INDOOR ENVIRONMENT-

New technology and sensors. “Setting the standard”

Professor Bjarne W. Olesen, PhD

Director

International Center for Indoor Environment and Energy

Department of Mechanical Engineering

Technical University of Denmark

INDOOR - OUTDOOR

- **Highest exposure to the indoor environment**

- **People spend ~90 % of the time indoors during work, during transportation and at home**

INTAKE FOR A PERSON PER DAY

- 1 kg FOOD
- 2 kg LIQUID
- 15 kg AIR

COMFORT-PRODUCTIVITY
Building costs

People	100
Maintenance	10
Financing	10
Energy	1

5 SENSES


Feel
Thermal
See
Light
Taste
Hear
Acoustic
Smell
Air quality

INDOOR ENVIRONMENT

- THERMAL
- AIR QUALITY
- ACOUSTIC
- LIGHT

Large field studies show substantial rates of dissatisfaction in practice

(Mendell, 1993; Fisk et al., 1993; Bluyssen et al., 1994; Sundell, 1994; Sekhar et al., 2000; Bischhof 2000)

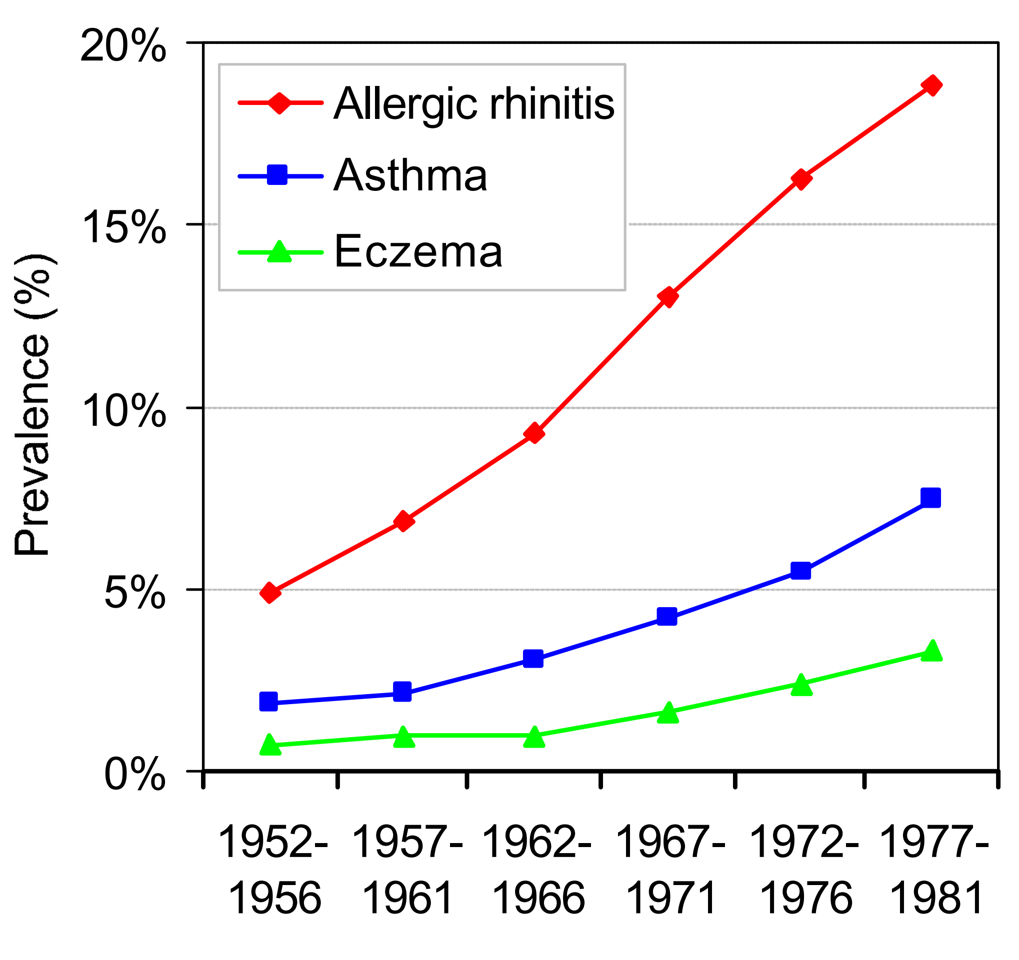
In typical office buildings

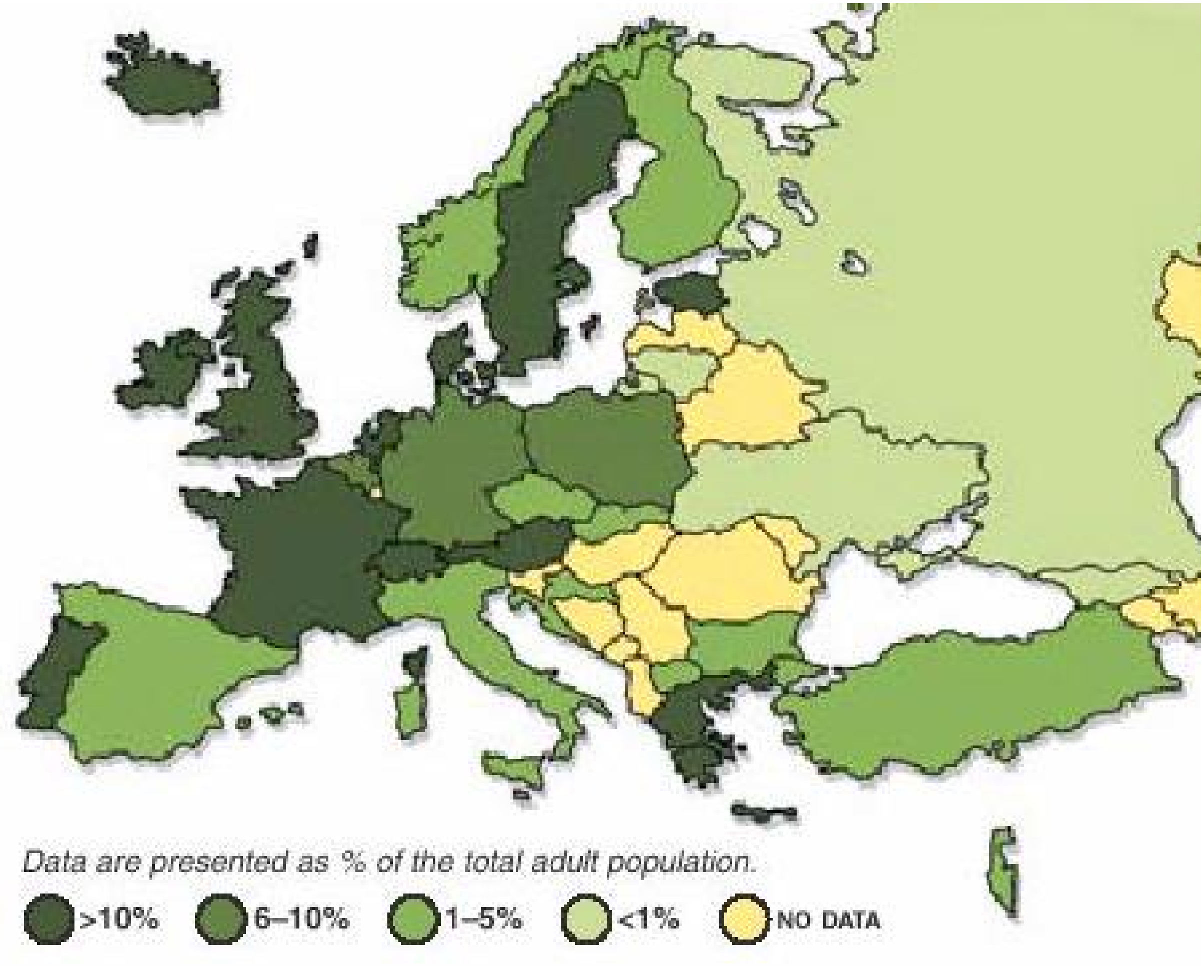
- 20-40% of occupants with SBS symptoms
- 20-40% of occupants finding the IAQ unacceptable

even though existing ventilation standards are met.

We guarantee that less than
30% of our customers will
be dissatisfied !

