Indoor environment in living and working spaces – future requirements

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Current requirements to the indoor environment

- The not unhealthy, uniform indoor environment that results in fewest dissatisfied

- Requirements based on group responses, which tend to mask individual needs

ASHRAE 55-1992
Thermal environmental conditions for human occupancy

"The purpose of this standard is to specify the combinations of indoor space environment and personal factors that will produce thermal environmental conditions *acceptable to 80% or more of the occupants within a space.*"

2004 version

"….acceptable to a majority of the occupants within the space."

Future requirements to the indoor environment

An indoor environment that is comfortable, healthy and inspiring

...at the lowest possible energy consumption

The human sensor system

- visual
- aural
- olfactory
- thermoreception
-
-

Indoor environment factors

- light
- sound
- indoor air quality
- temperature
-
-

Criteria for indoor air quality

	Recommended ventilation rates		
	For occupants L/(s person)	For building emissions L/(s m^2)	
		Low polluting	Non low-polluting
Category A	10	1.0	2.0
Category B	7	0.7	1.4
Category C	4	0.4	0.8

(prEN 15251)

Table A.5 - Design criteria for spaces in different type of buildings.

This table applies for the occupancy listed in the table and for a clothing insulation of 0.5 clo during the summer season and 1.0 clo during the winter season.

Type of building/ space	Activity W m^{-2}	Category	Operative temperature °C		Maximum mean air velocity* m s^{-1}	
			Summer (cooling season)	Winter (heating season)	Summer (cooling season)	Winter (heating season)
Single office Landscaped office Conference room Auditorium Cafeteria/Restau-rant Classroom	70	A	24.5±1.0	22.0±1.0	0.12	0.10
		B	24.5±1.5	22.0±2.0	0.19	0.16
		C	24.5±2.5	22.0±3.0	0.24	0.21**
Kindergarten	81	A	23.5±1.0	20.0±1.0	0.11	0.10**
		B	23.5±2.0	20.0±2.5	0.18	0.15**
		C	23.5±2.5	20.0±3.5	0.23	0.19**
Department store	93	A	23.0±1.0	19.0±1.5	0.16	0.13**
		B	23.0±2.0	19.0±3.0	0.20	0.15**
		C	23.0±3.0	19.0±4.0	0.23	0.18**

*The maximum mean air velocity is based on a turbulence intensity of 40% and air temperature = operative temperature according to section 5.1 and figure A2. A relative humidity of 60% and 40% is used for summer and winter, respectively. For both summer and winter the lower temperature in the range is used to determine the maximum mean air velocity.
**Below 20 °C limit (Figure A.2)

(prEN 15251)

Simultaneous exposure to several indoor environment factors

1K change in operative temperature had the same effect on human comfort as a change in noise level of 3.9 dB or a change in perceived air quality of 2.4 decipol

(Clausen et al. 1993)

New study

- Investigate people's priorities within a limited budget for improvements of a poor indoor environment
- Investigate whether individual choice of working environment affects work performance and individual perception of the indoor environment

(Clausen et al. 2005)

Experimental Plan

99 subjects randomly assigned to four groups:

- Group 1: Poor indoor environment
- Group 2: Improvements partly implemented, self selected improvements
- Group 3: Improvements partly implemented, non-self-selected
- Group 4: All improvements implemented

All subjects exposed once in pairs during 2 hours

Group 1: Poor indoor environment

- Traffic noise 55 dB(A)
- Poor lighting
- No view out
- Open plan office
- 27°C
- Poor IAQ

Group 4: All improvements implemented

- Traffic noise 45 dB(A)
- Good lighting
- View out
- Private office
- 22°C
- Good air quality (50L/s/p)

Group 2: Improvements partly implemented (Self selected improvements)

Condition	Relative cost of improvement	Low budget (20 %)	Medium budget (50 %)	High budget (75 %)
Traffic noise	4			
Lighting	4			
Office noise	37			
Air temperature	10			
Air quality	8			
Daylight (view out)	37			

Subjects exposed to self-optimized conditions at 50 % budget level

Improvements selected by the subjects

Improvement	Chosen by subjects (%)
Cooling	75
Low traffic noise	66
A quiet office	58
Better lighting	42
Better air quality	33
Daylight (view out)	24

All nine possible combinations selected

Group 3: Improvements partly implemented, not self-selected

- exposed to the conditions chosen by subjects from Group 2
- paired exposure (one person from Group 2 and one person from Group 3)

Experimental Plan

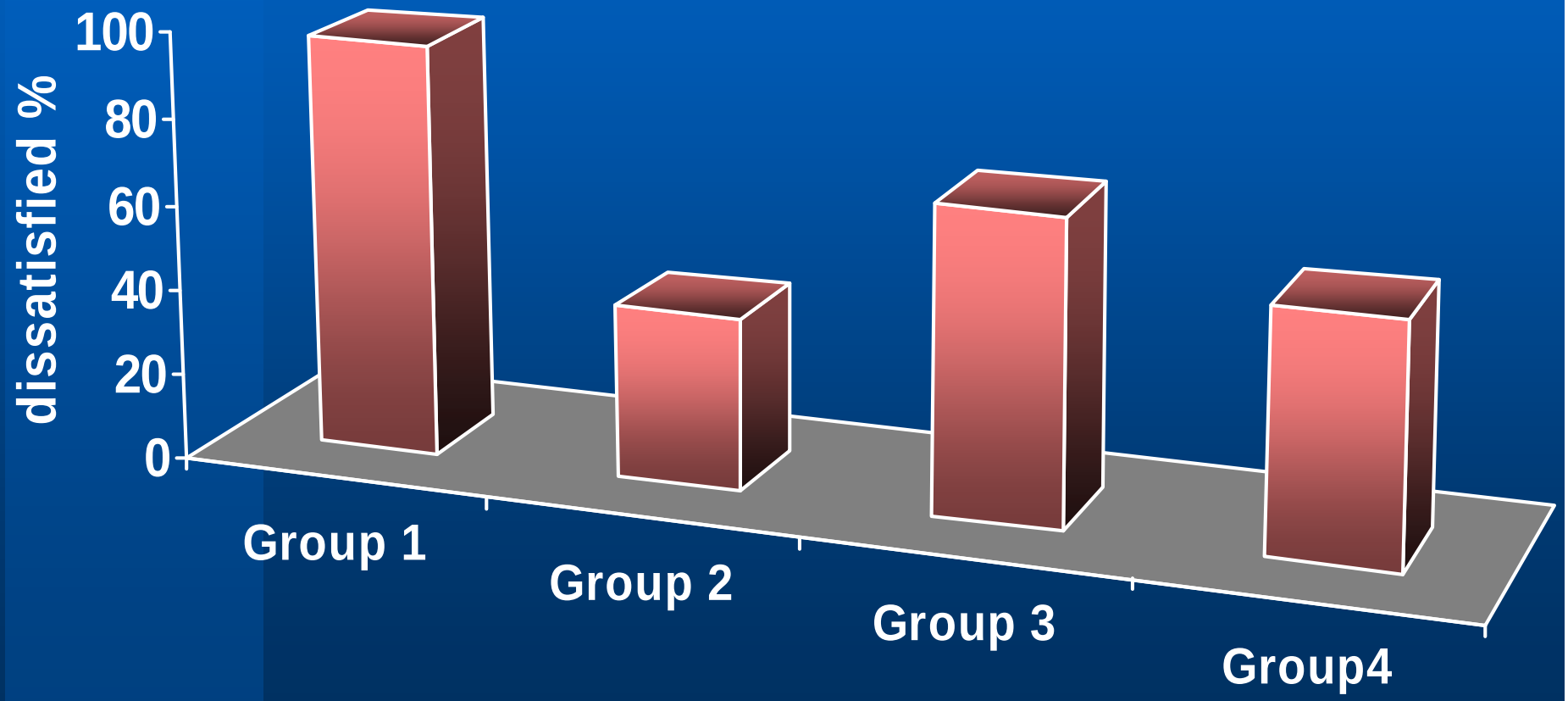
Tasks:

