An aerial night photograph of a city, likely Berkeley, California, showing illuminated buildings and a large stadium with a distinctive dome. The city lights are visible in the background, and the stadium is in the foreground. The text is overlaid on this image.

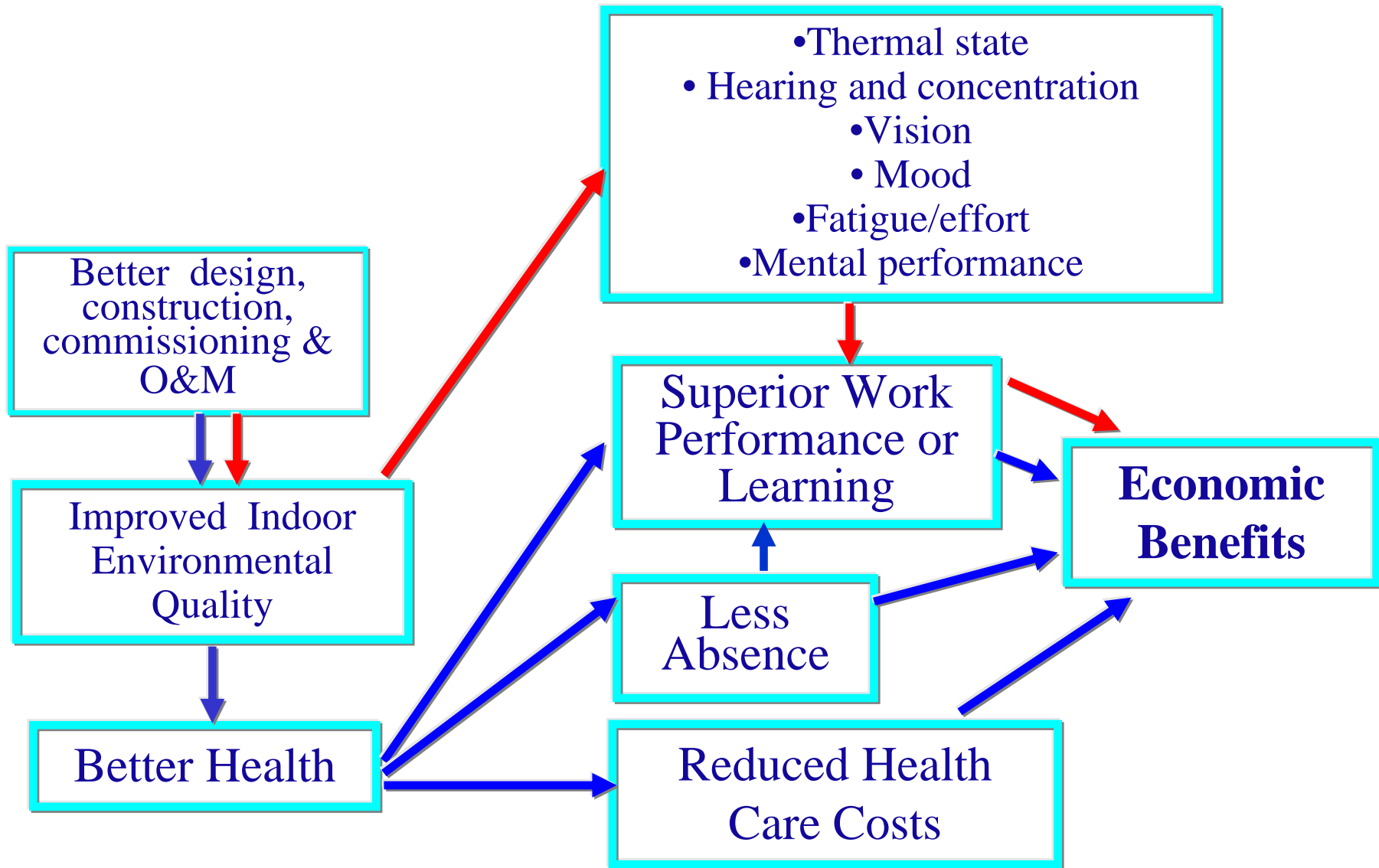
Performance and Health Benefits of Providing Better Indoor Environmental Quality (IEQ): A Brief Review

**IAQ Tools for Schools
National Symposium
December 2007**

William Fisk*

Lawrence Berkeley National Laboratory

How Better IEQ Can Improve Health & Productivity and Learning



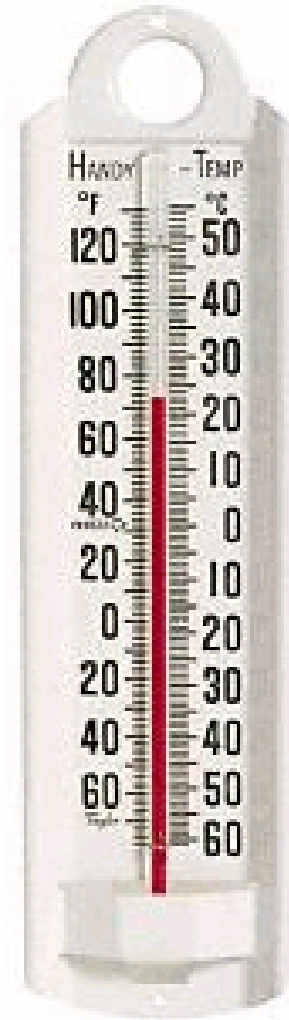
How the Impact of IEQ on Health and Work and School Performance Has Been Studied

Study Type

Study Outcomes

Experimental modifications of temperature, ventilation rates, pollutant sources, etc. in laboratory, office building, call center, or classroom	Change in prevalence of a health outcome Speed, accuracy of simulated office or school work Speed of call center work
Cross sectional surveys of large numbers of offices or classrooms with natural building-to building variability in ventilation rate, temperature, or another IEQ parameter	Surveys of health symptoms Recording of absence days Performance on academic achievement tests Clinical documentation of cases of disease

