

# How Poor Indoor Environmental Quality Affects Performance in Work Environments and Educational Buildings

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## THE CONTEXT

A framework for organisations is:

**to measure how their building impacts on their most valuable asset, their employees**



**Health, Wellbeing & Productivity in Offices**

The next chapter for green building  
**Key Findings**

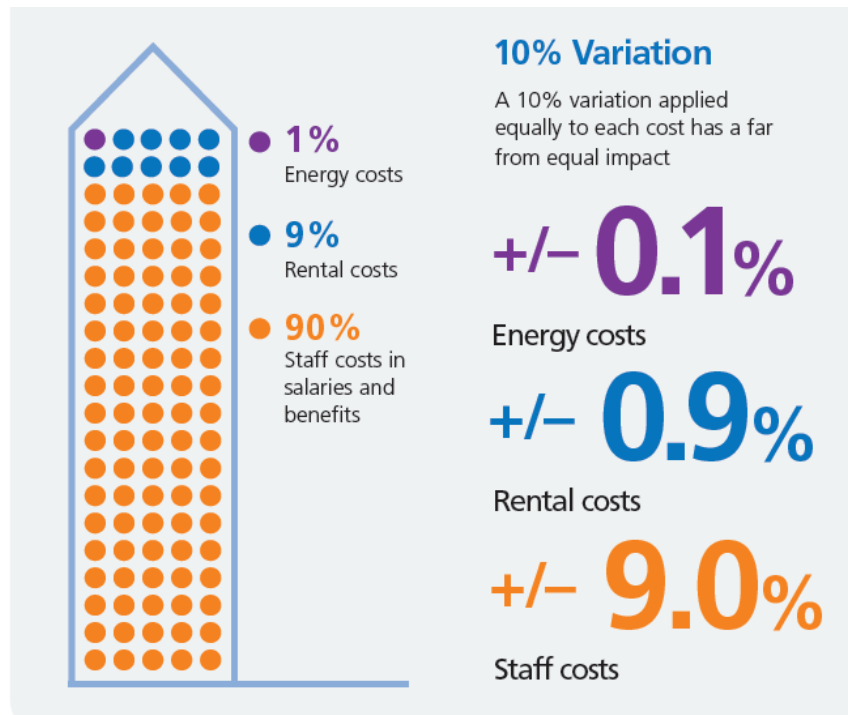
September 2014

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# TYPICAL BUSINESS OPERATING COSTS

Based on a typical split of business operating costs:  
**modest gains in staff health and wellbeing can deliver significant financial savings**



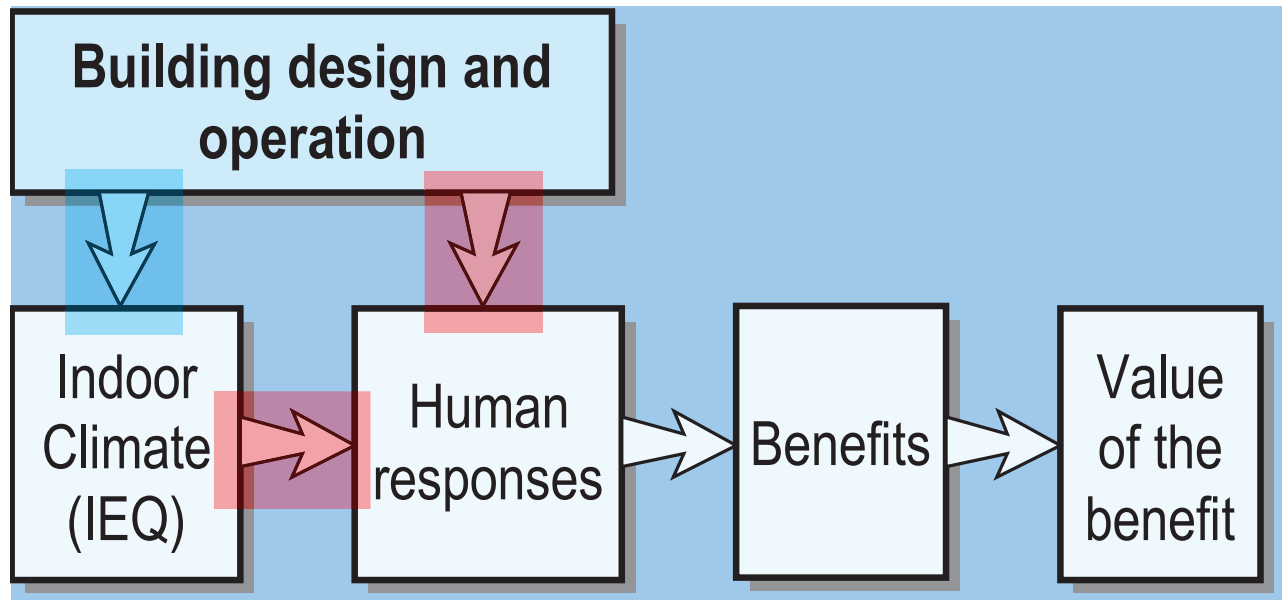
Source: World Green Building Council (2014)

## ENERGY & NON-ENERGY BENEFITS ARE LOW HANGING FRUITS...



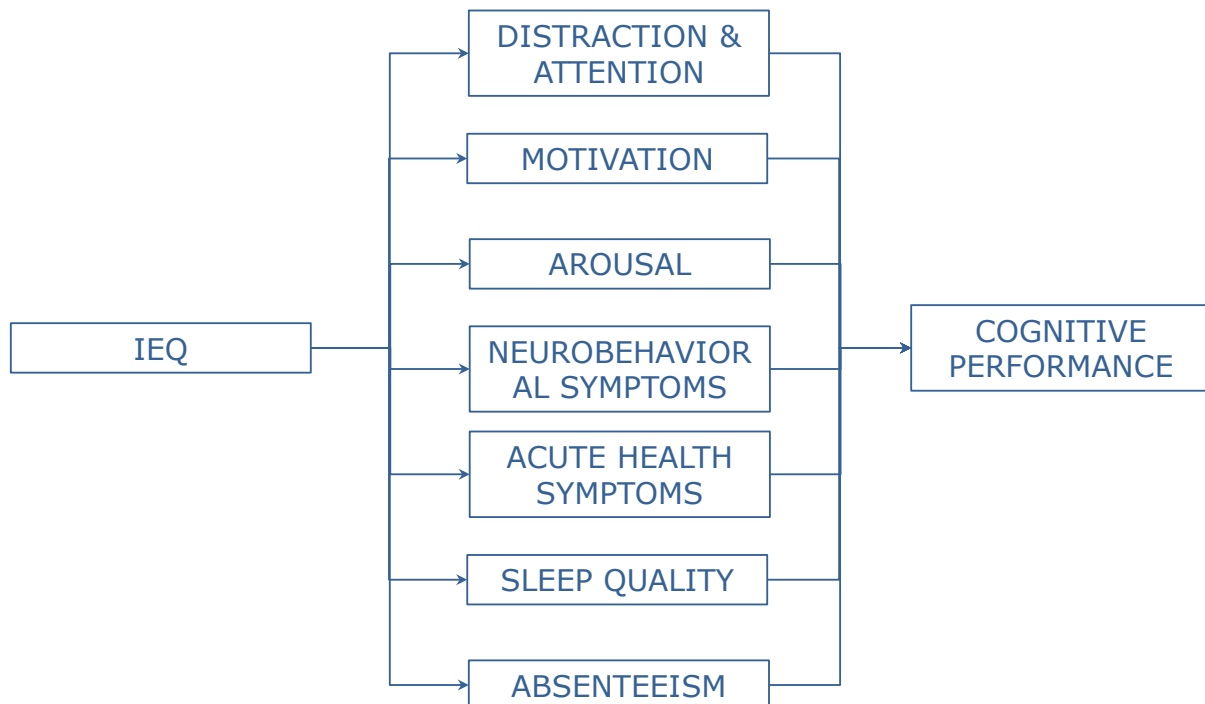
Source: [curtbeavers.com](http://curtbeavers.com)

