Providing Better Indoor Environmental Quality Brings Economic Benefits*

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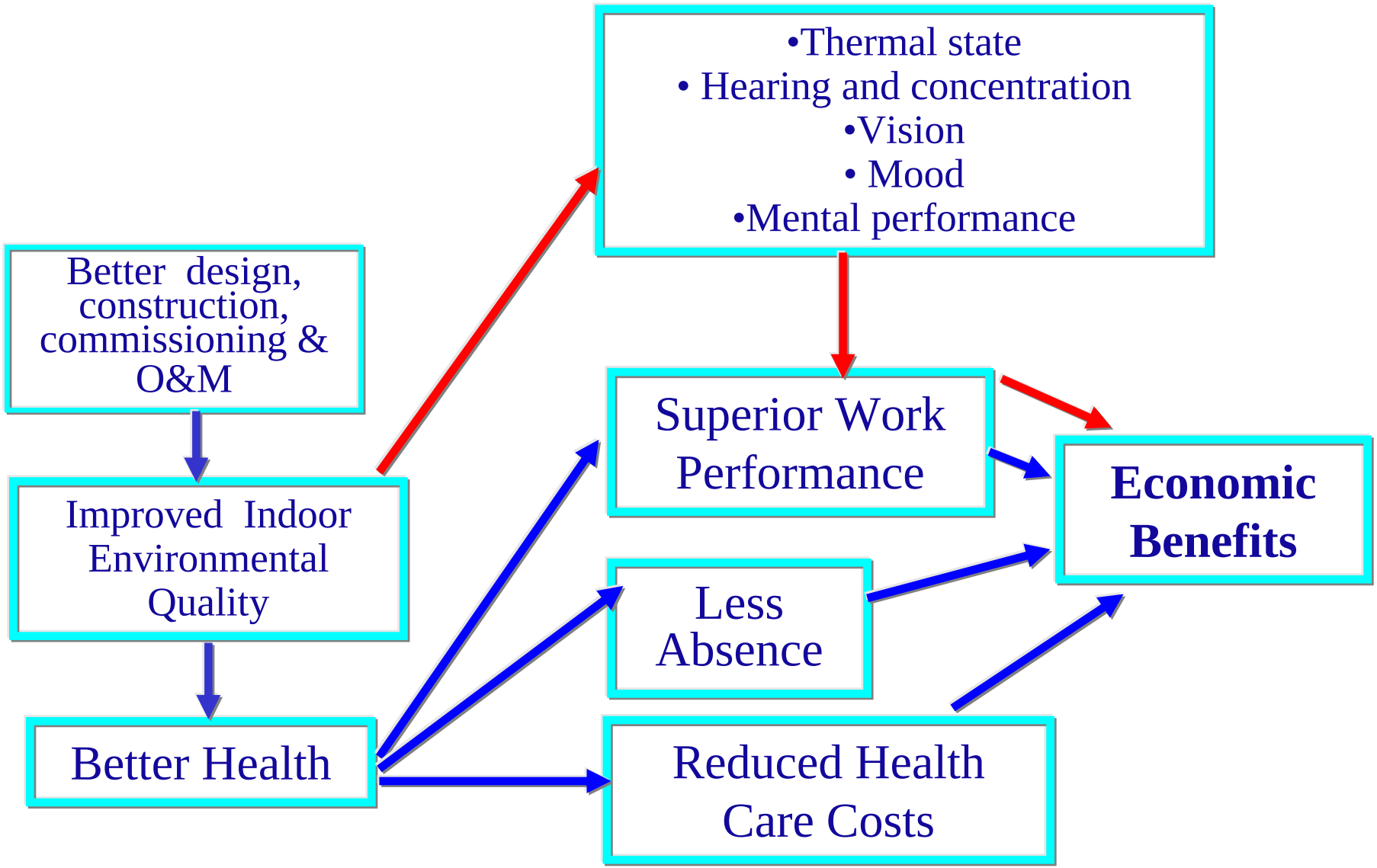
*with significant contributions from Pawel Wargocki and colleagues at the Danish Technical University

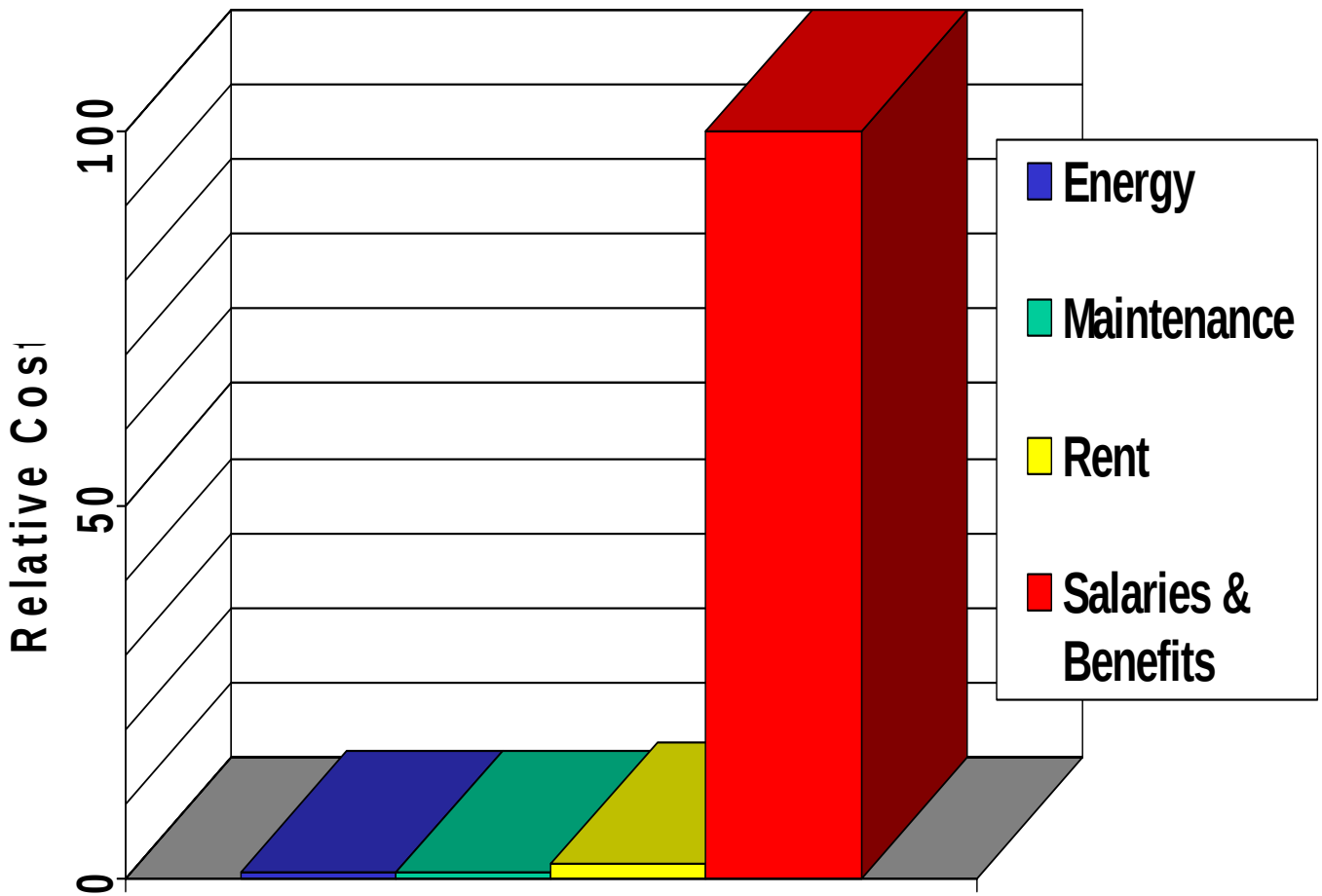
How Better IEQ Can Improve Health & Productivity



The Costs of People Overshadow Building Costs

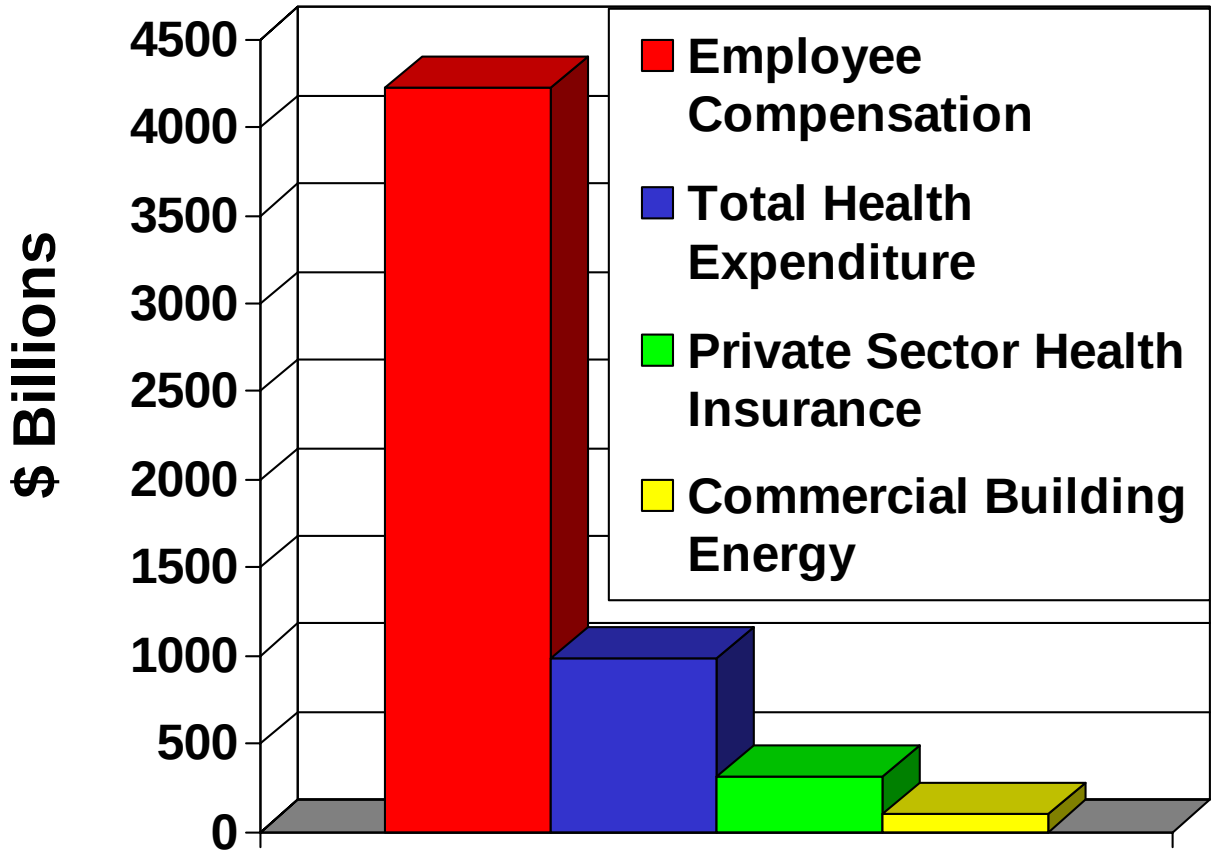
Significance

Very small percentage improvements in work performance will pay for large percentage increases in operation and maintenance costs.