- Landolt rings
- Proof-reading
- Addition
- Acoustic proof-reading

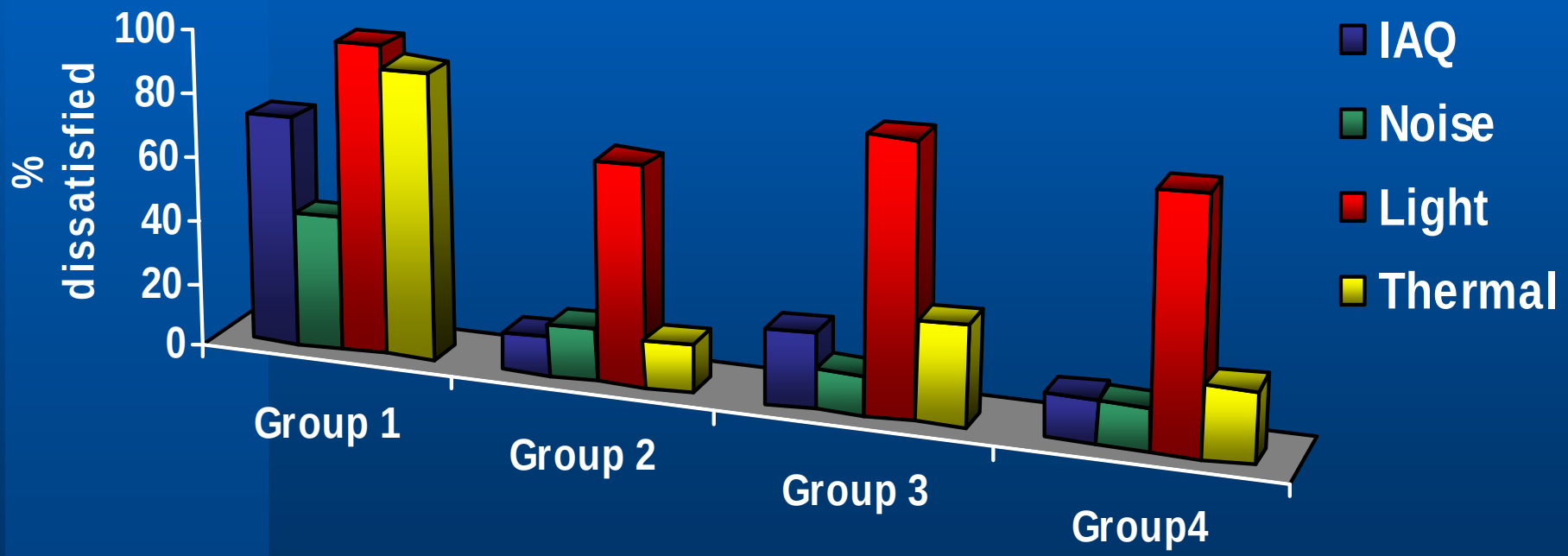
Questionnaires:

- IAQ
- Thermal sensation
- Overall indoor environment
- Acceptability of noise and lighting
- SBS symptom intensity

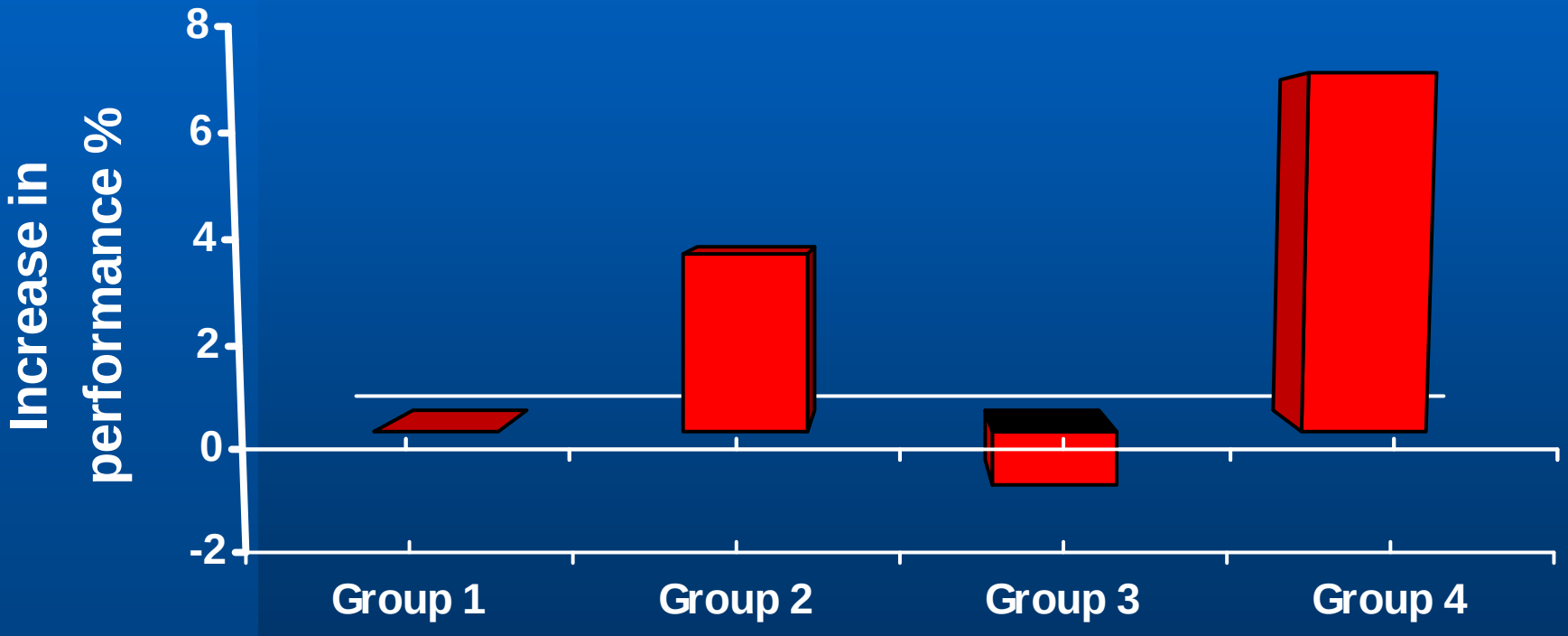
Dissatisfaction with overall indoor environment



Dissatisfaction with the indoor environment



Overall performance



Conclusions

- Subjects did not agree on which environmental factor it was most essential to improve
- The possibility to individually choose which parameters to improve within a given budget had a positive effect on the acceptability of the overall indoor environment

Basic infrastructure to meet workplace needs

- Fresh air and temperature control
- Lighting control
- Daylight and view out
- Privacy and working in quiet conditions

(Loftness 1996)

Database - field studies in office buildings

Q1:
To which degree do you feel you can control the indoor environment in your office?

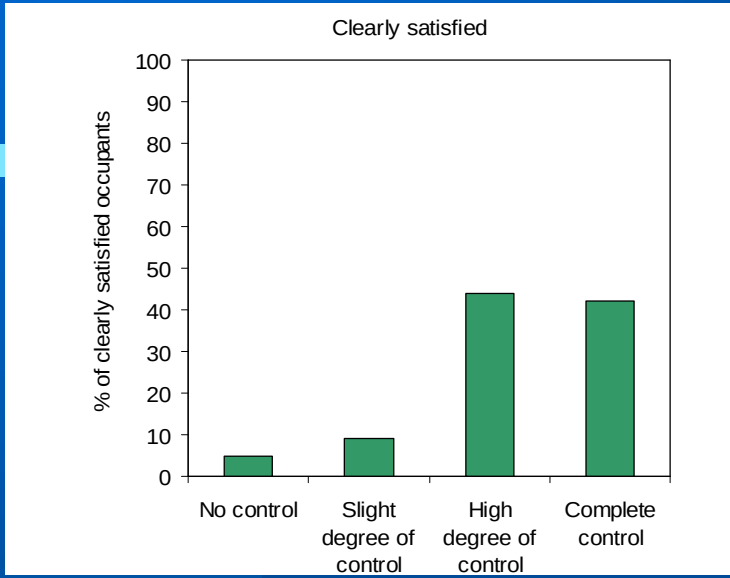
A1:
- No control
- Slight degree of control
- High degree of control
- Complete control

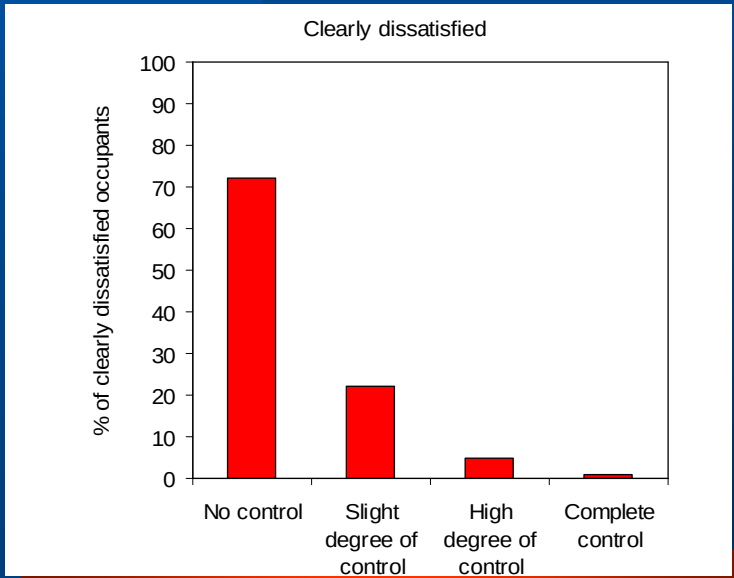
Q2:
How satisfied are you with the environmental conditions in your office?