# IEQ & HUMAN PERFORMANCE ABILITY TO PERFORM WORK



Source: Seppanen et al. (2005)

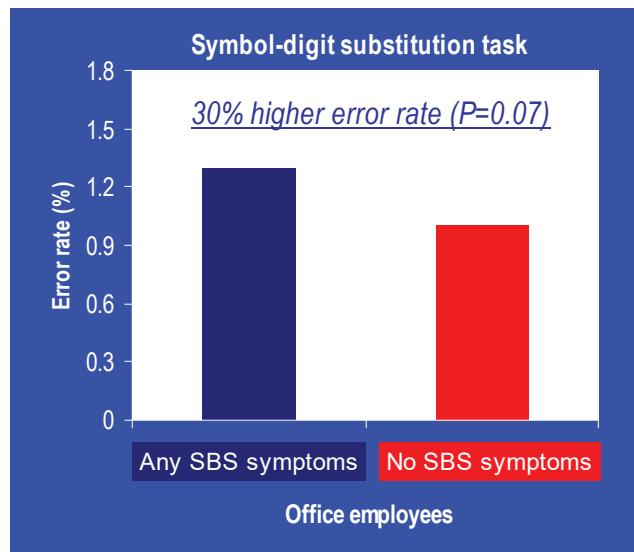
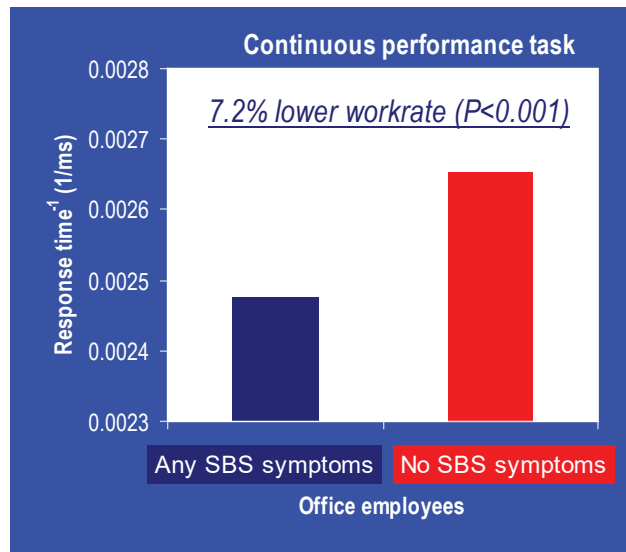
## POTENTIAL MECHANISMS



Source: Wargocki and Wyon (2017)

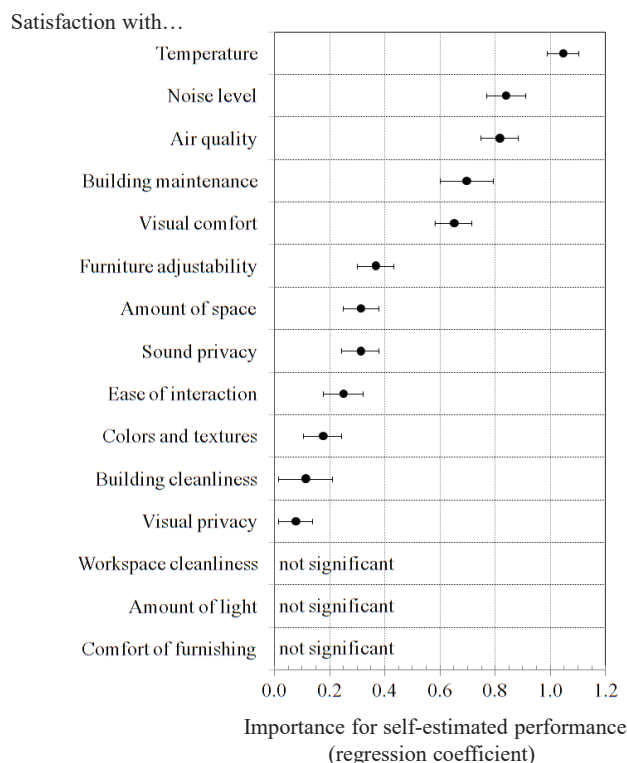


# ACUTE HEALTH SYMPTOMS AND PERFORMANCE



Source: Nunes et al. (1993)

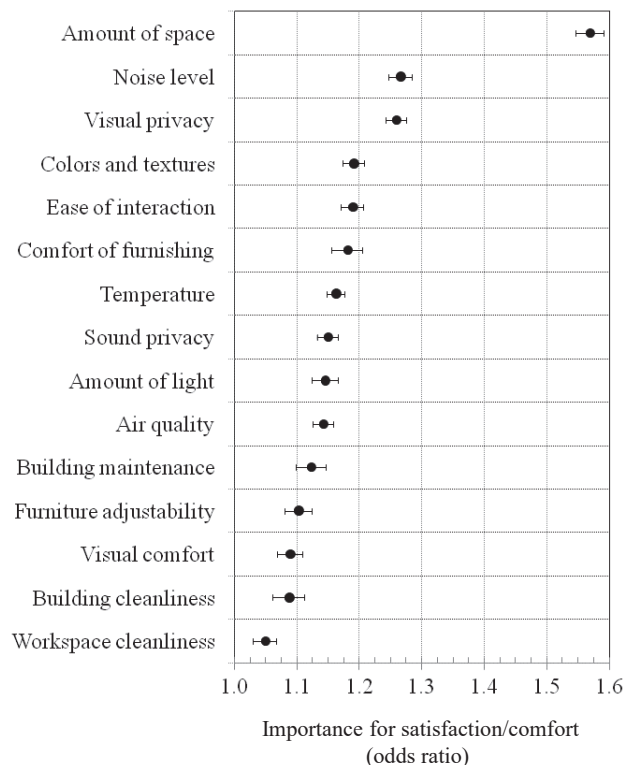
## SATISFACTION w/IEQ IMPORTANT FOR self-estimated PERFORMANCE



- Satisfaction with temperature, noise level and air quality = satisfaction with IEQ
- For example, ~15% increase in satisfaction with temperature would increase self-estimated job performance by ~1%

Source: Wargocki et al. (2012)

# BUILDING FEATURES ARE IMPORTANT FOR SATISFACTION



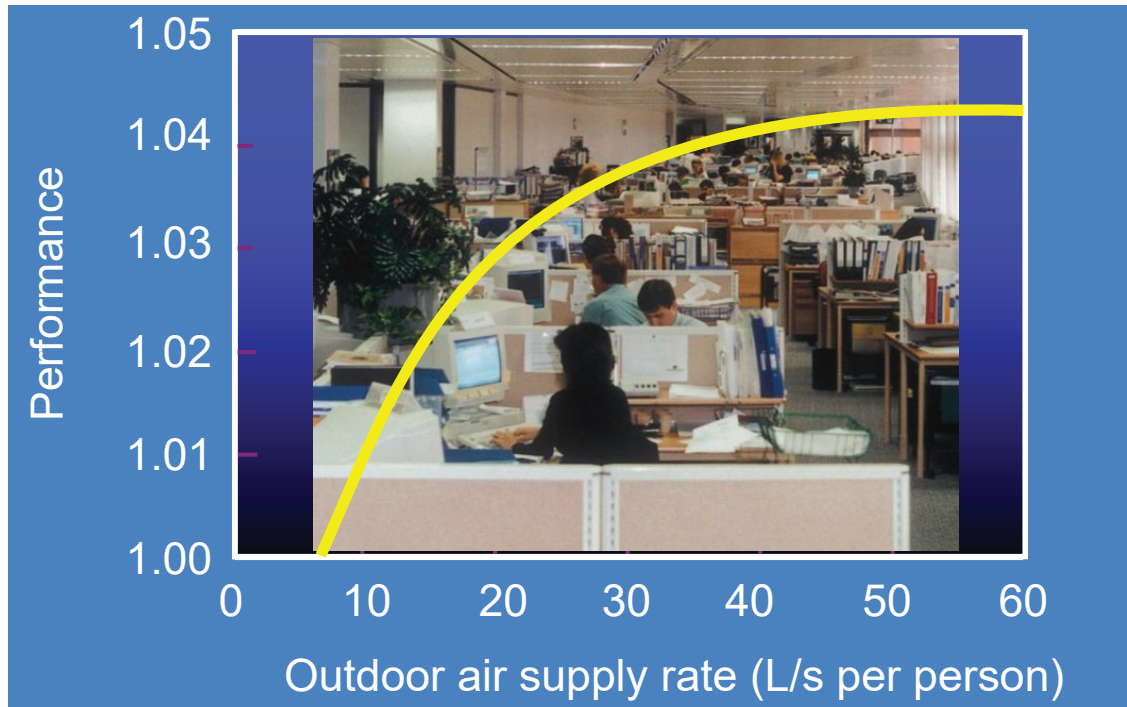
- All important ( $p < 0.05$ )
- The most important is satisfaction with amount of space the most important regardless occupants' gender and age, type of office (single office, shared office, cubicles) and distance from a window
- Other important parameters include satisfaction with, noise level, visual privacy, colors and textures, etc.
- IEQ is not the most important

