Indoor Air Quality in Schools: Influence on Health and Performance

William J. Fisk
Indoor Environment Group
Lawrence Berkeley National laboratory

Presentation at the Workshop

Environmental Health at School: Ignored Too Long

November 9, 2015

*development of this presentation was supported by the U.S. EPA, Indoor Environments Division

Scope of Presentation

- Indoor air quality (IAQ) conditions in schools
- Relationship of IAQ conditions, outdoor air quality, and building features with health and performance
- Excluded: asbestos, lead paint, effects of lighting conditions and noise on students or teachers

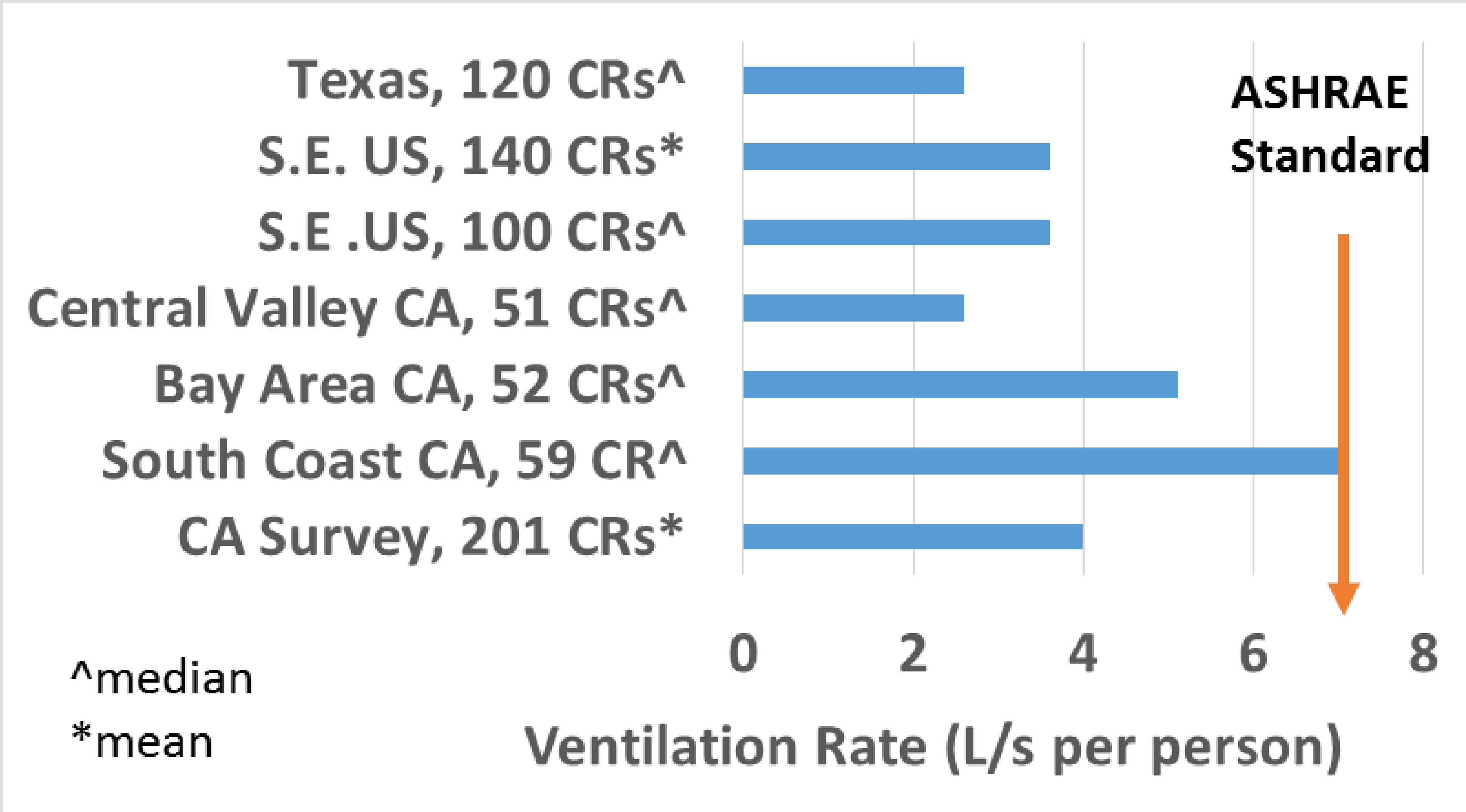
Classroom IAQ Conditions : Key Findings

- Ventilation rates (VR) often much less than specified in standards; indoor CO_2 often well above 1000 ppm