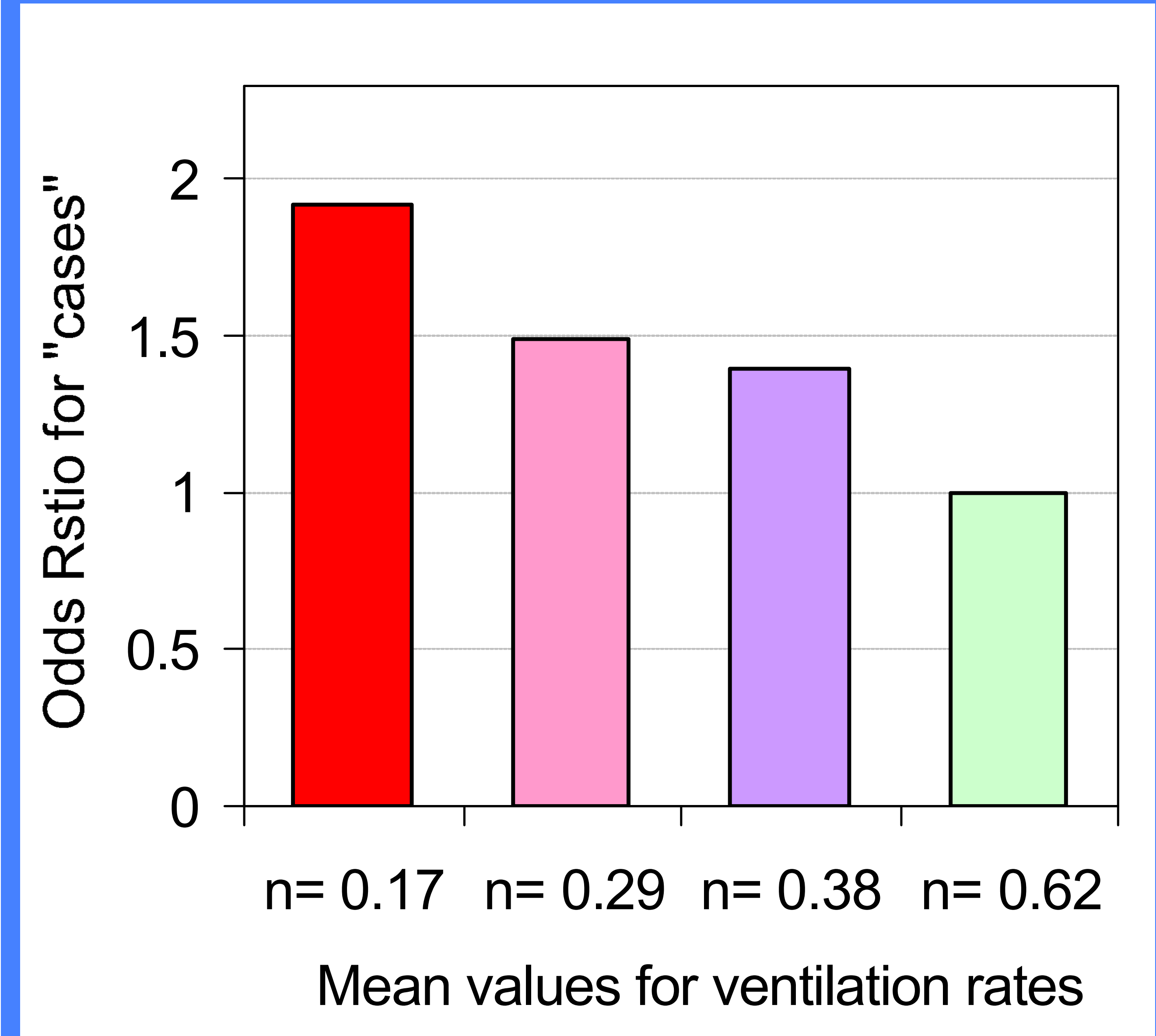
HEALTH



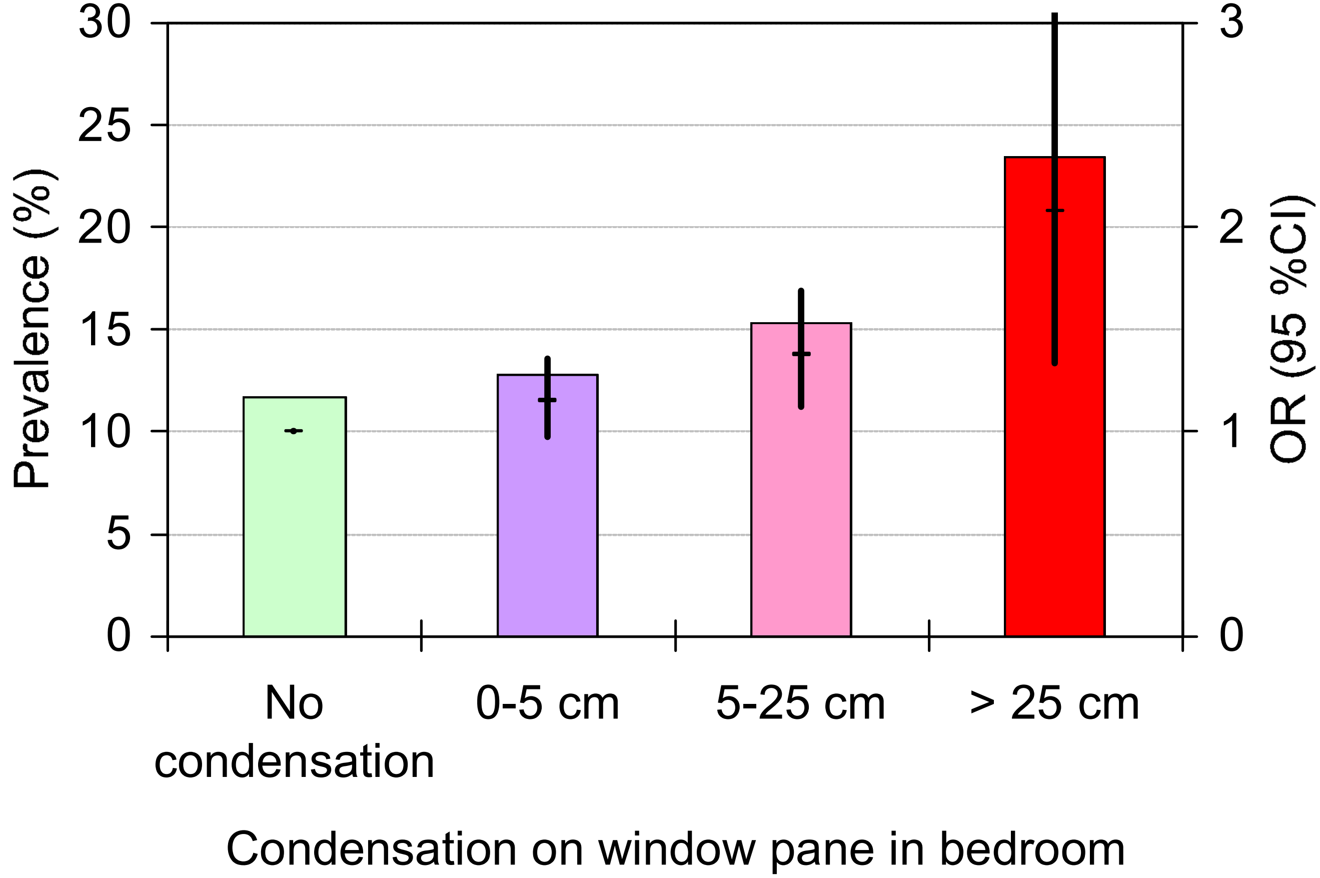


__Left:__ Trends for allergic rhinitis, asthma and eczema among male conscripts (17-20 years age) in Sweden (Bråbäck et al., 2004).

__Right:__ Current data on prevalence of asthma in adults in Europe (Loddenkemper et al., 2003).



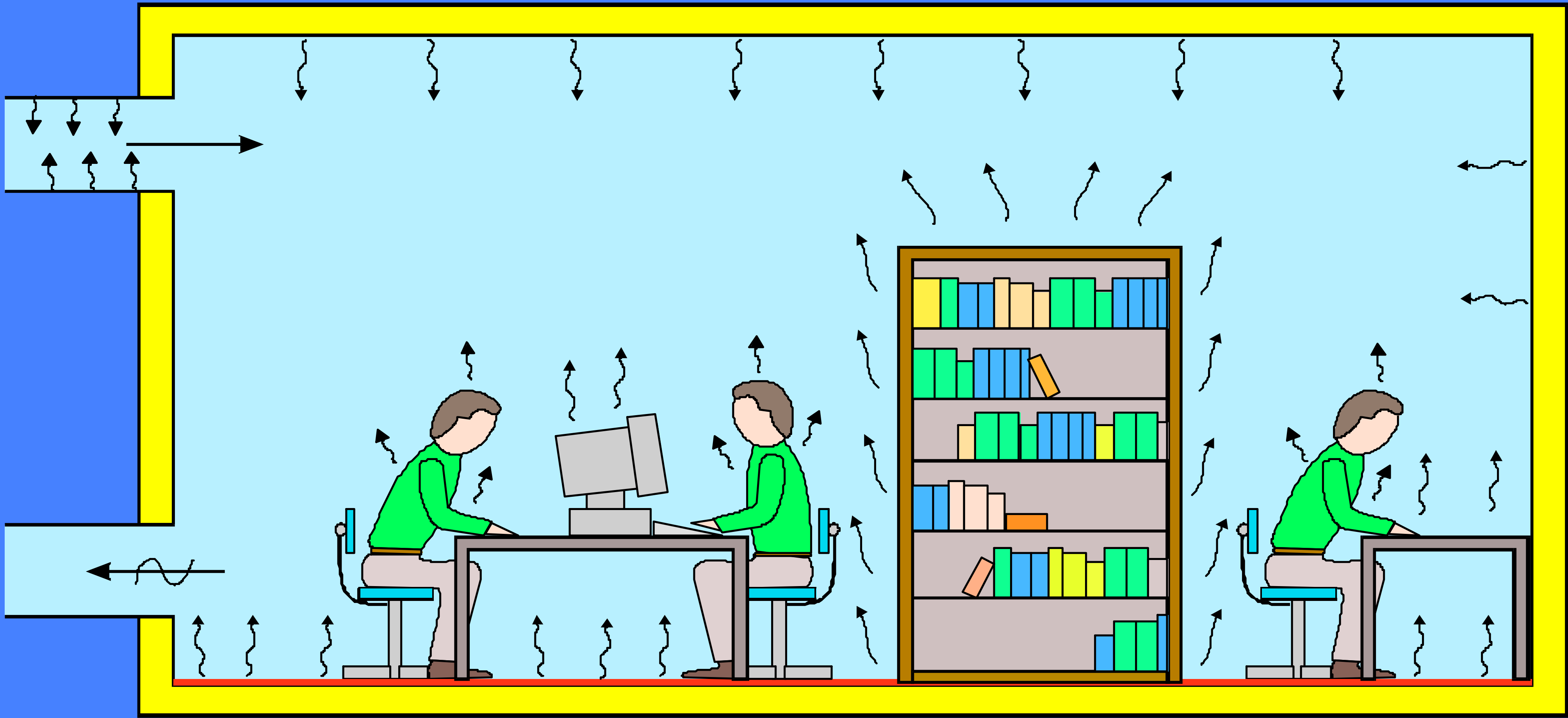
Odds ratio for being a "case", i.e. children with at least two symptoms of possible three (wheezing, rhinitis, eczema) as a function of ventilation rates, in single family houses. (Bornehag et al., 2003).



Left: Window water condensation is often a sign of poor ventilation in dwellings;

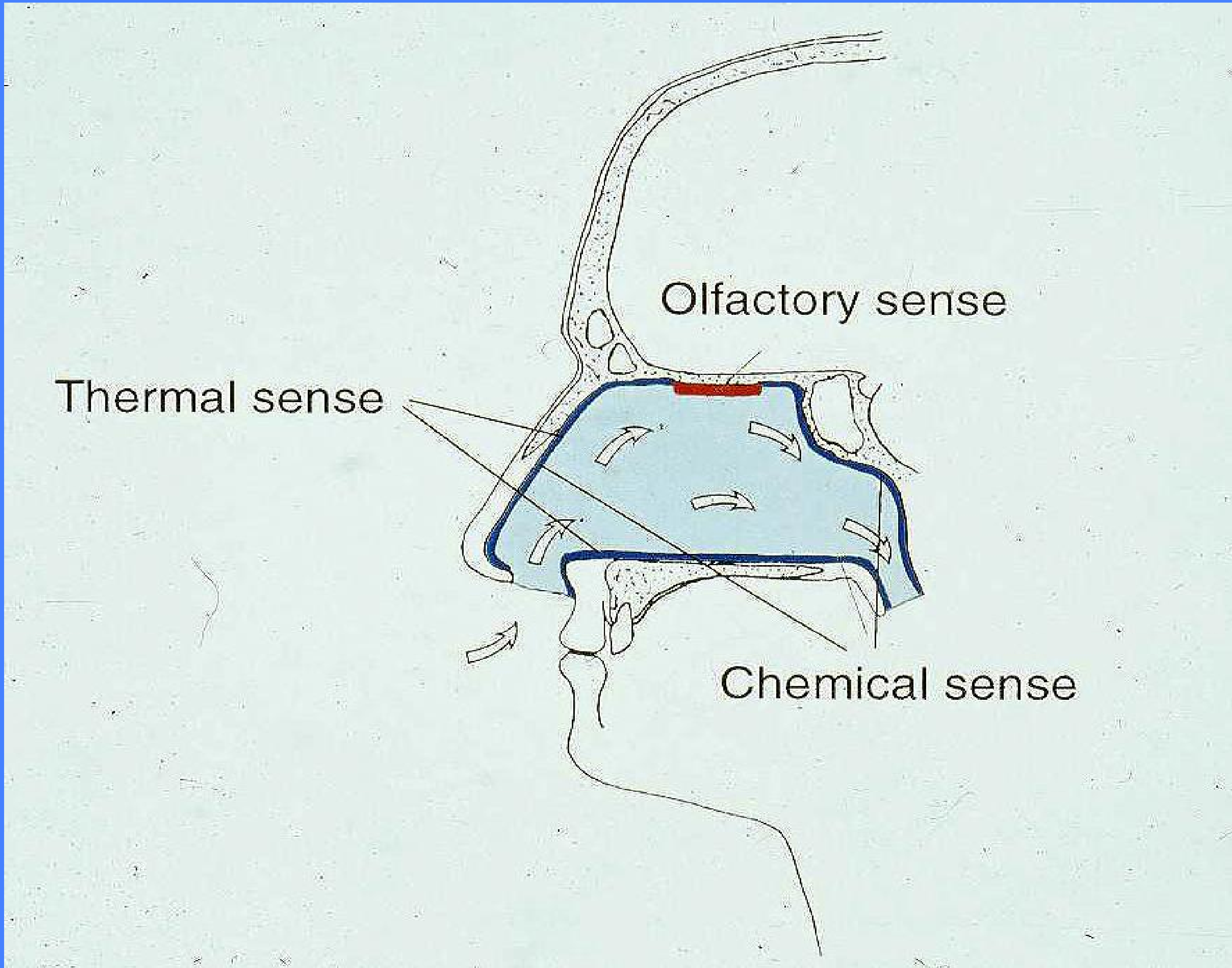
Right: Prevalence and odds ratio for rhinitis among children versus condensation on window pane in a bedroom (source: DBH-study group, in press).