Source: Frontczak et al. (2011)

## EVIDENCE: OFFICE WORK

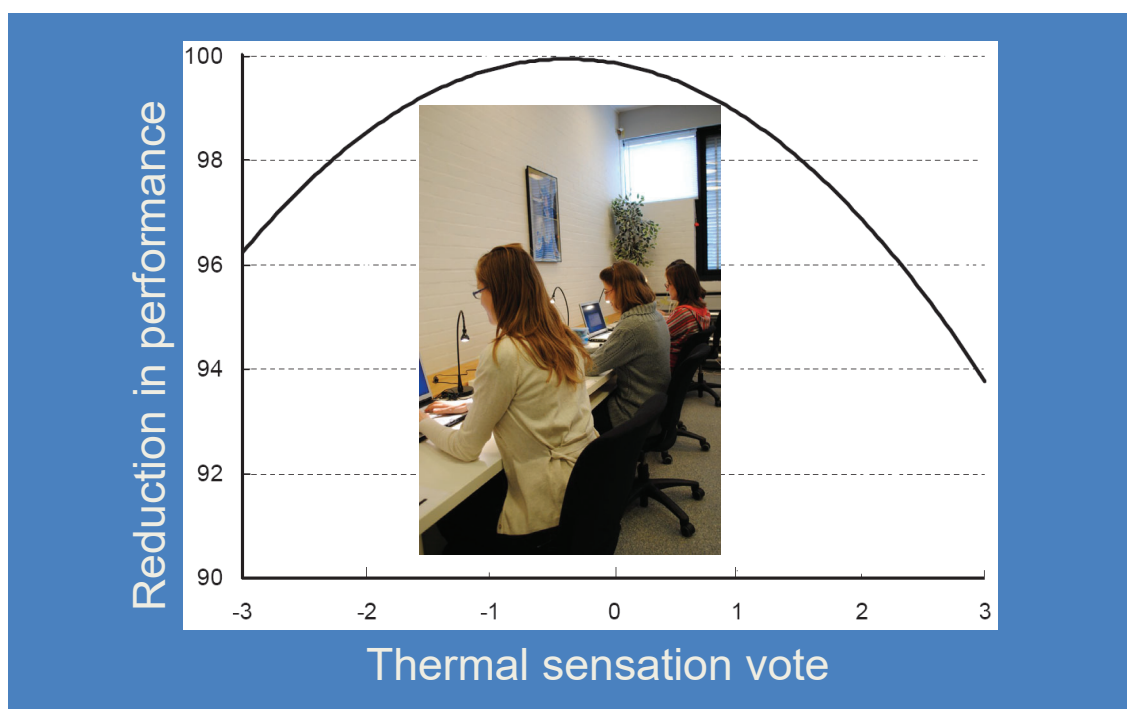
Elevated temperatures and poor air quality can affect performance of office work by 5% (laboratory) to 10% (field)

# VENTILATION AND PERFORMANCE OF OFFICE WORK



Source: Wargocki and Seppanen (2006)

# THERMAL DISCOMFORT AND PERFORMANCE OF OFFICE WORK

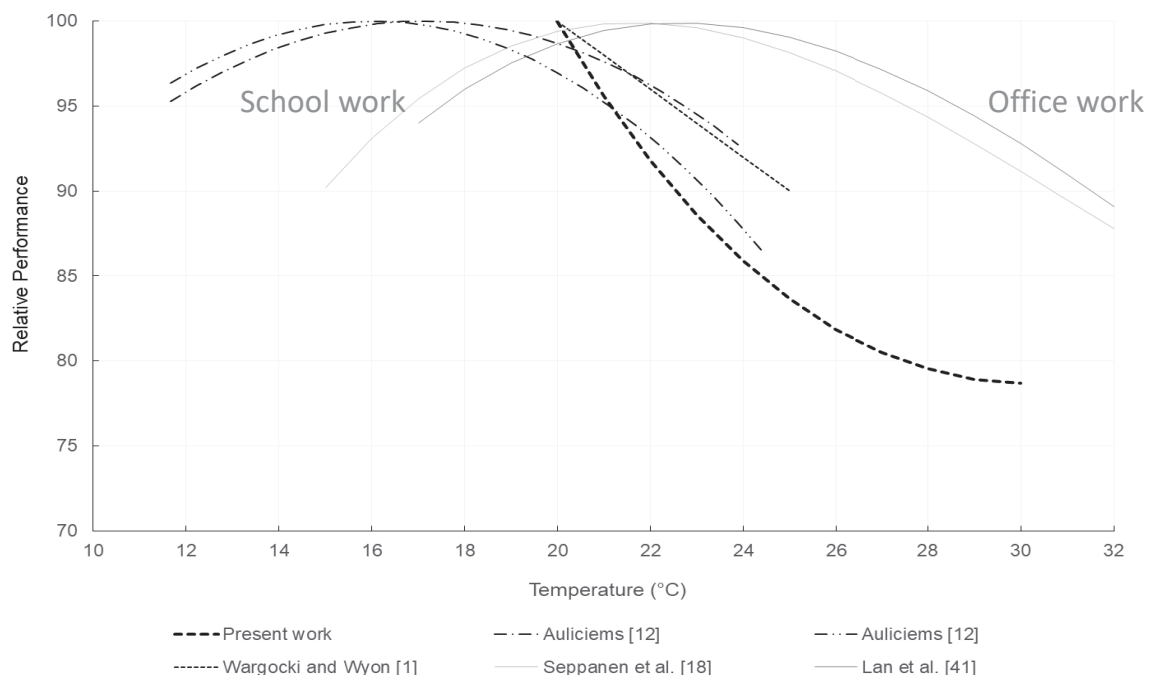


Source: Lan et al. (2011)

# EVIDENCE: SCHOOLWORK

Elevated temperatures and poor air quality can affect performance of schoolwork by children by over 15-20% (field)