Source : Woods (1989) Occupational Medicine 4: 753-770

Health Care Costs Are Substantial

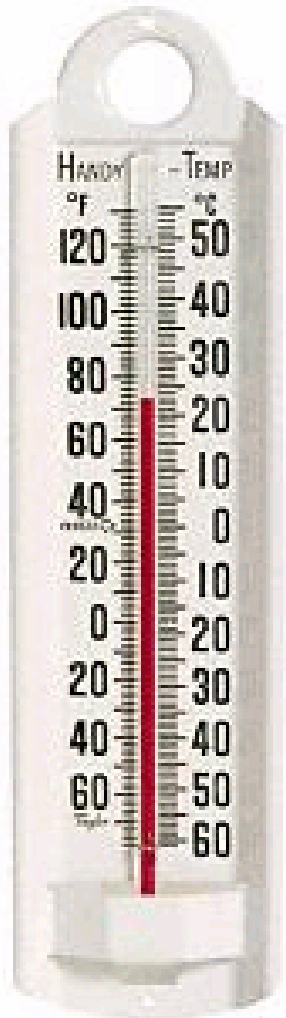


*U.S. Data from 1995 or 1996

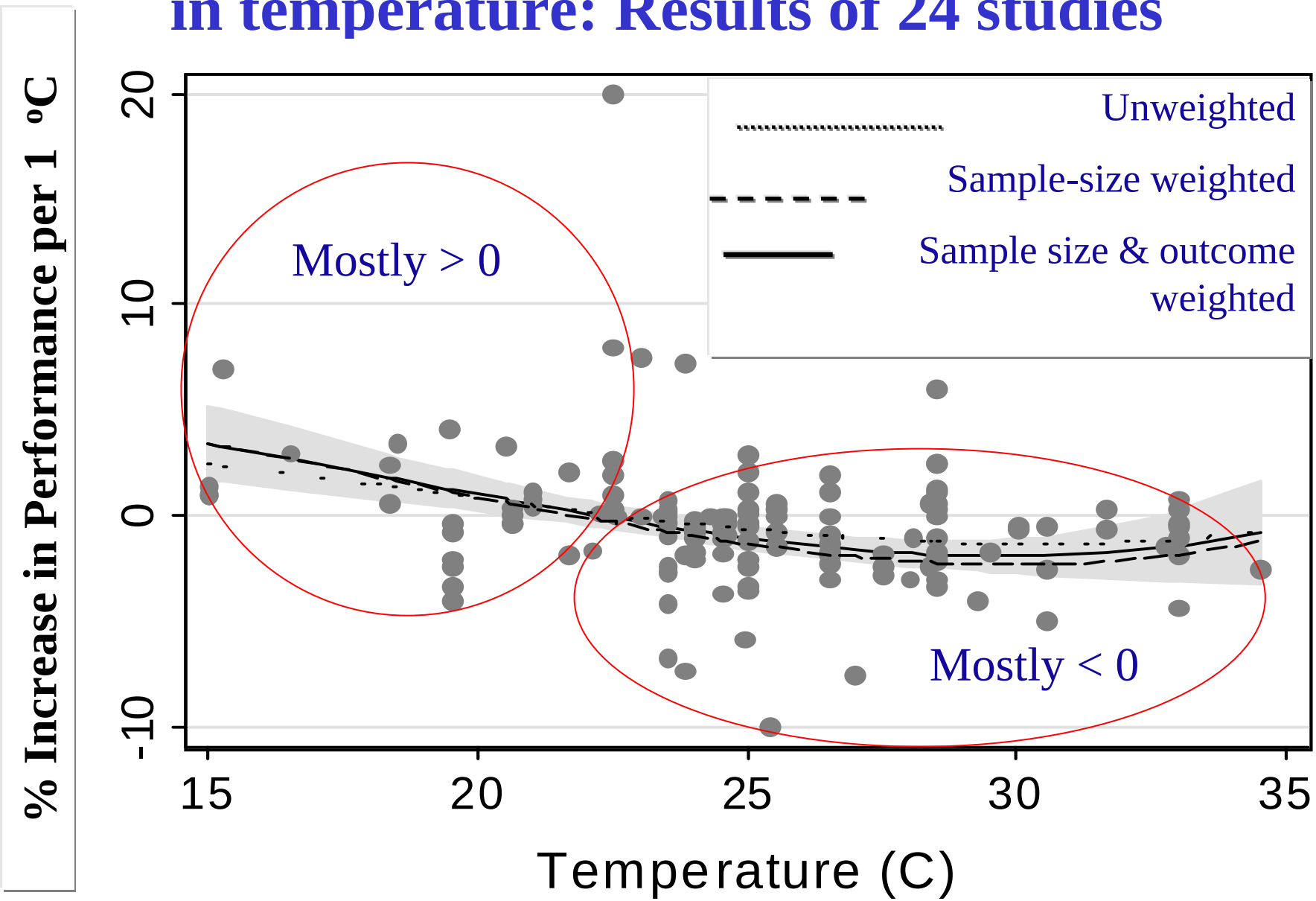
How the Impact of IEQ on Health and Performance Has Been Studied

Experimental modifications of temperature, ventilation rates, pollutant sources, etc. in laboratory, office building, call center, or classroom	Speed, accuracy of simulated work or simulated school work Speed of interaction with call center clients plus information processing Change in prevalence of a health outcome
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

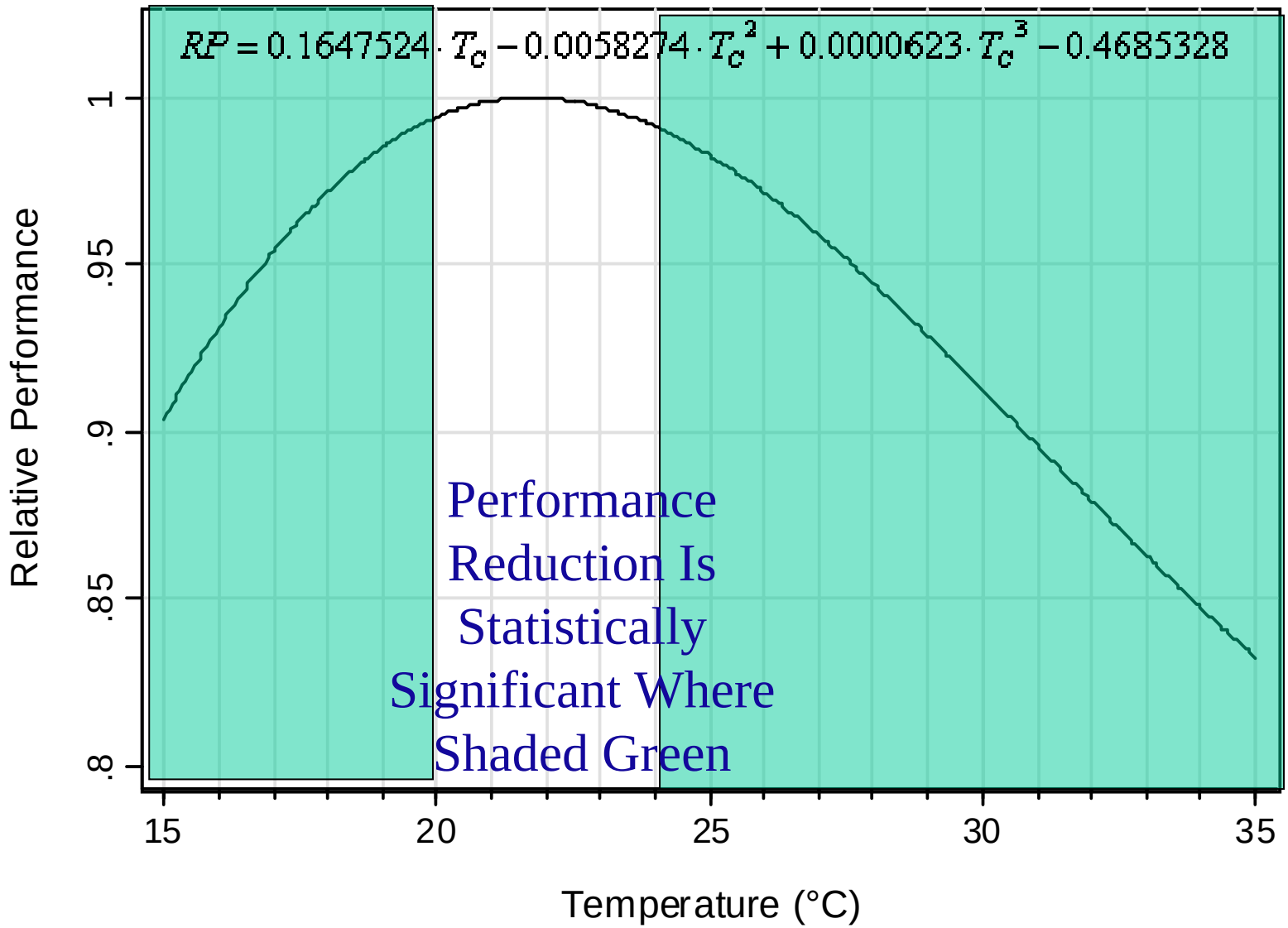
Benefits of Better Control of Indoor Temperature