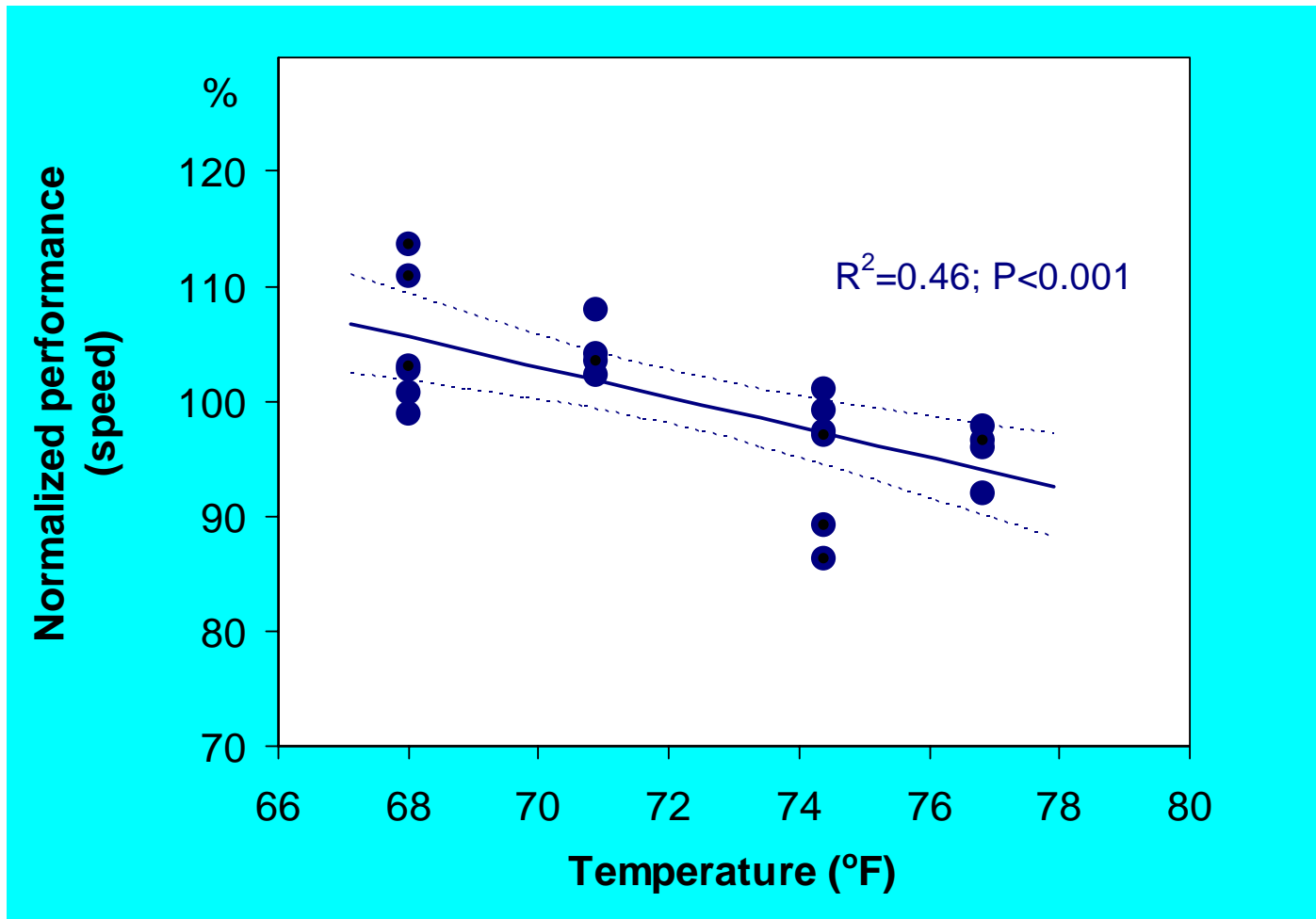
How Indoor Temperature Affects Performance and Health