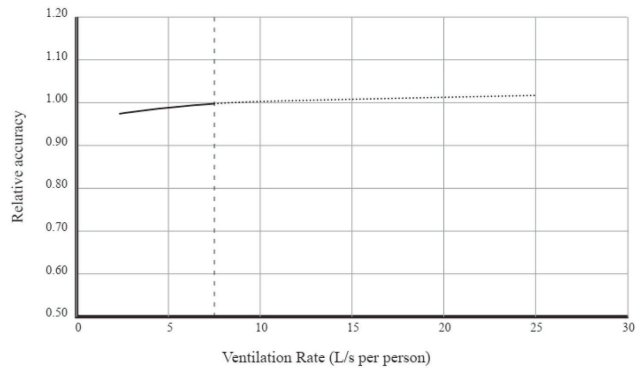
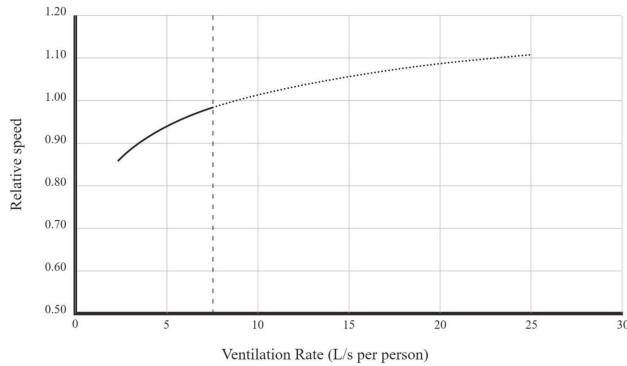
## CLASSROOM TEMPERATURE AND PERFORMANCE



Source: Wargocki et al. (2019)



# CLASSROOM VENTILATION AND PERFORMANCE

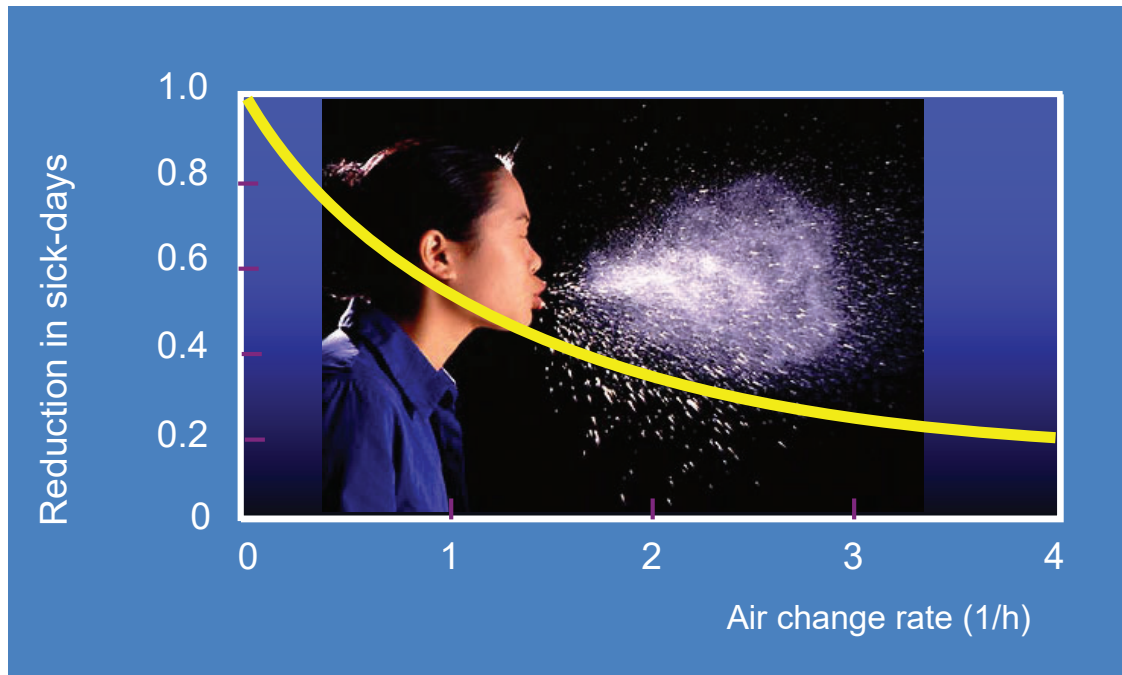


Source: Wargocki et al. (2019)

## EVIDENCE: ABSENCE RATES

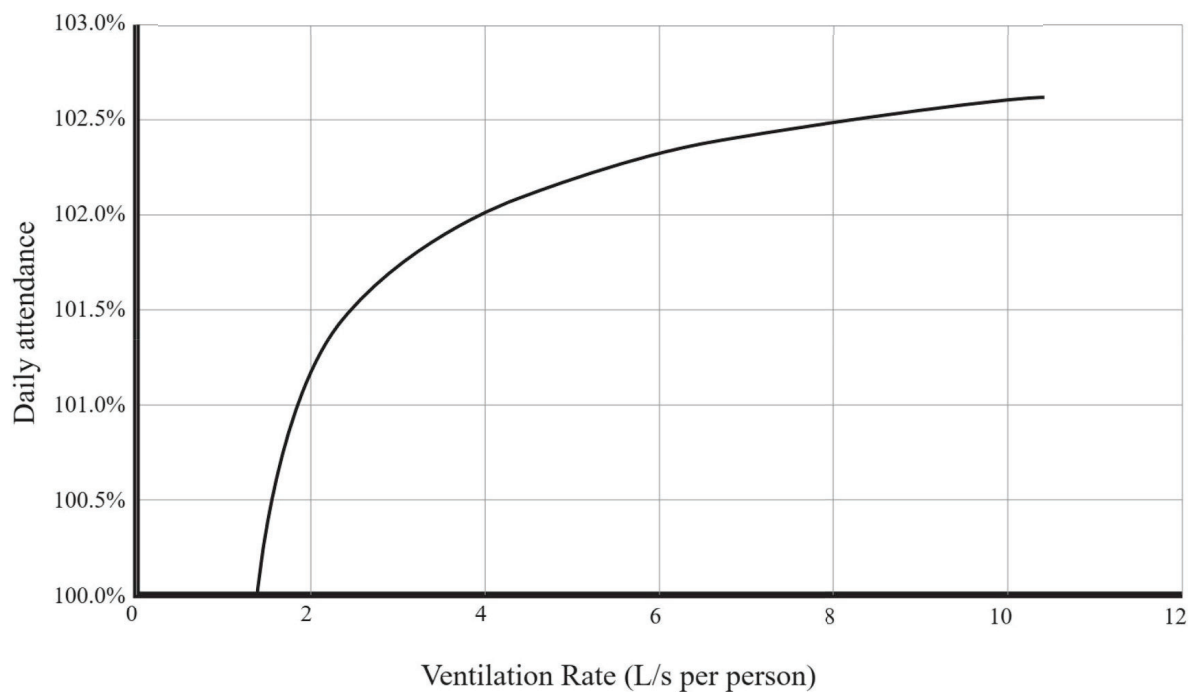
Poor IEQ increases the short term sick-leave by few days, usually by 1-2 days

# SHORT-TERM SICK-LEAVE AND VENTILATION



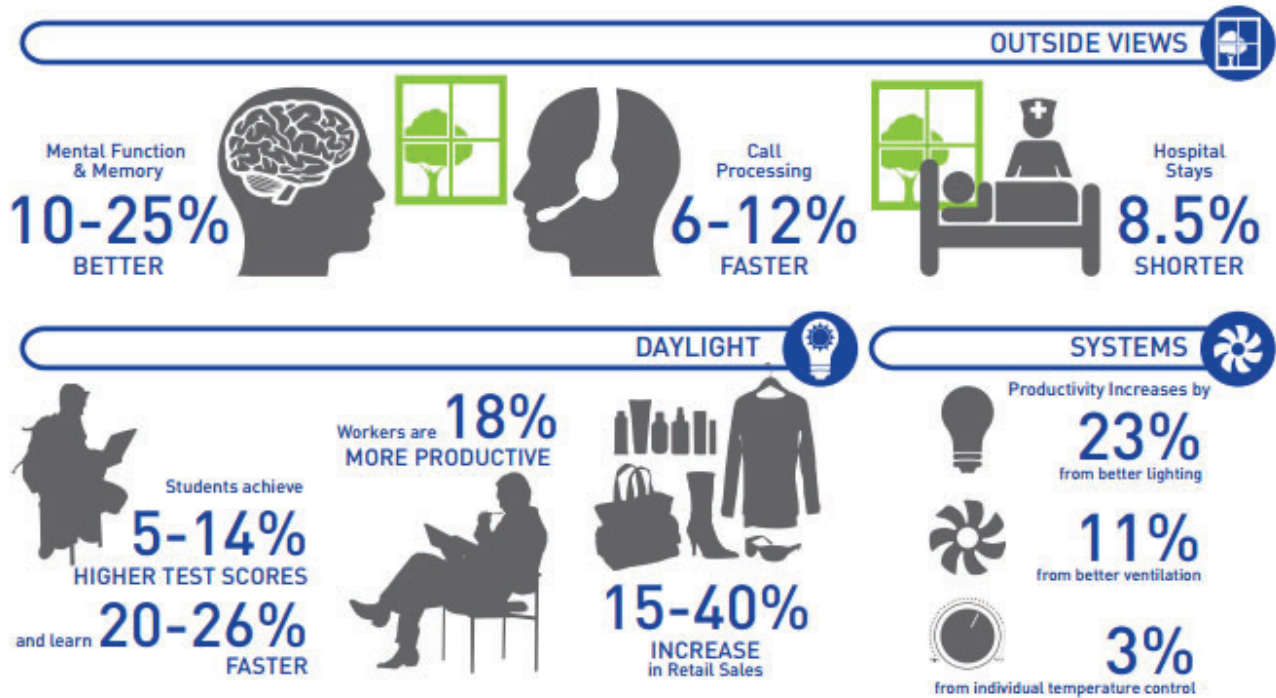
Source: Wargocki and Seppanen (2006)