- Particle mass concentrations often exceed guidelines and also exceed outdoor air concentrations
  - Both outdoor air particles and indoor sources are important

- Allergen levels vary with climate, location, culture
  - Pet allergen higher than in homes without pets
  - Cockroach and mouse allergens sometimes elevated
  - Mite allergens levels higher with high humidity, usually less than than in homes

Ventilation Rates US Elementary Classrooms#



#estimated from measured CO_2 concentrations

Classroom IAQ Conditions: Key Findings

- Dampness/water damage and mold problems are occur regularly
  - Prevalence likely to vary with climate and location
- Volatile organic compound concentrations usually less than guideline levels; except formaldehyde usually exceeds California's reference levels
- Radon concentrations similar to or lower than levels in homes

Classroom IAQ Conditions: Key Findings

- Airborne bacteria levels are high, endotoxin levels can be high relative to levels in homes
- Schools are often near major roads and located in urban centers; these locations increases levels of traffic-related pollutants in schools
- Significant levels of plasticizers and flame retardants
  - Data too sparse for broad conclusions

Health and Performance Findings: Cautions

- Findings primarily based on cross-sectional data, albeit with control for confounding
- Health data are usually survey responses, not objective signs

However

- Literature includes intervention studies in which ventilation rate (VR) is varied

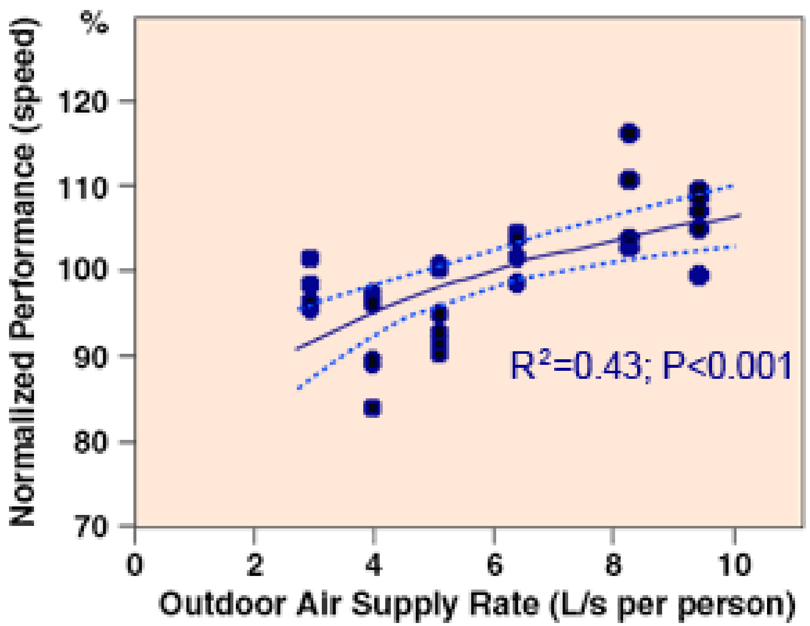
Student Performance

- Numerous studies found associations of reduced performance with lower ventilation rates or with higher CO_2 concentrations
  - Includes intervention studies

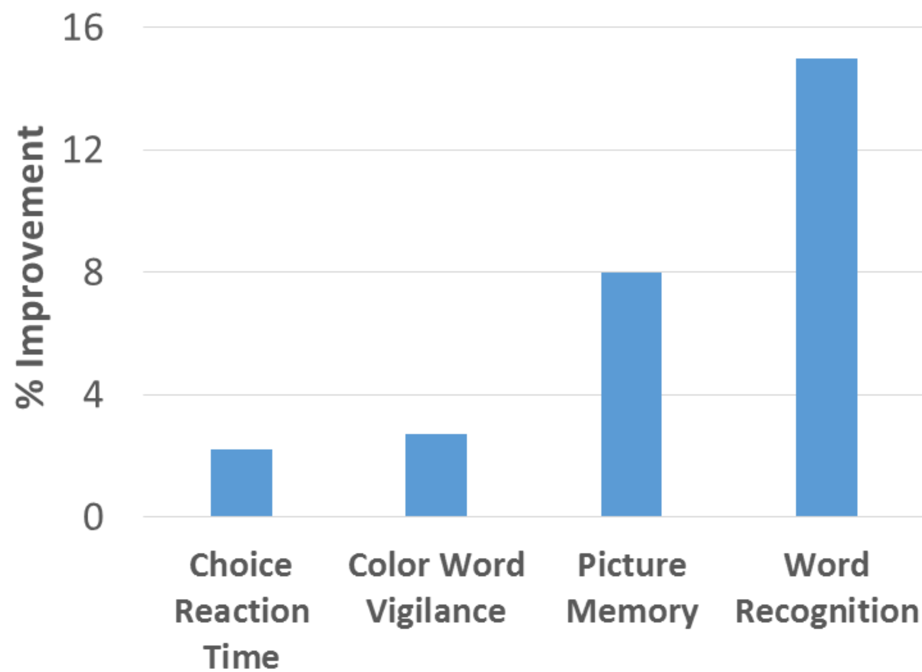
- Limited data indicate decreases in performance as temperature rises above 20 ^{o}C