Danish Study

Temperature and School Work

School Work Speed is Affected by Temperature

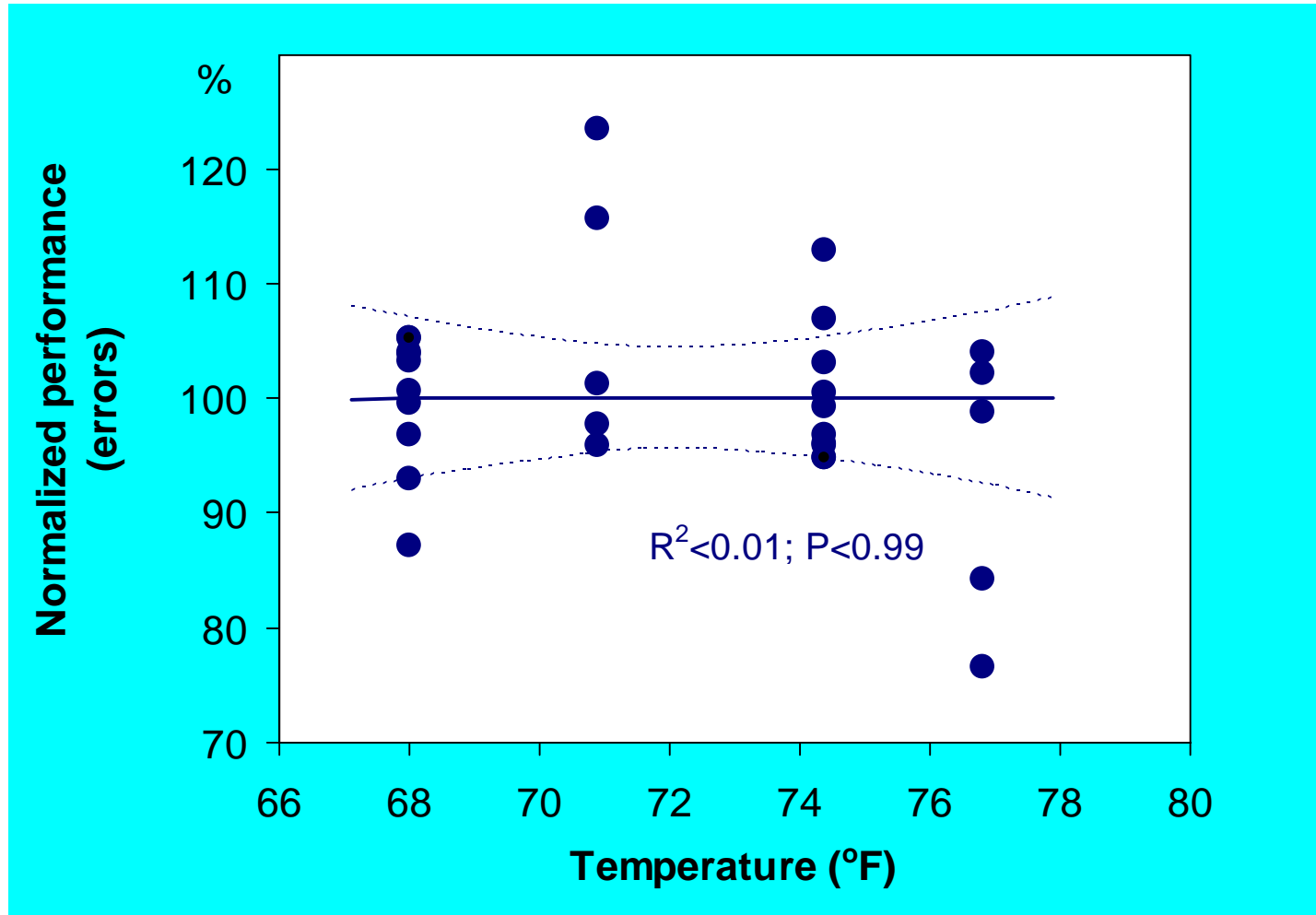


Source: Wargocki and Wyon, ASHRAE Journal, October 2006

Danish Study

Temperature and School Work

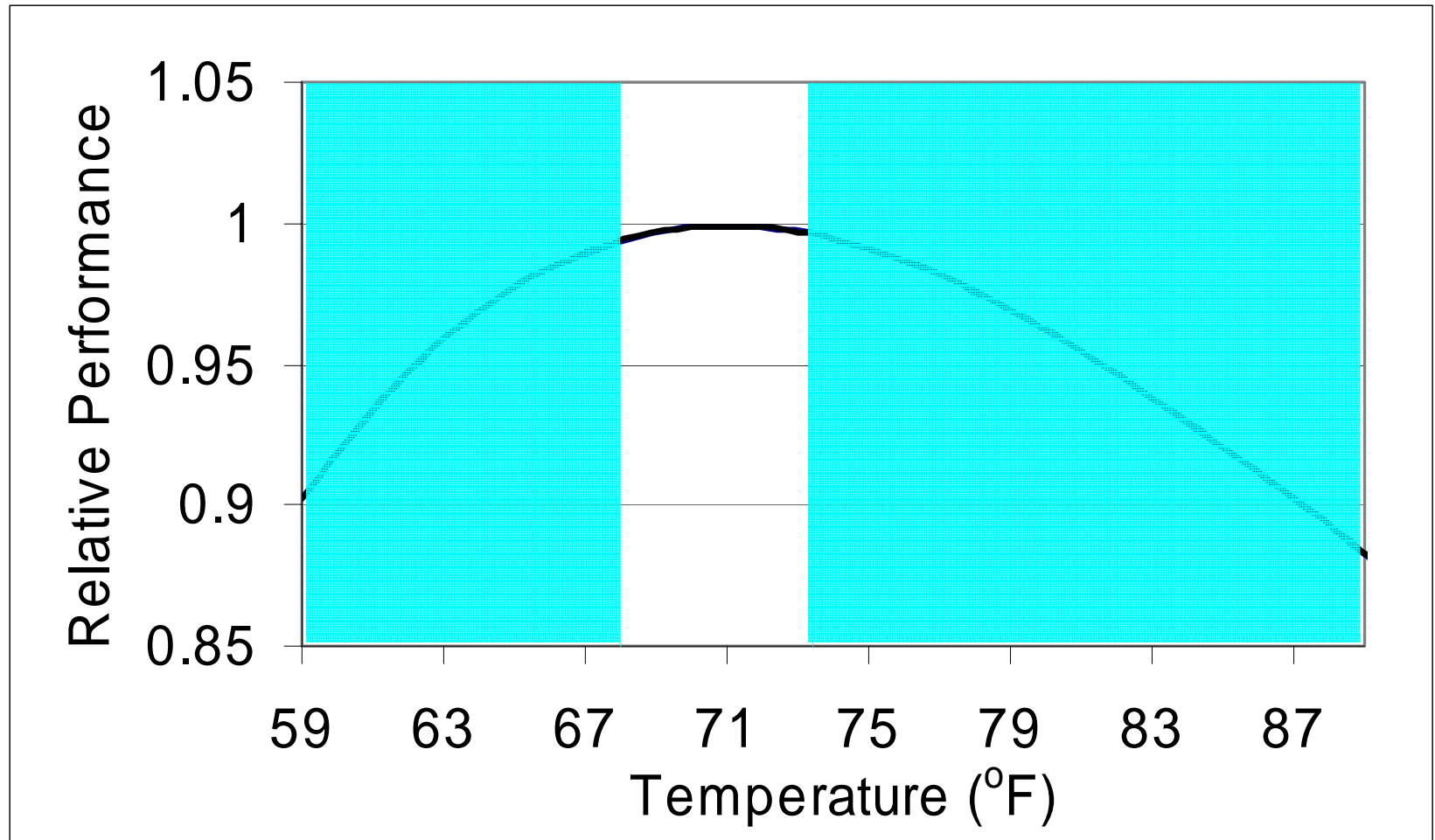
Accuracy is Not Significantly Affected by Temperature



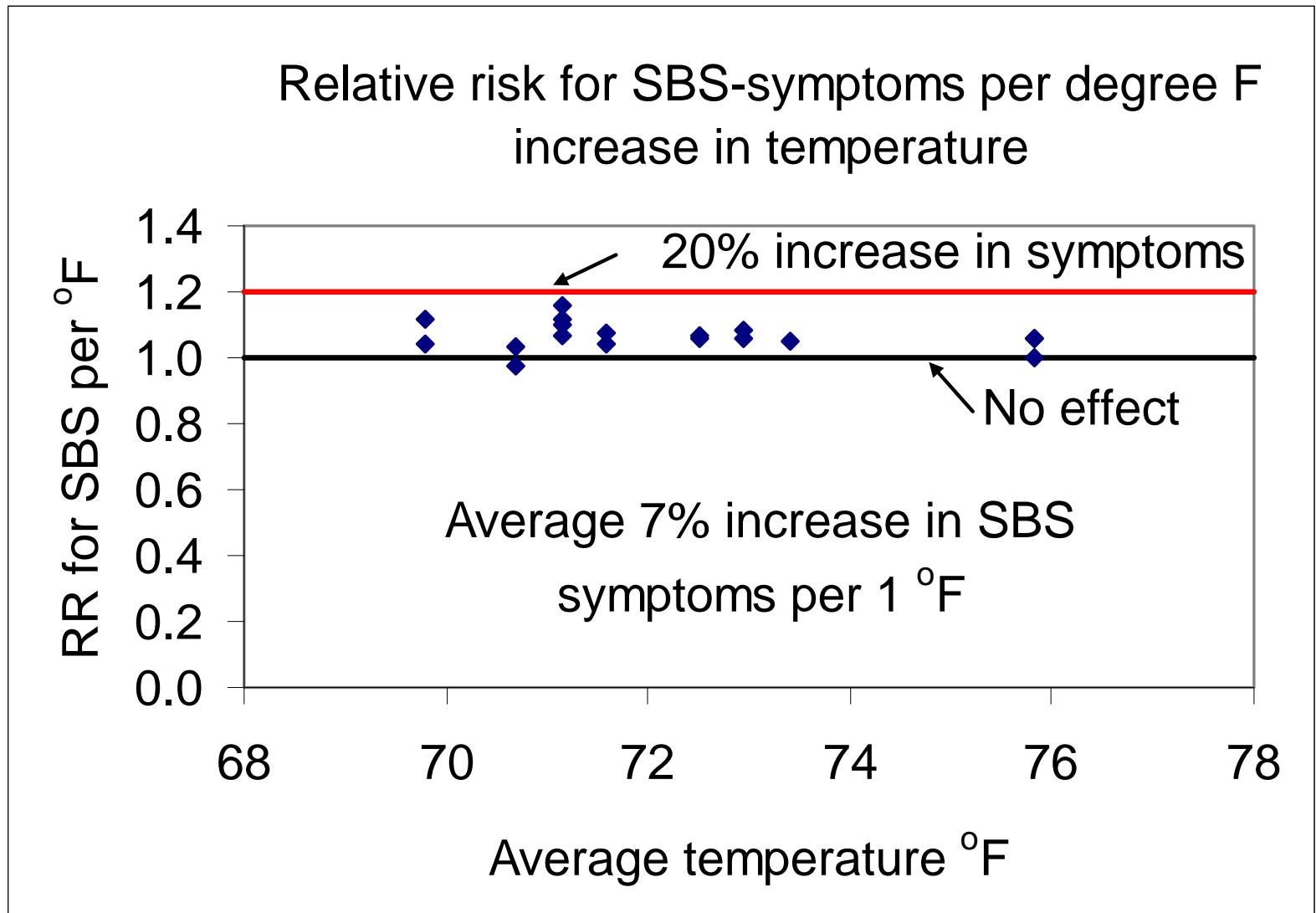
Source: Wargocki and Wyon, ASHRAE Journal, October 2006