A2:
- Clearly satisfied
- Just satisfied
- Just dissatisfied
- Clearly dissatisfied

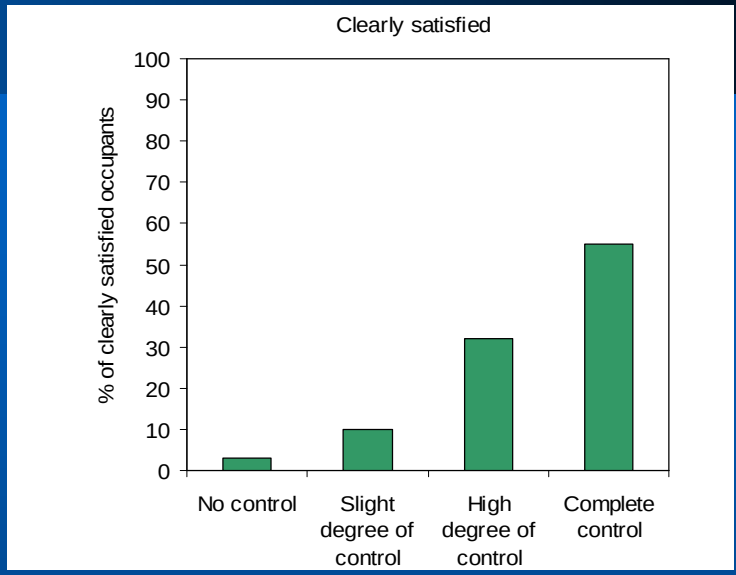
Clearly satisfied
Clearly dissatisfied

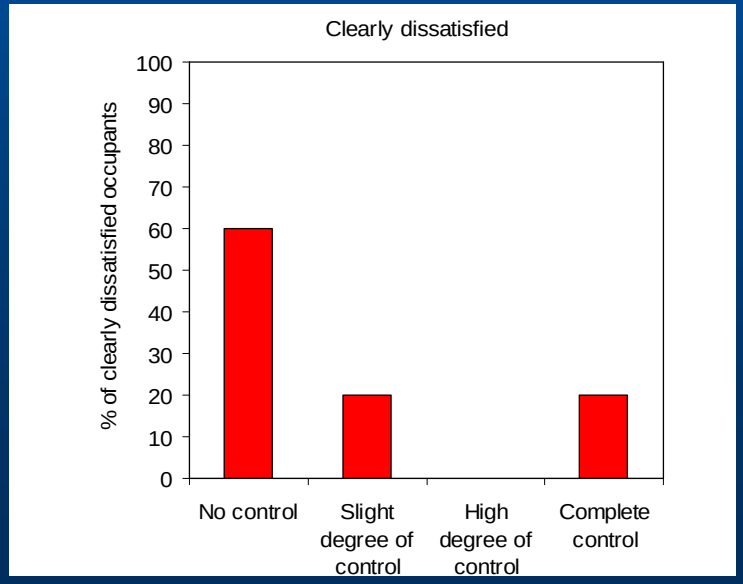
Mechanical ventilation (3 bldgs, n = 372)





Natural ventilation (5 bldgs, n = 173)





Future requirements

- Building occupants are exposed to a multitude of environmental stimuli and future indoor environment criteria should acknowledge this by integrating IEQ effects on comfort, health and performance

- The human sensory system has some adaptive capabilities, but building occupants like to feel they have a certain degree of control of the indoor environment

Factors motivating IEQ upgrades

At work:

Employee ⇨ Comfort

Employer ⇨ Health

Performance

⇒ Energy Investment

At home:

Private economy

Comfort

Health

⇒ Energy Investment

Work at home ⇒ ?