Indoor Pollution Sources

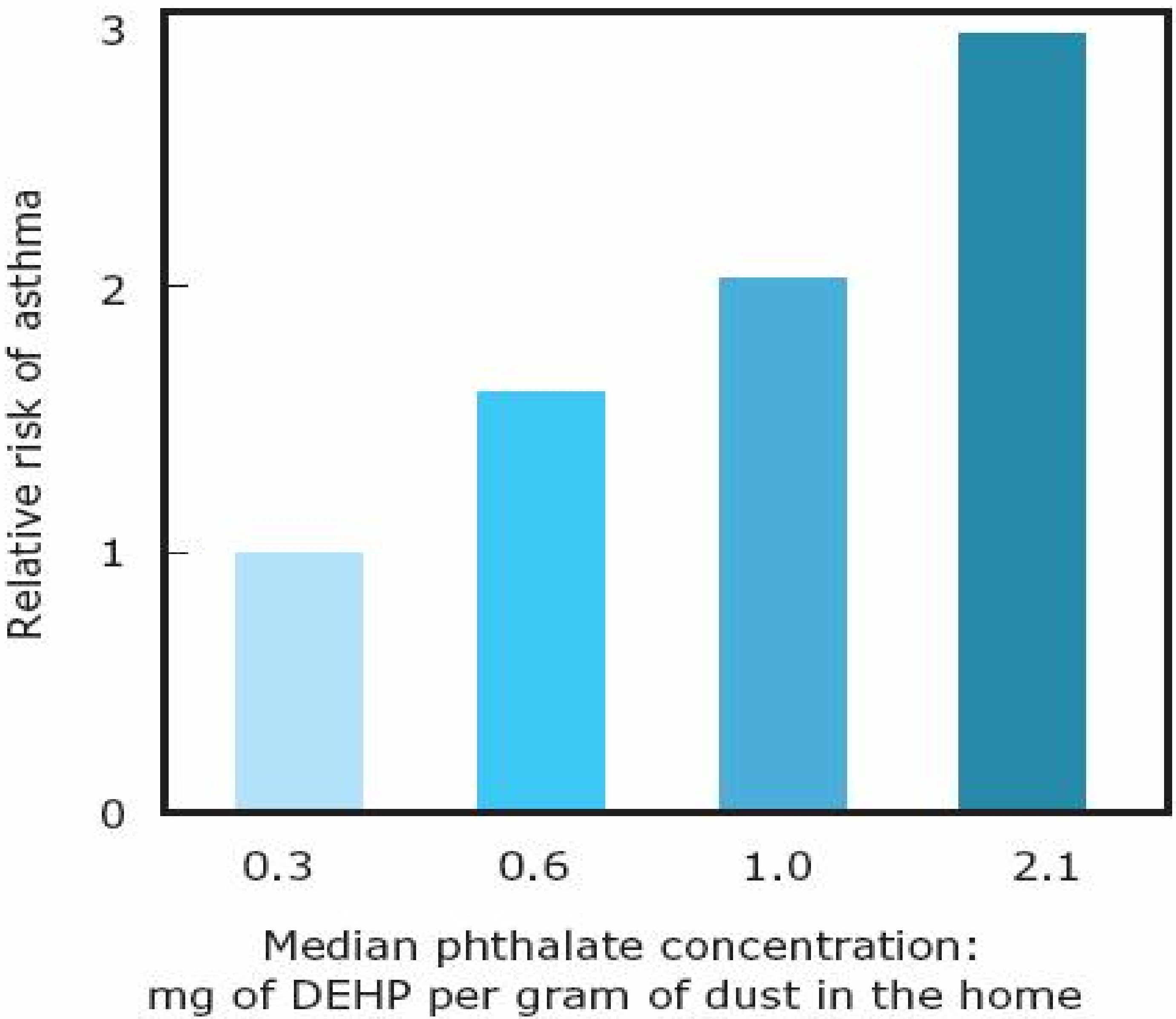


List of 350 common volatile organic compounds in indoor air

folk
HÄLSO
INSTITUTET



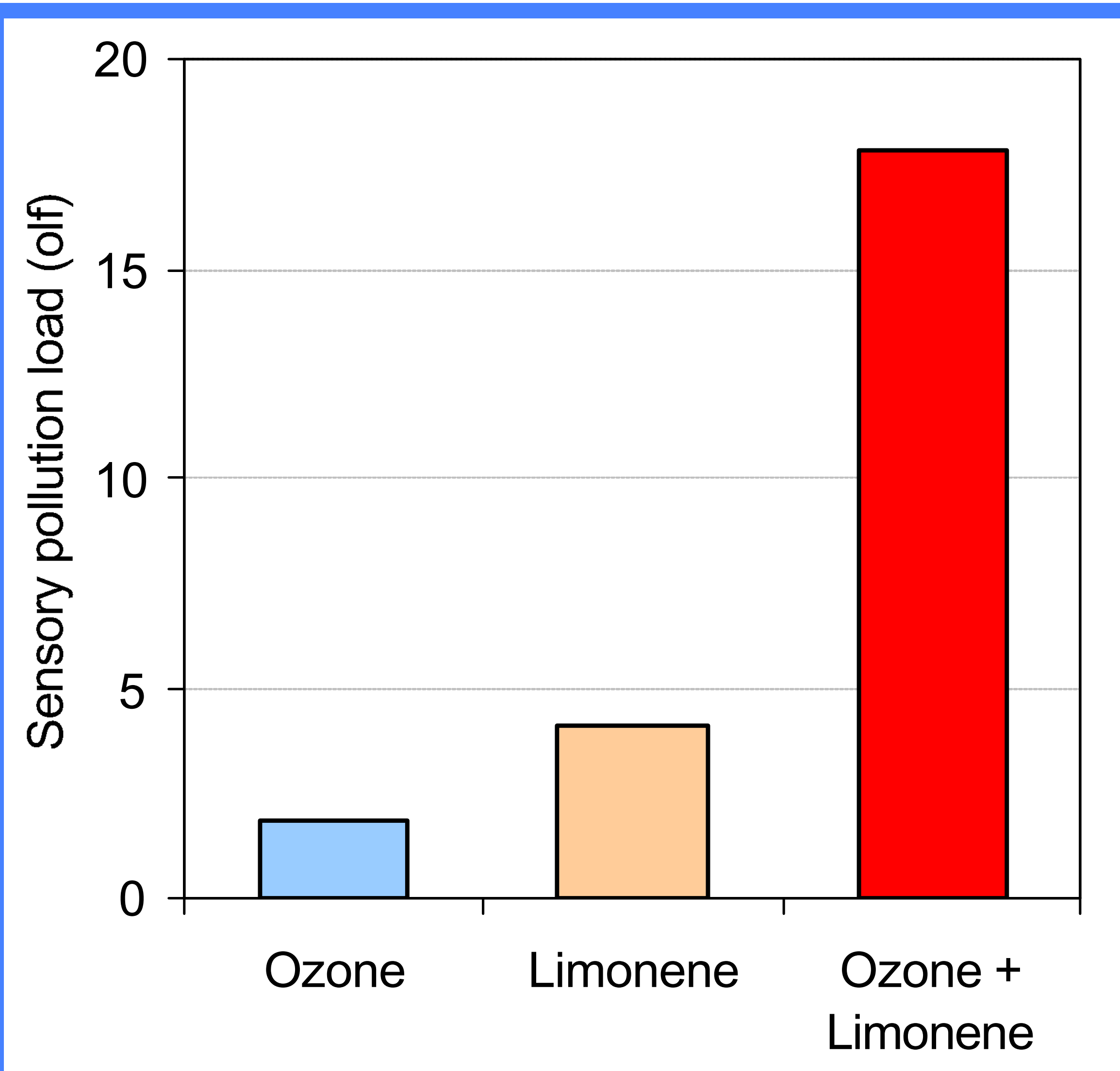
Olfactory sense
Thermal sense
Chemical sense



DEHP: di(2-ethylhexyl) phthalate.

Plasticizers from polyvinyl chloride in dwellings increase the risk of asthma among children.

Each column represents about 90 dwellings.



The sensory pollution load in an office where either ozone (15 ppb) or limonene (83 ppb) were present separately or both ozone and limonene (15 ppb+83 ppb respectively) were mixed in the office air (Tamás et al., 2005); the increased sensory pollution load is due to the presence of reaction products in the office air.

INDOOR ENVIRONMENT-PERFORMANCE

- Self evaluation of productivity-WEP
  - 9-Punkt scale
- WEP = 6.739-0.419E-0.164JD-0.048JS
- E = Dissatisfaction-Environment
- JD = Job satisfaction
- JS = Job stress

PERFORMANCE

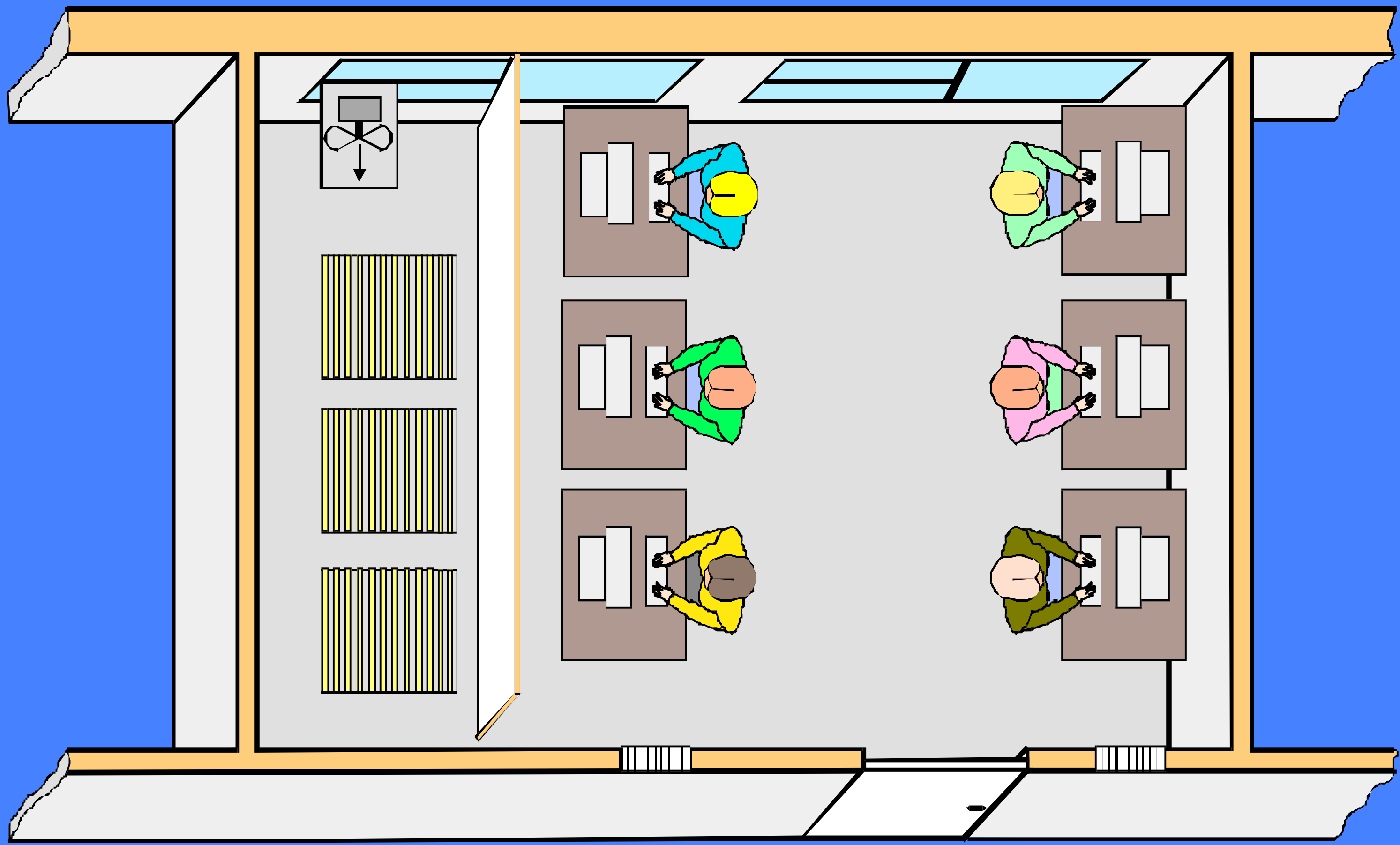
Studies on the relation between the indoor environment and peoples performance