Relative Office Work Performance vs. Temperature:

Results of Statistical Analysis of 24 Studies (maximum performance at 71.2 °F)



Avoiding High Temperatures Can Also Reduce Sick Building Syndrome (SBS) Symptoms*



*Data from office building studies, Applicable in schools?

Temperatures in Classrooms

Results from 201 CA Classrooms

Temperature Range	% Time	Estimated Performance Loss
< 17 °C (63 °F)	4.3	> 4%*
< 20 °C (68 °F)	20.5	> 0.6%*
> 23 °C (73 °F)	27.2	> 4% (work speed) ⁺
> 26 °C (79 °F)	4.4	> 8% (work speed) ⁺

***Estimated from office work data**

⁺ Based on results of Danish classroom study

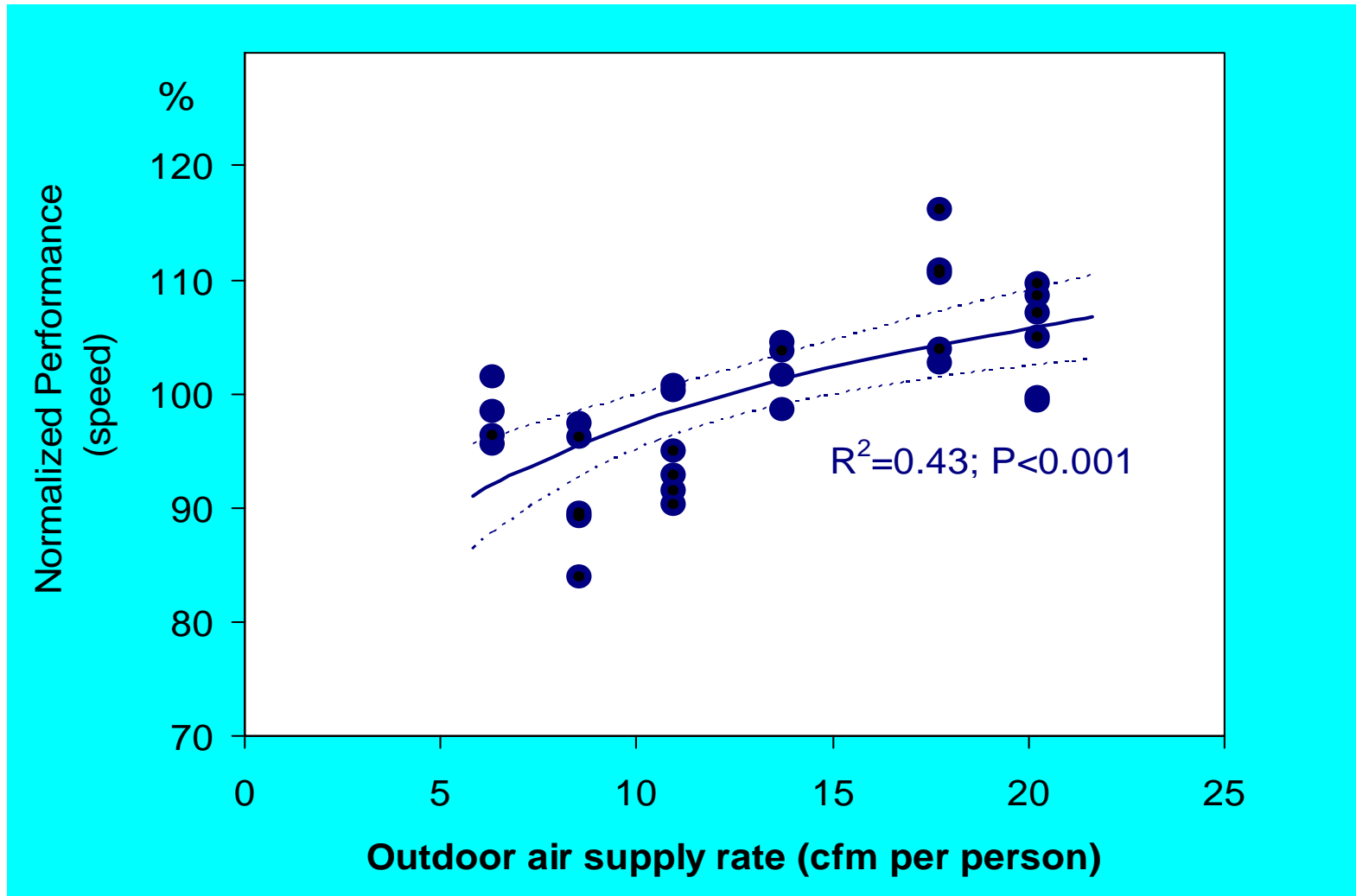
Importance of Ventilation Rate*



*outdoor air supply

Ventilation Rates and Performance in Schools Results of a Danish Study* - Work Speed