% Change in performance per 1 ºC increase in temperature: Results of 24 studies



Relative Work Performance vs. Temperature
(maximum performance at at 21.8 ºC, 72 ºF)



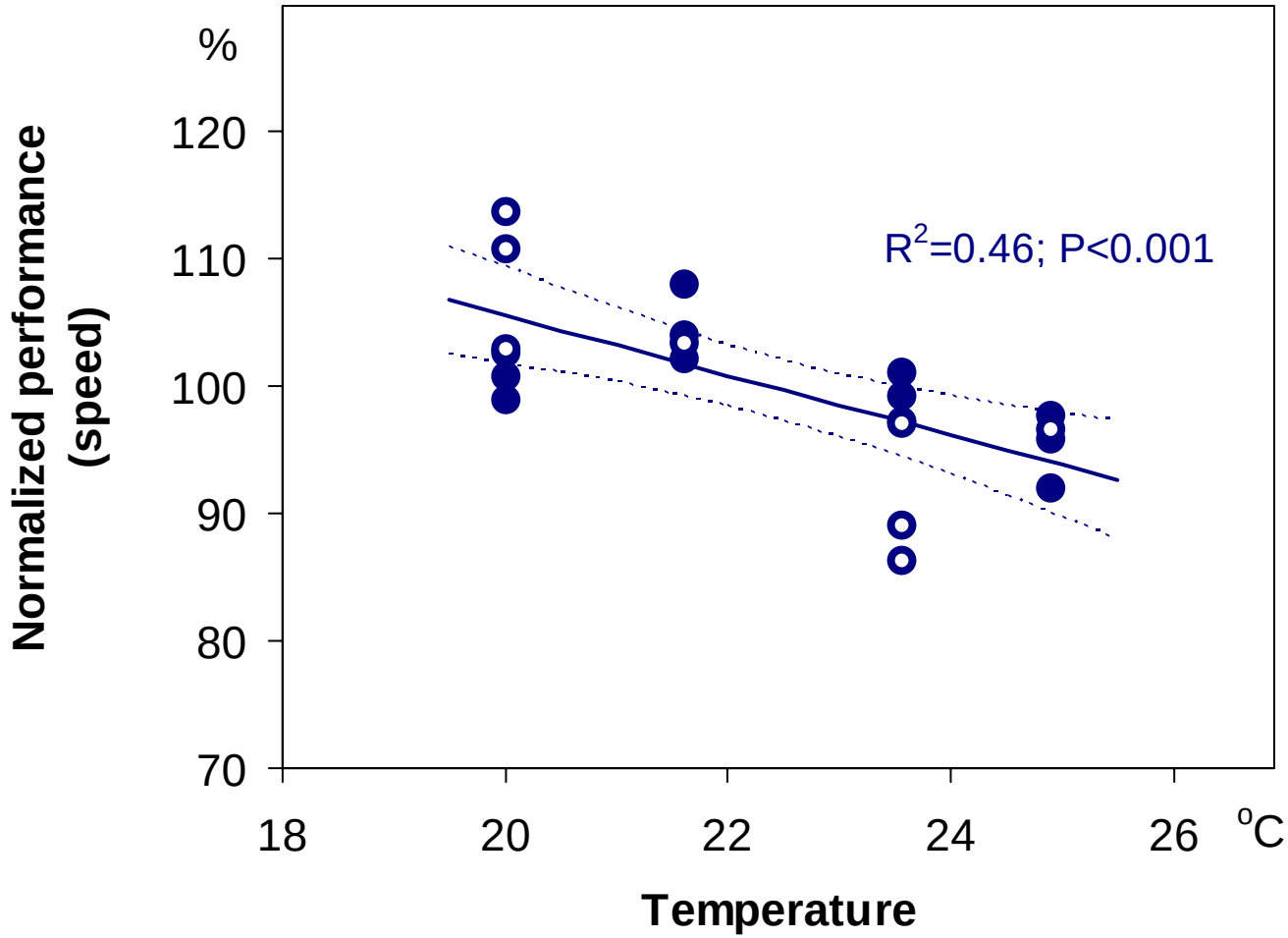
Estimated Economic Value of Work Performance Changes from 1 ºC (1.8 ºF) Shift in Temperature Toward Optimum

Temp. Change	Increase in Performance	Annual Economic Benefit Per Worker*
19 to 20 ºC 66.2 to 68 ºF	0.9%	680 € $900
20 to 21 ºC 68 to 69.8 ºF	0.4%	300 € $400
23 to 22 ºC 73.4 to 71.6 ºF	0.3%	230 € $300
24 to 23 ºC 75.2 to 73.4 ºF	0.6%	460 € $600

*Assuming 760000 € ($100K) cost per worker for salaries and benefits

Temperature and School Work

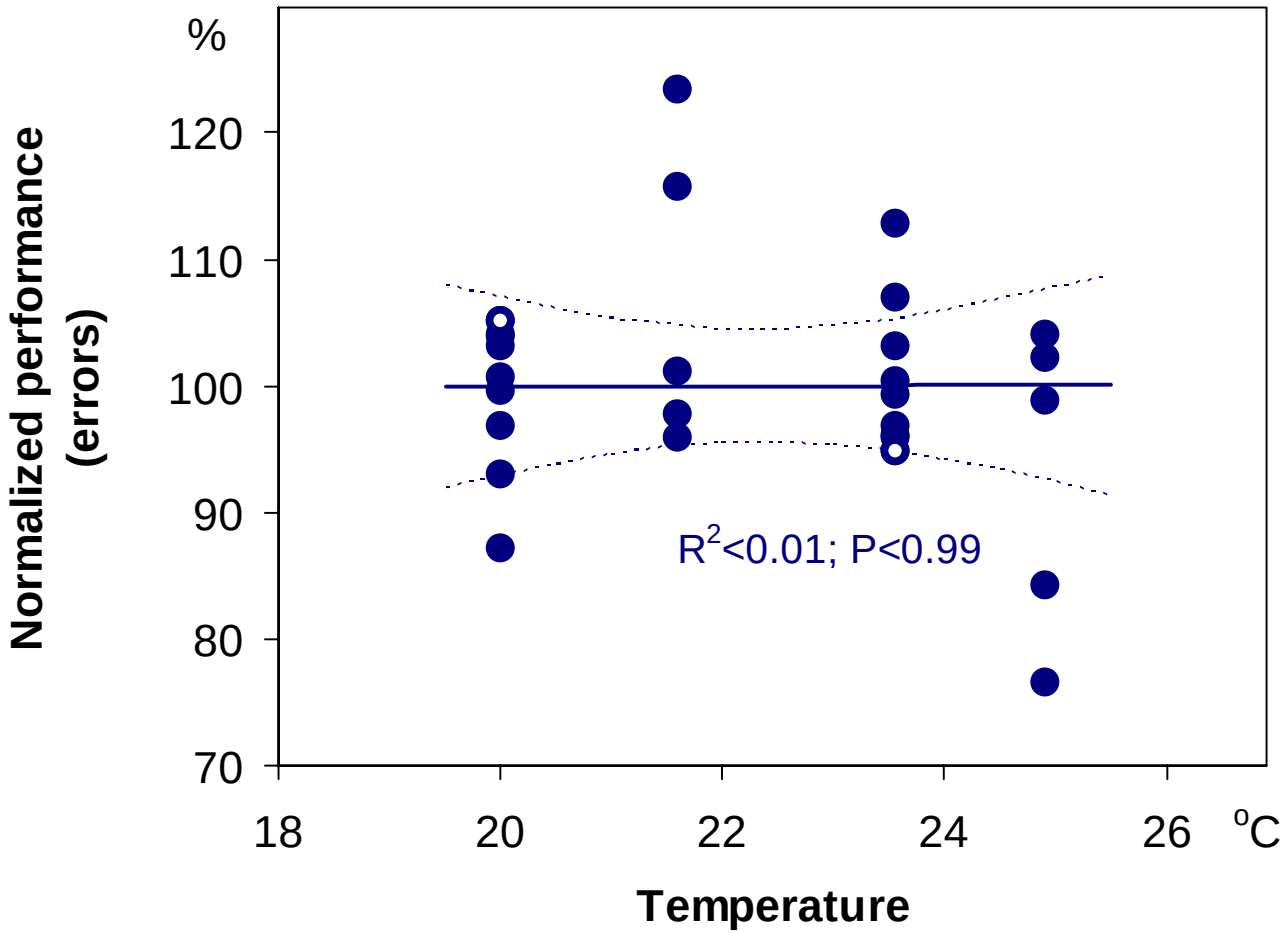
School Work Speed is Affected by Temperature