- Two studies find associations of reduced cognitive performance with increased outdoor pollutants
  - Industrial pollutants (Mohai Health Affairs 2011)
  - Traffic related pollutants (Sunyur Plos Med 2015)

Interventions that Increased Ventilation Rates in Classrooms Improved Student Task Performance

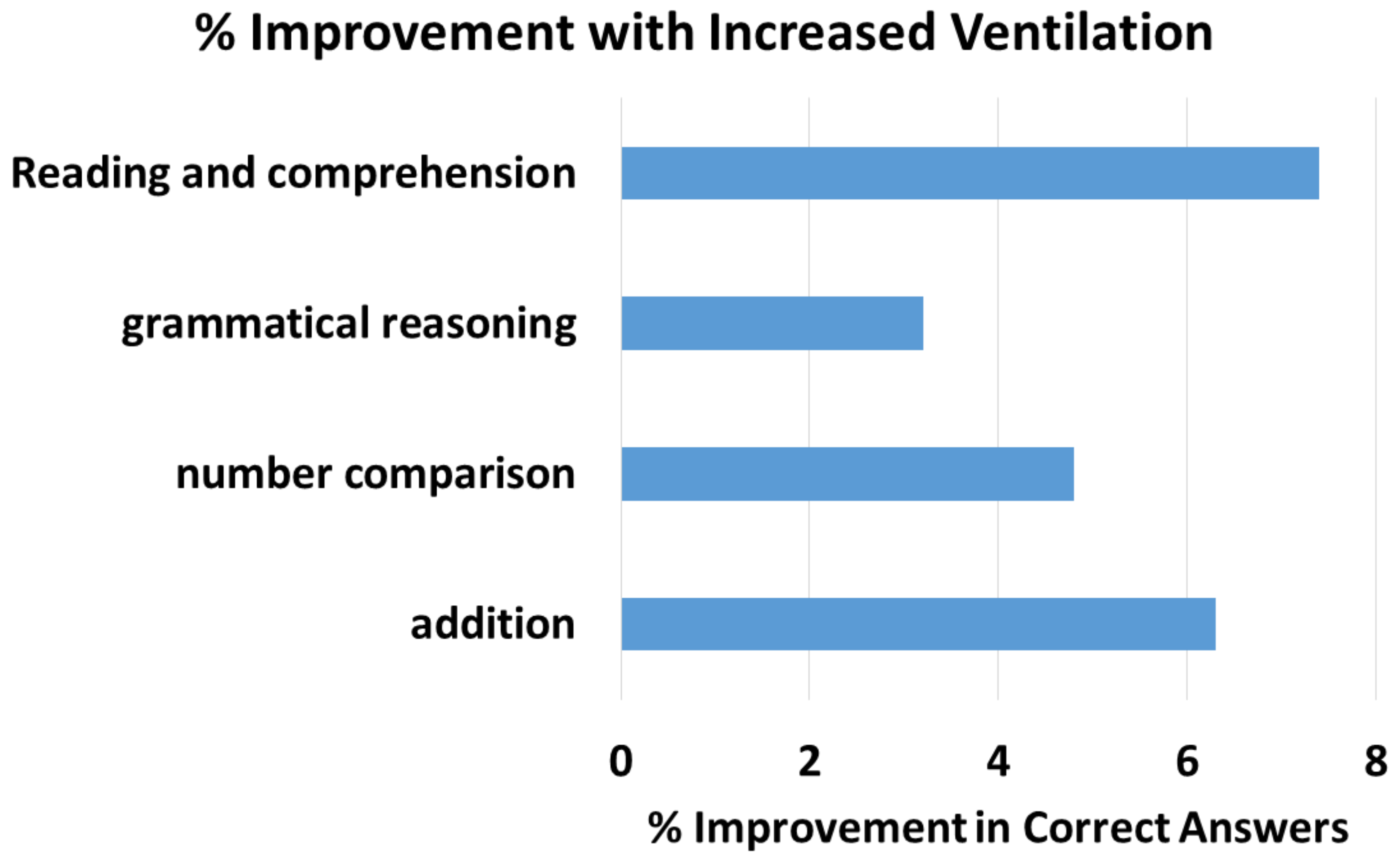


Danish Study in Four Classrooms, Speed increased with VR; accuracy not affected (Wargocki et al., HVAC&R Research 2007)