# ABSENCE RATES CLASSROOM VENTILATION



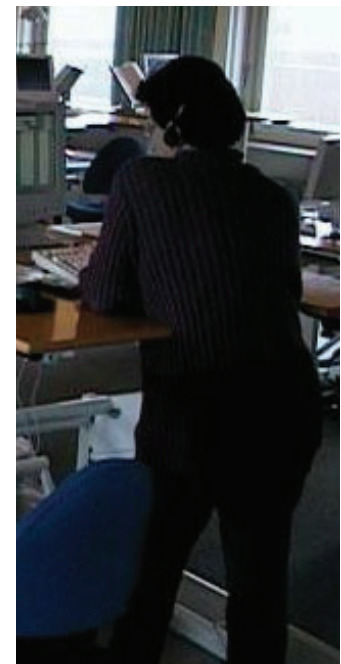
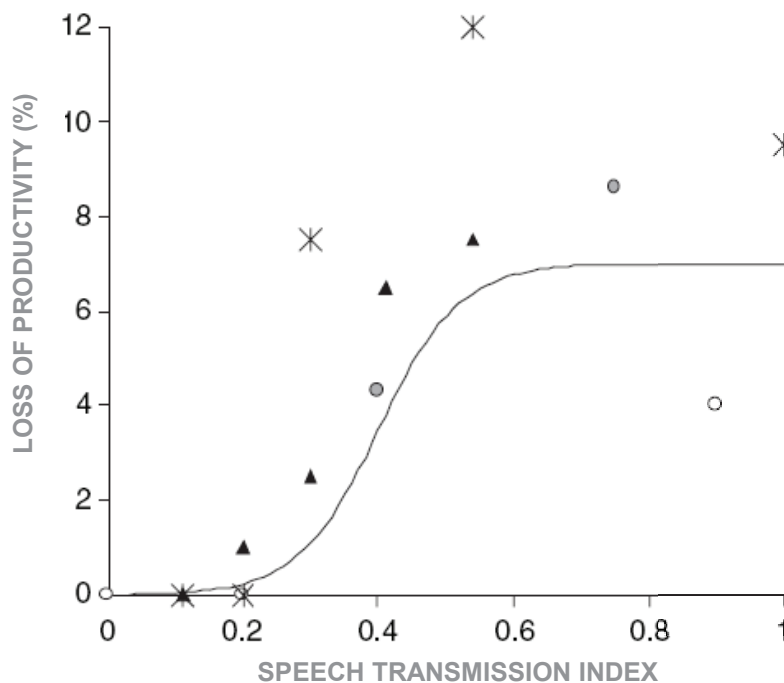
Source: Wargocki et al. (2020)

# POOR IEQ AFFECTS PERFORMANCE OF WORK



Source: World Green Building Council (2014)

# NOISE AND PERFORMANCE OF OFFICE WORK

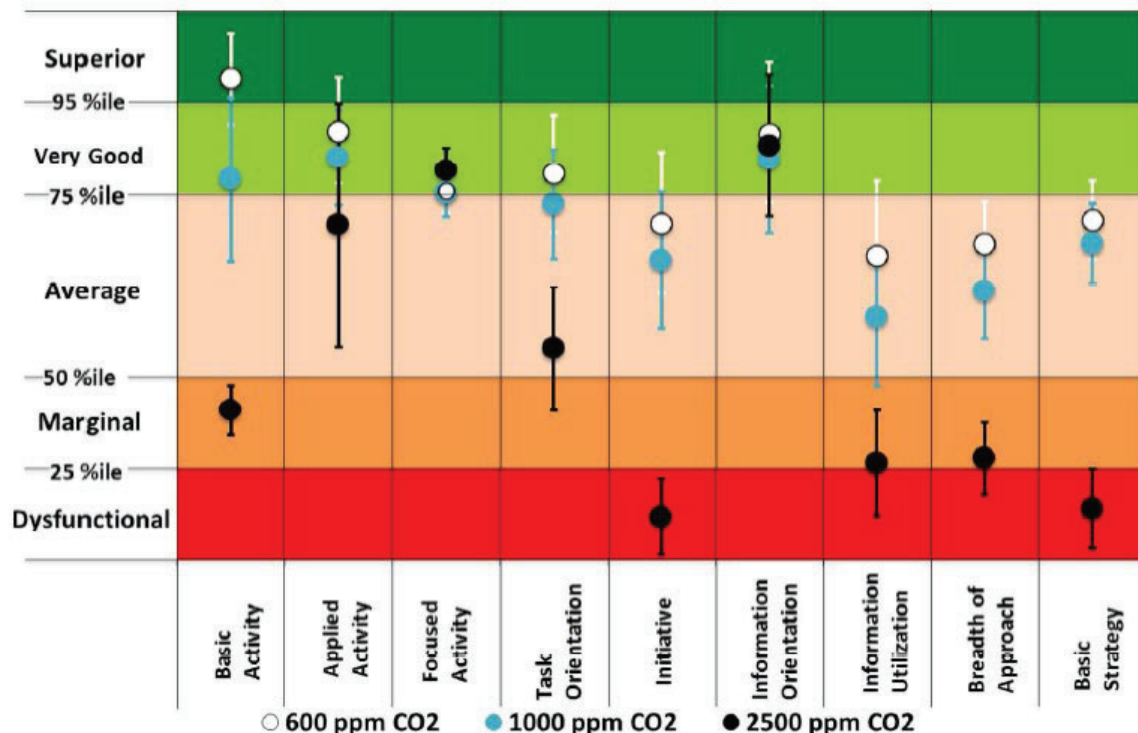


Source: Hongisto et al. (2005)