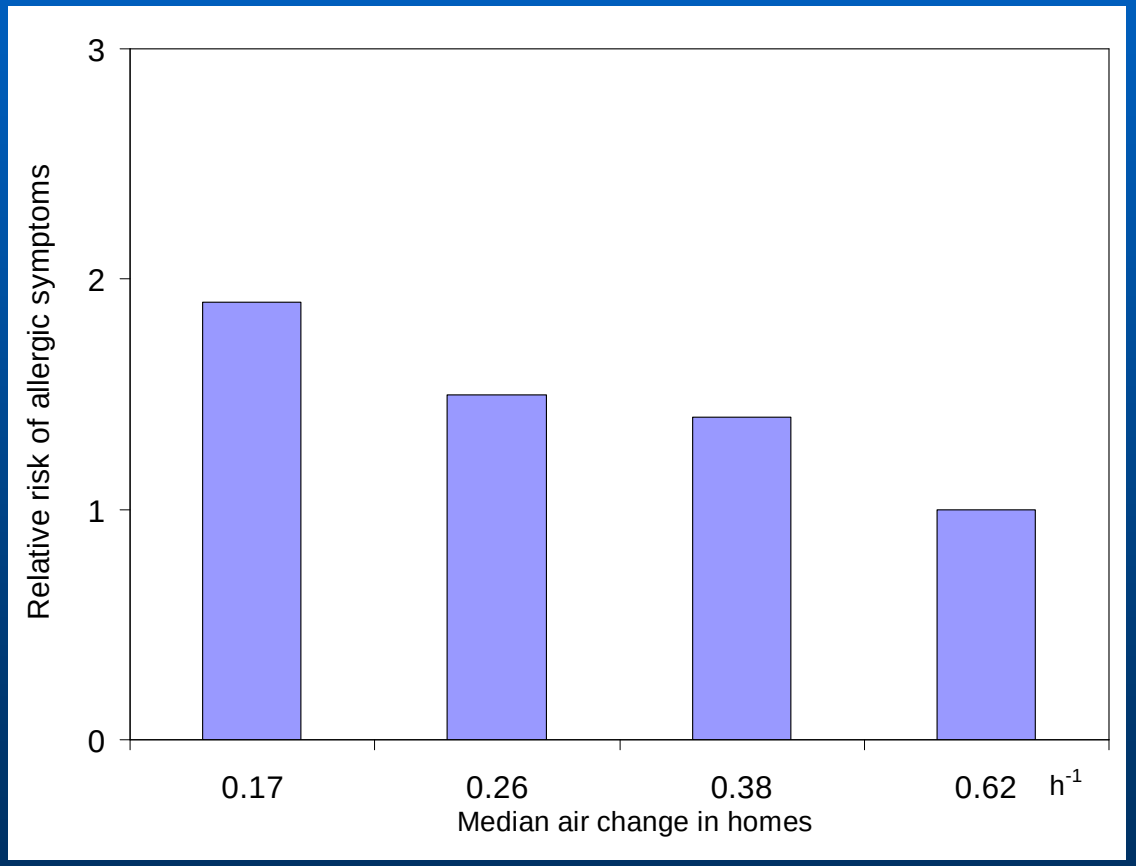
Field study in Swedish homes

1 stage: 11.000 children – questionnaires

2 stage: 400 children selected

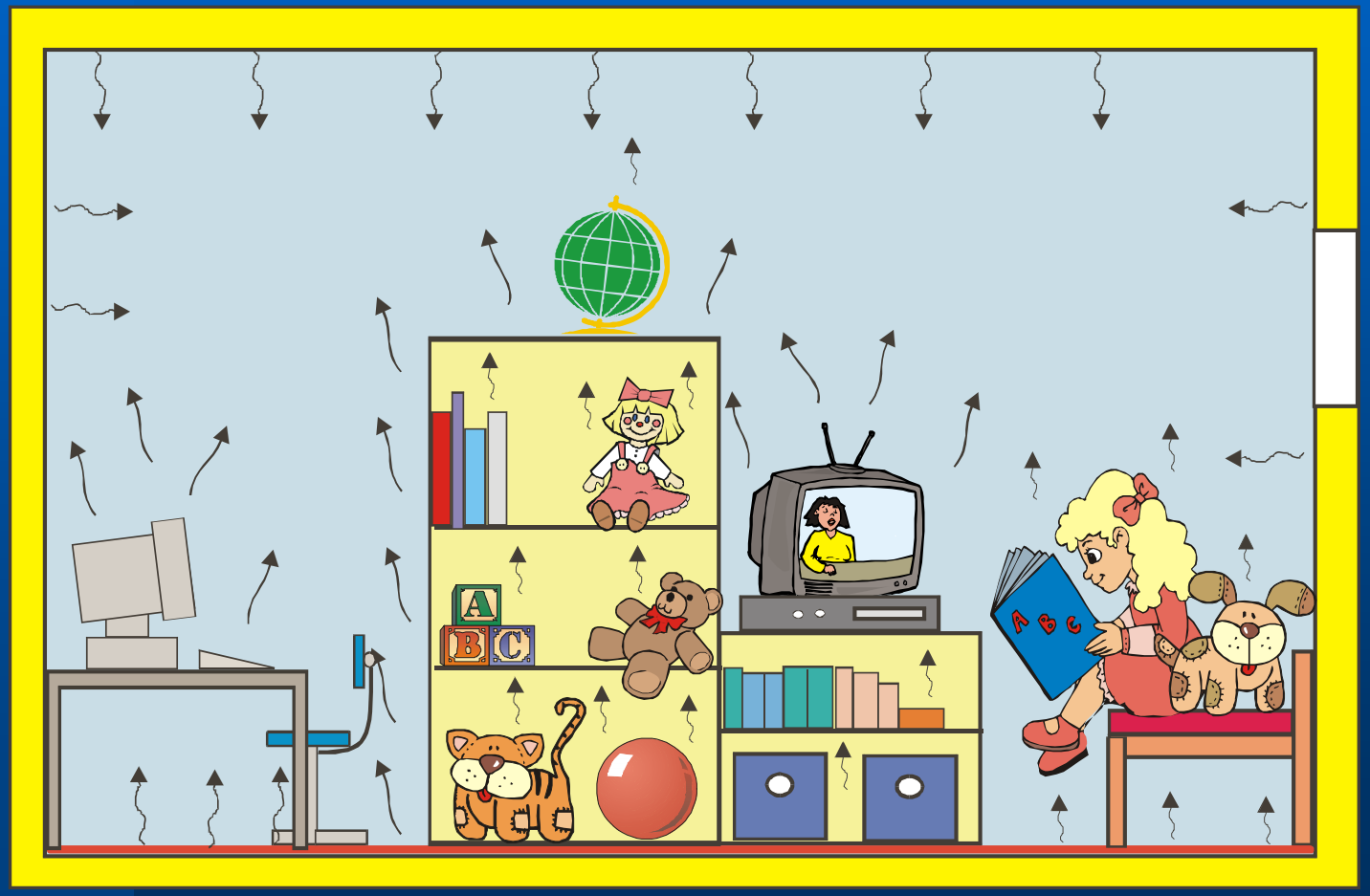
- 200 in case group
- 200 in control group

Ventilation and the risk of allergic symptoms among children

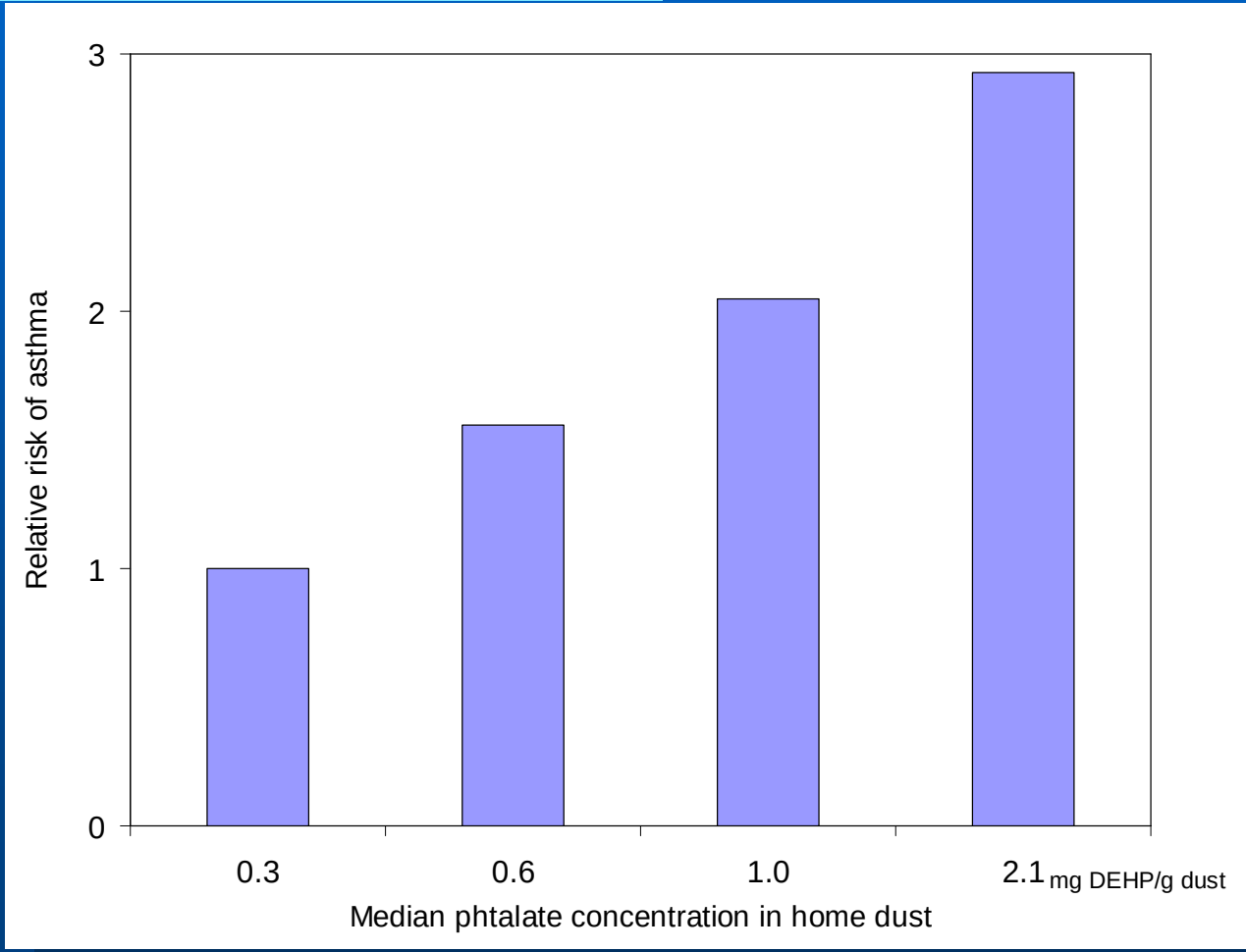


(Bornehag et al. 2005)