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)

Interventions that Increased Ventilation Rates in Classrooms Improved Student Task Performance



Danish Study in Four Classrooms with VR increased from 1.7 to 6.6 L/s per person, (Petersen et al., Indoor Air 2015)

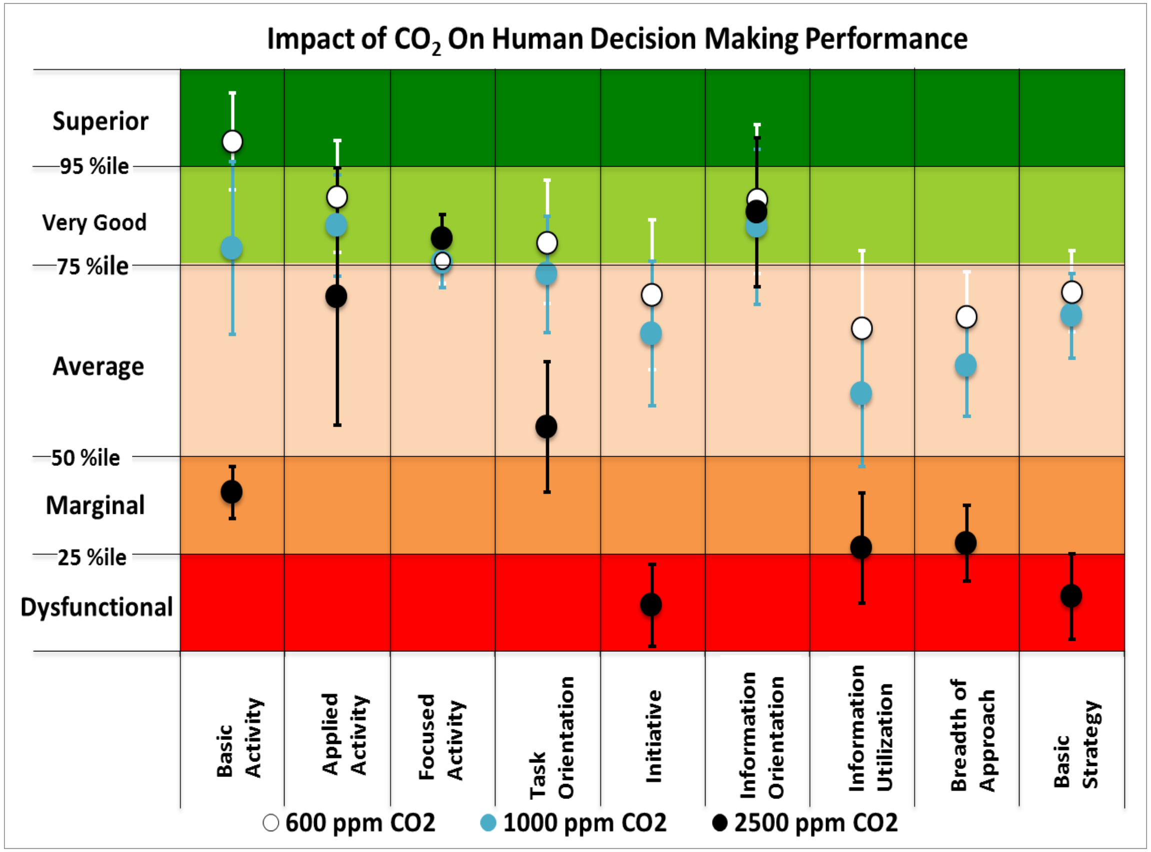
Associations of Ventilation Rates (VRs) with Students Scores on Standardized Tests: Mixed Findings