Method

Non-low-polluting building

Low-polluting building

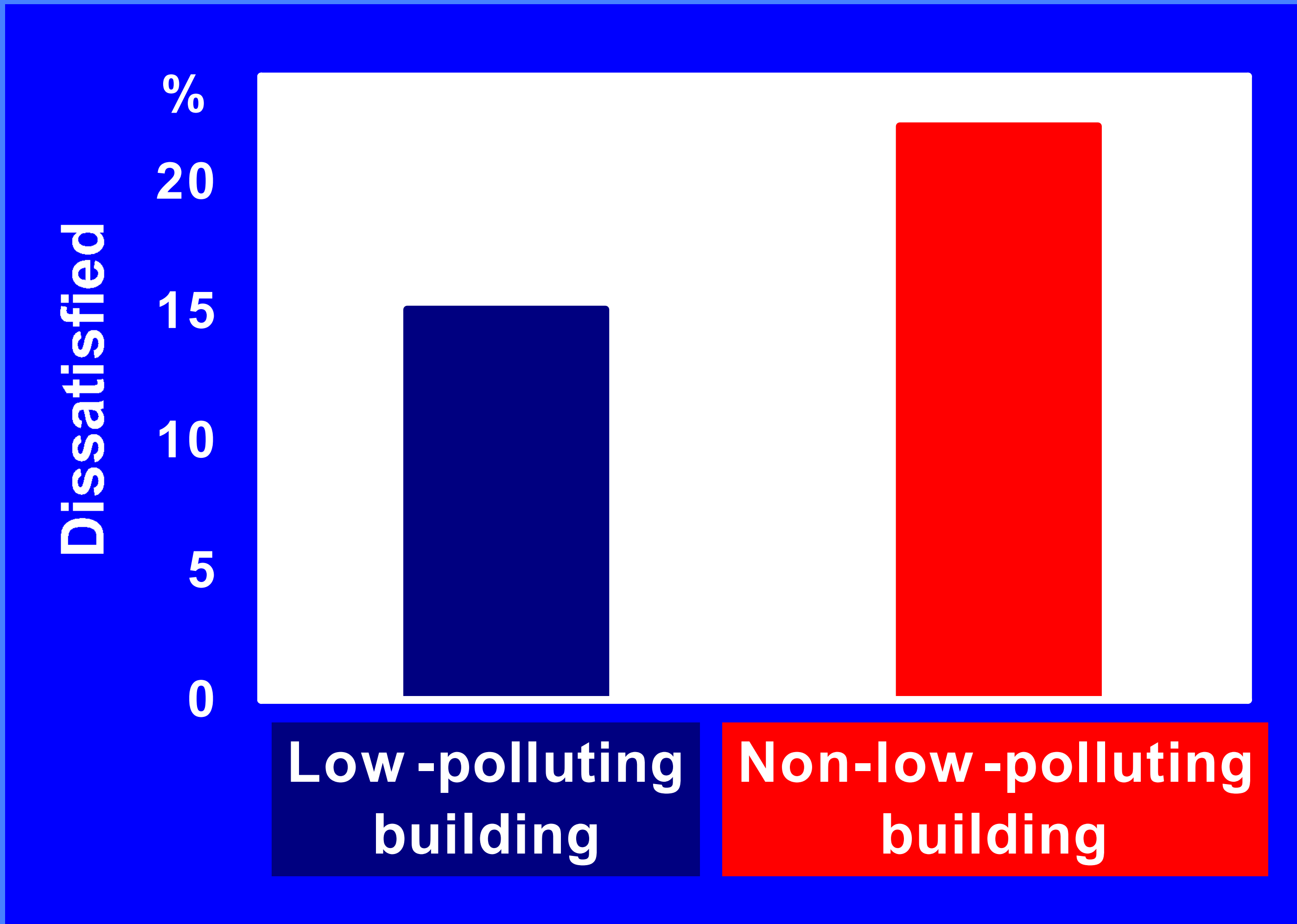
Experimental set-up



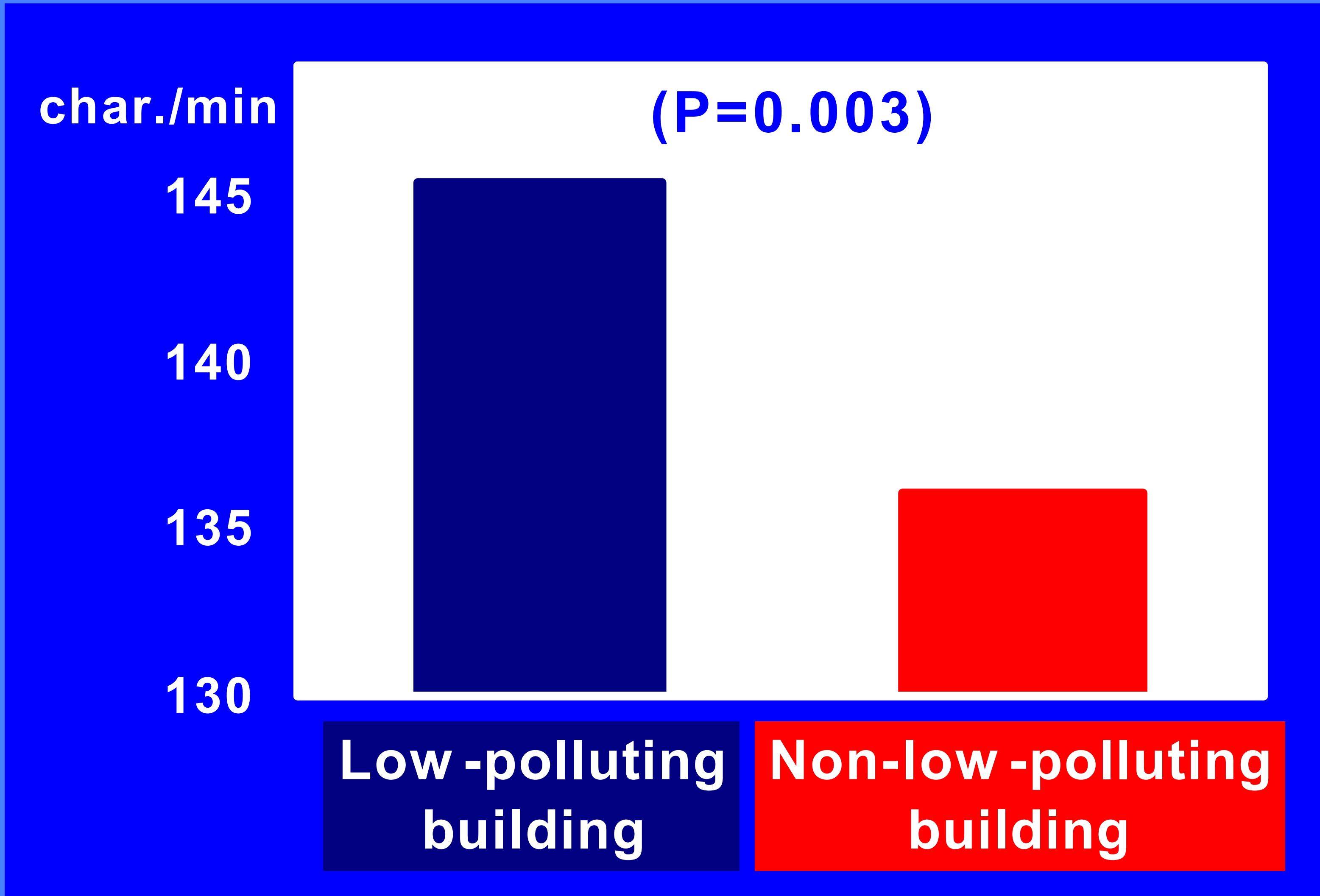
Subjects & procedure

- 30 healthy females
- 20-31 years old
- performed simulated office work during 4.4 hours' occupation of the office:
  - text typing
  - arithmetical calculations
  - creative thinking

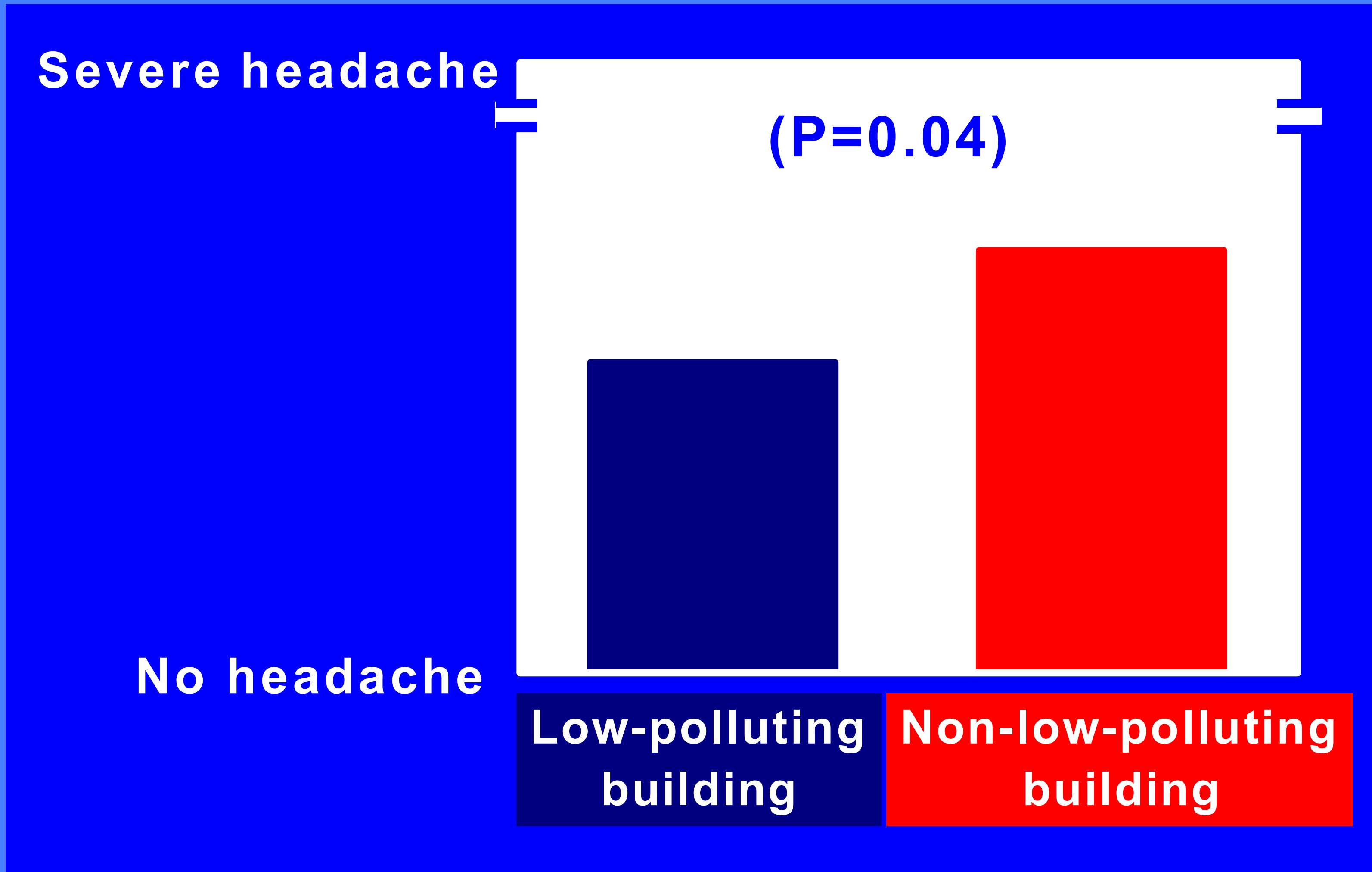
Perceived air quality



Speed of text typing



Headache


Severe headache
(P=0.04)
No headache
Low-polluting building
Non-low-polluting building

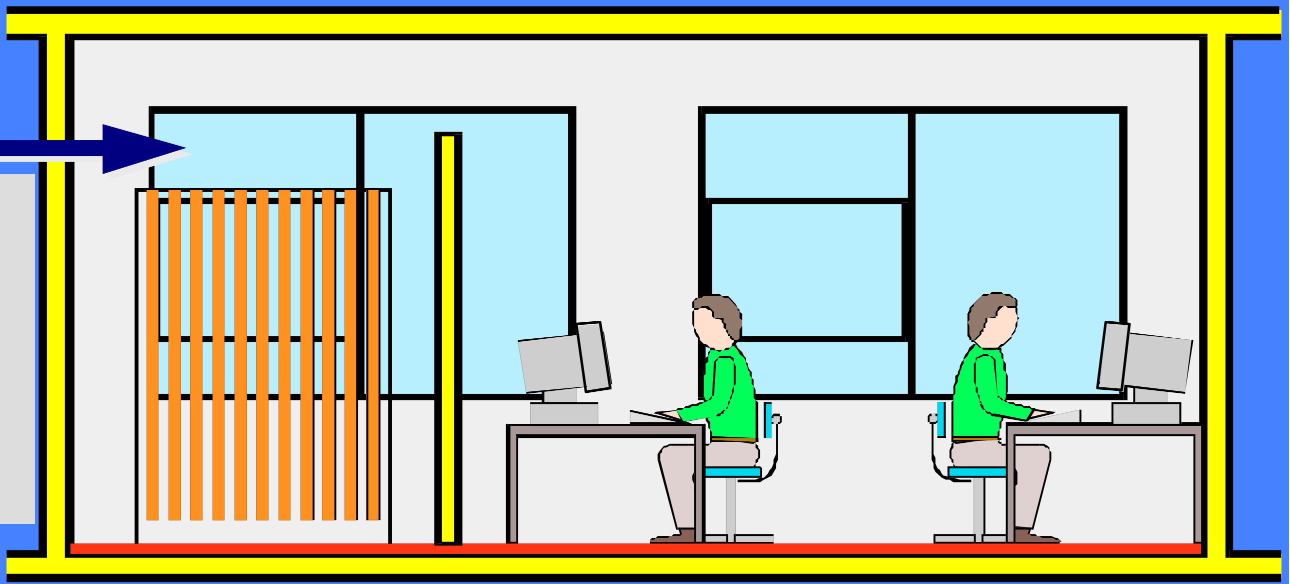
Methods

Outdoor air rates:

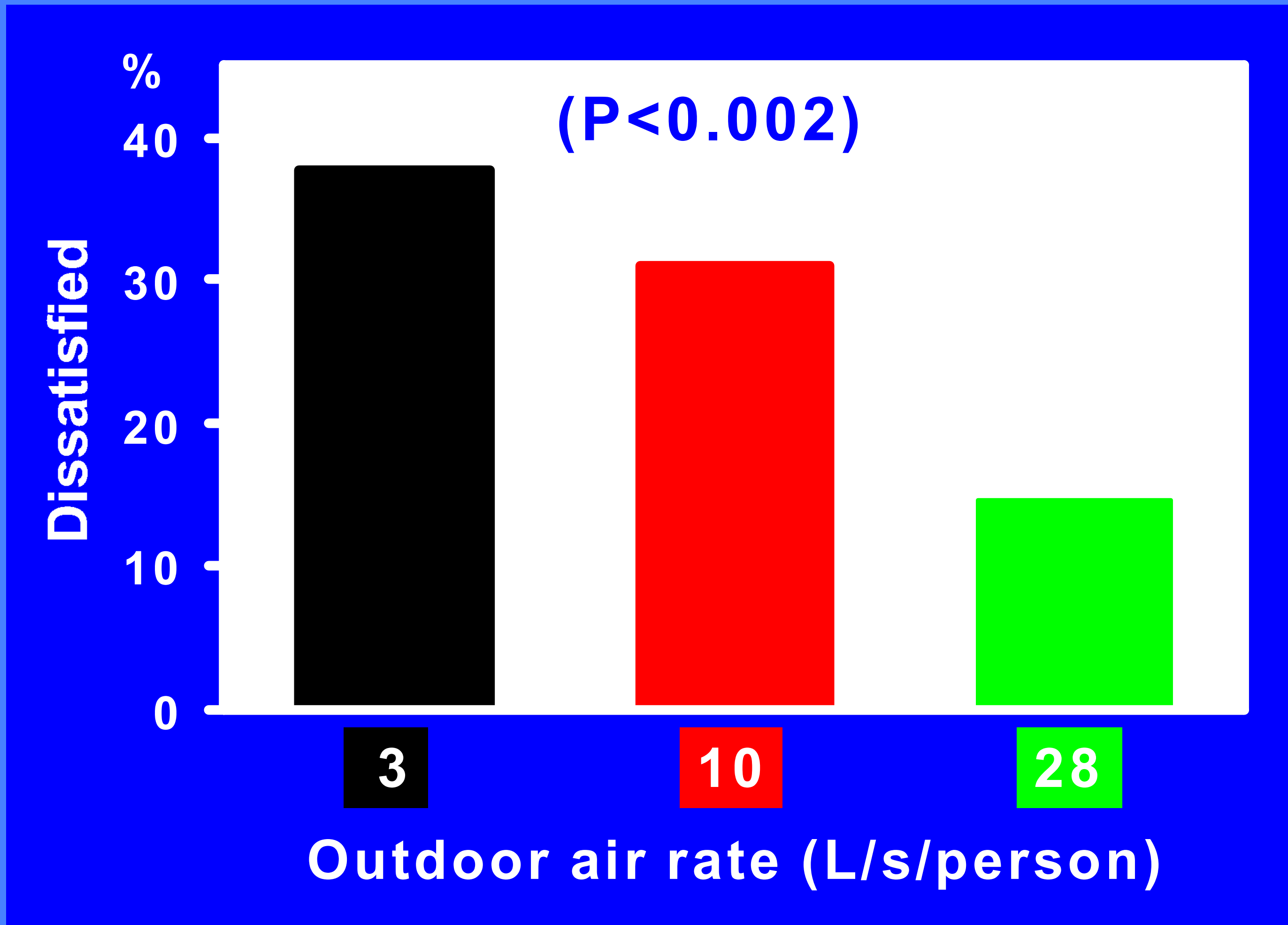
3 L/s/person (0.6 h^{-1})