Source: Wargocki and Wyon, ASHRAE Journal, October 2006

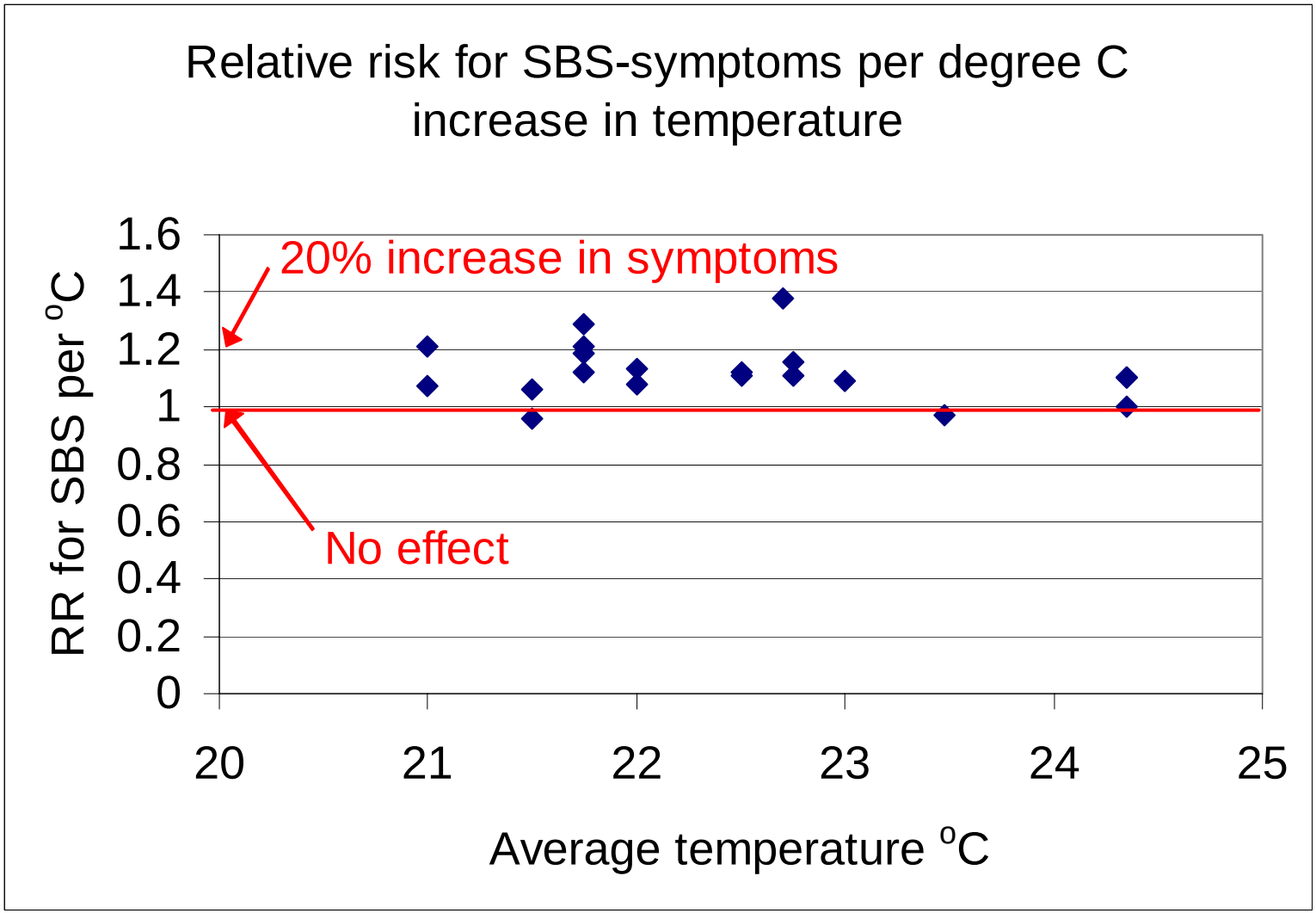
Temperature and School Work

School Work Accuracy is Not Significantly Affected by Temperature



Source: Wargocki and Wyon, ASHRAE Journal, October 2006

Avoiding High Temperatures can also reduce Sick Building Syndrome (SBS) Symptoms



Example Benefit-Cost Analyses of Cooling a Helsinki Office Building

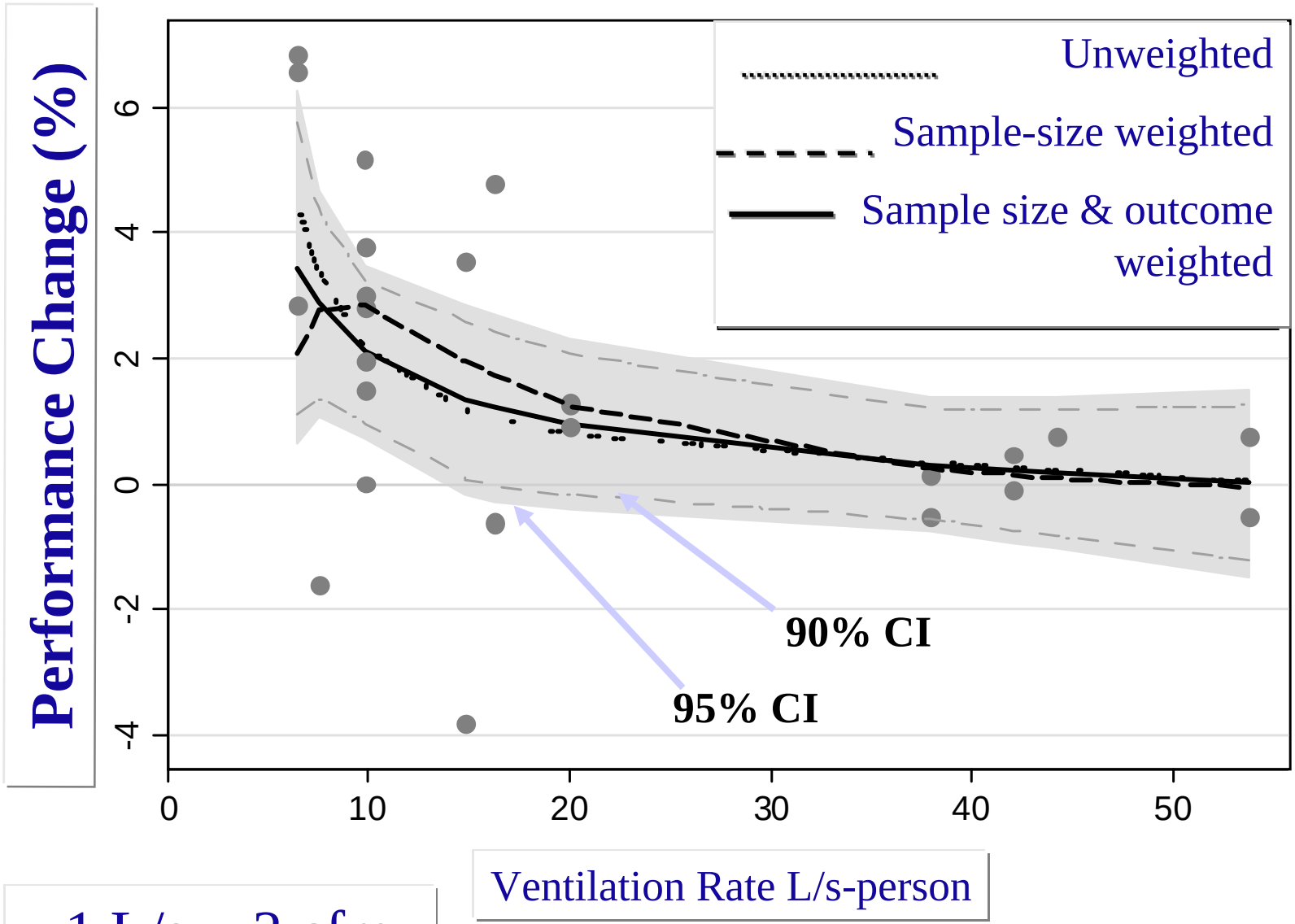
Factor	Base Case	Mechanical Cooling	Increased Operation Time (No Mech. Cooling)	Increased Outdoor Air Flow (No Mech. Cooling)
Increased annual energy plus first cost per person, €	--	54	6.3	95
Effective lost work hours per person-year, h	21.2	15.5	12.6	6.5
Value of lost work hours per person-year, €	686	501	408	211
Value of improved work, €	--	184	278	475
Total annual savings per person, €	--	**131**	**272**	**380**

Source: Wargocki et. al (2006) REHVA Guidebook 6 [65000 € per employee-year]

