

Commercial Buildings Ventilation Rates Affect Health, Human Performance and Building Energy Use

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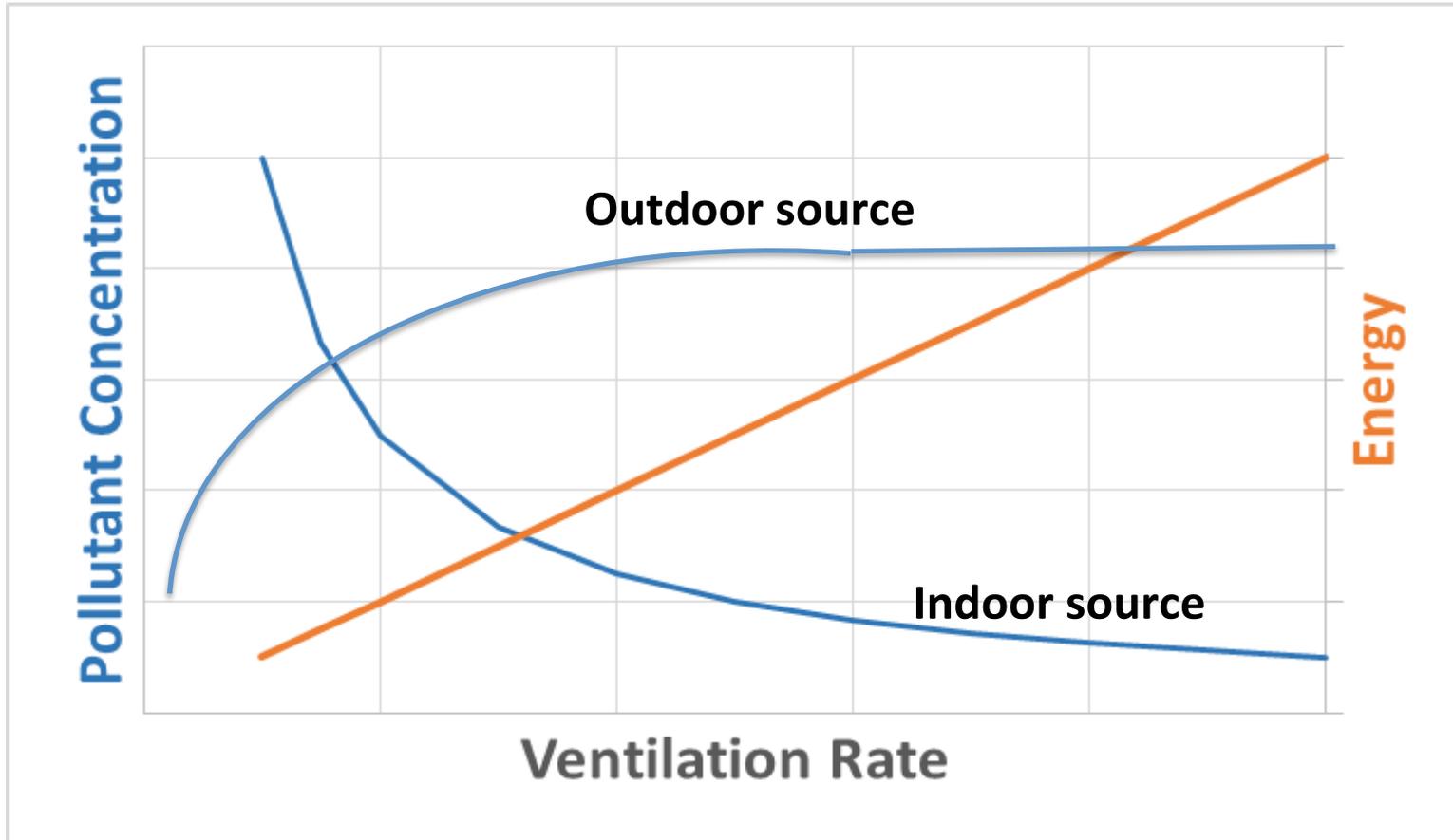
What is a Ventilation Rate?

- ◆ Rate of outdoor air supply (e.g., L/s or cfm)
- ◆ Ventilation rates are usually normalized by number of occupants, floor area, or indoor volume
 - L/s per person or cfm per person
 - L/s per square meter or cfm per square foot
 - Air changes per hour (1/h)

Why is Ventilation Necessary?

- ◆ Maintain sufficient oxygen
 - minimal requirement
- ◆ Prevent carbon dioxide from reaching levels that dangerous levels
 - less than 1 L/s (2 cfm) per person required
- ◆ Flush out and maintain acceptable concentrations of indoor generated air pollutants
 - standards usually specify a minimum of 7 L/s (15 cfm) per person

Tradeoffs



Minimum Ventilation Rate (MVR) Standards

ASHRAE Standard 62.1

- ◆ $MVR = A \times (\# \text{ people}) + B \times (\text{floor area})$
 - for offices, $A = 2.5 \text{ L/s}$ and $B = 0.3 \text{ L/s per square meter} \rightarrow MVR = 8.5 \text{ L/s per person at default occupancy}$