# (SOME) UNSOLVED MATTERS AND CHALLENGES

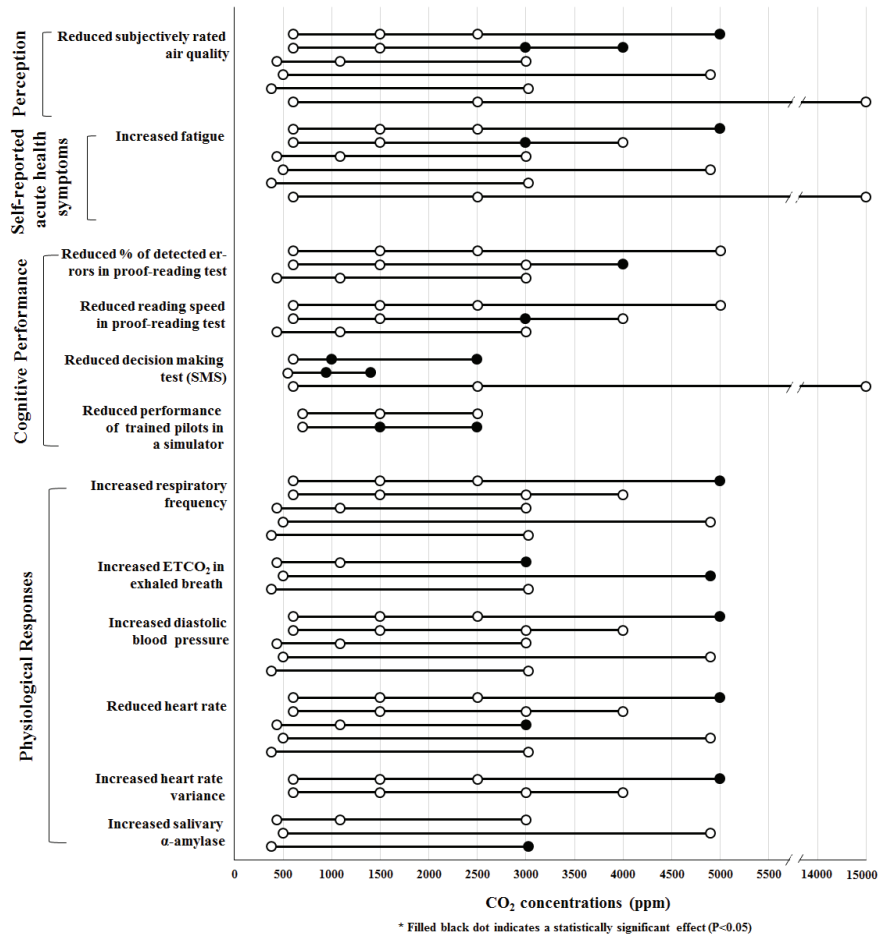
- Which pollutants can be associated with the effects on performance?
- Are there any risks for performance associated with the use of adaptive thermal comfort model?
- Do green buildings promote performance?
- How can performance be reliably measured?
- Can the evidence on the effects of IEQ on performance be used in economic calculations?
- What is the combined effect of several IEQ parameters on performance?
- To which extent is performance affected by sleep quality that is affected by IEQ?

## DOES CO<sub>2</sub> AFFECT (DECISION-MAKING) PERFORMANCE?

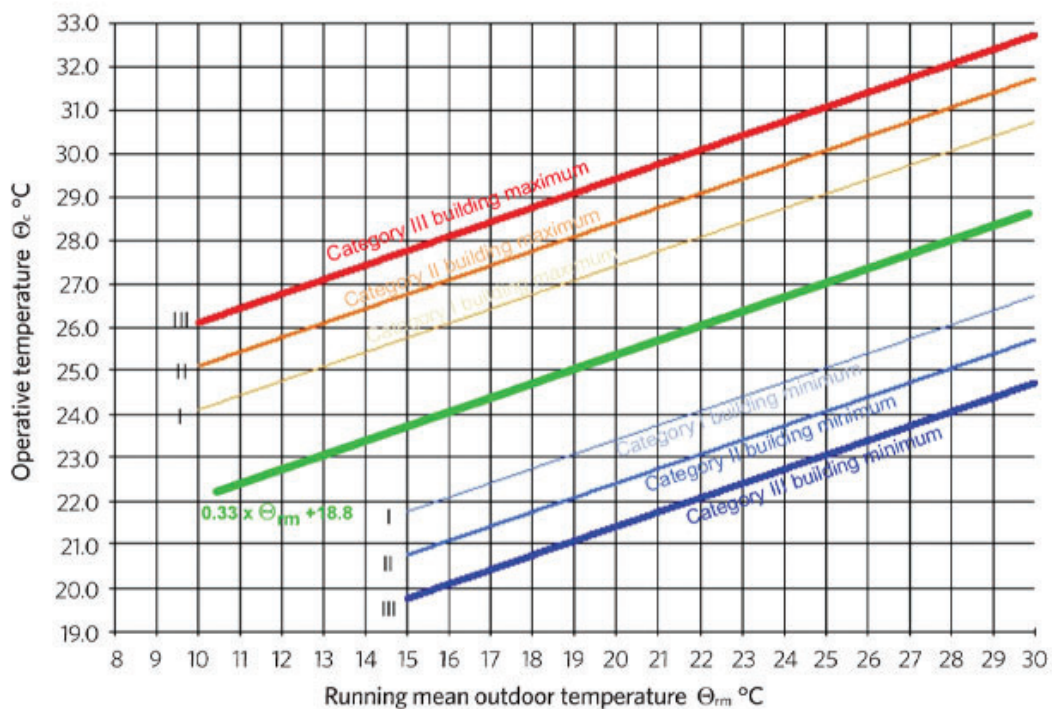


Source: Satish et al. (2012)

# IS CO<sub>2</sub> TRULY A POLLUTANT?



# DOES ADAPTIVE THERMAL COMFORT CREATE RISK?



# NEW RESULTS

- Keep indoor temperatures between 18-26 (27)°C and slightly cool environment to promote performance

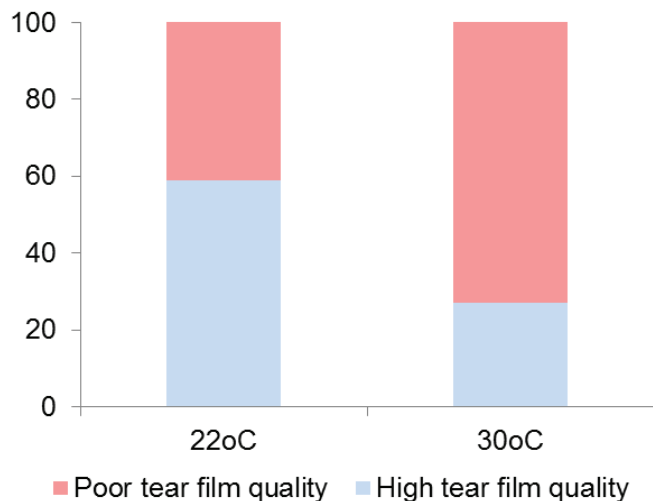
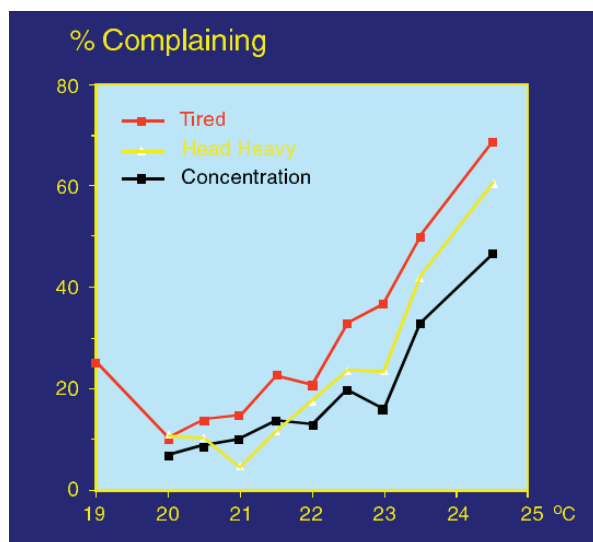
Thermal comfort

Not always



Optimum cognitive performance

## CONSEQUENCES OF ELEVATED TEMPERATURES



# GREEN BUILDINGS AND PERFORMANCE

- Review of 37 peer-reviewed papers and 12 white papers or reports
- Self-estimated productivity generally improved in green buildings (n=14); in n=3 studies reversed effect was seen. Size of the effect 2-16%.
- Sick-leave reduced at the level 5-39% but no information whether the effects remain at the same level after years of working or are temporary.