Importance of Building Ventilation*

*outdoor air supply

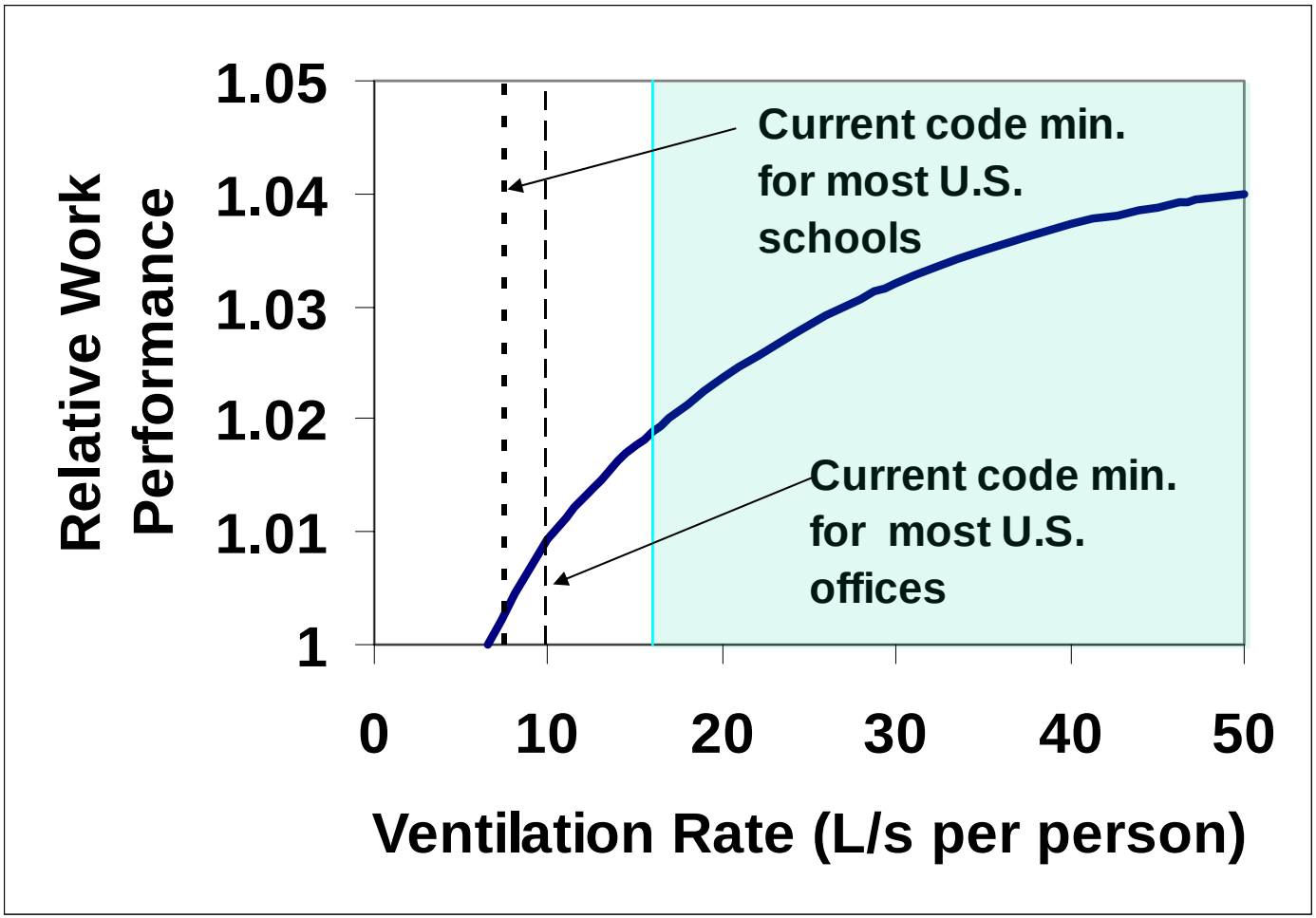
% Increase in work performance per 10 L/s-person increase in ventilation rate



1 L/s = 2 cfm

Performance relative to performance with 6.5 L/s-person (13 cfm/person)

Result of Analyses of 8 Studies with 24 Total Data Points

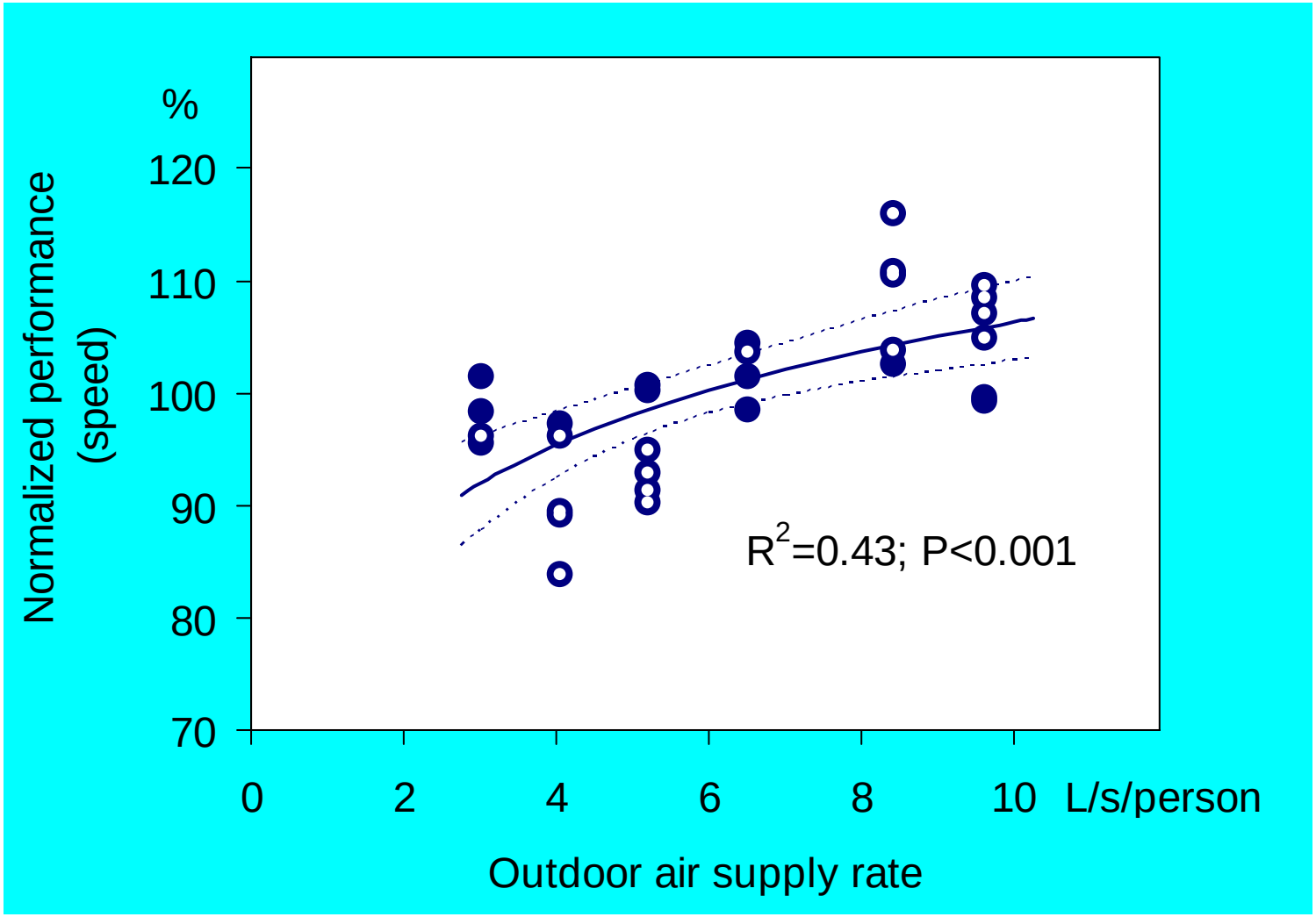


$RP = (5.56 \times 10^{-8}) V^3 - (1.48 \times 10^{-5}) V^2 + (1.49 \times 10^{-3}) T + 0.983$

Source: Seppanen, Fisk, Lei-Gomez (Indoor Air Journal 2005)

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

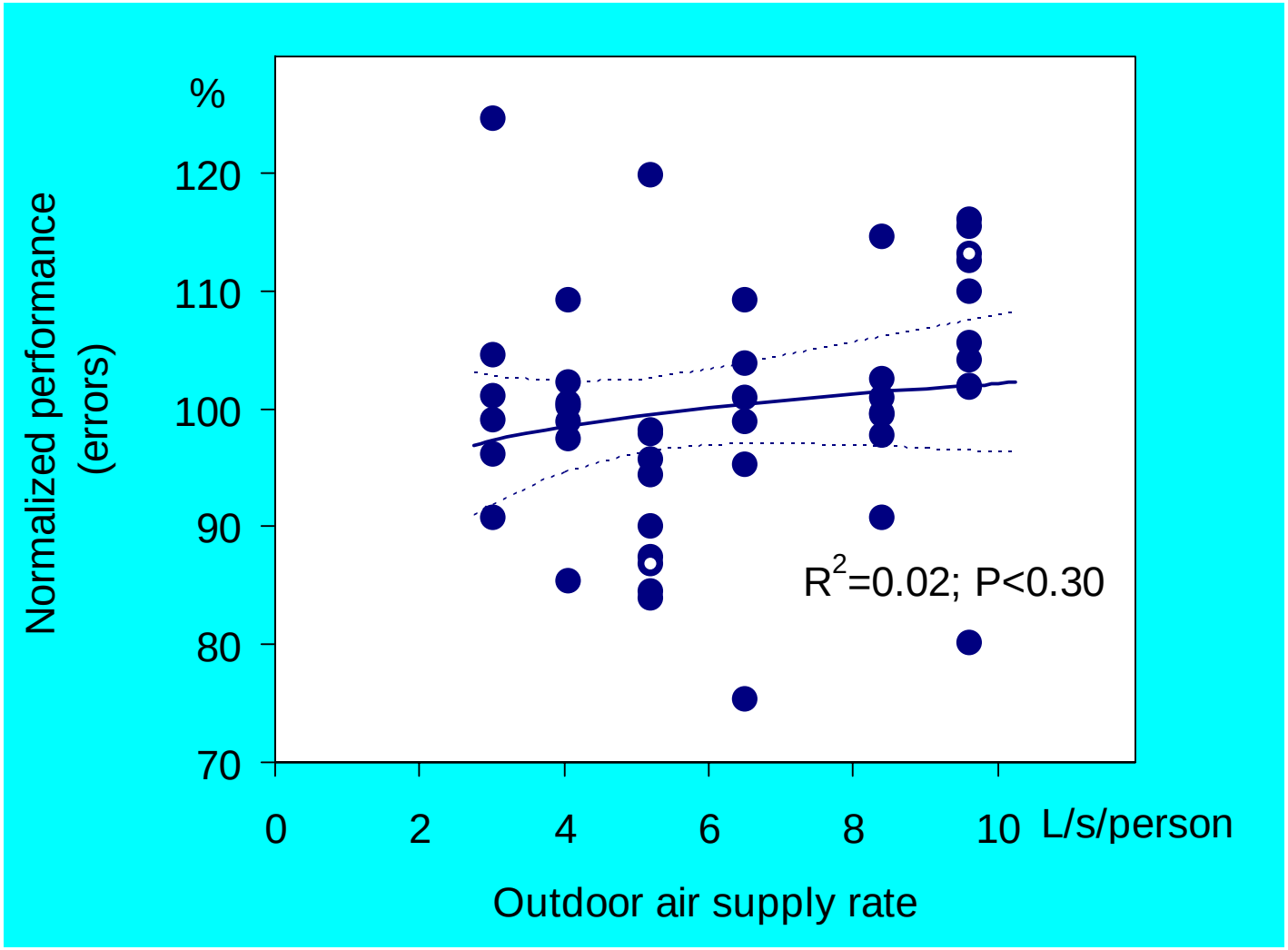
School Work Speed Increases with Ventilation Rate