California Title 24

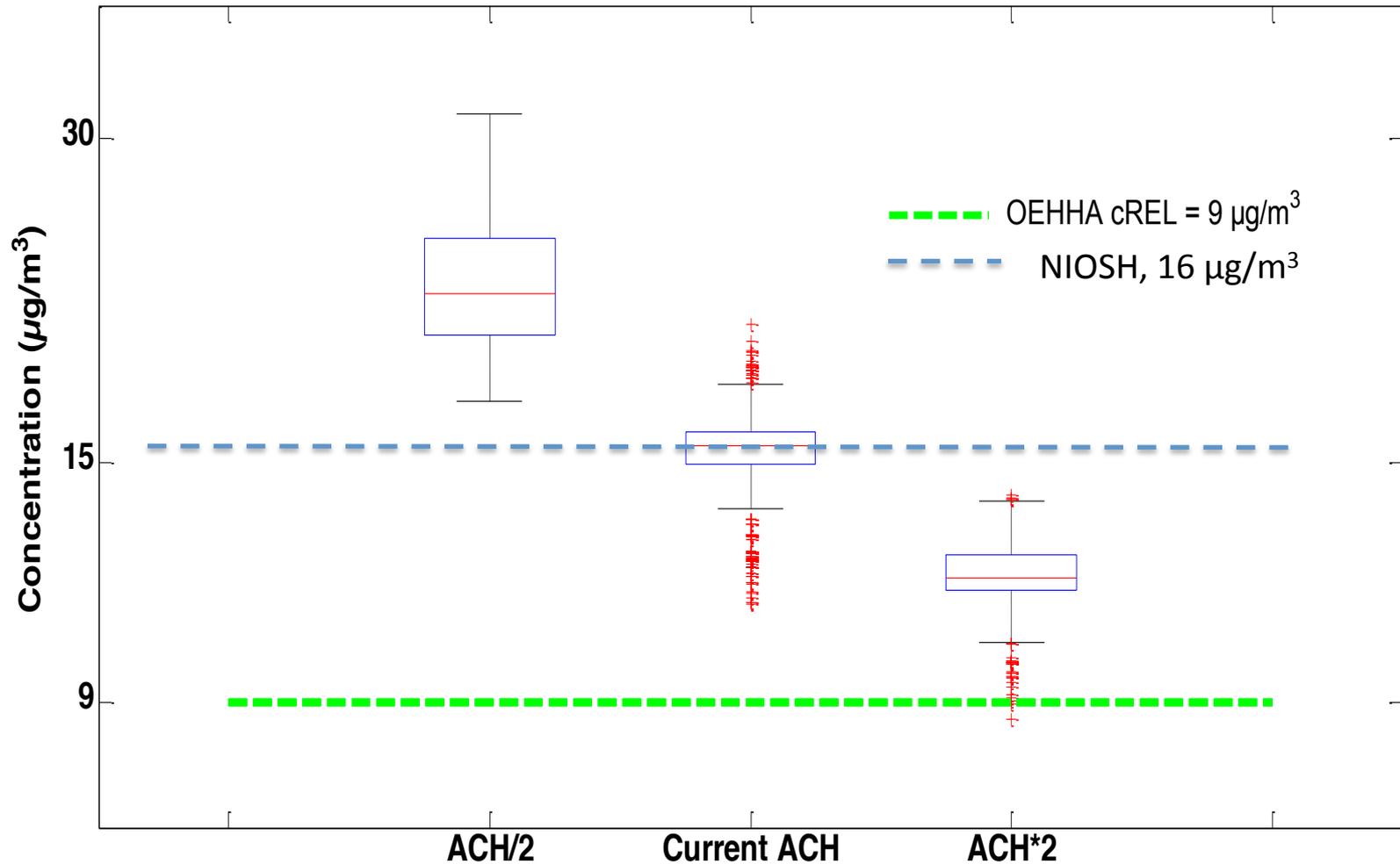
- ◆ $MVR = \text{larger of } 7.1 \text{ L/s per person and } C \times (\text{floor area})$
 - for offices at default occupancy $MVR = 7 \text{ L/s per person at default occupancy}$