Source: da Silva (2015)

## NO AGREED & VALIDATED METHOD FOR VERIFICATION

- Absence from work or workstation, unavailability on the telephone.
- Health costs, including sick leave (absenteeism), accidents and injuries.
- Interruptions to work, observed downtime.
- Controlled independent measurements of work quality and mood.
- Self-assessments of productivity.
- Component tasks, task measures, speed and accuracy of work, for instance using simulated office work comprising arithmetic calculations, proof-reading and creative thinking, as well as tasks embedded in normal office work or schoolwork.
- Output from pre-existing work groups and existing company measures such as talk time in call centers or claim handling time in insurance companies.
- Cost for the product of service.
- Exchanging output in response to graded reward.
- Voluntary overtime or extra time.
- Staff turnover.
- Cycle time from initiation to completion of process;.
- Multiple measures at all organizational levels.
- Individual measures of performance, health and well-being at work.
- Development of measures and patterns of change over time.
- Diagnostic psychological tests of short duration examining specific skills such as psychomotor performance, memory, verbal ability, mood, perceptual ability, etc., used normally to study the effects of drugs, sleep deprivation and relatively strong stressors;
- Physiological measures such as cerebral blood flow, measures of voice quality and breathing patterns.

**How do we measure (validate) performance benefits?**



# MEASUREMENTS OF SELF-ESTIMATED PERFORMANCE

On the following 5 scales, please rate how you have been working this past week:

- The work seemed:  
Very Easy ----- Very Hard
- My level of effort was:  
Low ----- High
- The time pressure was:  
Low ----- High
- I worked at:  
0 -- 100% of my full capacity
- My performance was:  
Poor ----- Excellent

Task Questionnaire  
Click on each scale at the point that best indicates your experience for the task

Mental Demand

Physical Demand

Temporal Demand

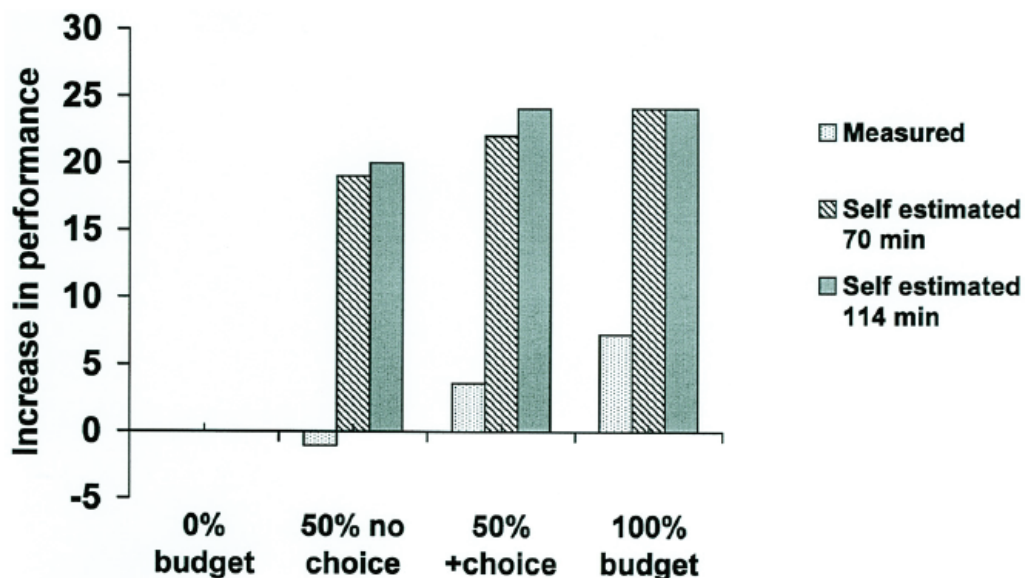
Effort

Frustration

Performance

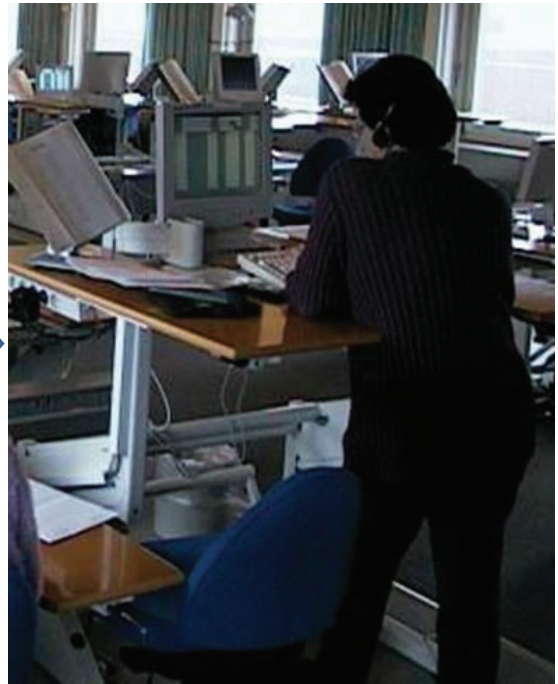
Cancel Continue

## SELF-ESTIMATED PERFORMANCE IS NOT EQUAL TO PERFORMANCE MEASURED OBJECTIVELY





# REAL WORK DATA ARE NECESSARY



Source: Wargocki and Wyon (in the Press)

## MEASURING FRAMEWORK FOR PERFORMANCE

- Physical: temperature, light level, CO<sub>2</sub>, noise, view
- Perceptual: physical comfort, job satisfaction (e.g., organizational commitment, engagement, corporate image)
- Financial: absenteeism, staff retention, revenue, medical symptoms and costs, complaints to building manager

Source: World Green Building Council (2014)

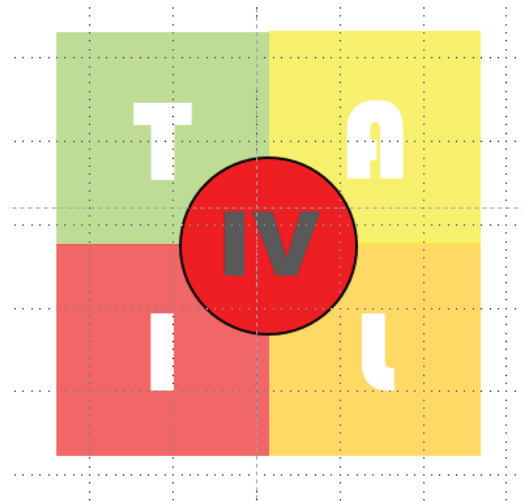
# TAIL RATING SCHEME

Four components:

- **T**hermal environment
- **A**coustic environment
- **I**ndoor air quality
- **L**ight – Luminous (visual) environment

Overall IEQ:

- 



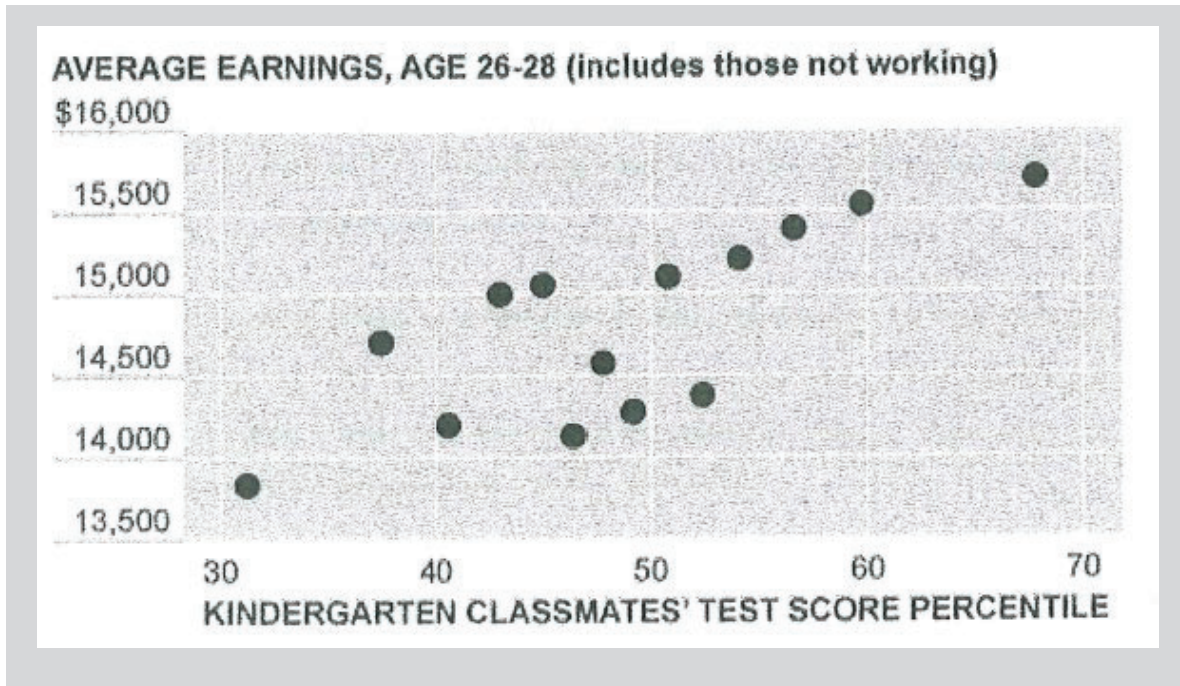
## ESTIMATED BENEFITS OF IMPROVING IAQ IN U.S. BUILDINGS