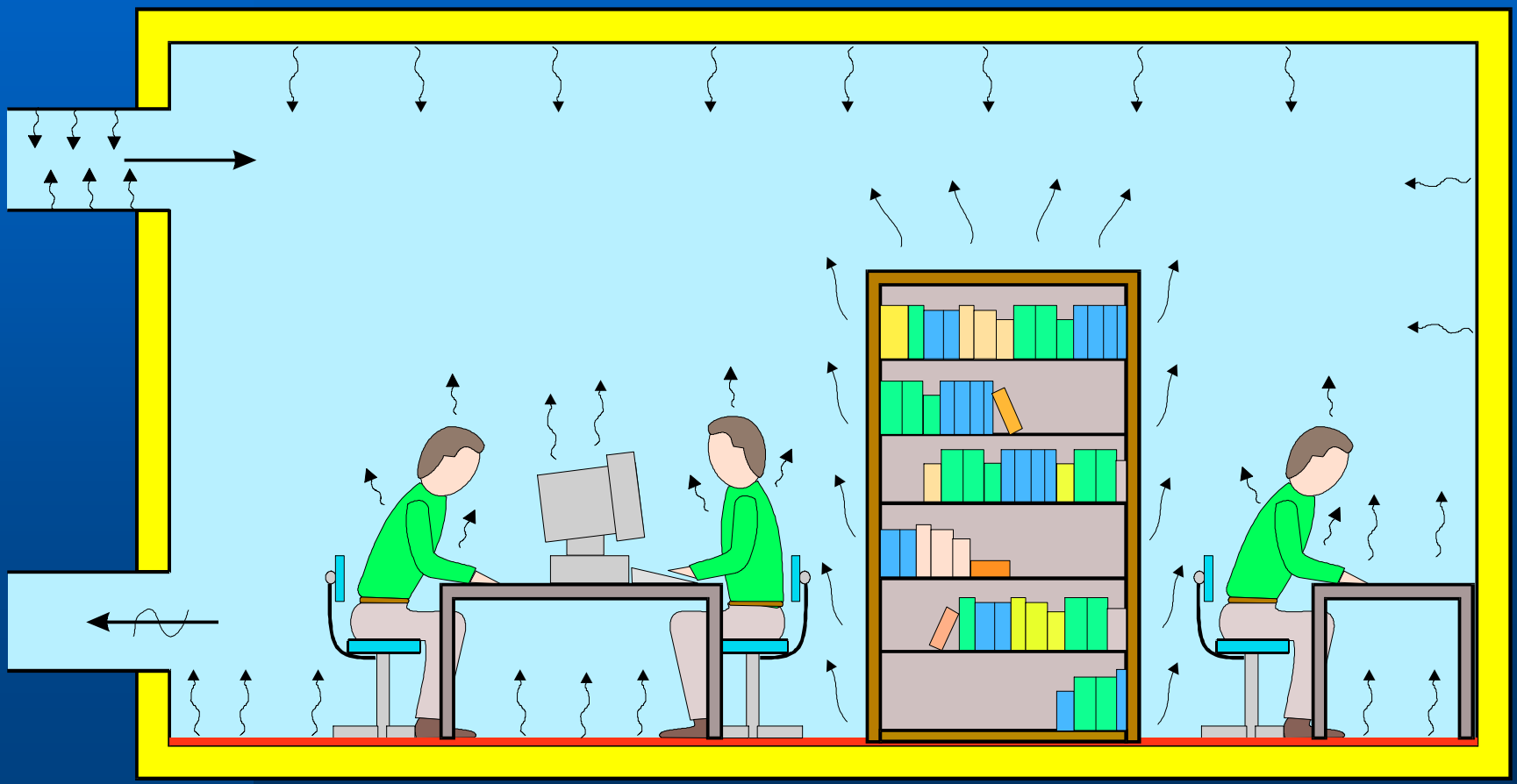
Pollution sources in homes



Plastiziser concentration in dust and the relative risk of asthma among children

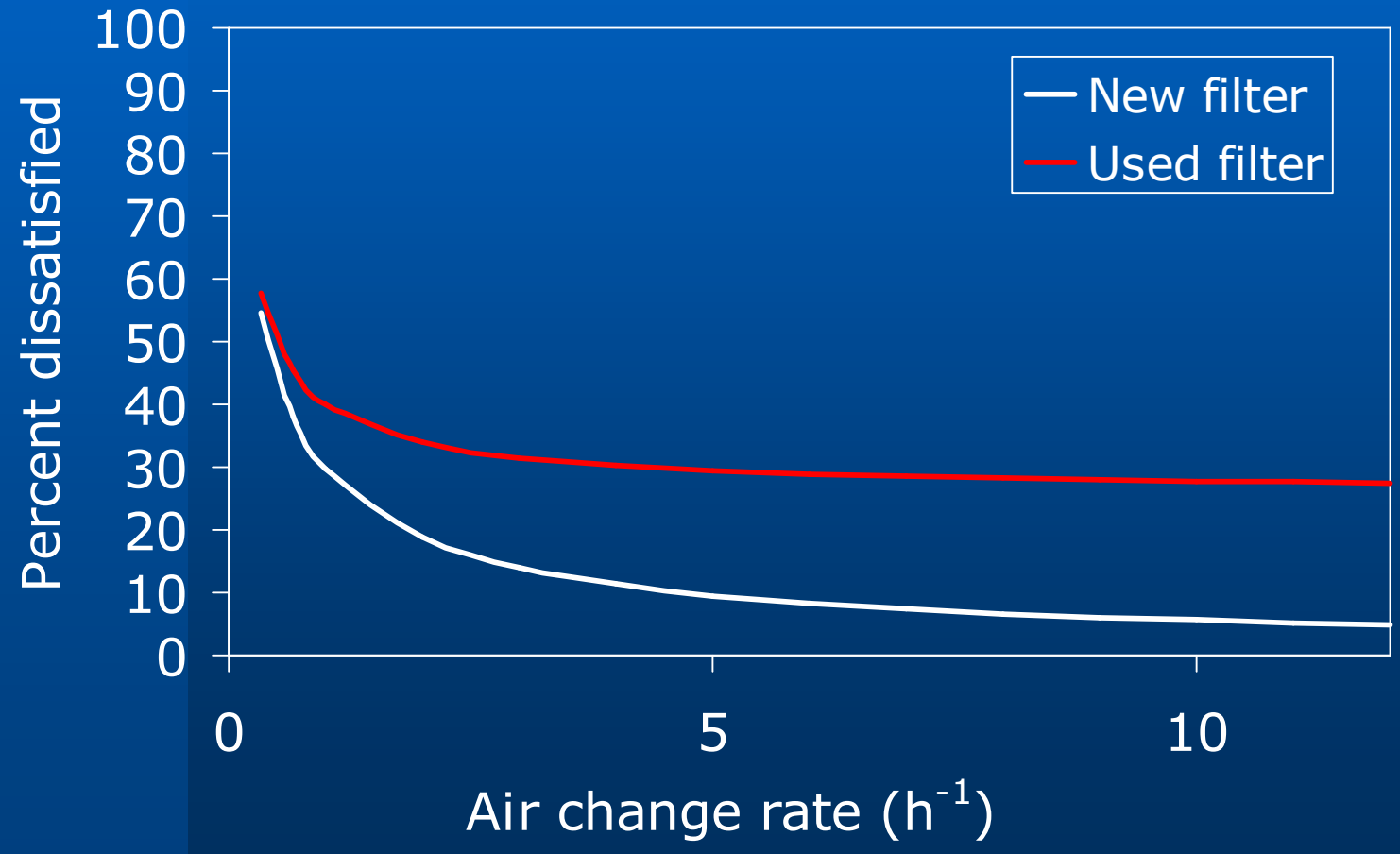


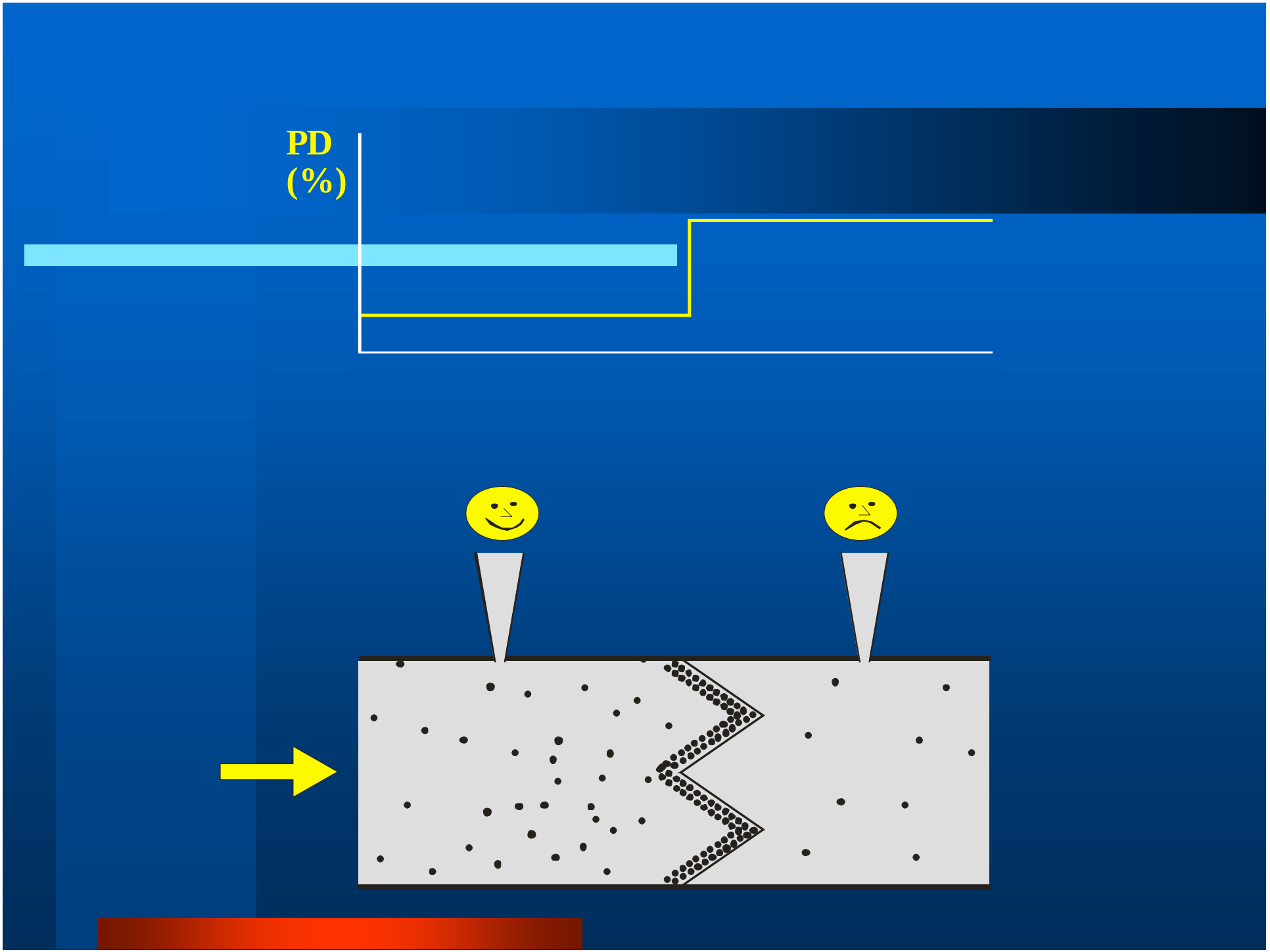
Pollution sources in offices



Filters in HVAC systems

Sensory pollution emitted by HVAC filters




PD
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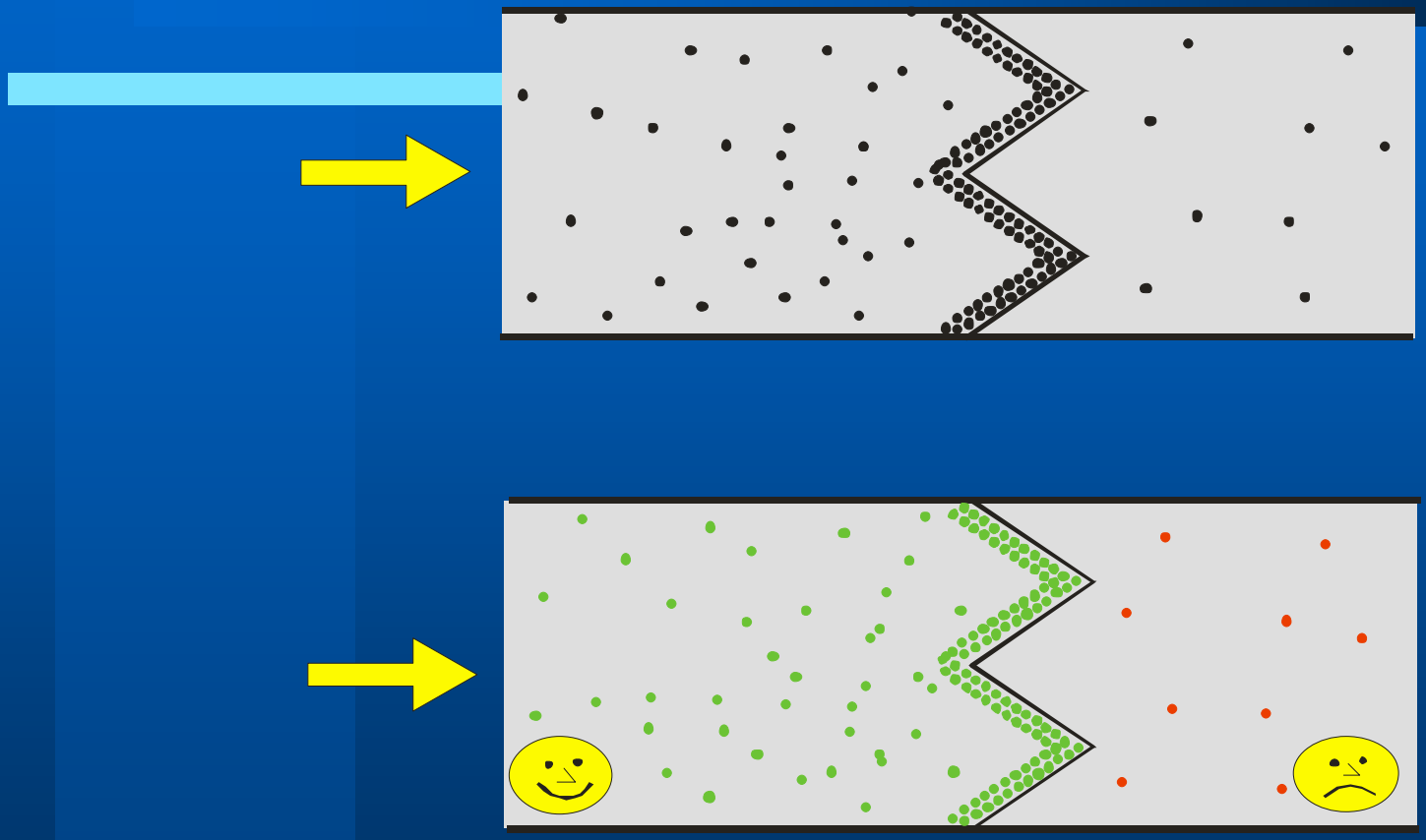
Pollution from particle filters



svocs sorbed on particles

Oxidized svocs

Chemical reactions in indoor air

(National Geographic 2006)

Future requirements

- Control of pollution sources indoors:
  - plastic toys
  - electronic equipment
  - consumer products
  - particle filters
    - new filtration technology
    - frequent replacement of used filters