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 Findings

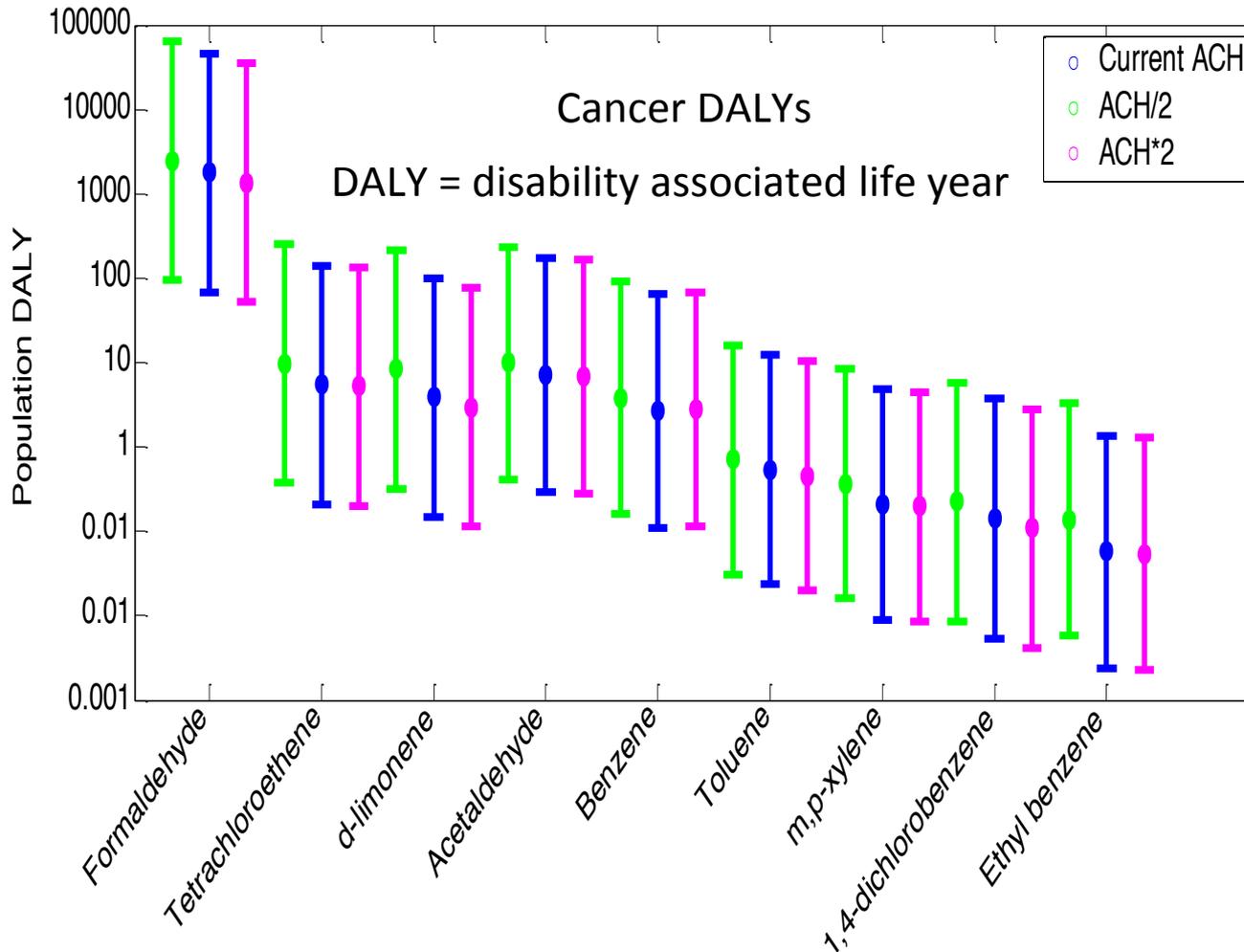
Modeled Formaldehyde Concentrations vs. VR

Formaldehyde concentration



How VR Affects Chronic Health Risks in Disability-Adjusted Life Years (DALYs) in U.S. Office Work Force

DALYs lost due to cancer effects



KEY FINDINGS

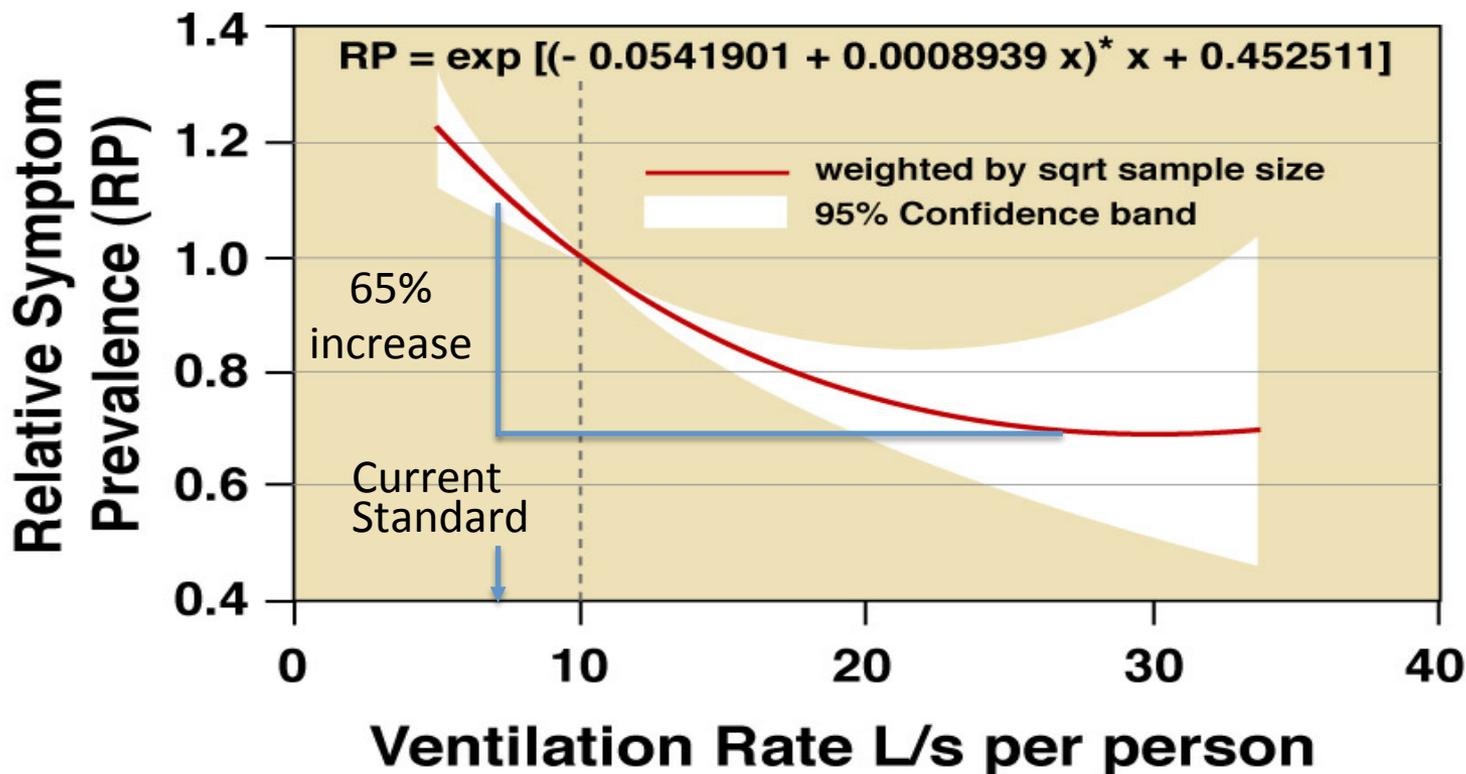
Increasing VR does not reduce, or much change, risks of particles (use filters)