Study	Ventilation Rates	Main Findings
Mendell et al. Indoor Air 2015, 150 classrooms	Medians of 2.5, 4.9. and 7.6 L/s per person in three districts	Small increases in test scores with VR, mostly not statistically significant
Haverinen-Shaughnessy et al. Plos 1 2015, 134 classrooms	Median 3.6 L/s per student	For classrooms with VR < 7.1 L/s per student, statistically significant 0.5% increase in Math score per 1 L/s per student increase in ventilation (NS trend for English and Science)
Haverinen-Shaughnessy et al. Indoor Air 2011, 87 classrooms	Mean 3.6 L/s per student	For classrooms with VR < 7.1 L/s per student, per each L/s increase in VR, statistically significant: • 2.9% increase in pass rate for Math • 2.7% increase in pass rate for Reading
Gaihre et. al. , J. School Health 2014, 60 classrooms	Peak CO_2 ranged from 1821 to 2750 ppm	• No significant association of peak CO_2 with % students at grade level based on standardized test

Direct Effects of CO_2 on Decision Making

Controlled Exposure Study, Satish et al. EHP 2012

- Varied CO_2, other factors constant



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

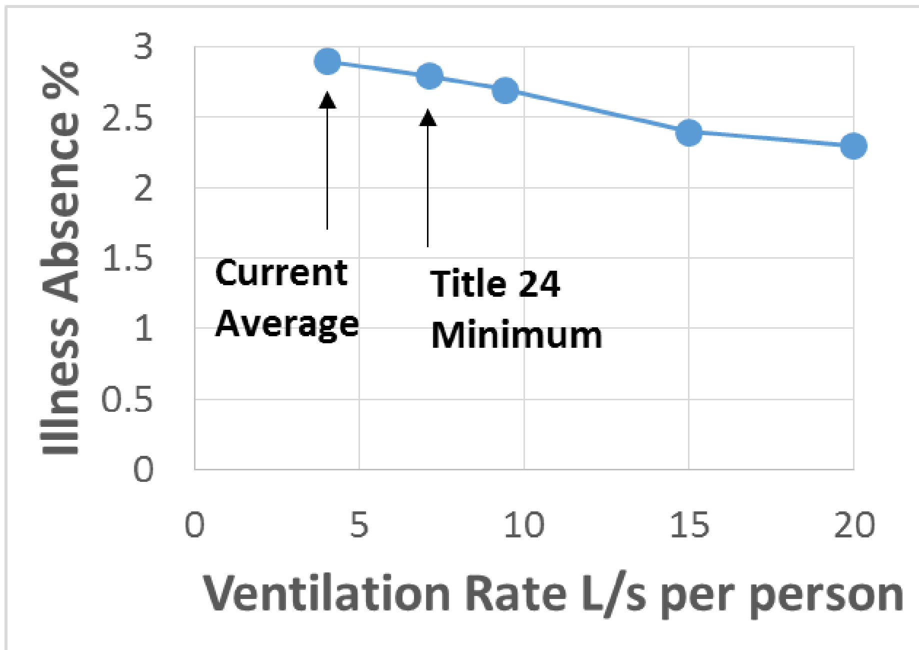
Higher CO_2, with all other factors constant, was associated with statistically significant degradation in decision making

- Moderate effects at 1000 ppm vs. 600 ppm, Large at 2500 ppm vs. 600 ppm
- Recent replication of findings reported by Allen et al. EHP 2015

Absence or Illness Absence

- Three out of four studies found statistically significant increase in student absence associated with lower ventilation rate or higher CO_2 concentration