School Work Speed Increases with Ventilation Rate

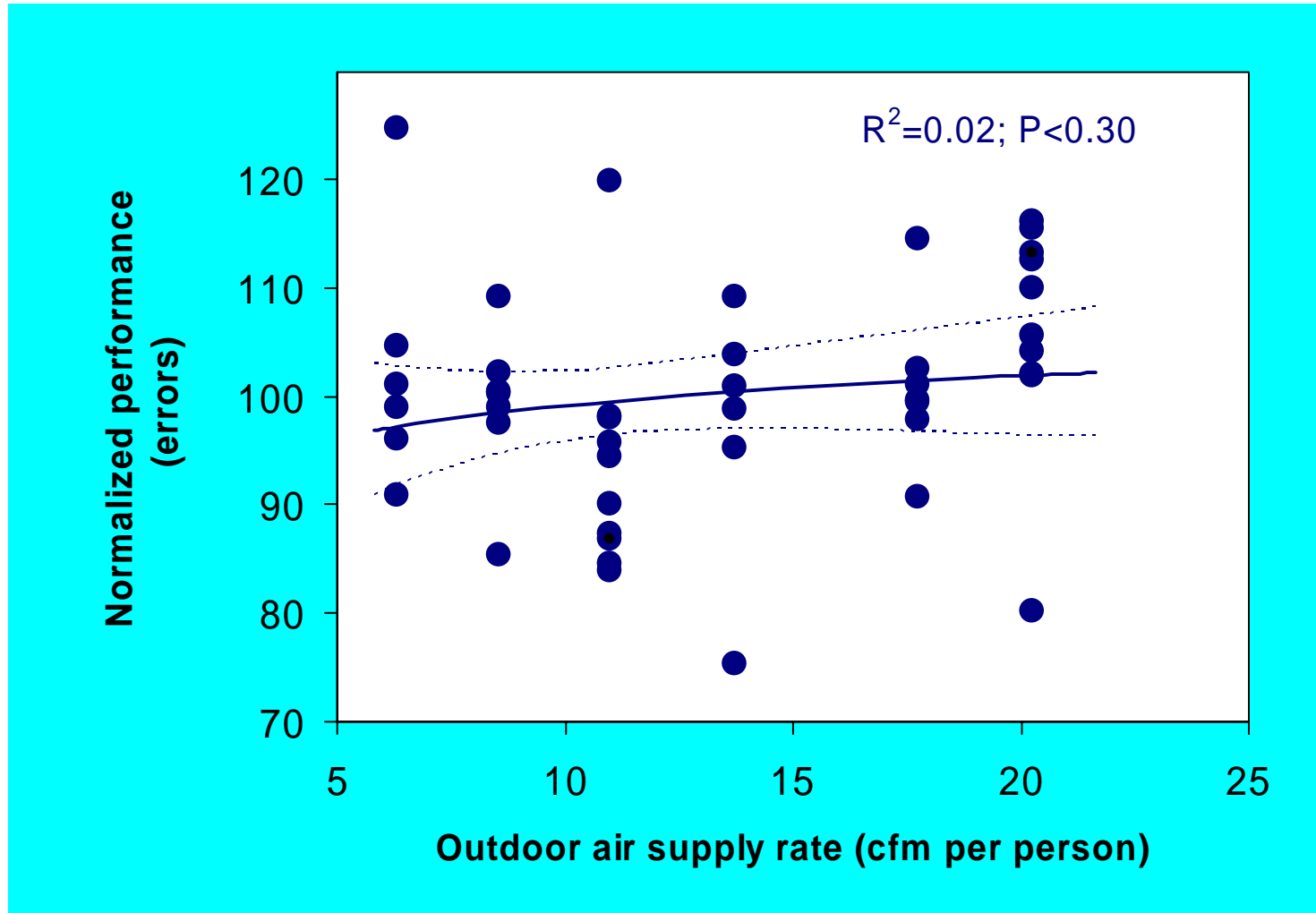


*Wargocki and Wyon, ASHRAE Journal, October 2006

Ventilation Rates and Performance in Schools

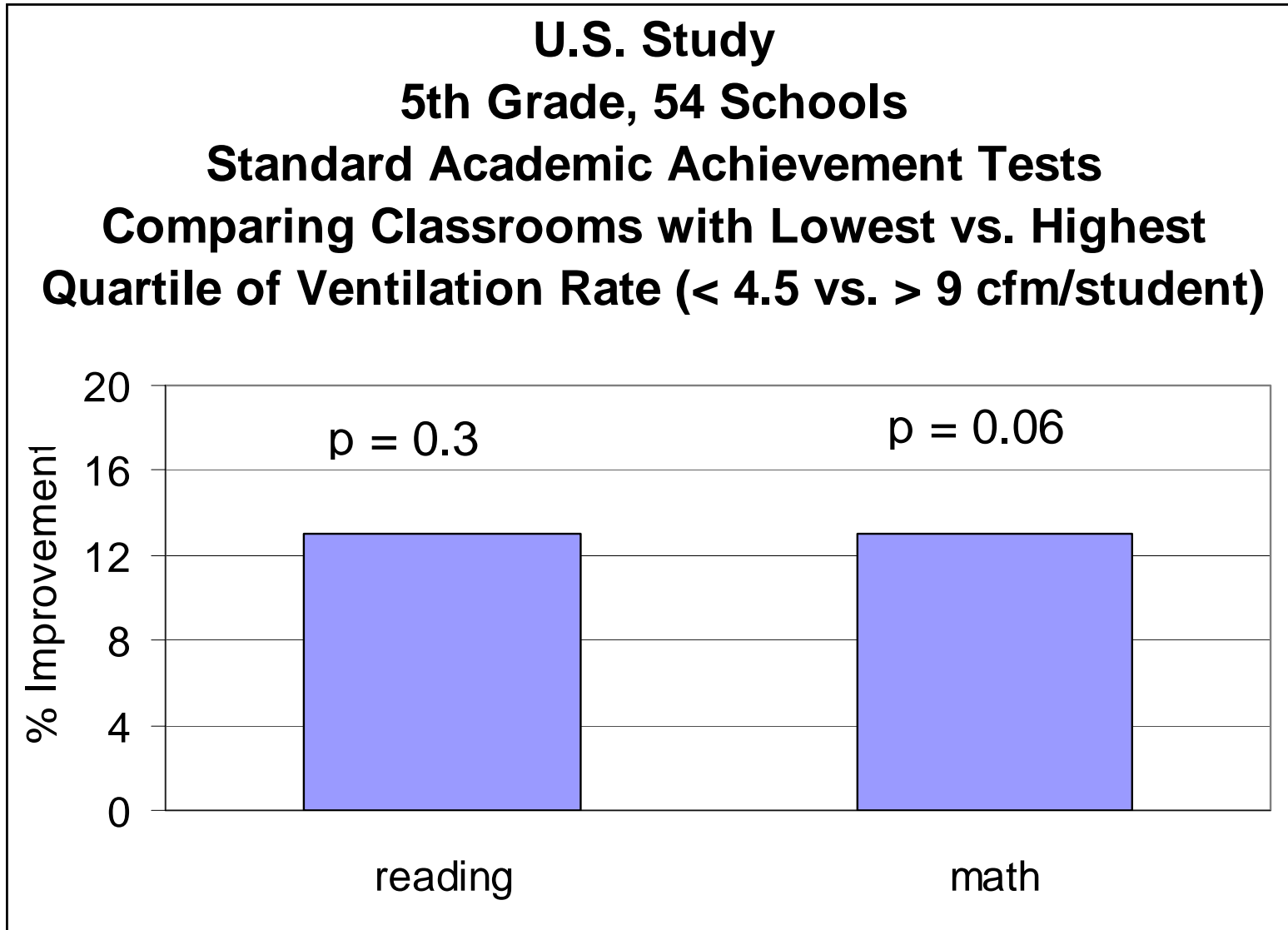
Results of a Danish Study* - Work Errors