For VOCs, cancer risks of formaldehyde dominate

Risks are low, individual cancer risk is ~0.5 in 1 million from halving existing VRs in offices

Increased Ventilation Rates in Offices Reduces Sick Building Syndrome Symptoms

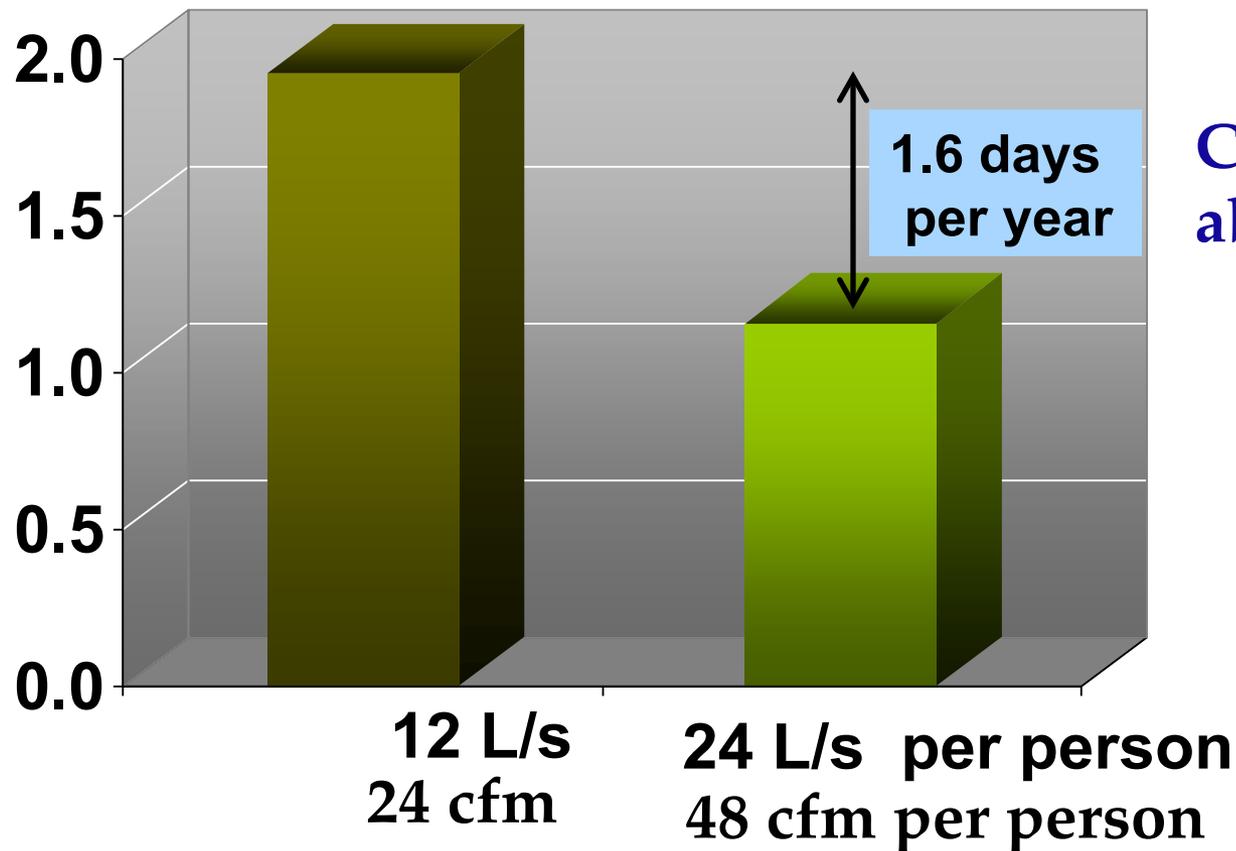
Statistical Analyses of 8 Studies with 43 data Points



Source: Fisk, Mirer, AG, Mendell, MJ (2009) Indoor Air 19(2): 159-165.