10 L/s/person (2 h^{-1})

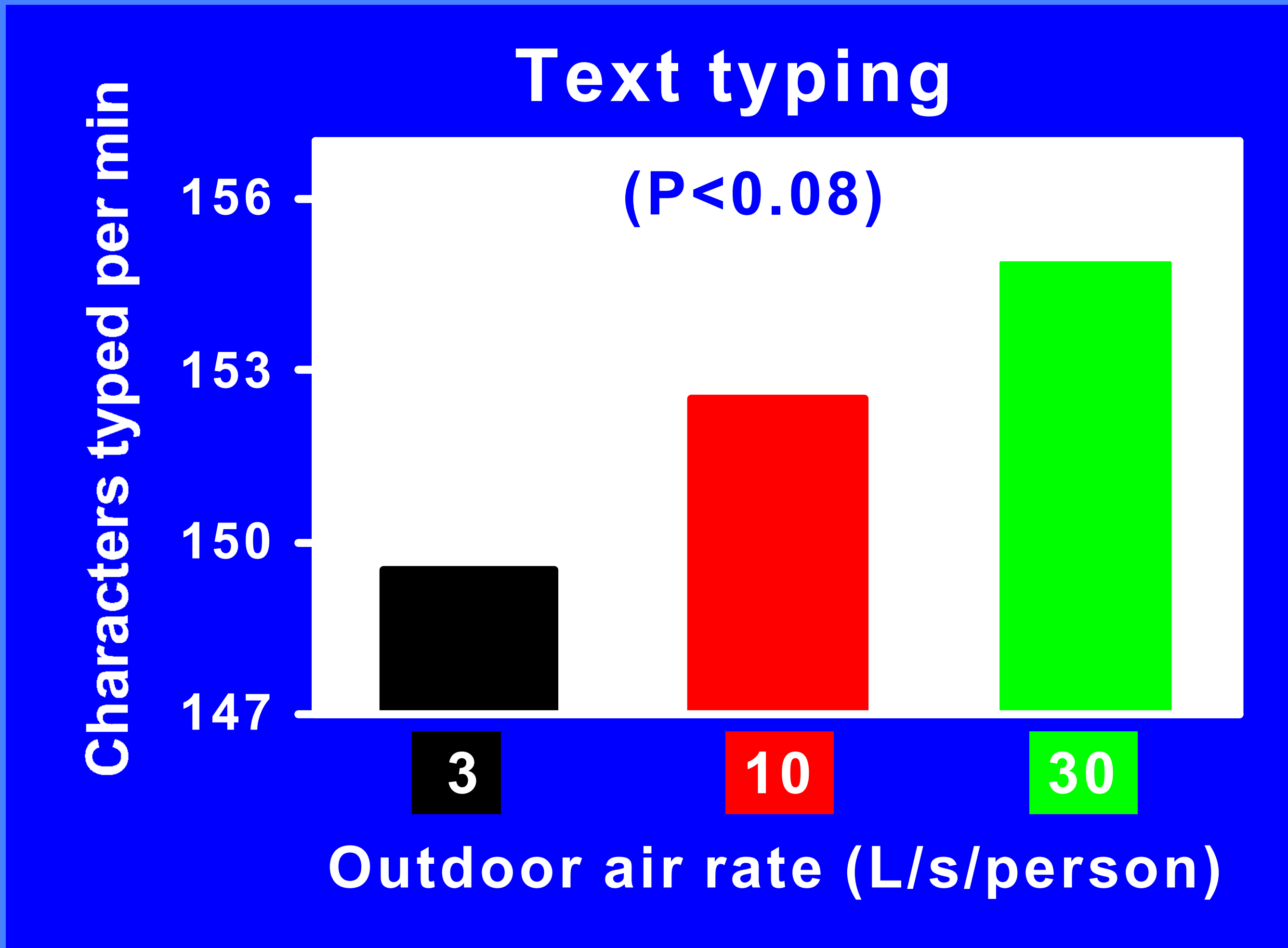
30 L/s/person (6.0 h^{-1})