School Work Errors Not Significantly Affected by Ventilation Rate

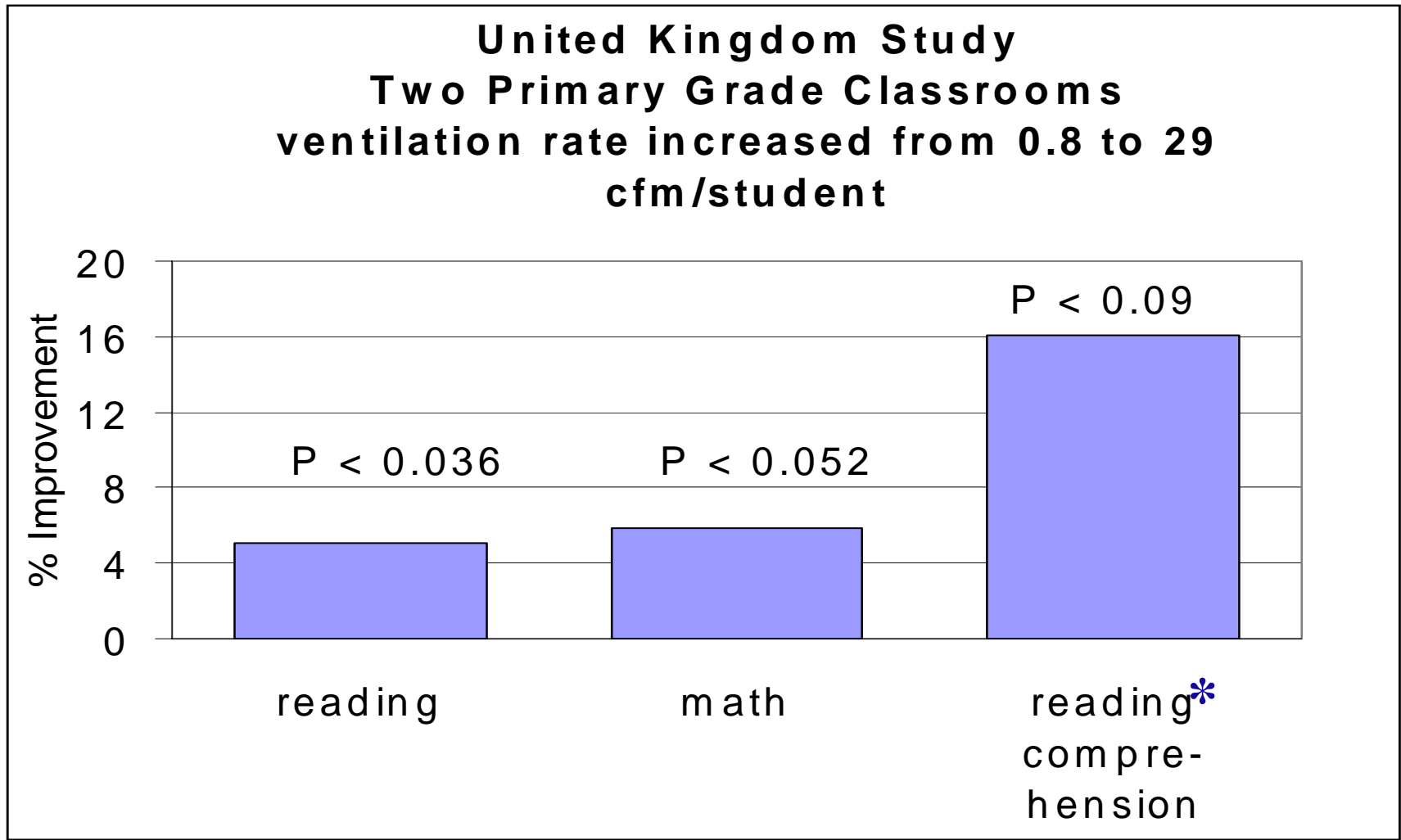


*Wargocki and Wyon, ASHRAE Journal, October 2006

U.S. Study, Ventilation Rate and Academic Achievement



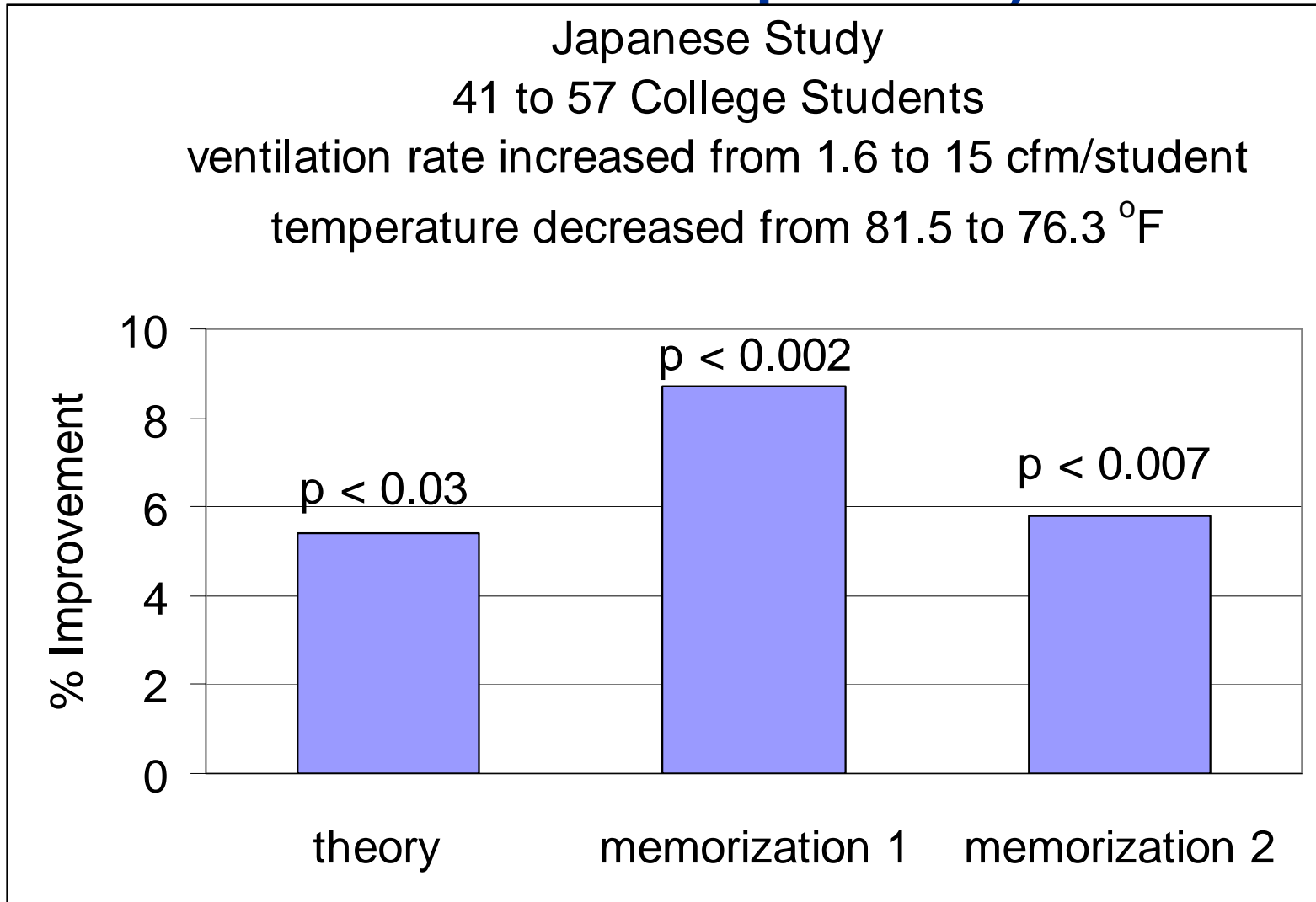
UK Study, Ventilation Rate and Student Work Performance