Ventilation and Short Term Sick Leave in Offices

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

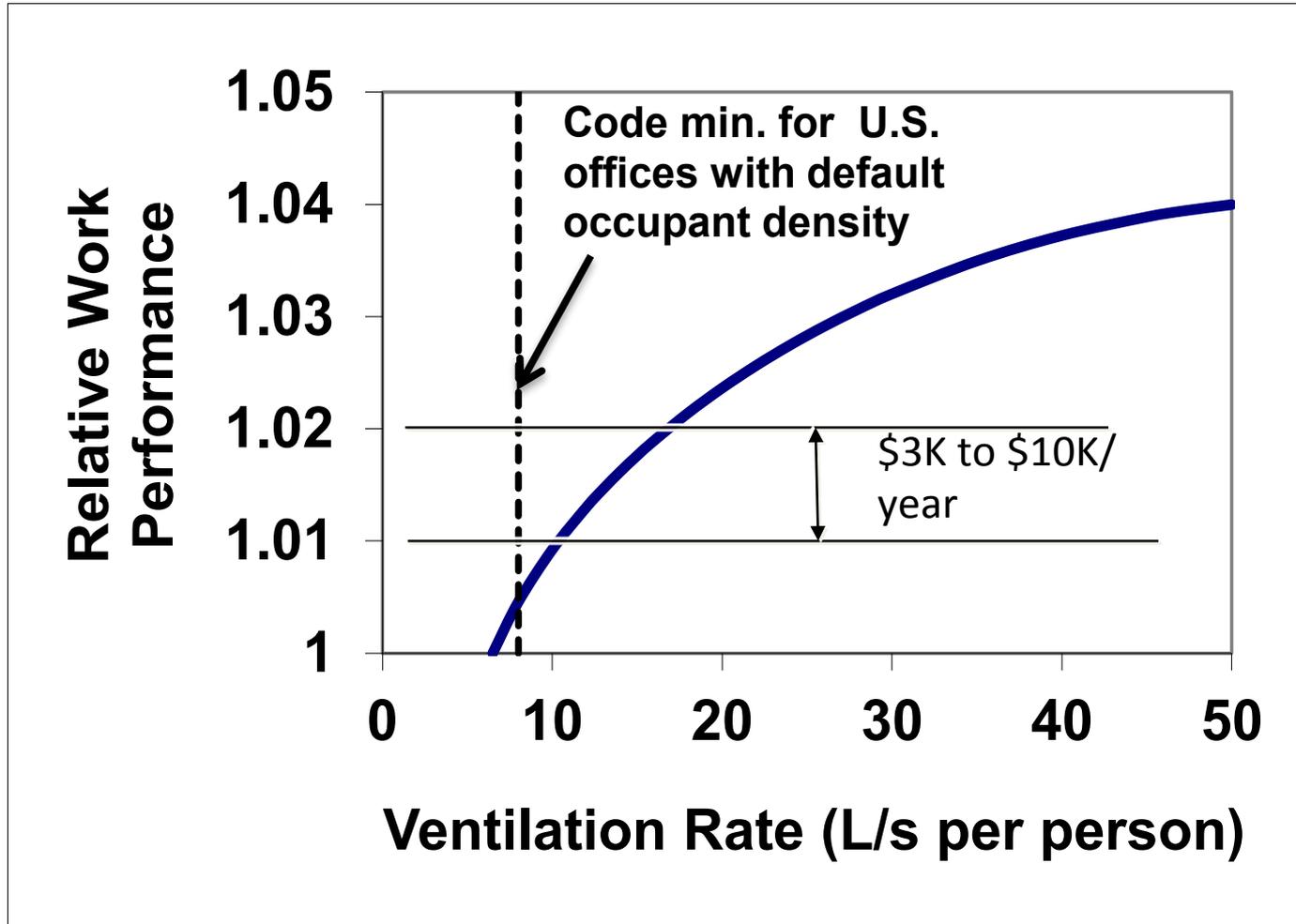


Cost of 1 day of absence ~ \$311

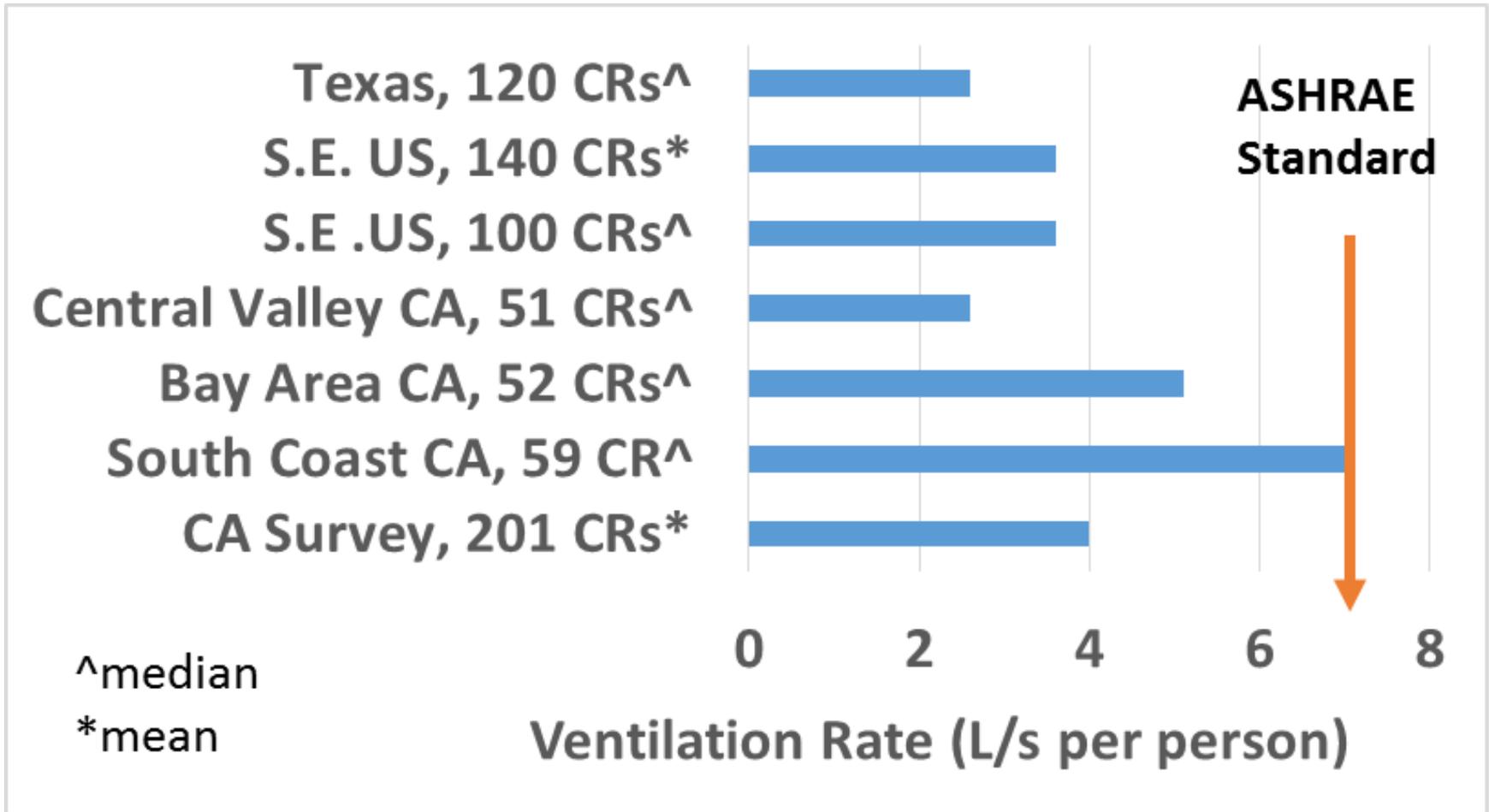
However, no effect seen in study of CA offices with high ventilation rates