*Wargocki and Wyon, ASHRAE Journal, October 2006

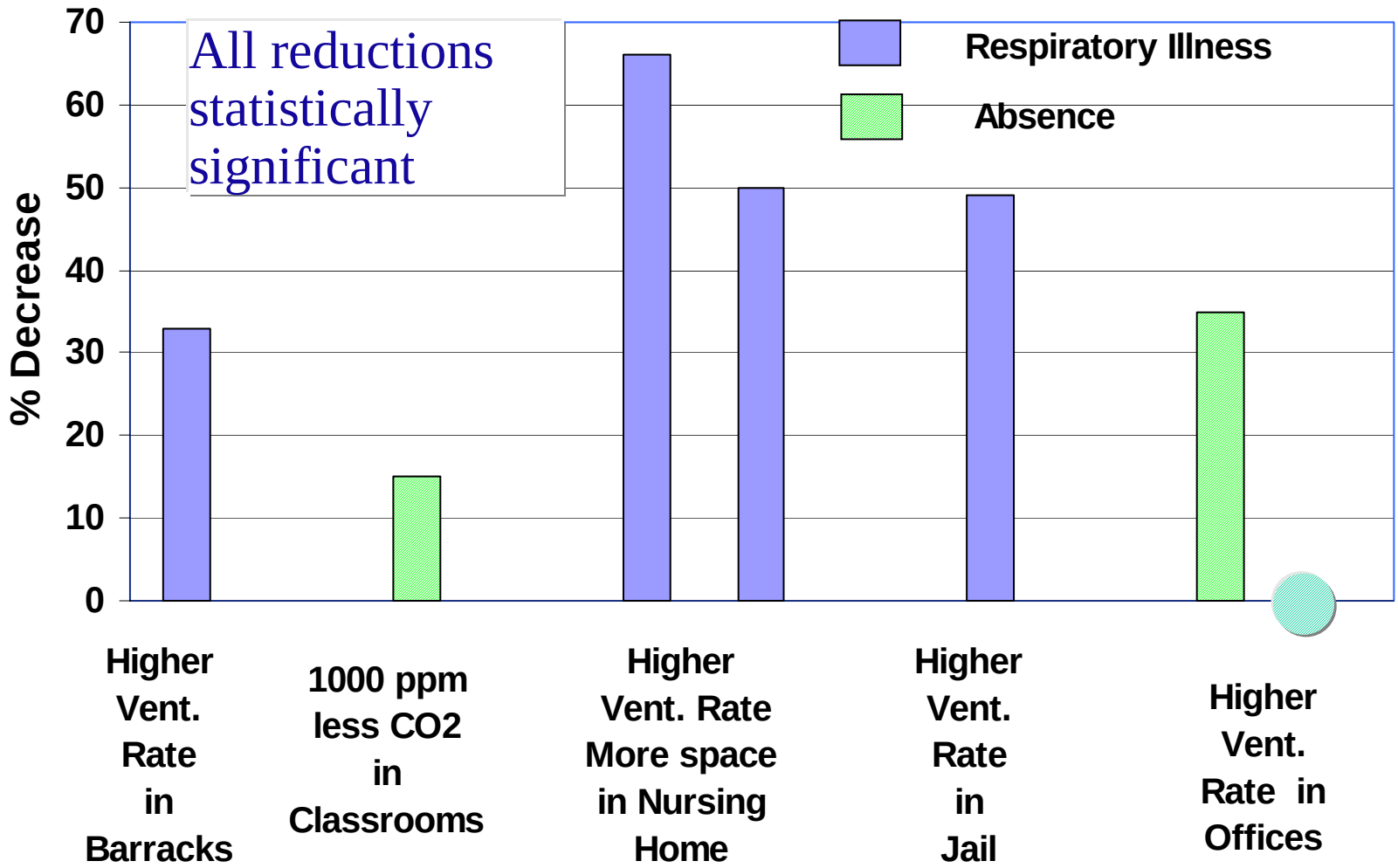
Ventilation Rates and Performance in Schools Results of a Danish Study* - Work Errors

School Work Errors Not Significantly Affected by Ventilation Rate



*Wargocki and Wyon, ASHRAE Journal, October 2006

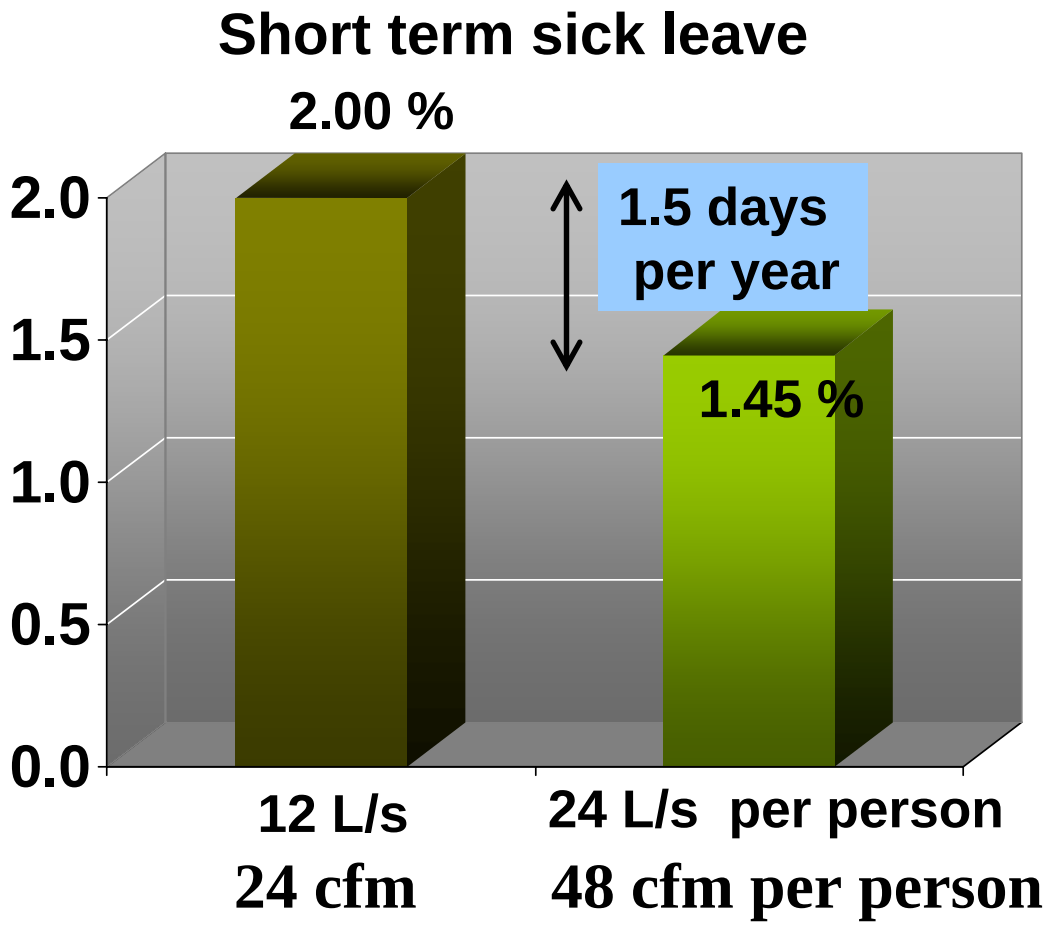
Decrease in Respiratory Illness or Absence With Increased Ventilation Rates