*based on one classroom, no significant change in second classroom

Source: Bako Biro et al (2007) Proc. Clima 2007

Japanese Study, Change in Student Performance with Increased Ventilation (& decreased temperature)



U.S. Classroom Study of Ventilation Rates and Student Absences

Study Features

- 434 elementary grade classrooms
- Indoor minus outdoor CO₂ used to indicate ventilation rate
- Controlled for grade level, classroom type, socio economic status, gender, ethnicity

Results

1% to 2% decrease in absence per each 100 ppm decrease in indoor minus outdoor CO₂

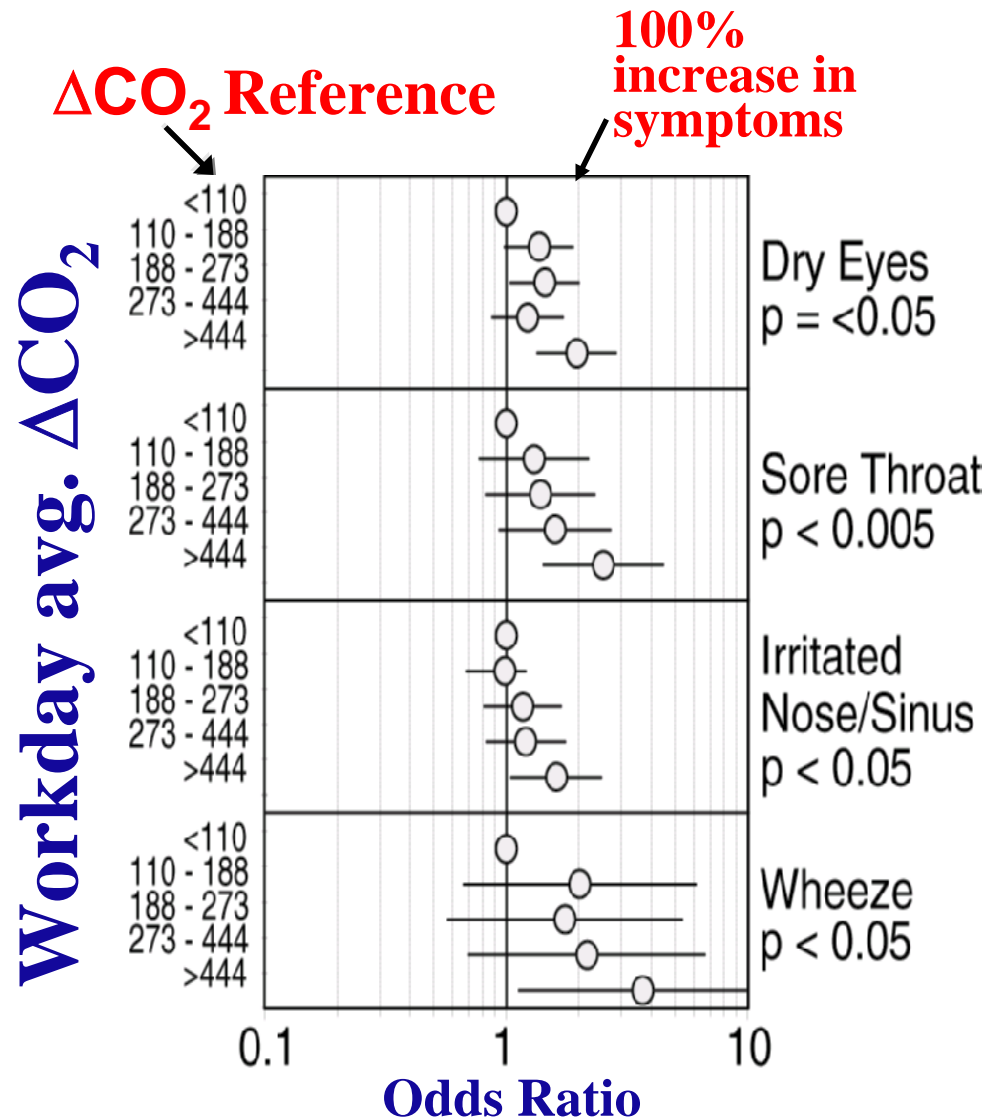


Approximately 0.4% to 0.9% decrease in absence for each cfm per per student increase in ventilation rate

Sick Building Syndrome (SBS) Symptoms in Offices Increase With Decreased Ventilation Rate

Results of a Critical Review

- With lower ventilation rate:
 - 20 of 27 studies found statistically significant increase in symptoms
 - 9 studies found >80% increase in prevalence of at least one symptom



Evidence of Low Ventilation Rates in Classrooms

Typical minimum requirement in standards is 15 cfm/occupant

- Implies PEAK CO₂ < 1000 ppm
- Implies AVERAGE CO₂ << 1000 ppm
- If peak CO₂ > 2000 ppm → ventilation rate < 7 cfm/person

Classroom CO₂ Data

CA Survey (201 Classrooms)	
School-Day Mean	1070 ppm
1 hr peak > 1000 ppm	43%
1 hr peak > 2000 ppm	10%
WA, ID Survey (434 classrooms)	
Grab-sample mean	1080 ppm
> 1000 ppm	45%
> 2000 ppm	4%
Maximum	4600 ppm