Office Work Performance Increases with Ventilation Rate

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

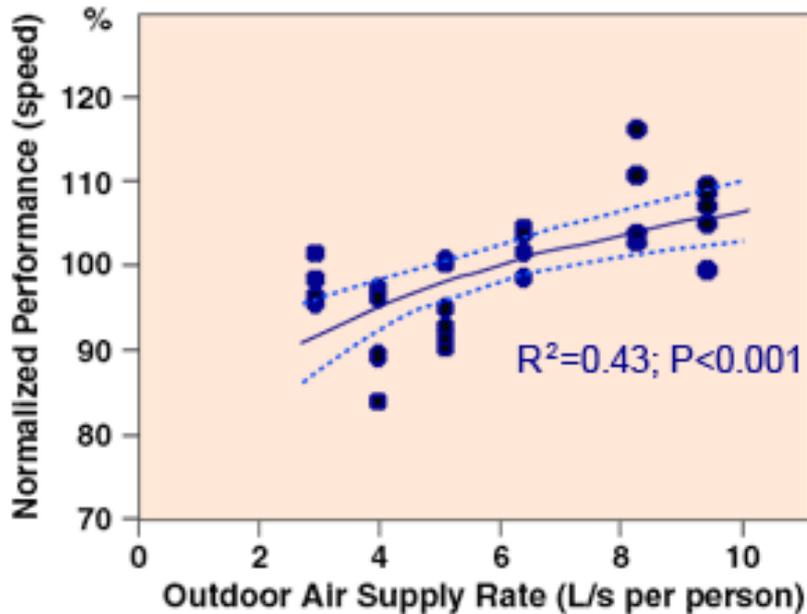


Low Ventilation Rates US Elementary Classrooms[#]

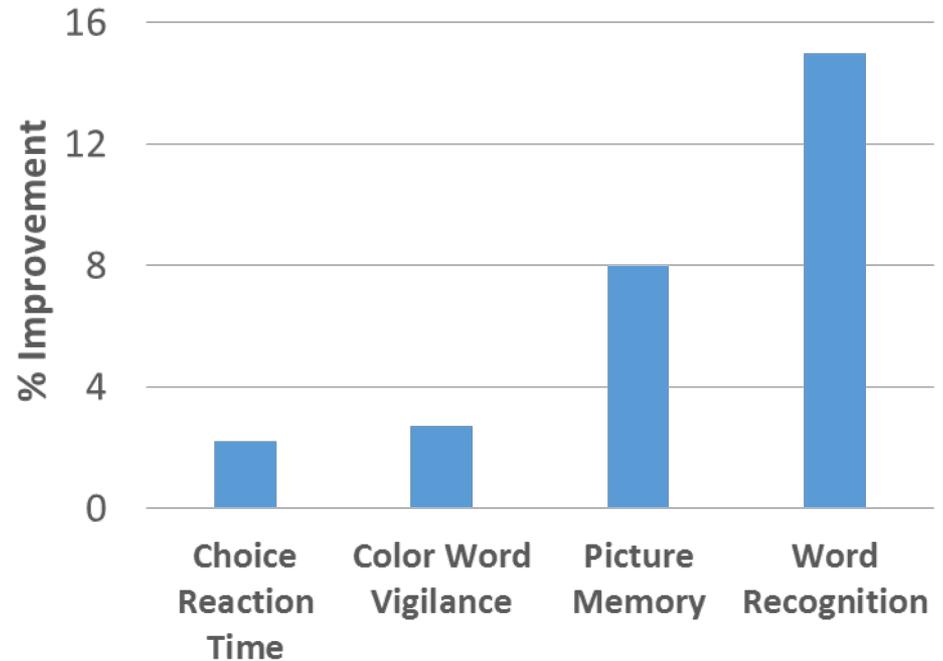


[#]estimated from measured CO₂ concentrations

Interventions that Increased Ventilation Rates in Classrooms Improved Student Task Performance



Danish Study in Four Classrooms, Speed increased with VR; accuracy not affected (Wargocki et al., HVAC&R Research 2007)



UK Study with Ventilation rates increased from ~ 1 to ~8 L/s per student in 12 Classrooms (Bako Biro et al., Build. and Env. 2012)