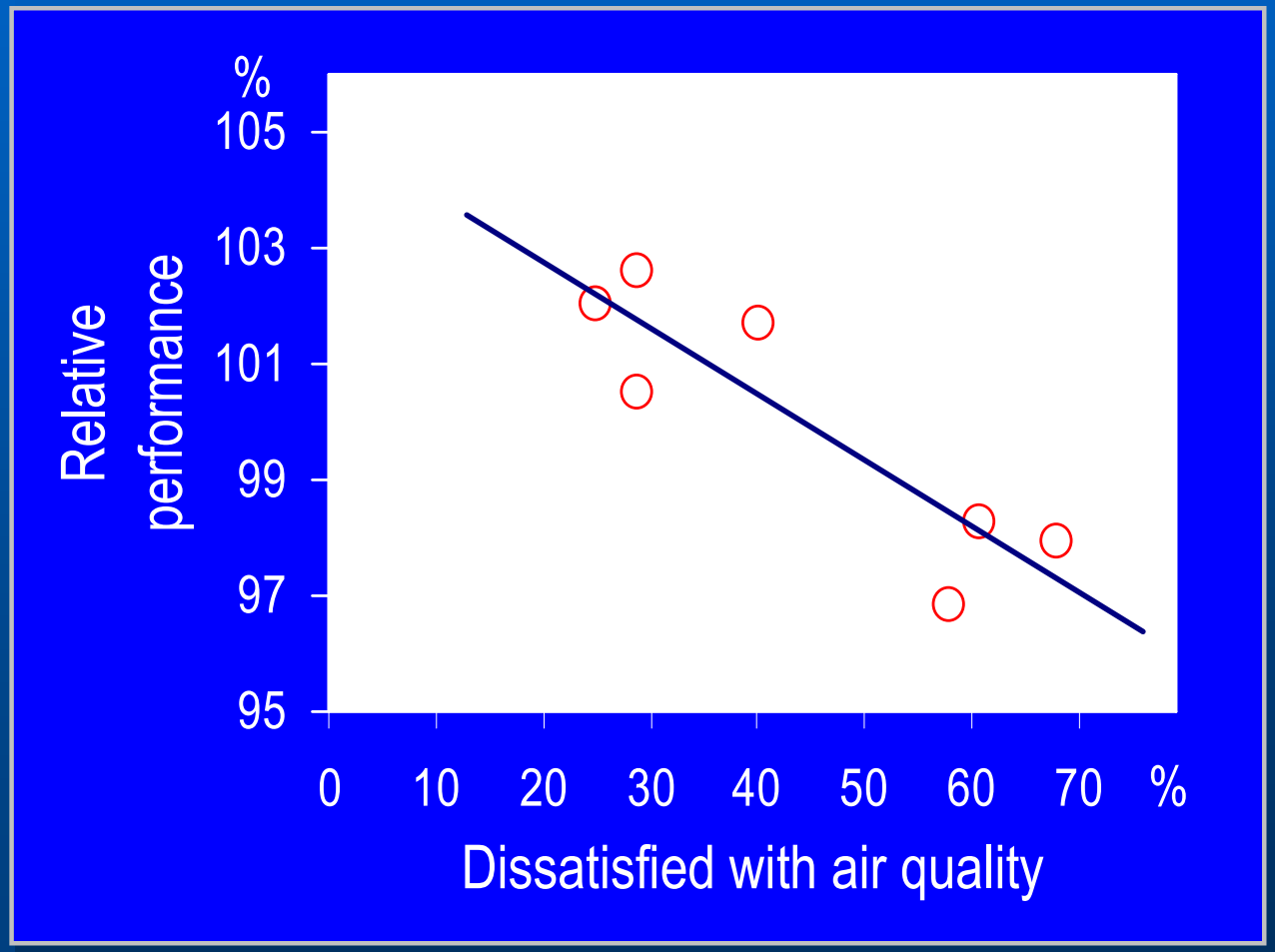
Consequences of current practice

In typical office buildings:

- 20-40% of the occupants suffer from SBS symptoms
- 10-60% of the occupants find the air quality unacceptable

- even though existing ventilation standards are met

Perceived air quality and office work performance



Comparison of energy and staff costs for North American offices

	Rosenfeld	Abdou & Lorsch	EPA	Woods	BOMA
Staff costs $/(ft^2 yr)	300	218	200	237	130
HVAC running costs $/(ft^2 yr)	-	2 - 10	6	12	2.9
Energy costs $/(ft^2 yr)	1.5	1 - 2	2	2	1.5
Ratio of staff to energy costs	200	114 - 218	100	118	87

(Clements-Croome 2000)

Estimated relation between perceived air quality and performance of office work

- 10% fewer dissatisfied with air quality $\Rightarrow$ 1.1% increase in performance
- reducing pollution load by 50% $\Rightarrow$ 1.6% increase in performance
- Doubling ventilation rate $\Rightarrow$ 1.8% increase in performance

Estimated relation between temperature and performance of office work

- Temperatures from 21°C to 25°C:
  Productivity loss = 0%
- Temperatures from 25°C-30°C:
  Productivity loss = 2% for each °C
- Temperatures >30°C
  Productivity loss = 10%

Source of productivity gain	Potential annual health benefits	Potential US annual savings or productivity gain (1996 USD)
Reduced respiratory illness	16 – 37 mill avoided cases of common cold or influenza	6 – 14 billion USD
Reduced allergies and asthma	18% to 25% decrease in symptoms for 53 million allergy sufferers and 16 million asthmatics	1 – 4 billion USD
Reduced SBS symptoms	20% to 50% reduction in SBS symptoms experienced by 15 mill workers	10 – 30 billion USD
Improved worker performance from changes in thermal environment and lighting		20 – 160 billion USD
Total cost of energy in US commercial buildings		70 billion USD

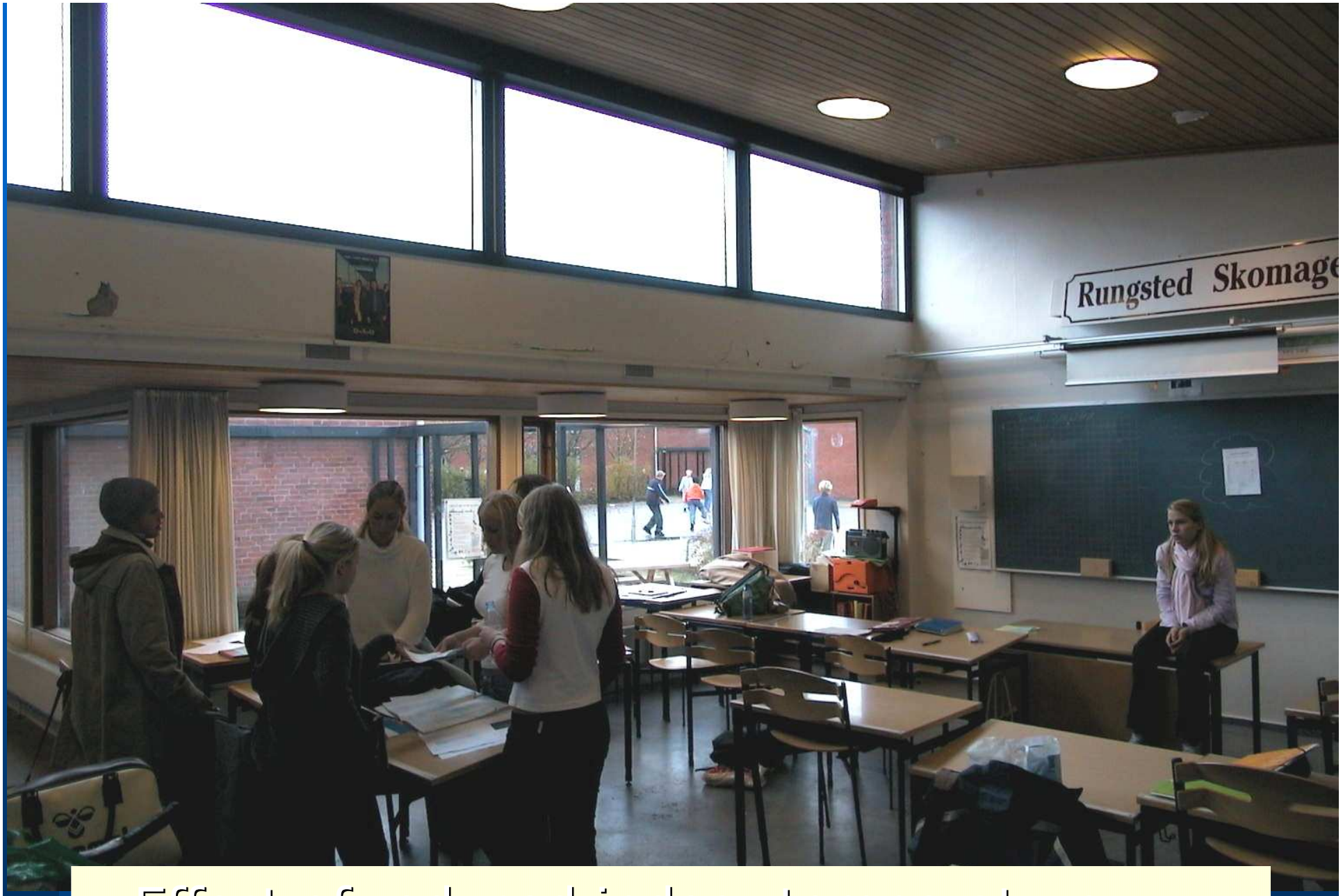
(Fisk 2000)

Implications

In the Nordic countries this will amount to approximately 3 – 20 billion USD from IEQ related improvements in worker performance