Source: Fisk Annual Rev. E&E 2000

An example of data on ventilation and short term sick leave of office workers

Milton et al. (2000) Indoor Air Journal



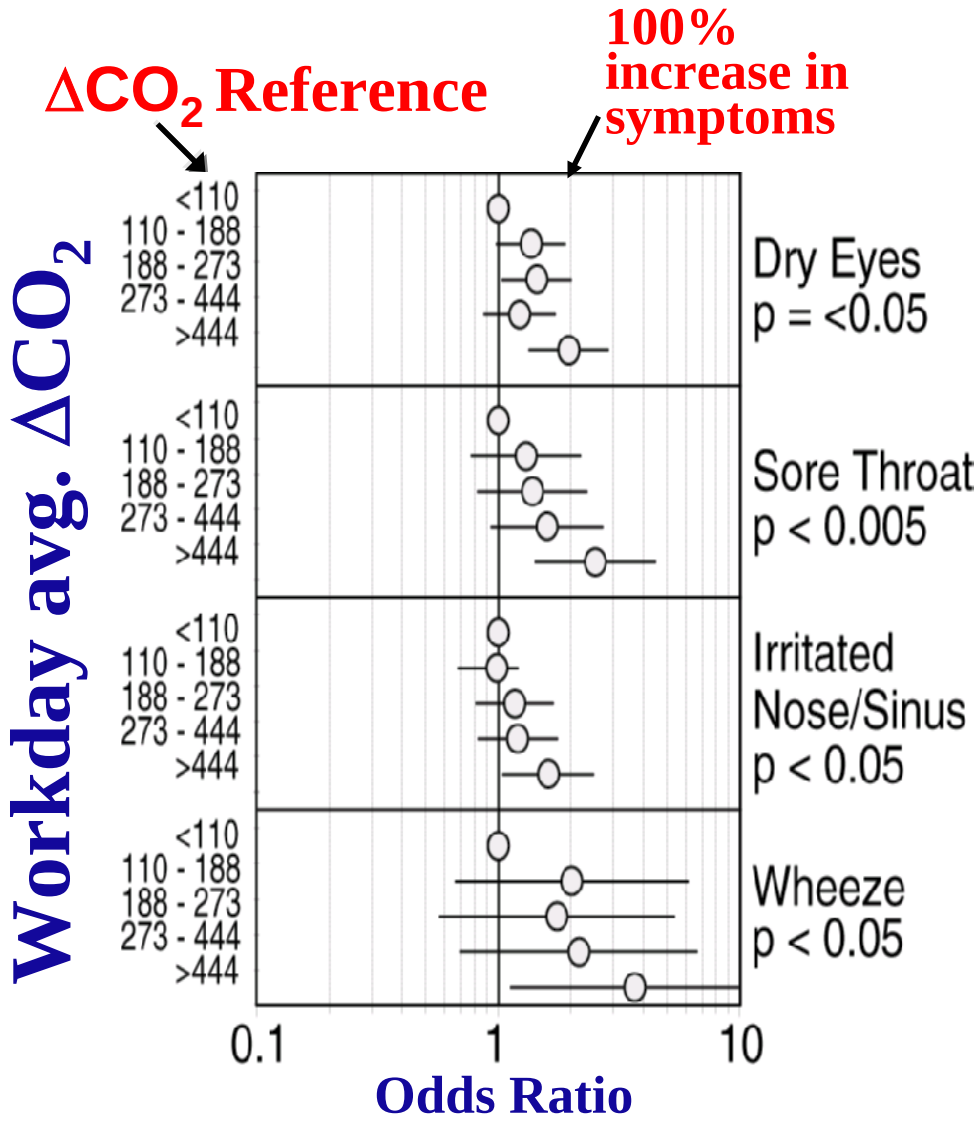
40 buildings in study

460 € ($600) per worker per year with annual cost of 76000 € ($100000)

Sick Building Syndrome (SBS) Symptoms 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
- Suggestion of benefits of increasing ventilation rate up to about 20 L/s-person



Source: Seppanen et al. Indoor Air 1999

Estimated Average Value of 5 L/s-person (10 cfm/person) Increase in Minimum Ventilation Rate

- **Better Work Performance**
  - **0.42% performance increase**
  - **+ 320 € ($420) per worker per year***
- **Reduced Absence**
  - **0.7 days per year**
  - **+190 € ($250) per worker per year**

*at 76000 € ($100K) annual salary plus benefits

Analyses of Energy and Non-Energy Benefits of Economizer Systems

Economizer Background

Purpose

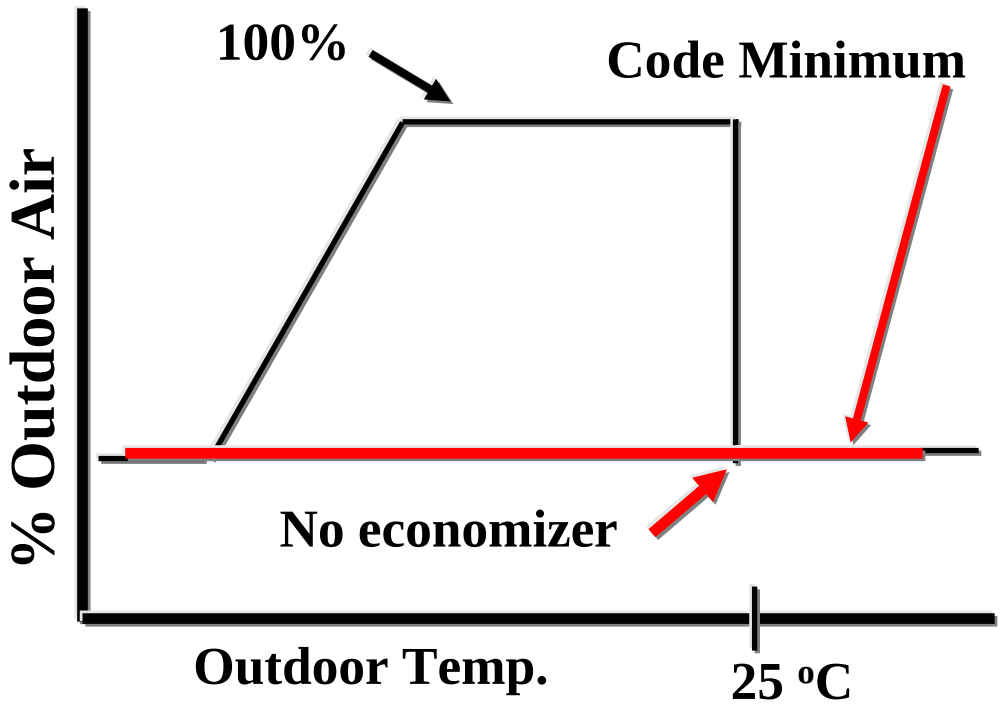
- Reduce HVAC energy
- Maintain minimum vent. rate

Method

- Use outdoor air for cooling when less expensive than mechanical cooling

Usage

- Common in large HVAC
- Considered too expensive for small HVAC



Estimated Annual Benefits of Economizer in a Washington D.C. Office Building

Increase in annual average vent. rate	**10 L/s-person**
Normally considered benefit **Annual Energy cost savings**	**23 € ($30) per person**
Normally neglected benefits **Annual value of reduced absence*** **Annual value of productivity increase** **Total**	**320 € ($420) per person** **760 € ($1000) per person** **1080 € ($1420) per person**

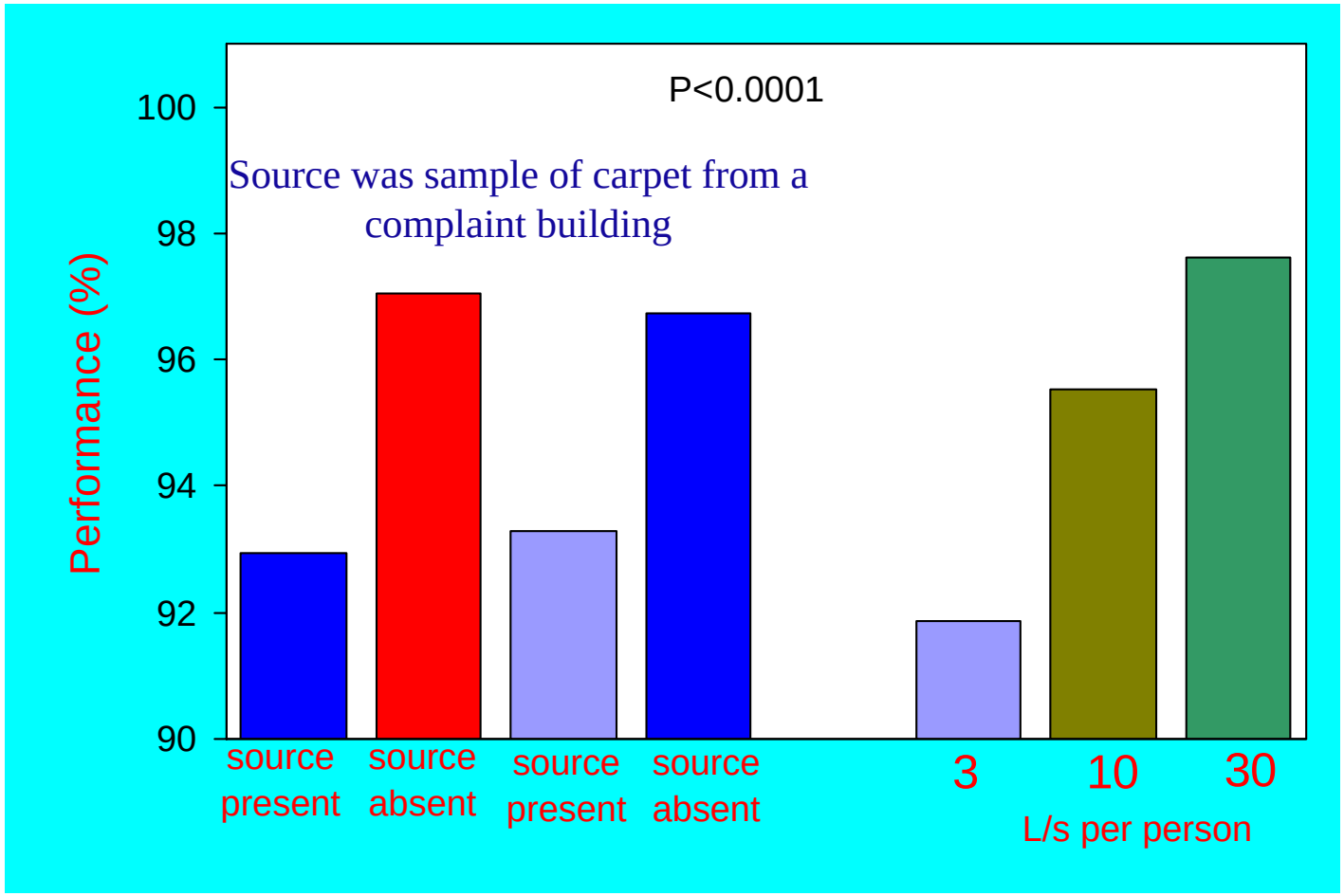
Estimated savings from increased work performance and reduced illness-related absence is 50 times the energy cost savings,

*estimated with disease transmission model calibrated with empirical data; 76000 € ($100K) annual compensation