Results of Mendell et al. Indoor Air 2013



Illness absence decreases 1.6% per each 1 L/s per student increase in VR

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

Asthma /Respiratory Outcomes and Non-Microbial Pollutants

STUDY	KEY FINDINGS
Annesi-Maesano et. al. , J Tox Env Health B Crit Rev 2012	Higher levels of **particles, acrolein, NO_2** associated with increased past year asthma
Kim et al. , Indoor Air 2007	Increased **plasticizers** associated with asthma symptoms
Marks et al. , EHP 2010	**Unflued gas heaters** associated with cough and wheeze, but not lung function
Mi et al. , Indoor Air 2006	Higher **CO_2 and NO_2** associated with current asthma and asthma medication, non-significant association of formaldehyde with asthma outcomes
Smedje et al. , Clin Exp Allergy 1997	Current asthma associated with **open shelves, lower temperature, higher RH, higher formaldehyde, higher VOCs**
Wallner et al. , J. Env. Monit. 2012	Reduced lung function associated with higher **formaldehyde, ethyl benzene, and xylenes** in air and with **benzylbutly phthalate, and polybrominated diphenylethers** in dust
Zhao et al., EHP 2007	Higher **SO_2** associated with wheeze and nocturnal breathlessness, higher **NO_2 and formaldehyde** associated with nocturnal breathlessness

Asthma /Respiratory Outcomes and Microbial Pollutants or Dampness

STUDY	KEY FINDINGS
Cai et al. , Ped Allergy Immun 2011	Some **positive and some negative associations** of types of **fungal DNA in dust** in Malaysia with respiratory symptoms and doctor reported asthma, cat allergen not associated with health
Chen et al. , Chest 2014	**Airborne fungal spores** of some types were associated with current asthma and with having fewer asthma symptoms on holidays
Lai et al. , Chest 2015	**Air endotoxin** associated with asthma symptoms in non-atopic children, but not in atopic children
Meklin et al. , Indoor Air 2002	In Finland, **moisture damage** associated with respiratory symptoms in concrete/brick schools but not in wood schools
Mi et al. , Indoor Air 2006)	**Observed molds** associated with asthma exacerbation
Norback et al. , Allergy 2000	Lower nasal patency associated with increased **airborne molds, aspergillus**
Sahakian et al. , J. School Health 2008	Employees of two **damp schools** had more respiratory symptoms than NHANES population. Employees of one damp school had increased Dr.-diagnosed asthma

Asthma /Respiratory Outcomes and Microbial Pollutants

STUDY	KEY FINDINGS
Saijo et al. Envir Health Prev Med 2010	Nasal symptoms and cough increased with various indications of **dampness or mold** in classrooms, but **most associations not statistically significant**
Simoni et al. , Ped Allergy Immun 2011	**Total viable molds in air** associated with cough and rhinitis; **Aspergillus/Penicillium DNA** associated with wheeze; **Aspergillus versicolor DNA** associated with wheeze, rhinitis, cough and lung function
Smedje et al. , Clin Exp Allergy 1997	Current asthma associated with **airborne viable molds** and bacteria
Smedje and Norback, Int J Tuberc Lung Disease 2001	In non-atopic children, **airborne molds** associated with new asthma diagnosis

Risks of Chronic Health Effects of Particles and VOCs in Schools

- **Considerably less than risks from exposures to particles and VOCs in homes (less time in schools)**
- **Particles are largest overall source of chronic health risk**
- **Formaldehyde is dominant source of cancer risk**
- **Pollutant source control and filtration more effective than ventilation in reducing chronic risks**

Source: Chan et al. Indoor Air 2015, considered a limited set of chronic outcomes

Key Findings

IAQ Conditions

- Frequent low ventilation rates and high particle concentrations, Dampness and mold common
- Cases of high reported pet, cockroach, and mouse allergens, airborne bacteria, and endotoxin (high relative to sensitization levels, guidelines, or levels in homes)

Commonly Found Associations

- Decrements in student performance with low ventilation rates
- Increases in absence with low ventilation rates
- Asthma and respiratory outcomes with NO_2 and formaldehyde
- Asthma and respiratory outcomes with various indicators of dampness or fungal exposures

Risks of Chronic Health Effects

- Less than in homes
- Particles largest source of risk
- Formaldehyde largest source of cancer risk

What Technical Actions Might Help

1. Separate systems for outdoor air ventilation, not part of heating and cooling systems
2. Better particle filtration systems
3. Maintenance to prevent/correct water leaks
4. HVAC systems for humid climates that control humidity
5. Integrated pest management
6. Regular, effective space cleaning
7. Source control for organic chemicals

What Practices Might Help

1. Guidelines adopted by states or districts
    a. Maximum contaminant levels, minimum ventilation rates
    b. Unacceptable conditions
    c. Focus on biggest sources of adverse effects
2. Regular inspections and measurements
    a. Make protocols available
    b. At classroom level?
    c. Frequency tied to prior results
    d. Results available to public
3. Corrective actions
    a. Guidance provided
4. Financial resources and incentives are essential

Questions ?