Perceived air quality



Productivity

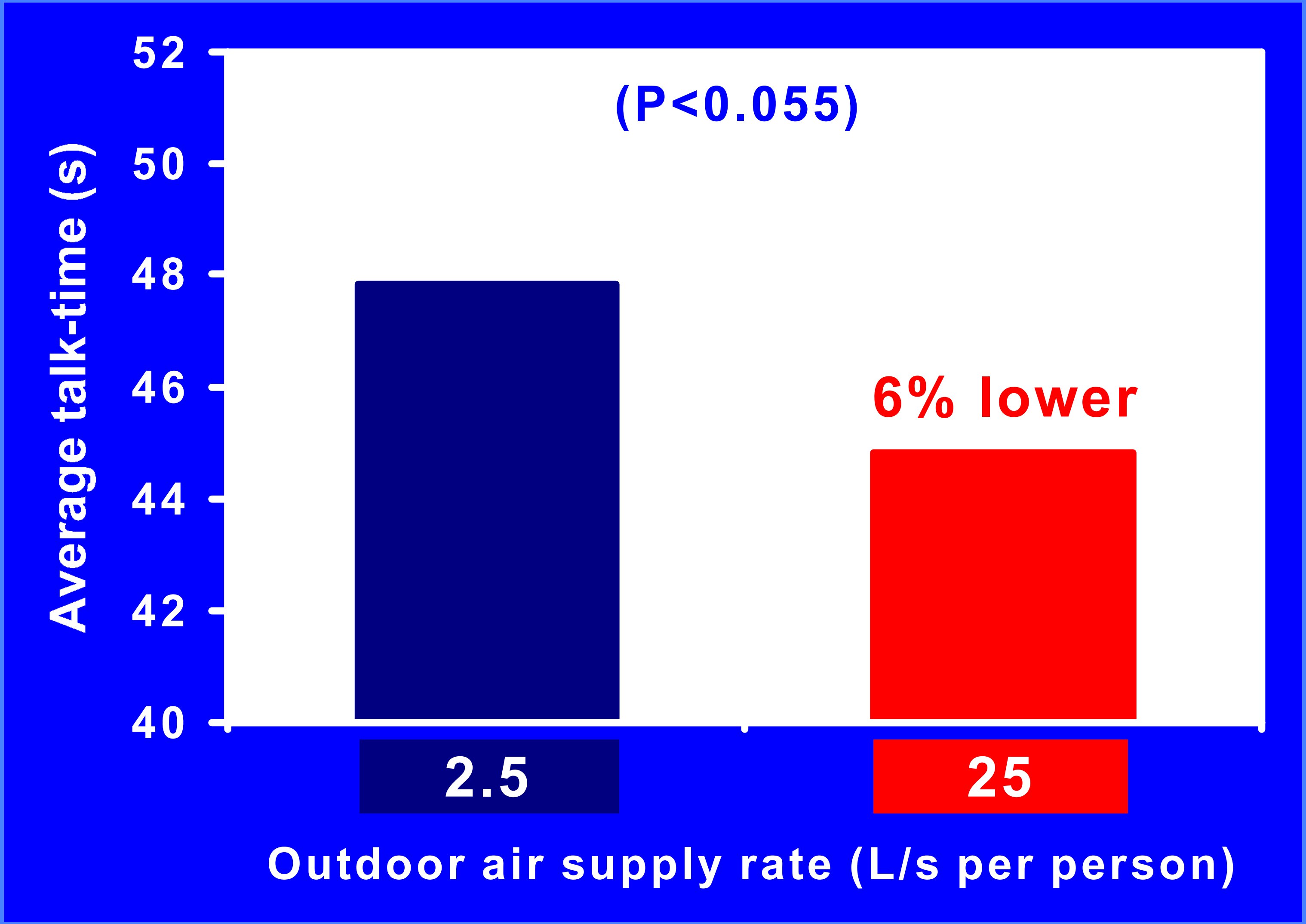


The results of these 3 studies were confirmed in actual workplace: a call-centre

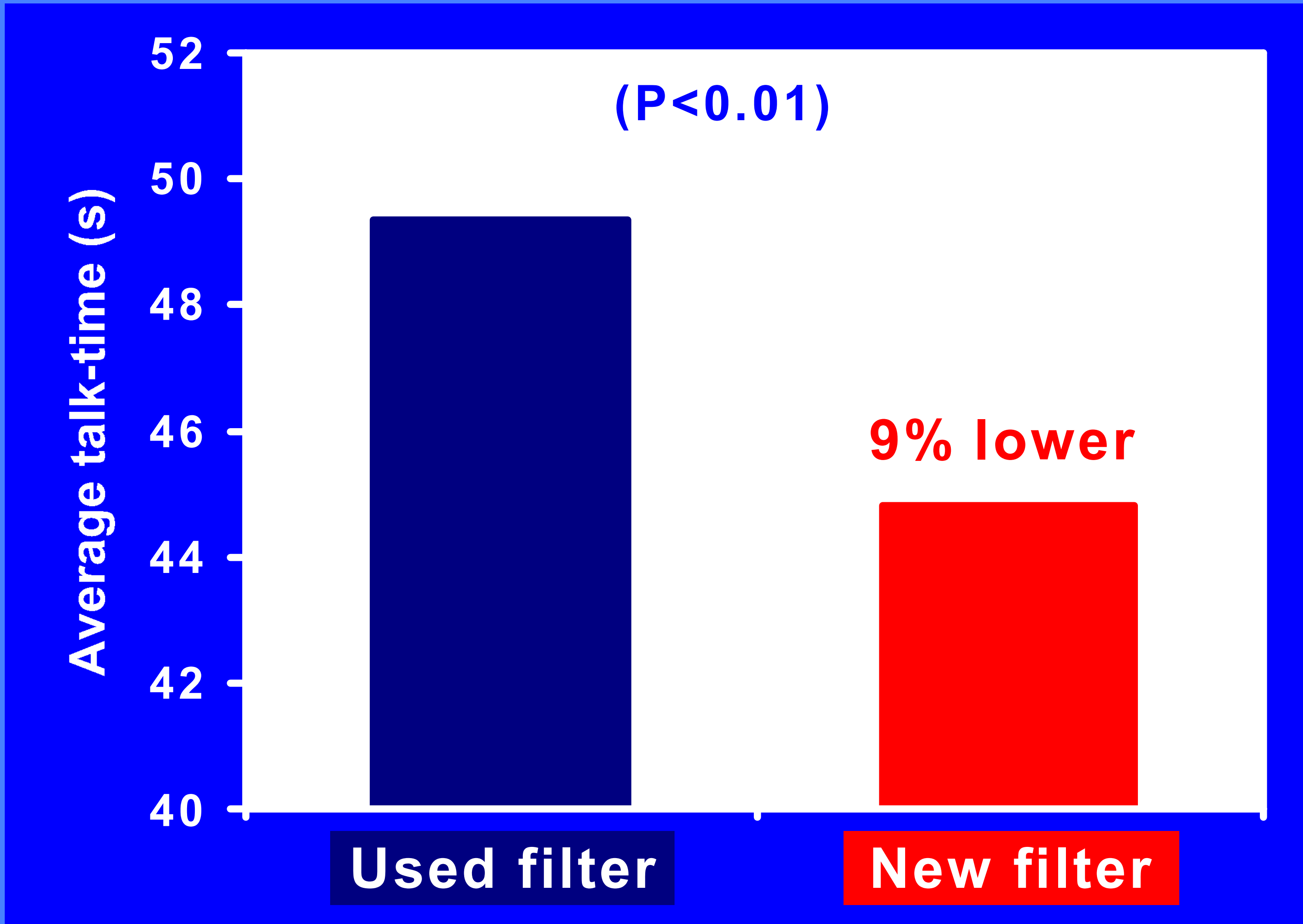
Performance measure

$$\text{Average talk time} = \frac{\text{Talk time}}{\text{Number of calls}}$$

Average talk-time with NEW FILTER

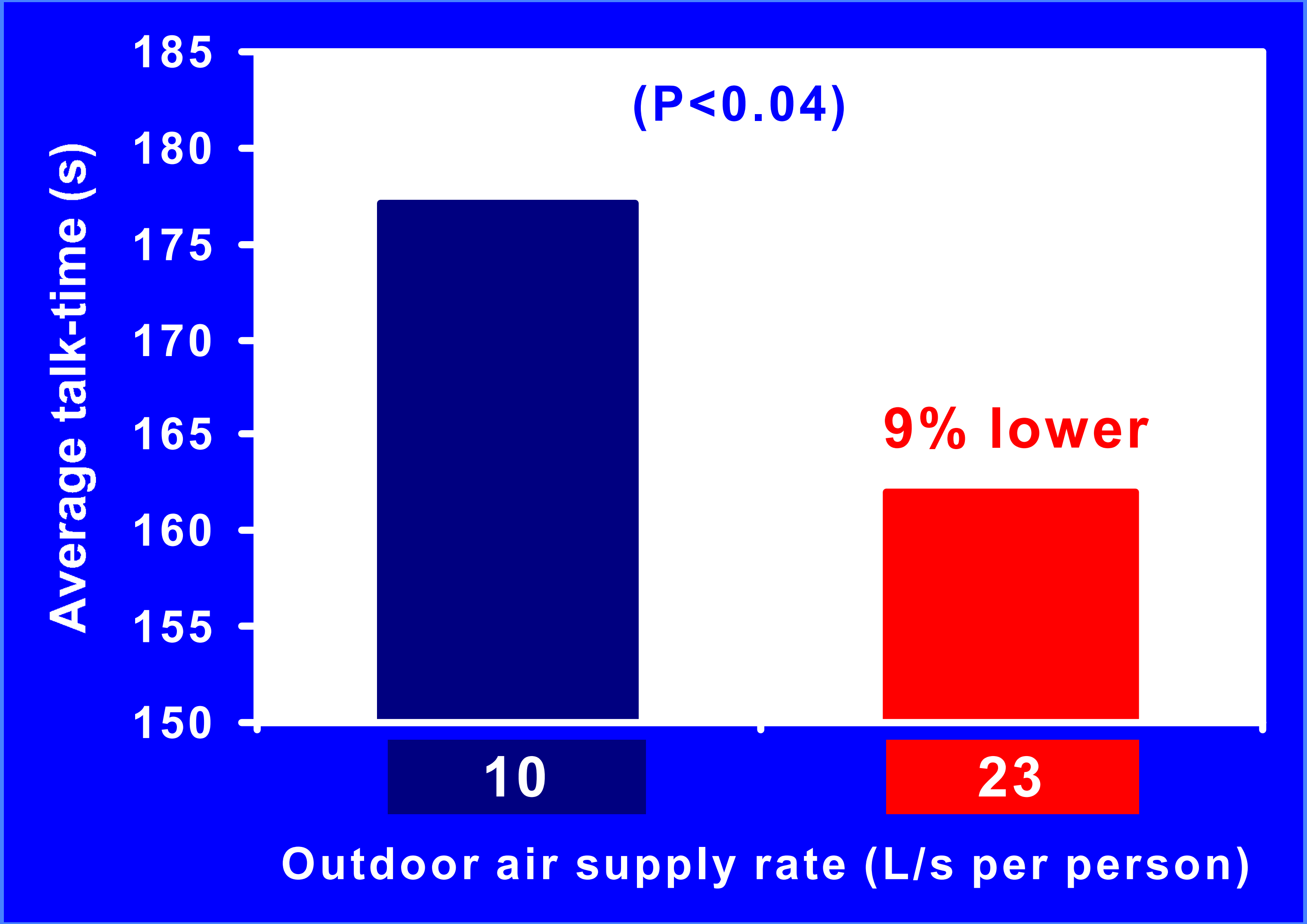


Average talk-time with
HIGH OUTDOOR AIR RATE

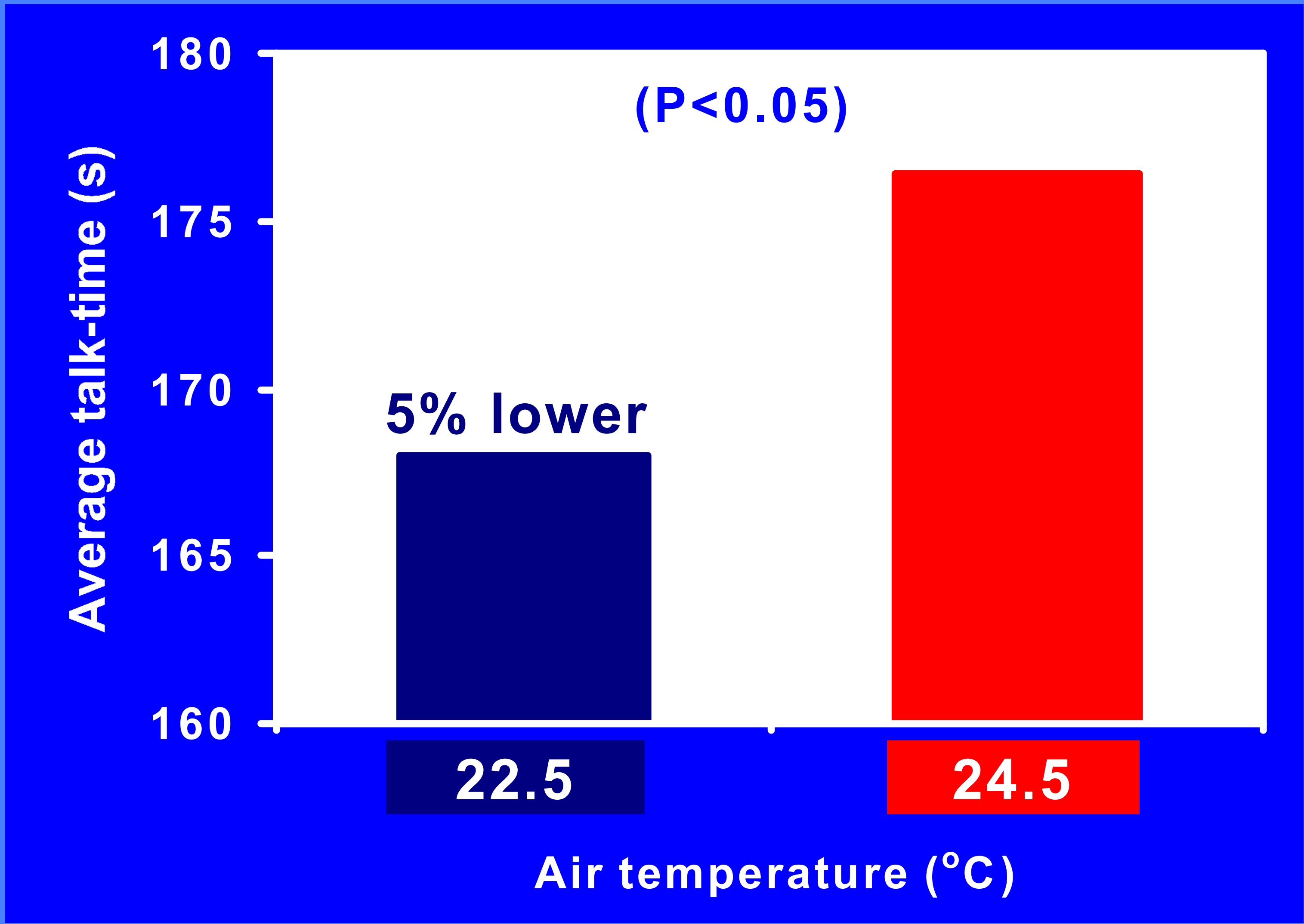


This study has been repeated in another country (Singapore) with similar results

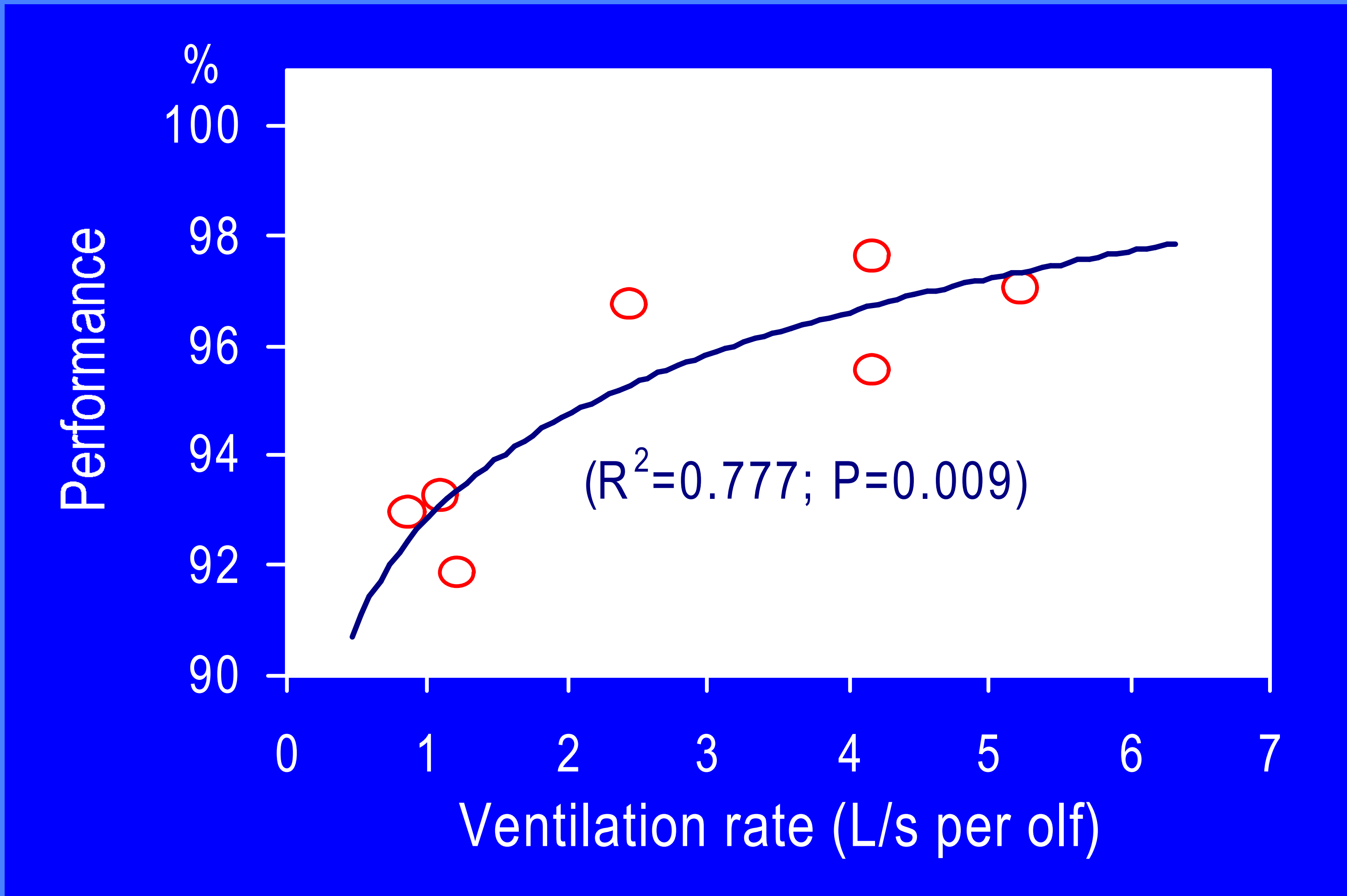
Average talk-time at
AIR TEMPERATURE 24.5ºC