Benefits of Indoor Pollutant Source Control

In Some Cases Removal of Pollutant Sources* has Increased Work Performance

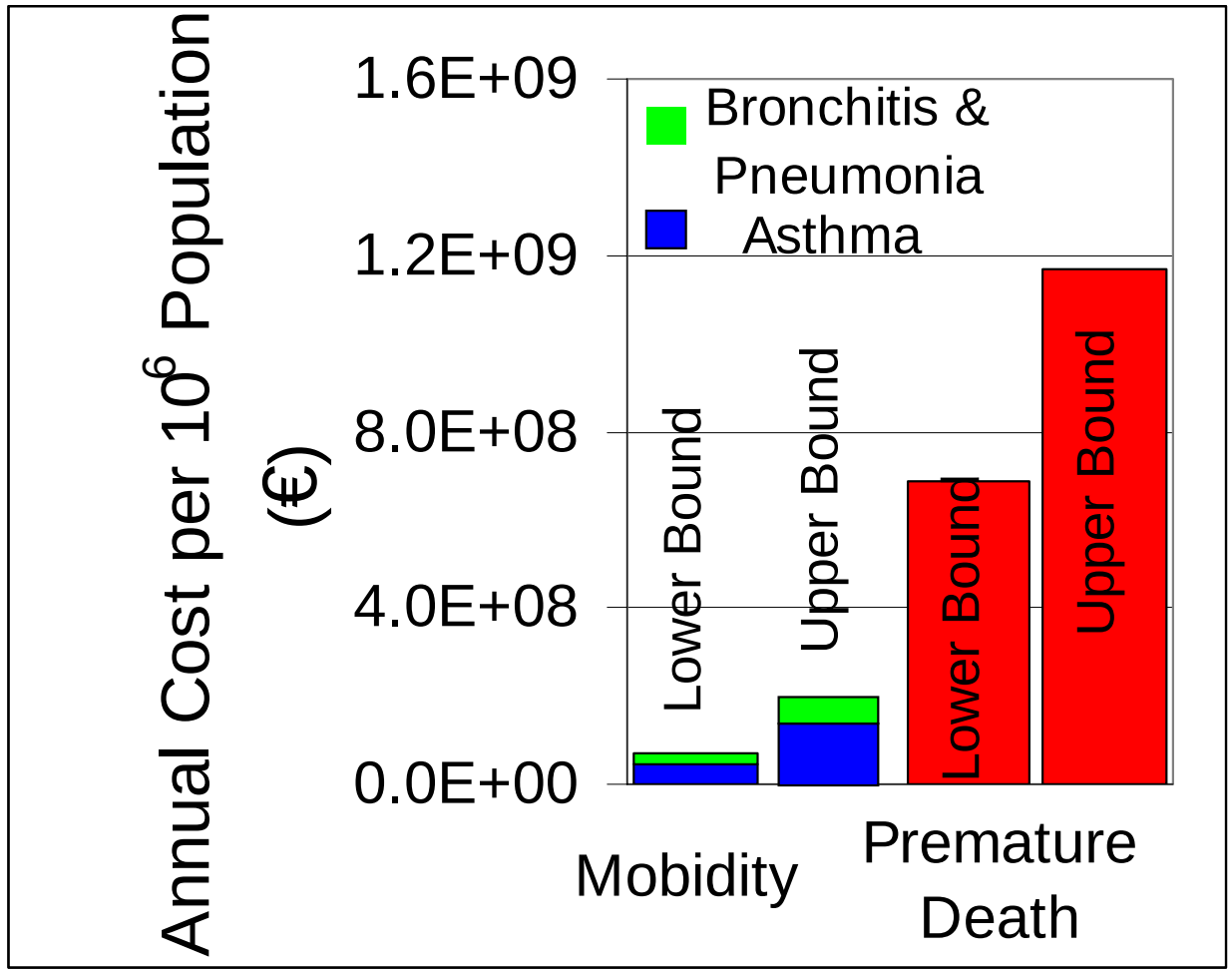
*Unlike increased ventilation, pollutant source control usually consumes no energy



Source: Pawel Wargocki, Danish Technical University

Possible Health-Related Economic Benefits of Eliminating Indoor Tobacco Smoking in the U.S.

- **Based on estimated numbers and unit costs for health effects**
- **Potential savings are higher in much of Europe because of higher smoking rates**



Cost of Damp and Moldy Homes

Statistical Analyses of 33 Studies

Increase Risks in Damp or Moldy Homes

Cough	50%
Wheeze	44%
Asthma Development	30%
Current Asthma	50%

Average of 6 Studies

Percentage of US Homes with Dampness or Mold

47%

Update of Two Prior Analyses

Annual Health Cost of Asthma in U.S.

$16.8 Billion

Asthma Attributable to Home Dampness or Mold

4.6 million cases in U.S.

21%

Cost of Asthma Attributable to Home Dampness and Mold

21%

$3.5 Billion/ year in U.S.

Workplace Dampness or Mold Also Increases Risks of Health Effects

Few studies, but nearly all find increased health effects

- **Examples**
  - **US office building with history of dampness: Current asthma was 120% > normal; adult onset of asthma was 230% > normal; 12% of sick leave attributable to respiratory symptoms at work**
  - **Working in moldy buildings in Finland → 54% more adults developed asthma**
  - **In 80 complaint US office buildings where drainage of cooling coil drain pan was poor, number of occupants with multiple asthma symptoms was increased by 260%***

*Note: Findings not replicated in analyses of data from 100 non-complaint office buildings

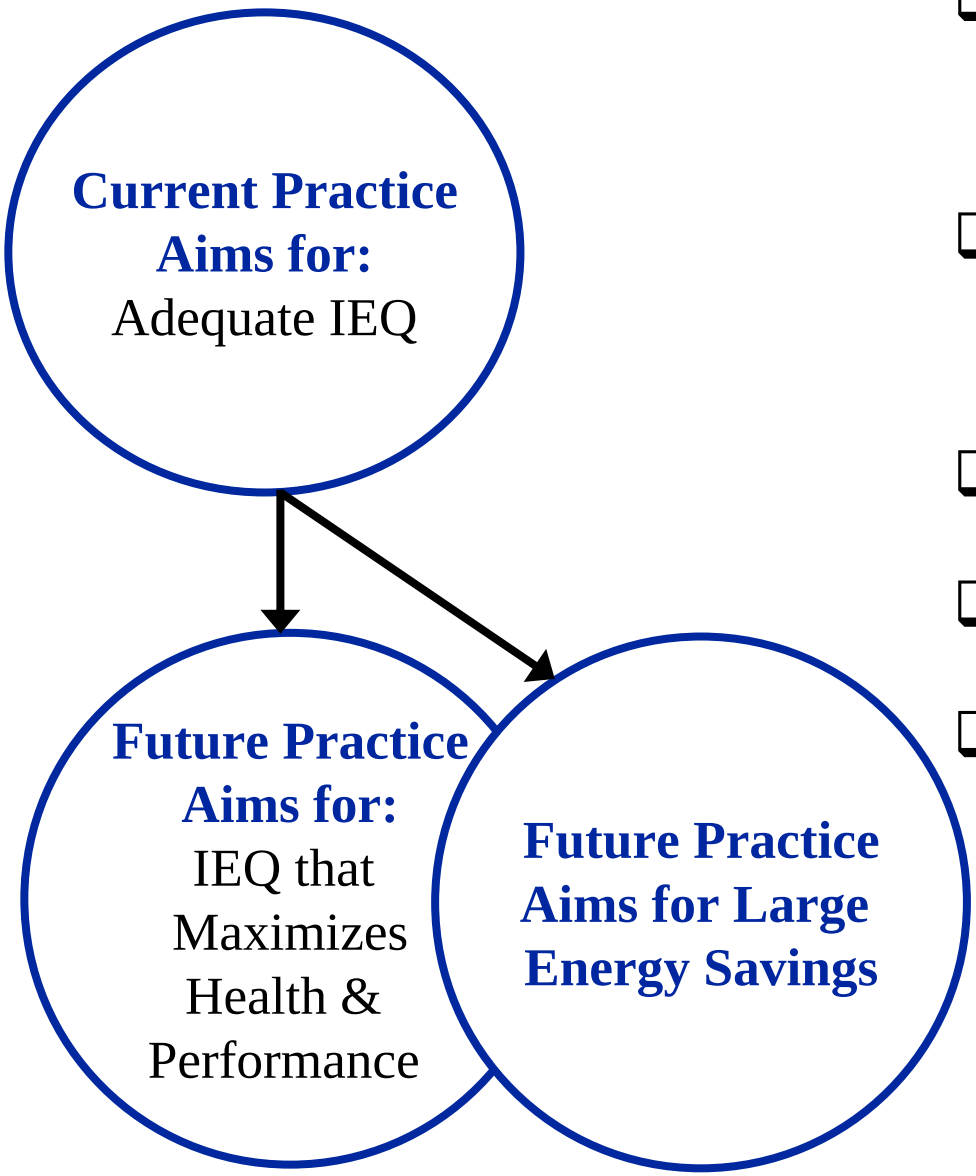
Summary

- Better temperature control → Large potential financial benefits from improved work performance
- Increased ventilation rates up to ~ 20 L/s per person → Large potential financial benefits from improved work performance and health
- Reducing indoor pollutant sources→ Substantial potential economic benefits from improved work performance and health
  - Without the energy needed for increased ventilation
  - Indoor tobacco smoking and dampness deserve special attention
- Potential economic benefits are large relative to costs of improved building design or operation
  - Benefit cost ratios can exceed 10
  - Per employee savings up to 500 € per year

Limitations

- **Uncertainty in magnitude of work performance and health improvements remains large**
  - **Improvements will vary among buildings and with type of work and with outdoor air quality**
  - **Benefits may be distributed among employer, building owner, employee**
- **Research to date has not evaluated how IEQ affects high level cognitive performance such as critical decision making**
- **Cost benefit analyses have not accounted for true long term cost of energy use and climate change**
  - **Strongly encourage use of energy efficient technologies and practices to improve IEQ**
- **We don't yet understand why or how IEQ affects work performance**
  - **Motivation? Metabolic rate? Fatigue? Mental processing?**

What You Can Do



- ❑ Make greater effort to design buildings that improve IEQ while saving energy
- ❑ Implement periodic or continuous commissioning to maintain building and HVAC performance
- ❑ Educate building professionals
- ❑ Develop incentives for better IEQ
- ❑ Develop better methods to integrate energy conservation and IEQ improvement