In a life cycle assessment of a building a lost annual productivity of 5% becomes completely dominating

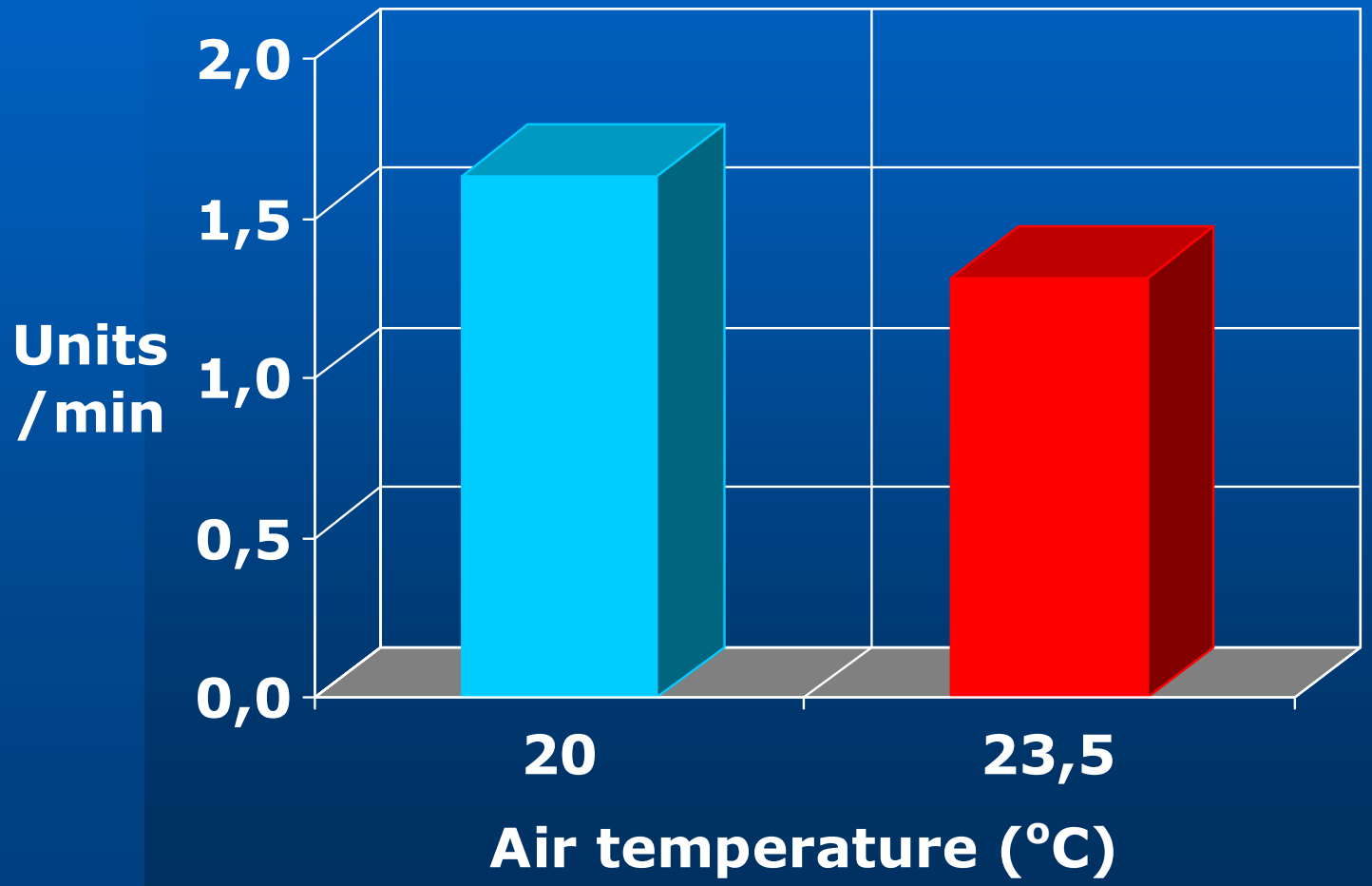
Another kind of productivity – Learning in schools



- Effect of reduced indoor temperature
- Effect of increased outdoor air supply rate

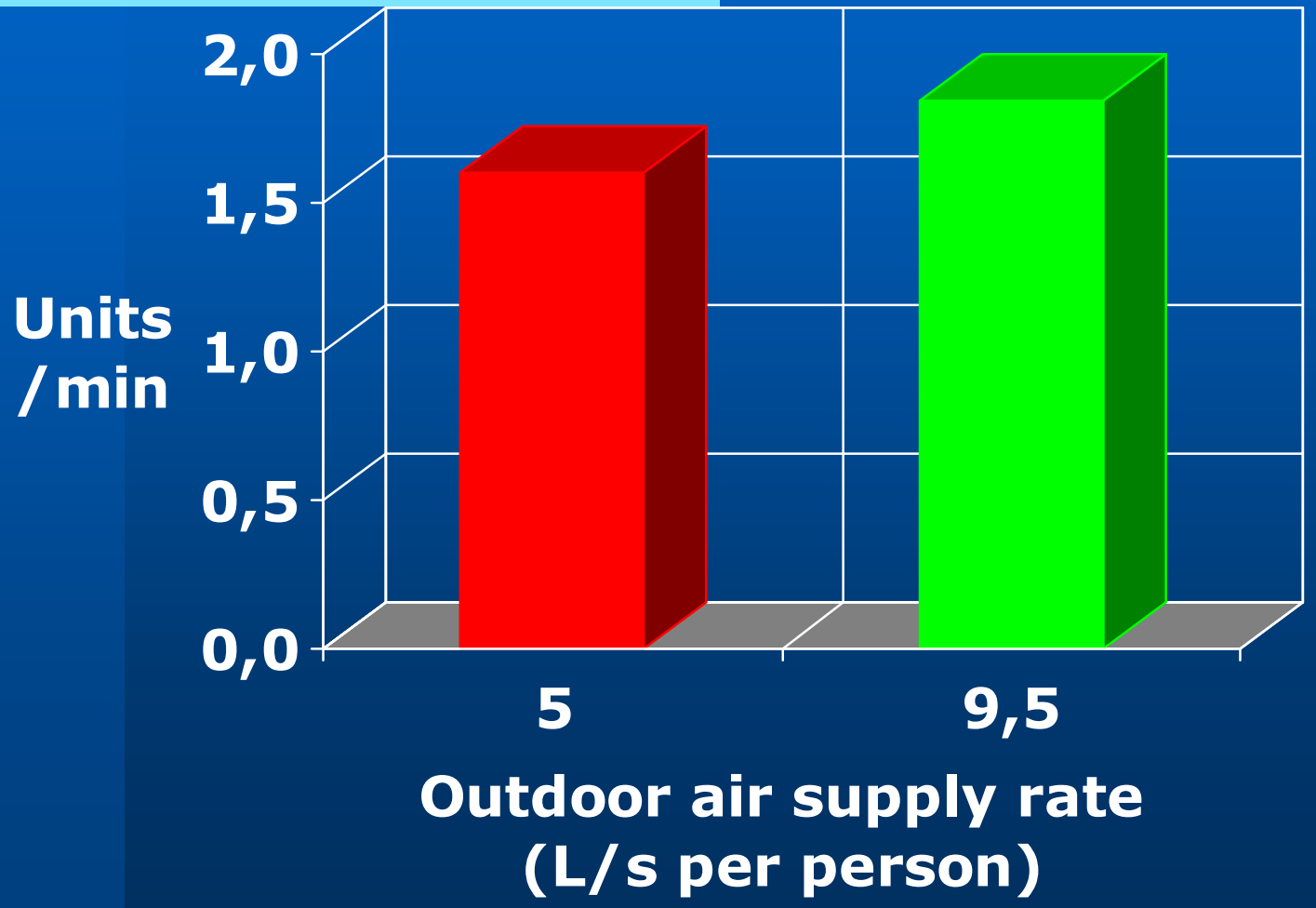
Effect of reduced temperature

Workrate - reading test



Effect of increased ventilation

Workrate - multiplication



Future requirements to indoor environments

Control of multifactorial exposures rather than one factor at a time, as we learn more

Include the occupant in the control loop

More weight on health and performance aspects of the indoor environment at work and educational facilities, as we learn more

Conservation of energy with due consideration to IEQ effects on humans