Average talk-time with LOW OUTDOOR AIR RATE



Ventilation vs performance



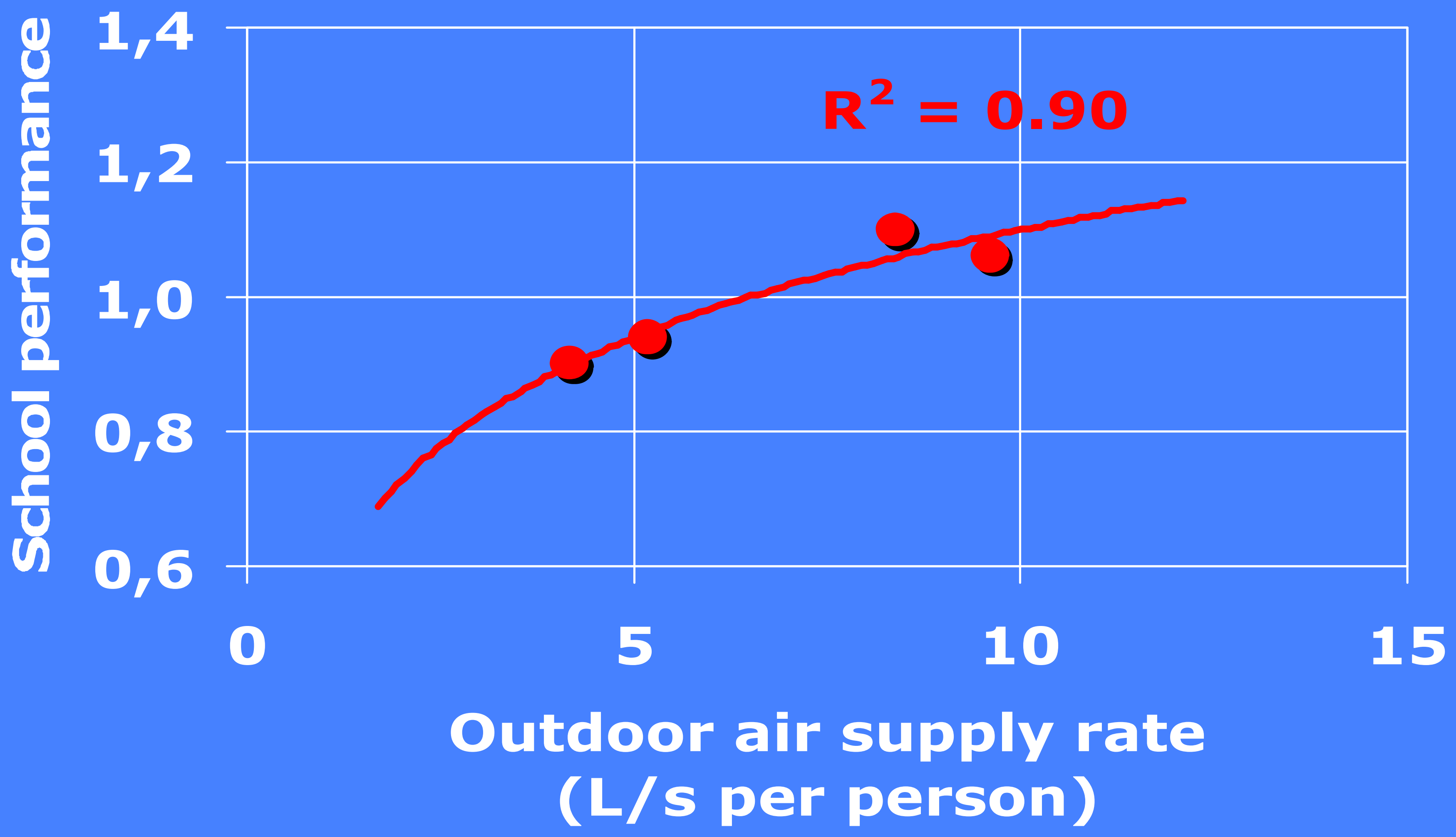
5 elementary schools

1 school in Rungsted (Denmark)

4 schools in Lund (Sweden)

- Children at an age of 10-12 years old (4-6 grade)

School performance and ventilation
Pilot study- ASHRAE project



Concept for calculation of design ventilation rate

People Component

Building Component

Breathing Zone Outdoor Airflow

$$V_{bz} = R_p P_z + R_s S_d + R_a A_z$$

Minimum l/s/Person

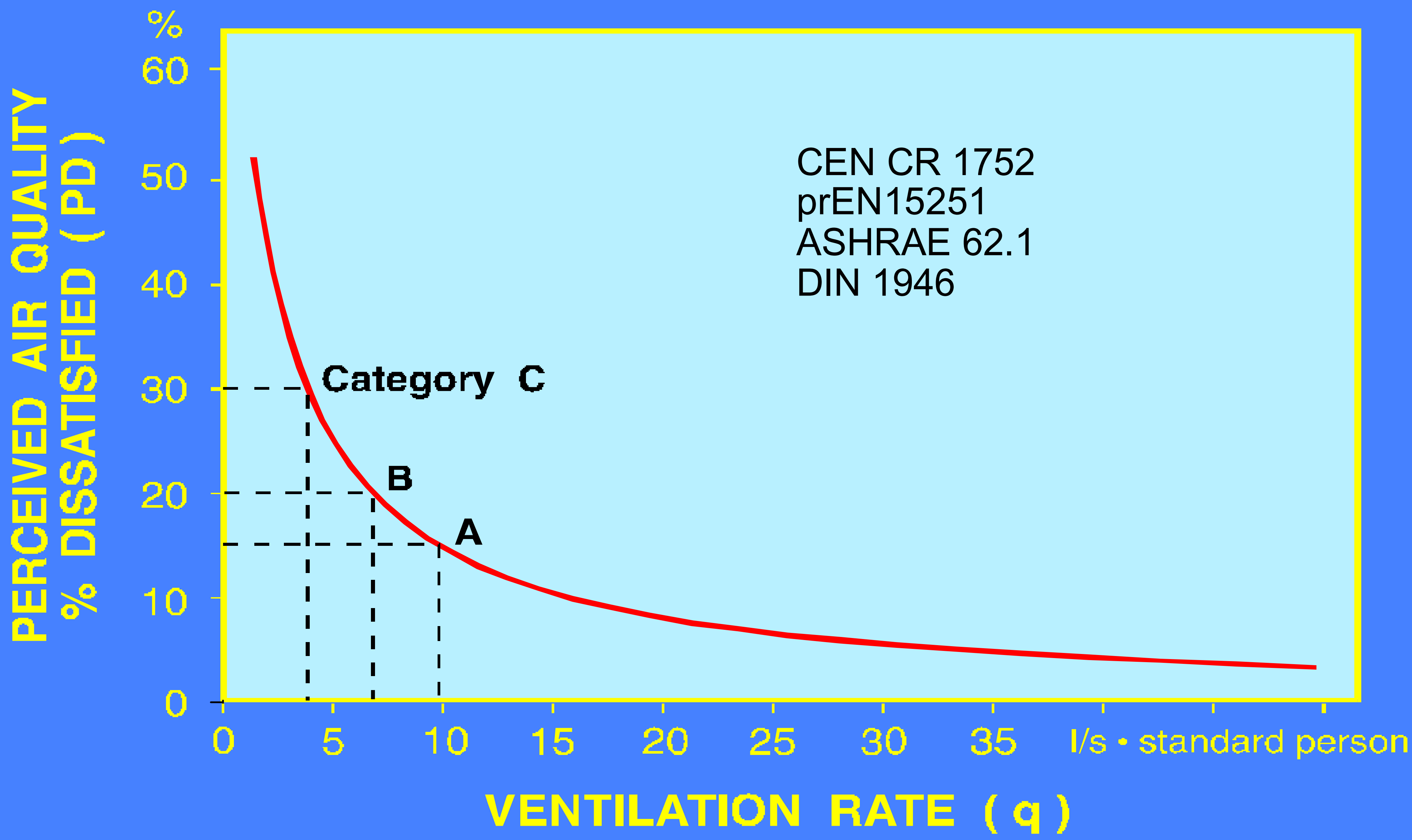
Number of People

Ventilation per Smoker

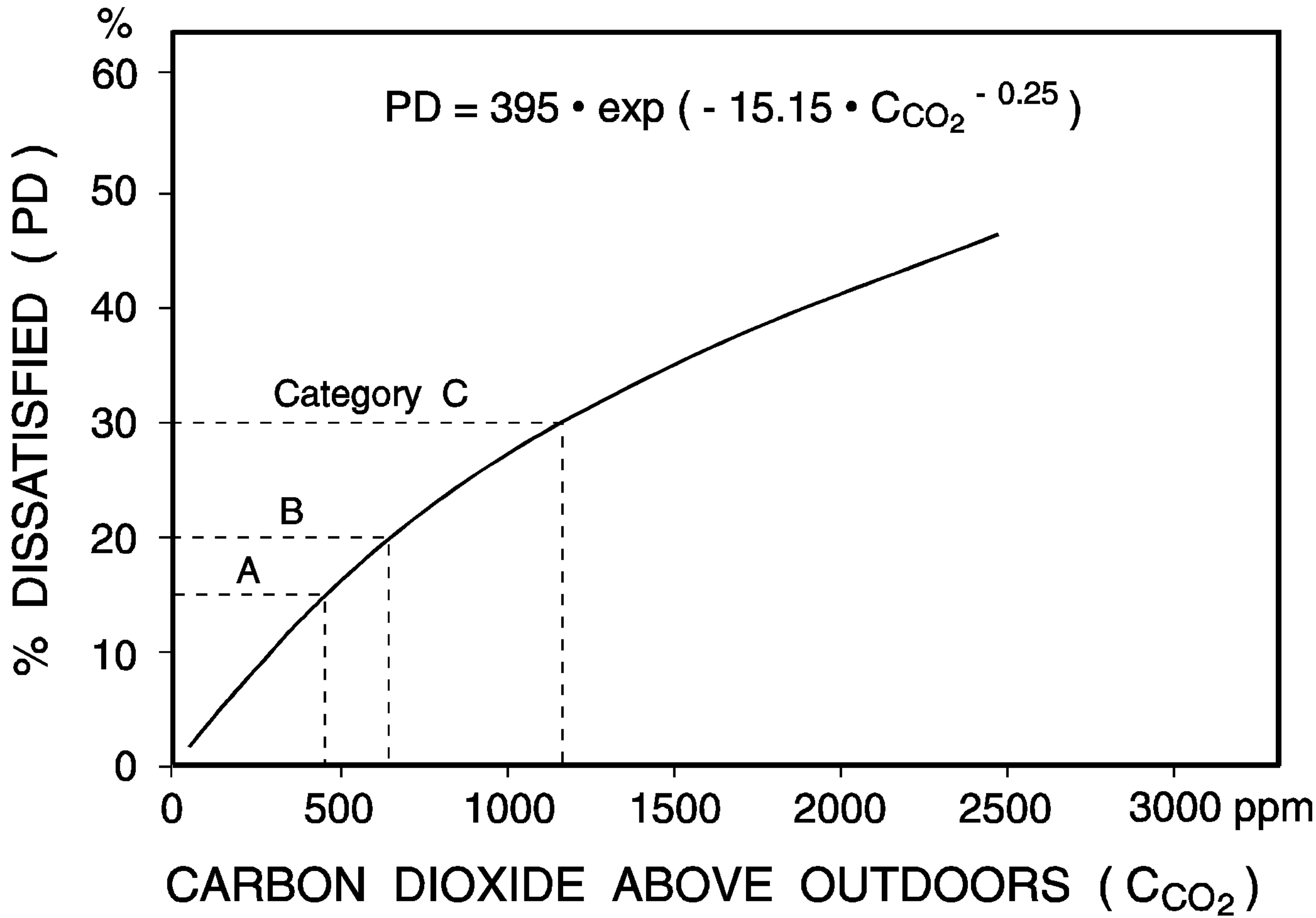
Number of Smokers

Building Area

Minimum l/s/m²


PERCEIVED AIR QUALITY
% DISSATISFIED (PD)
%
60
50
40
30
20
10
0
CEN CR 1752
prEN15251
ASHRAE 62.1
DIN 1946
Category C
B
A
0
5
10
15
20
25
30
35
l/s • standard person
VENTILATION RATE (q)

CO2 as reference



Generation of pollution from occupants

	Sensory pollution load olf/ occupant	Carbon dioxide l/(h· occupant)	Carbon monoxide [1] l/(h· occupant)	Water vapour [2] g/(h· occupant)
Sedentary, 1-1.2 met				
0% smokers	1	19		50
20% smokers [3]	2	19	$11 \cdot 10^{-3}$	50
40% smokers [3]	3	19	$21 \cdot 10^{-3}$	50
Physical exercise				
Low level, 3 met	4	50		200
Medium level, 6 met	10	100		430
high level (athletes), 10 met	20	170		750
Children				
Kindergarten, 3-6 years, 2,7 met	1,2	18		90
School, 14-16 years, 1-1,2 met	1,3	19		50

[1] from tobacco smoking

[2] applies for persons close to thermal neutrality

[3] average smoking rate 1,2 cigarettes/hour per smoker, emission rate 44 ml CO/cigarette

POLLUTANT FROM BUILDING, FURNISHING AND SYSTEM	Sensory pollution load olf/m²	
	Average	Range
Existing buildings		
Offices [a)]	0,3 [d)]	0,02-0,95
Offices [b)]	0,6 [c)]	0 - 3
Class rooms [a)]	0,3	0,12-0,54
Kindergarten [a)]	0,4	0,20-0,74
Auditorium [a)]	0.3 [d)]	0,13-1,32
New buildings (No-smoking)		
Low polluting buildings	0,1	
Not-low polluting buildings	0,2	
Very low polluting buildings	0.02	

[a)] Data from more than 40 mechanical ventilated buildings in Denmark.

[b)] Data from an European Audit program, 1992-1995.

[c)] Includes pollutant load from smokers

[d)] Includes pollutant from earlier smoking.

