutant Source Control or VOC Air Cleaning

- In 1 of 13 stores, IAQP VR < T24 VR, if use CA EPA limit for formaldehyde
- In 4 of 13 stores, IAQP VR < T24 VR, if use NIOSH limit for formaldehyde
- In 7 of 13 stores, IAQP VR < T24 VR, If formaldehyde is ignored
- In all furniture and apparel stores, and the big box store, formaldehyde was the critical contaminant driving the IAQP VR
- In grocery stores, acetaldehyde or octanal were the critical contaminants

Limited Opportunity for Energy Savings Unless:

- Use high limit for formaldehyde, or
- Reduce indoor pollutant sources, or
- Employ air cleaning for gaseous pollutants

"IAQP" Options for Title 24

1. No IAQP

2. Add Ventilation Rate Procedure Option 2

3. Add "Equivalent IAQ" Procedure (EIAQP)

4. Add ASHRAE-like IAQP with More Detailed Prescriptions

LESS ← | → MORE

Flexibility

Complexity

Incentive for Innovation

Potential to Improve IAQ

Potential to Save Energy

Potential for IAQ Failures

2. Ventilation Rate Procedure Option 2

Allow reduced ventilation rate by X% where X~ 35% if certain conditions are met to otherwise maintain IAQ:

Possible conditions

- High efficiency particle filtration (MERV > 12) with specified minimum filtration air flow rates

and

- All combustion pollutant sources have vents or capture hoods that exhaust to outdoors

and

- Application of LEED (or some other set of) source control measures

or

- Application of specified types of air cleaning for gas phase pollutants

3. "Equivalent IAQ" Procedure (EIAQP)

Allows reduced ventilation rate by X (cfm) when user can demonstrate via calculation and/or data that indoor levels of critical indoor-generated contaminants will not be higher than experienced with application of standard ventilation rate procedure

- **List of Critical contaminants is provided**
- **Maximum reduction in ventilation rate is specified**

Example

Can reduce outdoor air supply by 1000 cfm, if you install an air cleaning system that makes up for the lost pollutant removal for all critical contaminants (CCs)

Air Cleaner Flow Rate x Pollutant Removal Efficiency ≥ 1000 cfm for all CCs

4. ASHRAE-like IAQP with More Detailed Prescriptions

Allows reduced ventilation rate by any amount as long as:

1) **indoor air concentrations of critical contaminants are maintained below concentration limits**
2) **acceptability of air quality is maintained above target**

Added Detailed Prescriptions

Critical contaminants

- Minimum set of critical contaminants is specified
- Concentration limits for critical contaminants are specified

Air Quality Acceptability?

- Metric of air quality acceptability is specified
- Acceptability target is specified
- Method of assessing acceptability is specified.

Take Home Messages

- Control indoor particles using filters & with source control, not with ventilation
- Chronic health risks of gaseous pollutants are moderate in offices, schools, and stores, formaldehyde cancer risk dominates (control sources to extent possible)
- Acute symptoms, performance, and probably absence are affected by VR, large economic implications
- Energy use increases moderately with increased minimum VR, but economizers increase VRs and save energy
- CO_2 appears to be more than a proxy for other pollutants (affects performance)
  - Should performance be considered in VR standard setting?
- Many CA classrooms, and classrooms elsewhere, have far less ventilation than specified in standards, leading to increased absence and reduced student performance
- The ASHRAE IAQP will save little energy in CA retail stores, unless one selects a high limit for formaldehyde, or uses source control or air cleaning
- We have suggested alternatives to the ASHRAE IAQP that are simpler, could stimulate pollution source control and air cleaning and save energy
- Current minimum VR standards have not explicitly accounted for related scientific findings; we have suggested a procedure for producing more scientifically defensible standards

Papers and Reports

1. Benne, K., B. Griffith, N. Long, P. Torcellini, D. Crawley and T. Logee (2009). Assessment of the energy impacts of outside air in the commercial sector, NREL/TP-550-41955. Golden, CO, National Renewable Energy Laboratory
2. Dutton, S. M., et al. (2014). Energy and indoor air quality implications of alternative minimum ventilation rates in California offices. *Building and Environment, Volume 82, December 2014, Pages 121-127*
3. Dutton, S. M. et al. "Evaluation of the indoor air quality minimum ventilation rate procedure for use in California retail buildings" Indoor Air, in press*
4. Fisk, W. J., et al. (2009). "Quantitative relationship of sick building syndrome symptoms with ventilation rates." Indoor Air **19**(2): 159-165.
5. Fisk , W. J., et al. (2013). "Is CO2 an indoor pollutant?" ASHRAE Journal **55**(3): 84-85.
6. Fisk , W. J., et al. (2011). "Changing ventilation rates in U.S. offices: implications for health, work performance, energy, and associated economics." Building and Environment **47**: 368-372.
7. Fisk , W. J. (2013). Should title 24 ventilation requirements be amended to include an indoor air quality procedure? Berkeley, CA, Lawrence Berkeley National Laboratory.
8. Haverinen-Shaughnessy, U., D. J. Moschandreas and R. J. Shaughnessy (2011). "Association between substandard classroom ventilation rates and students' academic achievement." Indoor Air **21**(2): 121-131.
9. Maddalena, R., et al. (2013). Impact of independently controlling ventilation rate per person and ventilation rate per floor area on perceived air quality, sick building symptoms and decision making. Berkeley, CA, Indoor Air Journal (see early view at http://onlinelibrary.wiley.com/journal/10.1111/(ISSN)1600-0668/earlyview)
10. Mendell, M. J., et al. (2013). "Association of classroom ventilation with reduced illness absence: a prospective study in California elementary schools." Indoor Air **23**(6): 515-528.
11. Milton, D. K., P. M. Glencross and M. D. Walters (2000). "Risk of sick leave associated with outdoor air supply rate, humidification, and occupant complaints." Indoor Air **10**(4): 212-221.
12. Parthasarathy, S., et al. (2012). Modeling indoor exposure to VOCs and SVOCs as ventilation rates vary. Healthy Buildings 2012. Brisbane, Australia.
13. Parthasarathy, S., et al. (2013). Effect of ventilation on chronic health risks in schools and offices. Berkeley, CA, Lawrence Berkeley National Laboratory. **LBNL-6121E**.*
14. Seppänen, O. and W. J. Fisk (2002). "Association of ventilation system type with SBS symptoms in office workers." Indoor Air **12**(2): 98-112.
15. Seppänen, O. and W. J. Fisk (2006). "Some quantitative relations between indoor environmental quality and work performance or health." International Journal of HVAC&R Research **12**(4): 957-973.
16. Satish, U., et al. (2012). "Is CO_2 an indoor Pollutant? Direct effects of low-to-moderate CO_2 concentrations on human decision-making performance." Environmental Health Perspectives **120**(12): 1671-1677.
17. Sundell, J., H. Levin, W. W. Nazaroff, W. S. Cain, W. J. Fisk, D. T. Grimsrud, F. Gyntelberg, Y. Li, A. K. Persily, A. C. Pickering, J. M. Samet, J. D. Spengler, S. T. Taylor and C. J. Weschler (2011). "Ventilation rates and health: multidisciplinary review of the scientific literature." Indoor Air **21**(3): 191-204.

*related journal paper under development or submitted or accepted

ALSO SEE WWW.IAQSCIENCE.LBL.GOV