- Total benefits - \$62.7 billion/year
  - Productivity gains = \$54.7 billion
  - Health-related savings = \$8 billion: acute respiratory diseases = \$1.2 billion; building-related illness (e.g. humidifier fever) = 0.8\$ billion; IAQ illnesses including SBS = \$6 billion)
- Total costs - \$87.9 billion (initial)  
(in 40% of US buildings regarded unhealthy)  
+ 4.8 billion/year (maintenance)



Pay-back time = 1.4 years

# LONG-TERM SOCIO-ECONOMIC CONSEQUENCES



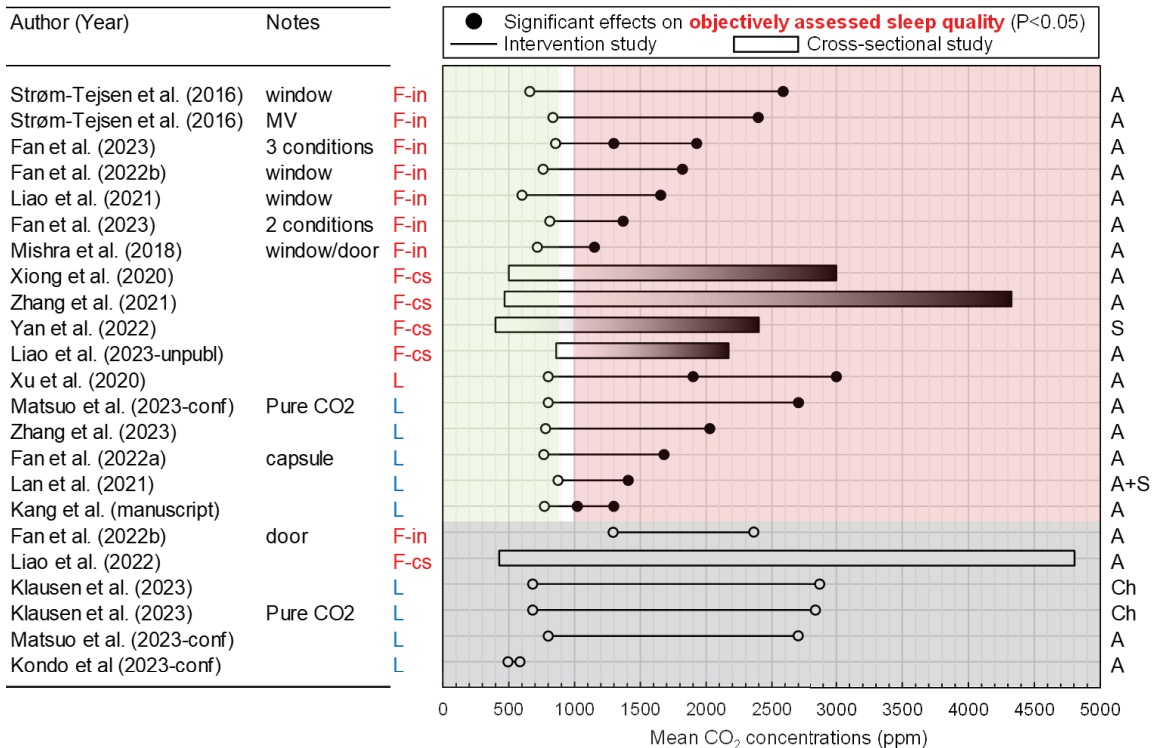
Source: Chetty et al. (2010)

## TEMPERATURE AND SLEEP

- It is difficult to fall asleep and to stay asleep when the bedroom is too cold or too hot
- There is no single temperature that is ideal at all stages of the night
- Sleep quality seems to be enhanced when bedroom temperatures are warm when falling asleep and when waking but cool in between

Source: Pan et al. (2014); Lan et al. (2016)

# Ventilation and sleep



## CONCLUSIONS AND "TAKE AWAYS"

- It is well documented that both thermal conditions and indoor air quality do affect the performance of office work and schoolwork.
- The mechanisms that mediate the effects of thermal conditions and indoor air quality on performance are surprisingly similar.
- Thermal conditions and indoor air quality tend to affect performance "across the board", suggesting that it is the ability to concentrate and to think clearly that is affected, as this is common to all aspects of mental performance.
- It is not proven that subjective acceptance of indoor environmental conditions leads to optimal performance.
- Self-estimated performance is not an indicator of objectively measured performance.
- Motivation to perform well may itself be influenced by the indoor environment.
- Performance tests, however environmentally sensitive, may not in fact predict the performance of real work.
- The results obtained in laboratory experiments using paid subjects, simulated work and limited exposure times must be validated in field intervention experiments in which the performance of real work is monitored over time in normally functioning offices and schools.

# QUESTIONS.....

sustainability  
 energy  
 council  
 health  
 green  
 credits  
 offices  
 performance  
 environmental  
 certification  
 economy  
 absenteeism  
 building  
 indoor  
 quality



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## ADDITIONAL READING...

TECHNICAL FEATURE

### How Indoor Environment Affects Performance

By David K. Wyon, Ph.D., Member ASHRAE, Pawel Wargocki, Ph.D., Member ASHRAE

As experienced researchers in the effects of thermal comfort and indoor air quality on performance, we are often asked to give our best estimate of how, and to what extent, performance is affected by different aspects of indoor climate. This article provides a brief summary of our personal opinions, in the form of answers to 40 frequently asked questions. Our answers are based on the results of behavioral experiments conducted to date. We offer no opinions on long-term health effects of indoor environmental quality. We provide some references to relevant sources, but there is not enough space for all such references. We list some questions we cannot answer as topics for future research in this area.

**Relevance**  
 Why should we be interested in thermal and air quality effects on performance?  
 There are four main reasons:  
 • It is the added value of occupant performance that pays for indoor environmental quality.  
 • Performance is affected in the short-term by the combined effects of all indoor environmental factors, while subjective and physiological responses are usually selected because they are a function of one specific factor.  
 • It turns out that thermal and air quality effects on performance can be observed even when there are no observable effects on comfort or on health-related symptom intensity.<sup>1,2</sup> and  
 • The primary purpose of factory, office and school buildings is to provide an optimal indoor environment for work and for learning to work.

**Effects**  
 What effects do related temperatures and poor air quality have on performance?  
 We have found that they usually reduce the rate of working, with little or no effect on accuracy.<sup>3,4</sup>

**About the Authors**  
 David K. Wyon, Ph.D., is professor and Pawel Wargocki, Ph.D., is associate professor at the International Centre for Indoor Environment and Energy at the Technical University of Denmark in Kongens Lyngby, Denmark.

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