Health and Economic Effects of Building Dampness



Exposures Associated With Building Dampness

Molds and bacteria (many types)

- Spores a few micrometers in size, bacterial cells, microbial fragments sometimes less than one micrometer
 - may carry allergens, inflammatory agents, toxins
 - settling and resuspension → inhalation exposures
- Microbial volatile organic compounds → odors

Chemicals

- Formaldehyde
- Alcohols and products of degradation of plasticizers
 - Damp concrete and PVC flooring

House dust mites

- Survival depends on sufficient indoor humidity

Cockroach

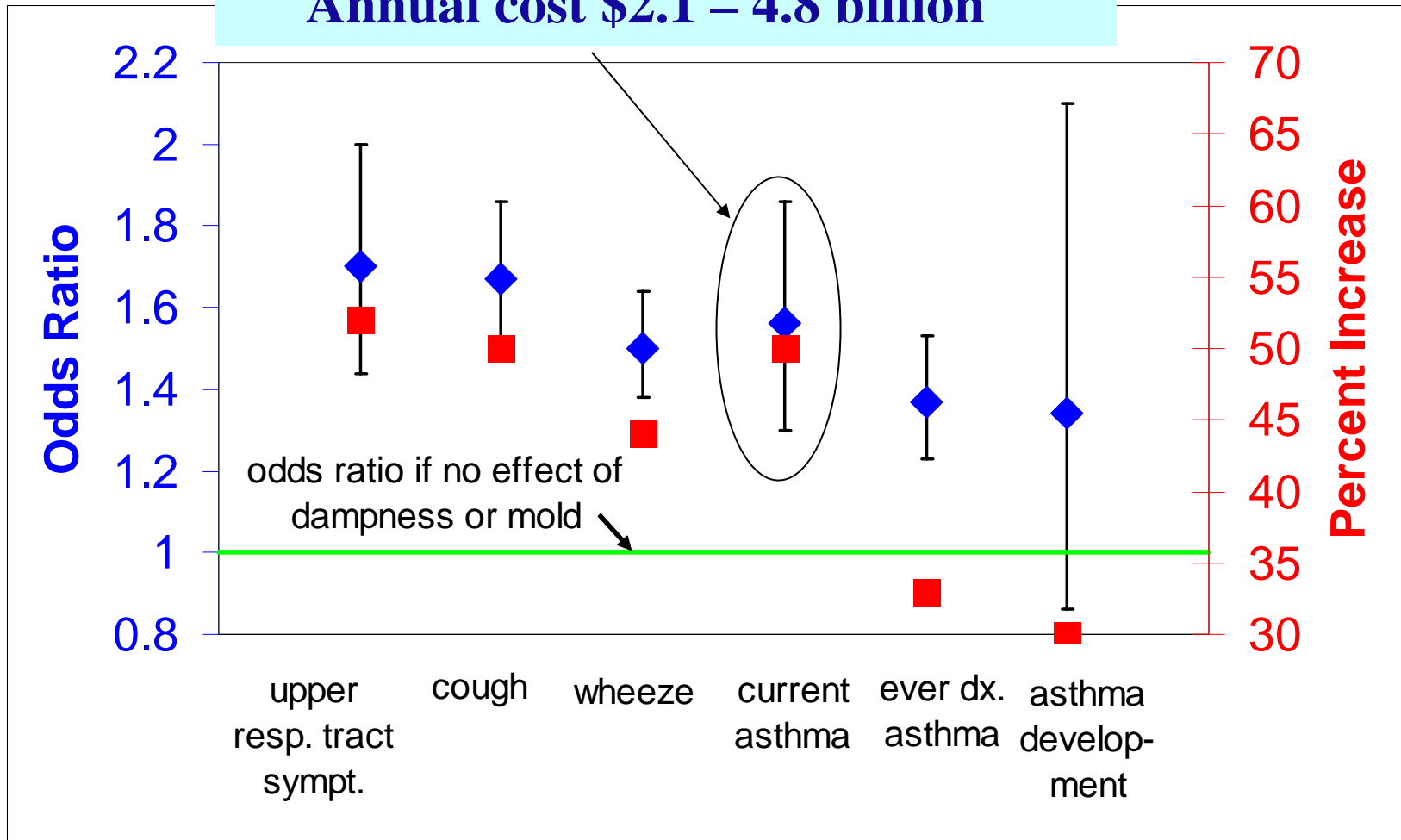
Health Effects of Dampness and Mold?

Results of a Review by the National Academy of Science, Institute of Medicine (IOM)

- **Dampness or mold in homes is associated with increased:**
 - **Nasal and throat symptoms**
 - **Wheeze**
 - **Cough**
 - **Asthma exacerbation**

Quantifying the Health Risk – Results of Statistical Analyses

12% to 29% of total current asthma
Annual cost \$2.1 – 4.8 billion



Dampness and Molds in Schools:

What do We Know?

Dampness is common in (CA) schools

- CA Survey of 1181 classrooms
- 11% had mold or mildew
- 43% had water damage

Few quality health studies*

- 14 studies published in journals
- Most studies small in size – some had weak designs
- Most studies reported statistically significant increases in some health effects

**Given Evidence from School Studies
and Strong Evidence of Health Risks in Damp/Moldy Homes
Dampness and Mold in Classrooms should be Minimized**

Summary

□ Classroom temperature

- Affects school work performance
- Affects health symptoms (offices)
- Often not well controlled

□ Classroom ventilation rate (outdoor air supply)

- Lower rates → slower school work and poorer performance on standard academic tests
- Lower rates → increased student absence
- Lower rates → increased health symptoms (offices)
- Minimum standards violated in almost half of classrooms

□ Dampness and mold

- In homes → increased irritation, respiratory and asthma symptoms
- In schools → few quality studies → potential large adverse effects given data from studies in homes
- In schools → dampness and mold are common

Take Home Messages

- ❑ IEQ in schools can significantly affect student performance and health
- ❑ IEQ problems are common in classrooms
- ❑ Opportunity exists for substantial improvements in student health and performance

What Changes are Needed

- Greater effort to design schools that improve IEQ while saving energy
- Better commissioning, operation, and maintenance of school buildings and HVAC performance
- Must address the problem of widespread low ventilation rates
- Educate building professionals and school district leaders about importance of IEQ
- Develop incentives for better IEQ performance

Limitations in Current Knowledge

- **Uncertainty in magnitude of effects of IEQ on school work performance and health remain large**
- **Research to date has not evaluated how IEQ affects high level cognitive performance such as critical decision making**
- **We don't yet understand why or how IEQ affects work performance**
 - **Motivation? Metabolic rate? Fatigue? Mental processing?**