Some Recommended Papers

Abramson, S.L., Turner-Henson, A., Anderson, L., Hemstreet, M.P., Bartholomew, L.K., Joseph, C.L., Tang, S., Tyrrell, S., Clark, N.M. and Ownby, D. (2006) Allergens in school settings: results of environmental assessments in 3 city school systems, *J Sch Health*, **76**, 246-249.

Annesi-Maesano, I., Hulin, M., Lavaud, F., Raherison, C., Kopferschmitt, C., De Blay, F., Charpin, D.A. and Denis, C. (2012) Poor air quality in classrooms related to asthma and rhinitis in primary schoolchildren of the French 6 Cities Study, *Thorax*, **67**, 682-688.

Bakó-Biró, Z., Clements-Croome, D., Kochhar, N., Awbi, H. and Williams, M. (2012) Ventilation rates in schools and pupils' performance, *Building and Environment*, **48**, 215-223.

Bradman, A., Castorina, R., Gaspar, F., Nishioka, M., Colon, M., Weathers, W., Egeghy, P.P., Maddalena, R., Williams, J., Jenkins, P.L. and Mckone, T.E. (2014) Flame retardant exposures in California early childhood education environments, *Chemosphere*, **116**, 61-66.

Forns, J., Dadvand, P., Foraster, M., Alvarez-Pedrerol, M., Rivas, I., Lopez-Vicente, M., Suades-Gonzalez, E., Garcia-Esteban, R., Esnaola, M., Cirach, M., Grellier, J., Basagana, X., Querol, X., Guxens, M., Nieuwenhuijsen, M.J. and Sunyer, J. (2015) Traffic-Related Air Pollution, Noise at School, and Behavioral Problems in Barcelona Schoolchildren: A Cross-Sectional Study, *Environ Health Perspect*, **http://dx.doi.org/10.1289/ehp.1409449**.

Gaihre, S., Semple, S., Miller, J., Fielding, S. and Turner, S. (2014) Classroom carbon dioxide concentration, school attendance, and educational attainment, *J Sch Health*, **84**, 569-574.

Geelen, L.M., Huijbregts, M.A., Ragas, A.M., Bretveld, R.W., Jans, H.W., Van Doorn, W.J., Evertz, S.J. and Van Der Zijden, A. (2008) Comparing the effectiveness of interventions to improve ventilation behavior in primary schools, *Indoor Air*, **18**, 416-424.

Haverinen-Shaughnessy, U. and Shaughnessy, R.J. (2015) Effects of Classroom Ventilation Rate and Temperature on Students' Test Scores, *PLoS One*, **10**, e0136165.

Hutter, H.P., Haluza, D., Piegler, K., Hohenblum, P., Frohlich, M., Scharf, S., Uhl, M., Damberger, B., Tappler, P., Kundi, M., Wallner, P. and Moshammer, H. (2013) Semivolatile compounds in schools and their influence on cognitive performance of children, *International journal of occupational medicine and environmental health*, **26**, 628-635.

Kim, J.L., Elfman, L., Mi, Y., Wieslander, G., Smedje, G. and Norback, D. (2007) Indoor molds, bacteria, microbial volatile organic compounds and plasticizers in schools--associations with asthma and respiratory symptoms in pupils, *Indoor Air*, **17**, 153-163.

Lai, P.S., Sheehan, W.J., Gaffin, J.M., Petty, C.R., Coull, B.A., Gold, D.R. and Phipatanakul, W. (2015) School endotoxin exposure and asthma morbidity in inner-city children, *Chest*, **doi: 10.1378/chest.15-0098**.

Lignell, U., Meklin, T., Putus, T., Rintala, H., Vepsalainen, A., Kalliokoski, P. and Nevalainen, A. (2007) Effects of moisture damage and renovation on microbial conditions and pupils' health in two schools--a longitudinal analysis of five years, *J Environ Monit*, **9**, 225-233.

Meklin, T., Potus, T., Pekkanen, J., Hyvarinen, A., Hirvonen, M.R. and Nevalainen, A. (2005) Effects of moisture-damage repairs on microbial exposure and symptoms in schoolchildren, *Indoor Air*, **15 Suppl 10**, 40-47.

Mendell, M.J., Eliseeva, E.A., Davies, M.M. and Lobscheid, A. (2015) Do Classroom Ventilation Rates in California Elementary Schools Influence Standardized Test Scores? Results from a Prospective Study, *Indoor Air*, **doi:10.1111/ina.12241**.