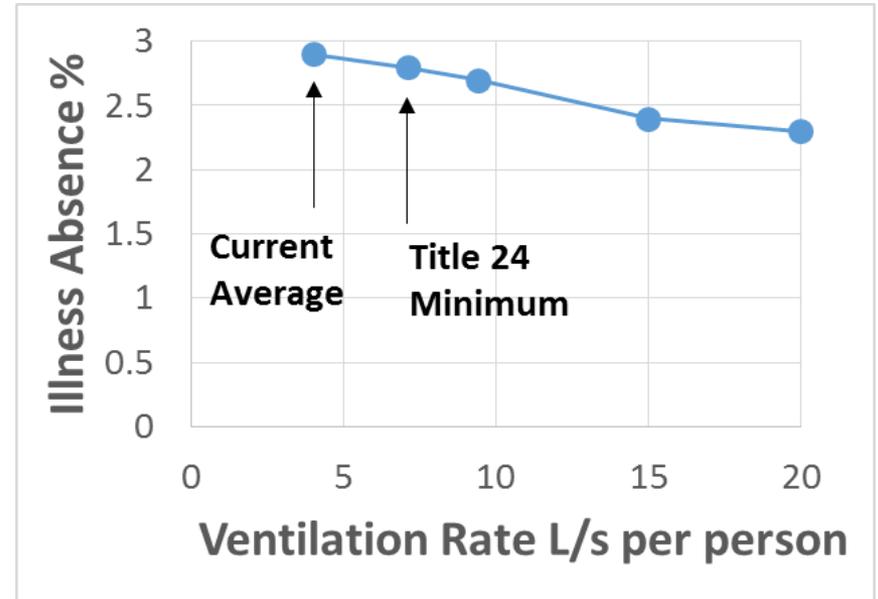
Illness Absence in CA Classrooms Diminished With Increased VR (160 classrooms, 2 years)

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



If Average VR in CA is Increased to Current Standard

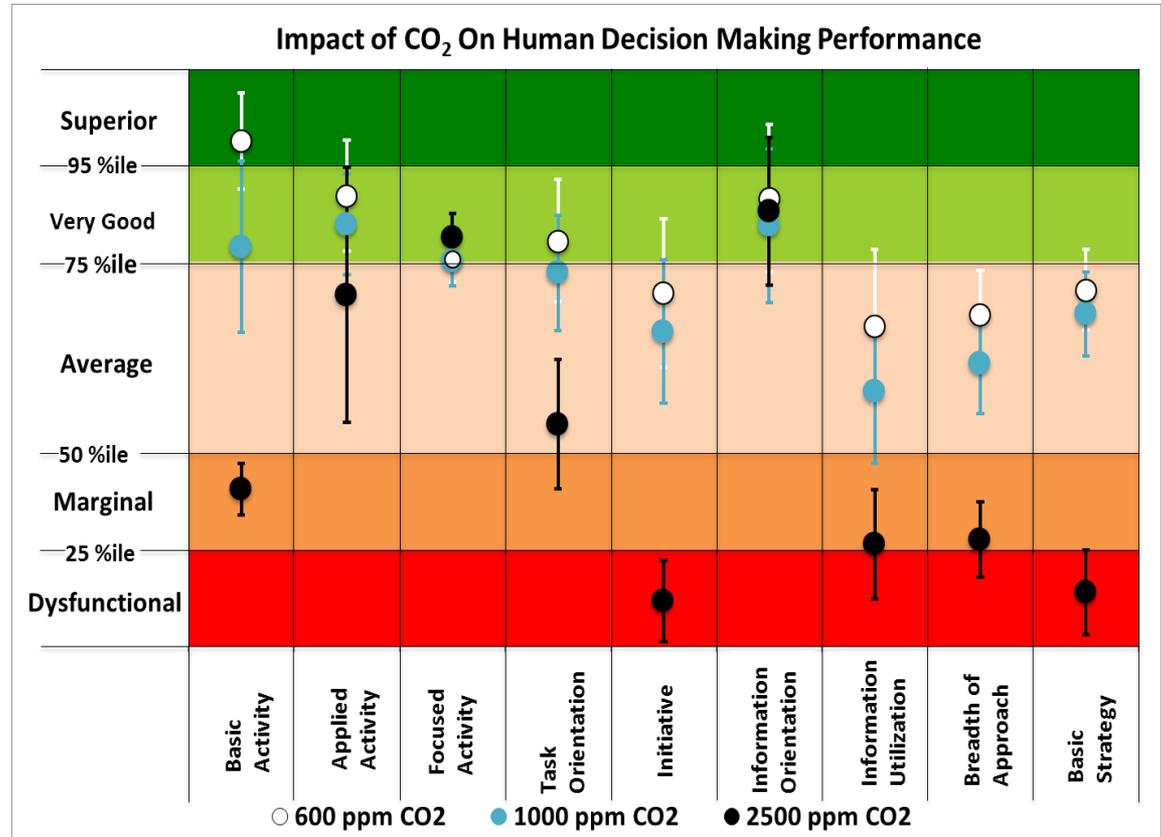
- \$6.2 million annual energy cost increase
- \$33 million increased revenue to school districts
- \$80 million reduced care giver costs

CO₂ Affects Decision Making

Higher CO₂, with all other factors constant, associated with statistically significant degradation in decision making

Moderate effects at 1000 ppm vs. 600 ppm, Large at 2500 ppm vs. 600 ppm

Source: Satish et al EHP 2012; recently replicated by Allen et al. EHP 2015

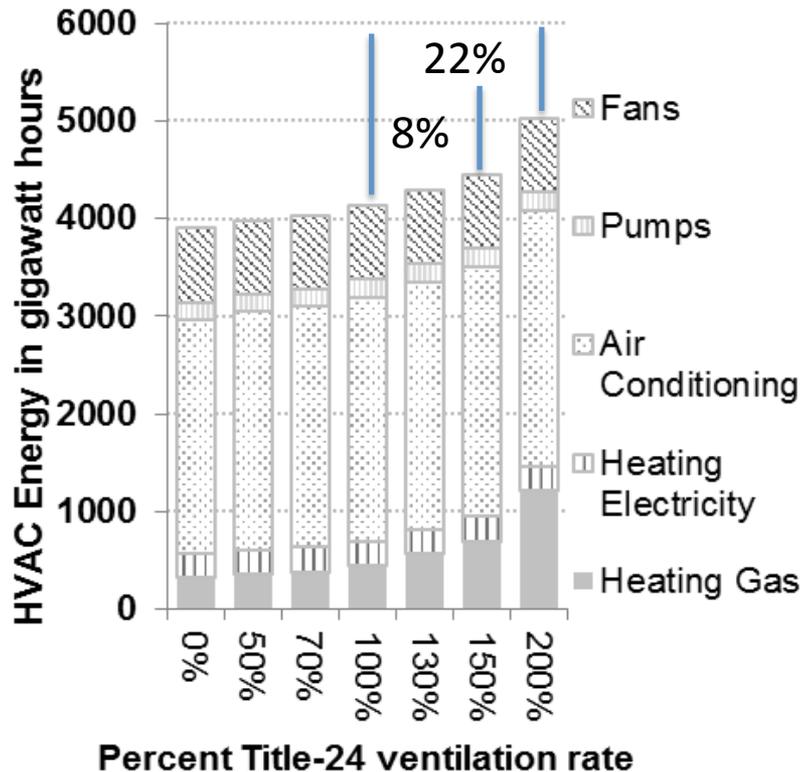


Error bars reflect variability among subjects, within-subject changes are highly statistically significant

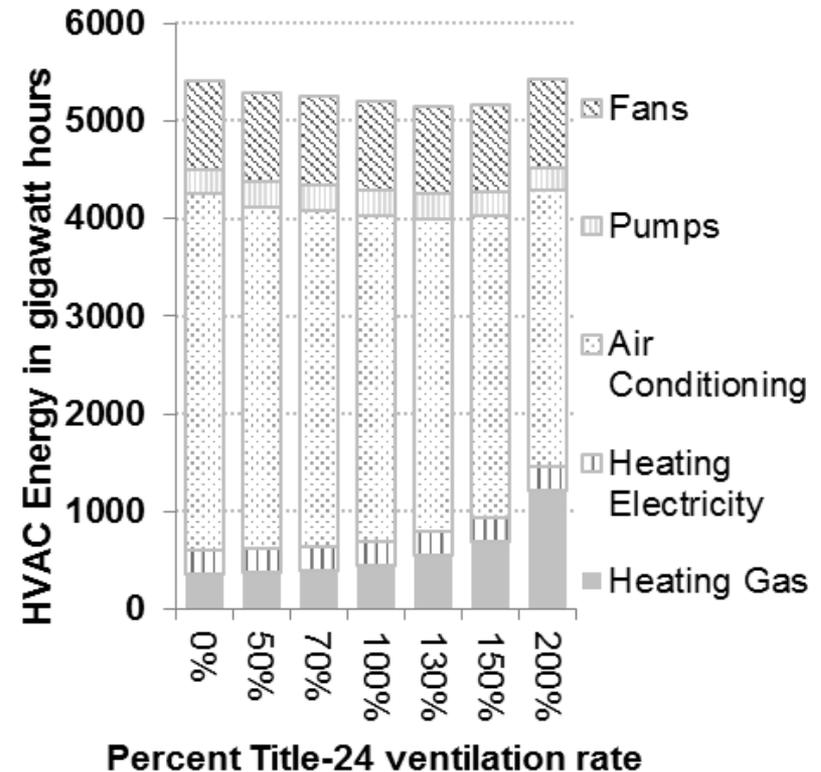
Energy Significance of Ventilation

How Minimum VRs (MVRs) Affect HVAC Energy in California Offices

Buildings with Economizers



Buildings without Economizers



Statewide in CA offices, mechanical ventilation at Title 24 specified rates increases HVAC energy use by ~6% (Dutton et al. Building and Environment 2014)

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

Estimated Benefits of Increasing VRs in US Offices

	Scenario 1 MVR 8 to 10 L/s-p	Scenario 2 MVR 8 to 15 L/s-p	Scenario 3 Economizers in all Buildings
Population Affected	41.3 M	41.3 M	20.7 M
Performance	+ 0.3%	+0.9%	+1.6%
SBS Symptoms	-5%	-15%	-25%
Absence	-9 M days/yr	-30 M days/yr	-28 M days/yr
Energy	Small Increase	Small Increase	Small Decrease

Estimated Annual Economic Impacts of Increasing VRs 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

Take Home Messages

- ◆ Control indoor particles using filters & with source control, not with ventilation
- ◆ Chronic health risks of gaseous pollutants are small, formaldehyde dominates (control sources)
- ◆ Acute symptoms, absence, and performance are affected by VR, large economic implications
- ◆ Widespread under-ventilation in schools
- ◆ Energy use increased moderately with increased minimum VR, but economizers increase VR and save energy
- ◆ CO₂ more than a proxy for other pollutants (affects performance)

Questions?