More Recommended Papers

Mendell, M.J., Eliseeva, E.A., Davies, M.M., Spears, M., Lobscheid, A., Fisk, W.J. and Apte, M.G. (2013) Association of classroom ventilation with reduced illness absence: a prospective study in California elementary schools, *Indoor Air*, **23**, 515-528.

Mi, Y.H., Norback, D., Tao, J., Mi, Y.L. and Ferm, M. (2006) Current asthma and respiratory symptoms among pupils in Shanghai, China: influence of building ventilation, nitrogen dioxide, ozone, and formaldehyde in classrooms, *Indoor Air*, **16**, 454-464.

Norback, D. and Nordstrom, K. (2008) Sick building syndrome in relation to air exchange rate, CO_2, room temperature, and relative humidity in university computer classrooms: an experimental study, *Int Arch Occup Environ Health*, **82**, 21-30.

Norback, D., Walinder, R., Wieslander, G., Smedje, G., Erwall, C. and Venge, P. (2000) Indoor air pollutants in schools: nasal patency and biomarkers in nasal lavage, *Allergy*, **55**, 163-170.

Petersen, S., Jensen, K., Pedersen, A. and Rasmussen, H. (2015) The effect of increased classroom ventilation rate indicated by reduced CO2 concentration on the performance of schoolwork by children, *Indoor air*, **doi:10.1111/ina.12210**.

Saijo, Y., Nakagi, Y., Ito, T., Sugioka, Y., Endo, H. and Yoshida, T. (2010) Dampness, food habits, and sick building syndrome symptoms in elementary school pupils, *Environ Health Prev Med*, **15**, 276-284.

Salo, P.M., Sever, M.L. and Zeldin, D.C. (2009) Indoor allergens in school and day care environments, *J Allergy Clin Immunol*, **124**, 185-192, 192.e181-189; quiz 193-184.

Simoni, M., Annesi-Maesano, I., Sigsgaard, T., Norback, D., Wieslander, G., Nystad, W., Canciani, M., Sestini, P. and Viegi, G. (2010) School air quality related to dry cough, rhinitis and nasal patency in children, *Eur Respir J*, **35**, 742-749.

Simoni, M., Cai, G.H., Norback, D., Annesi-Maesano, I., Lavaud, F., Sigsgaard, T., Wieslander, G., Nystad, W., Canciani, M., Viegi, G. and Sestini, P. (2011) Total viable molds and fungal DNA in classrooms and association with respiratory health and pulmonary function of European schoolchildren, *Pediatr Allergy Immunol*, **22**, 843-852.

Sunyer, J., Esnaola, M., Alvarez-Pedrerol, M., Forns, J., Rivas, I., Lopez-Vicente, M., Suades-Gonzalez, E., Foraster, M., Garcia-Esteban, R., Basagana, X., Viana, M., Cirach, M., Moreno, T., Alastuey, A., Sebastian-Galles, N., Nieuwenhuijsen, M. and Querol, X. (2015) Association between traffic-related air pollution in schools and cognitive development in primary school children: a prospective cohort study, *PLoS Med*, **12**, e1001792.

Twardella, D., Matzen, W., Lahrz, T., Burghardt, R., Spegel, H., Hendrowarsito, L., Frenzel, A.C. and Fromme, H. (2012) Effect of classroom air quality on students' concentration: results of a cluster-randomized cross-over experimental study, *Indoor Air*, **22**, 378-387.

Wang, J., Smedje, G., Nordquist, T. and Norback, D. (2015) Personal and demographic factors and change of subjective indoor air quality reported by school children in relation to exposure at Swedish schools: a 2-year longitudinal study, *Sci Total Environ*, **508**, 288-296.

Wargocki, P. and Wyon, D.P. (2007) The effect of moderately raised classroom temperatures and classroom ventilation rate on the performance of schoolwork by children, *HVAC&R Research*, **13**, 193-220.

Wargocki, P. and Da Silva, N.A. (2015) Use of visual CO2 feedback as a retrofit solution for improving classroom air quality, *Indoor Air*, **25**, 105-114.

Zuraimi, M., Tham, K., Chew, F. and Ooi, P. (2007) The effect of ventilation strategies of child care centers on indoor air quality and respiratory health of children in Singapore, *Indoor air*, **17**, 317-327.