Type of building/ space	Occupancy person/m²	Category CEN	Occupants only l/s person		Additional ventilation for building (add only one) l/s·m²			Total l/s·m²	
			ASHRAE Rp	CEN	CEN low-polluting building	CEN *Non*-low-polluting building	ASHRAE Ra	CEN Low Pol.	ASHRAE
Single office (cellular office)	0,1	A	2,5	10	1,0	2,0	0,3	2	0,55
		B		7	0,7	1,4		1,4	
		C		4	0,4	0,8		0,8	
Landscaped office	0,07	A	2,5	10	1,0	2,0	0,3	1,7	0,48
		B		7	0,7	1,4		1,2	
		C		4	0,4	0,8		0,7	
Conference room	0,5	A	2,5	10	1,0	2,0	0,3	6	1,55
		B		7	0,7	1,4		4,2	
		C		4	0,4	0,8		2,4	

1 l/s m² = 0.2 cfm/ft²

MODERATE THERMAL ENVIRONMENT

- ISO EN 7730-2005
  - Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort effects.
- ASHRAE 55-2004
  - Thermal environment conditions for human occupancy
- CR 1752
  - Ventilation of buildings-Design criteria for the indoor environment
- prEN15251 (European Energy Performance of Buildings Directive)
  - Criteria for the indoor environmental quality
- EN 13779
  - Ventilation for non-residential buildings - performance requirements for ventilation and room-conditioning systems
- TC204WG5 Building Environmental Design
  - Thermal Environment

MODERATE ENVIRONMENTS

- GENERAL THERMAL COMFORT
  - PMV / PPD, OPERATIVE TEMPERATURE
- LOCAL THERMAL DISCOMFORT
  - Radiant temperature asymmetry
  - Draught
  - Vertical air temperature difference
  - Floor surface temperature

GENERAL THERMAL COMFORT

- Personal factors
  - Clothing
  - Activity
- Environmental factors
  - Air temperature
  - Mean radiant temperature
  - Air velocity
  - Humidity

PMV-index

$$PMV = \left(0{,}303e^{-0{,}036M} + 0{,}028\right)\begin{bmatrix}(M-W) - 3{,}05\cdot 10^{-3}\{5733 - 6{,}99(M-W) - p_a\} - 0{,}42\{(M-W) - 58{,}15\} \\ -1{,}7\cdot 10^{-5}M(5867 - p_a) - 0{,}0014M(34 - t_a) \\ -3{,}96\cdot 10^{-8} f_{cl}\left\{(t_{cl}+273)^4 - (\bar{t}_r + 273)^4\right\} - f_{cl}h_c(t_{cl} - t_a)\end{bmatrix}$$

where

$$t_{cl} = 35{,}7 - 0{,}028(M-W) - I_{cl}\left[3{,}96\cdot 10^{-8} f_{cl}\left\{(t_{cl}+273)^4 - (\bar{t}_r+273)^4 + f_{cl}h_{cl}(t_{cl} - t_a)\right\}\right]$$

$$h_c = 2{,}38(t_{cl} - t_a)^{0,25} \quad \text{for} \quad 2{,}38(t_{cl} - t_a)^{0,25} > 12{,}1\sqrt{v_{ar}}$$

$$= 12{,}1\sqrt{v_{ar}} \quad \text{for} \quad 2{,}38(t_{cl} - t_a)^{0,25} < 12{,}1\sqrt{v_{ar}}$$

$$f_{cl} = 1{,}00 + 1{,}290 I_{cl} \quad \text{for} \quad I_{cl} < 0{,}078 m^2\cdot KW^{-1}$$

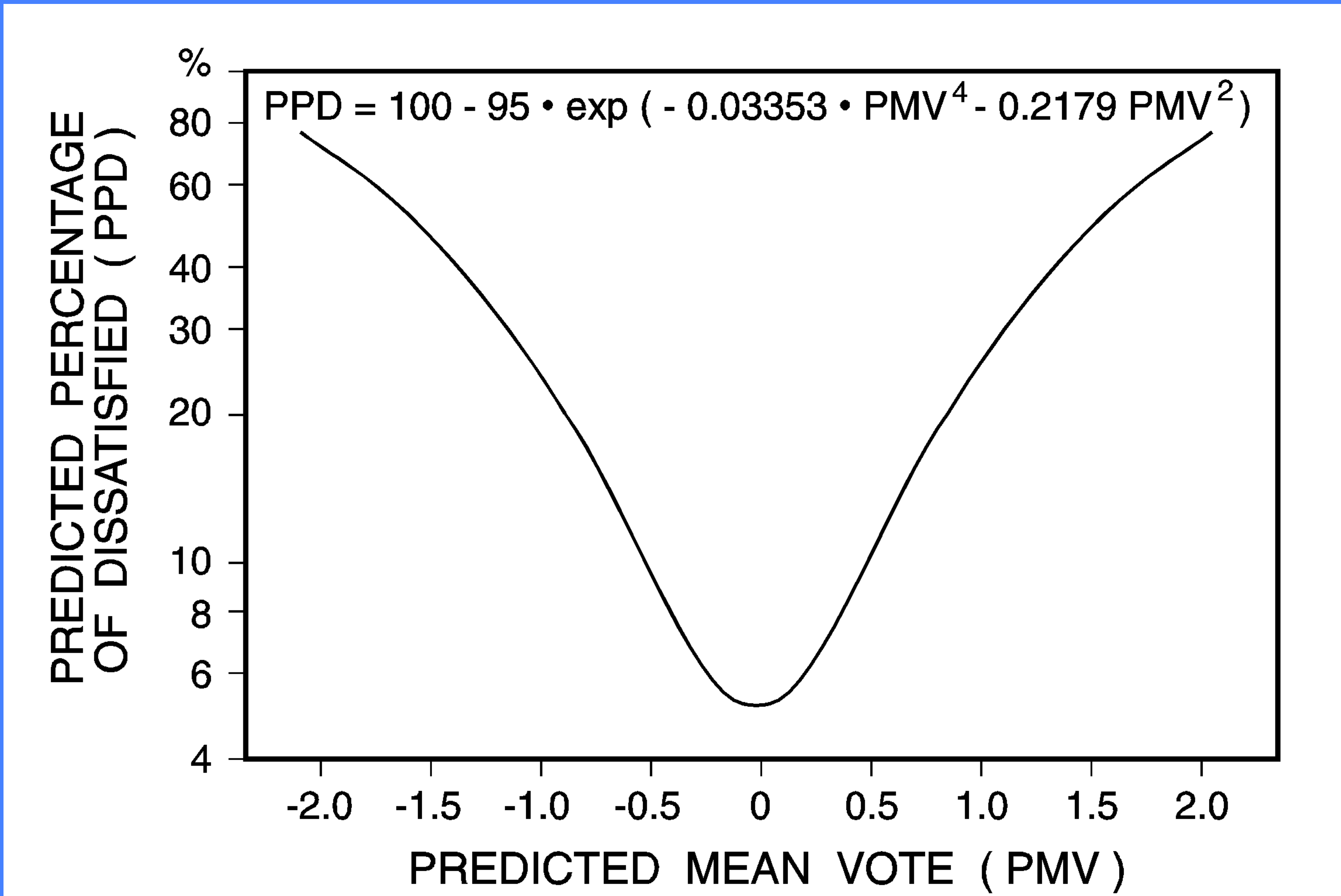
$$= 1{,}05 + 0{,}545 I_{cl} \ \ldots \quad \text{for} \quad I_{cl} > 0{,}078 m^2\cdot KW^{-1}$$

PMV	=	Predicted Mean Vote
M	=	Metabolic rate Wm^{-2}
W	=	Effective mechanical power Wm^{-2}
I_{cl}	=	Clothing insulation $(1clo = 0{,}155 m^2 KW^{-1})$
f_{cl}	=	Clothing area factor
t_a	=	Air temperature, °C
$\bar{t}_r$	=	Mean radiant temperature, °C
v_{ar}	=	Relative air velocity, ms^{-1}
p_a	=	Water vapour particle pressure, P_a
h_c	=	Convective heat transfer coefficient, $W\cdot m^{-2}K^{-1}$
t_{cl}	=	Clothing surface temperature, °C

PMV-index

-3	Cold
-2	Cool
-1	Slightly cool
0	Neutral
+1	Slightly warm
+2	Warm
+3	Hot

GENERAL THERMAL COMFORT




0,5 clo
2,2 met
21°C


0,8 clo
1,6 met
21°C


1 clo
1,6 met
20°C

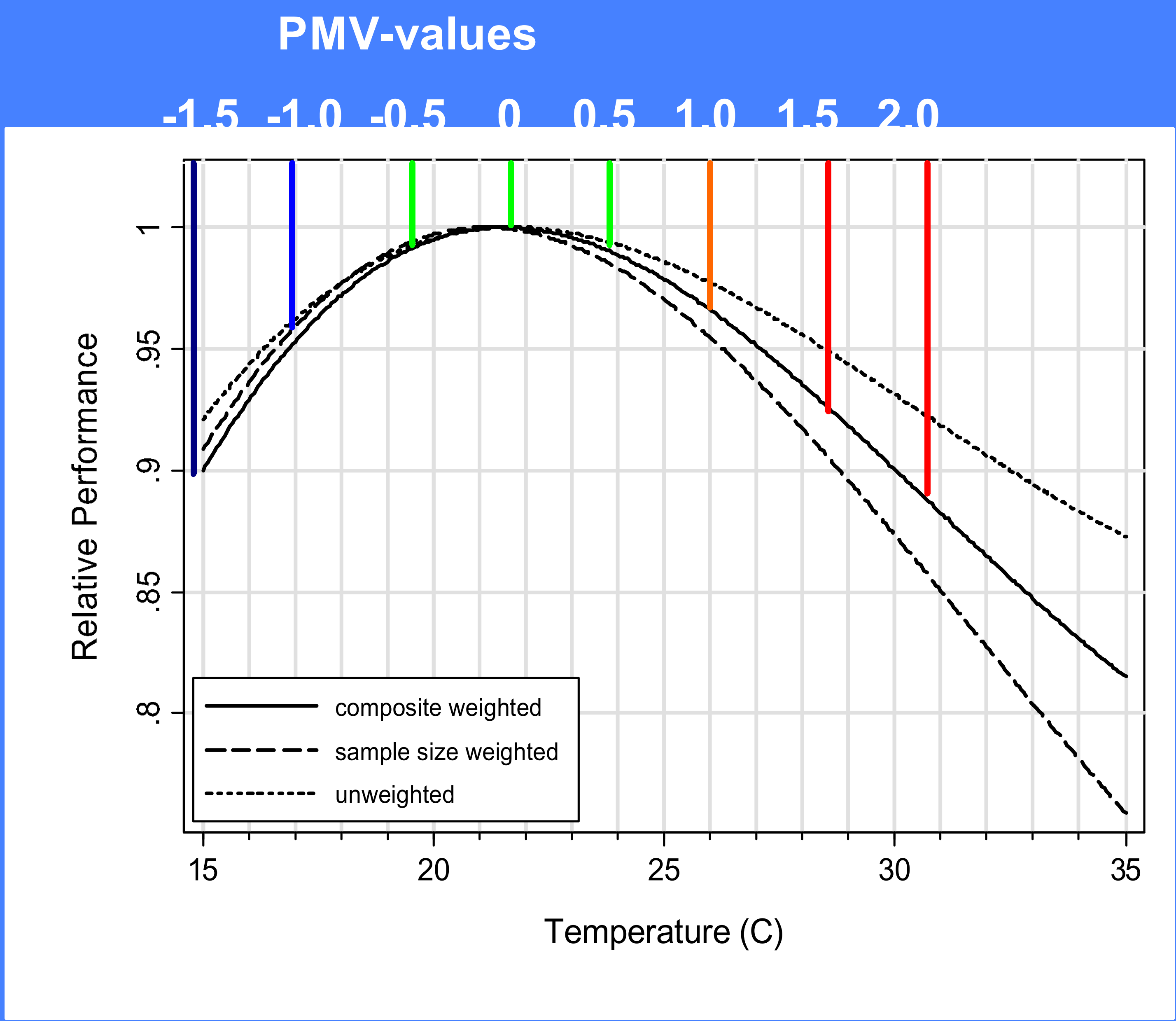

0,8 clo
1,6 met
21°C

GENERAL THERMAL COMFORT

Category	***Thermal state of the body as a whole***	
	PPD %	Predicted Mean Vote
A	< 6	-0.2 < PMV < + 0.2
B	< 10	-0.5 < PMV < + 0.5
C	< 15	0.7 < PMV < + 0.7

THERMAL COMFORT

- OPERATIVE TEMPERATURE
- -0,5 < PMV < +0,5 ; PPD < 10 %
- SPACES WITH MAINLY SEDENTARY OCCUPANTS :
  - SUMMER CLOTHING 0,5 clo
  - ACTIVITY LEVEL 1,2 met
- 23 °C < t_o < 26 °C.



from Seppänen and Fisk 2005a

PMV-value	PPD-Value %	Reduction in performance %	Summer 1.2 met 0.5 clo °C	Summer 1.6 met 0.5 clo °C	Winter 1.2 met 1.0 clo °C	Winter 1.6 met 1.0 clo °C
+2.0	75	12	*31.0*	*30.5*	*30.9*	*30.5*
+1.5	50	7	29.5	28.4	28.7	27.7
+1.0	25	3	27.8	26.2	26.4	24.6
+0.5	10	1	26.0	24.0	24.0	21.5
0	5	0	24.5	21.8	22.0	18.5
-0.5	10	1	23.0	19.7	19.6	15.2
-1.0	25	3	21.2	17.5	17.1	12.1
-1.5	50	10	19.6	15.3	15.0	
-2.0	75		*18.0*	*13.1*	*12.5*	

PERSONAL CONTROL

Garment Description	Thermal Insulation clo	Change of Operative Temp. K
Sleeveless vest	**0,12**	**0,8**
Thin sweater	**0,20**	**1,3**
Light jacket	**0,25**	**1,6**
Normal jacket	**0,35**	**2,2**

Thermal Comfort- Performance

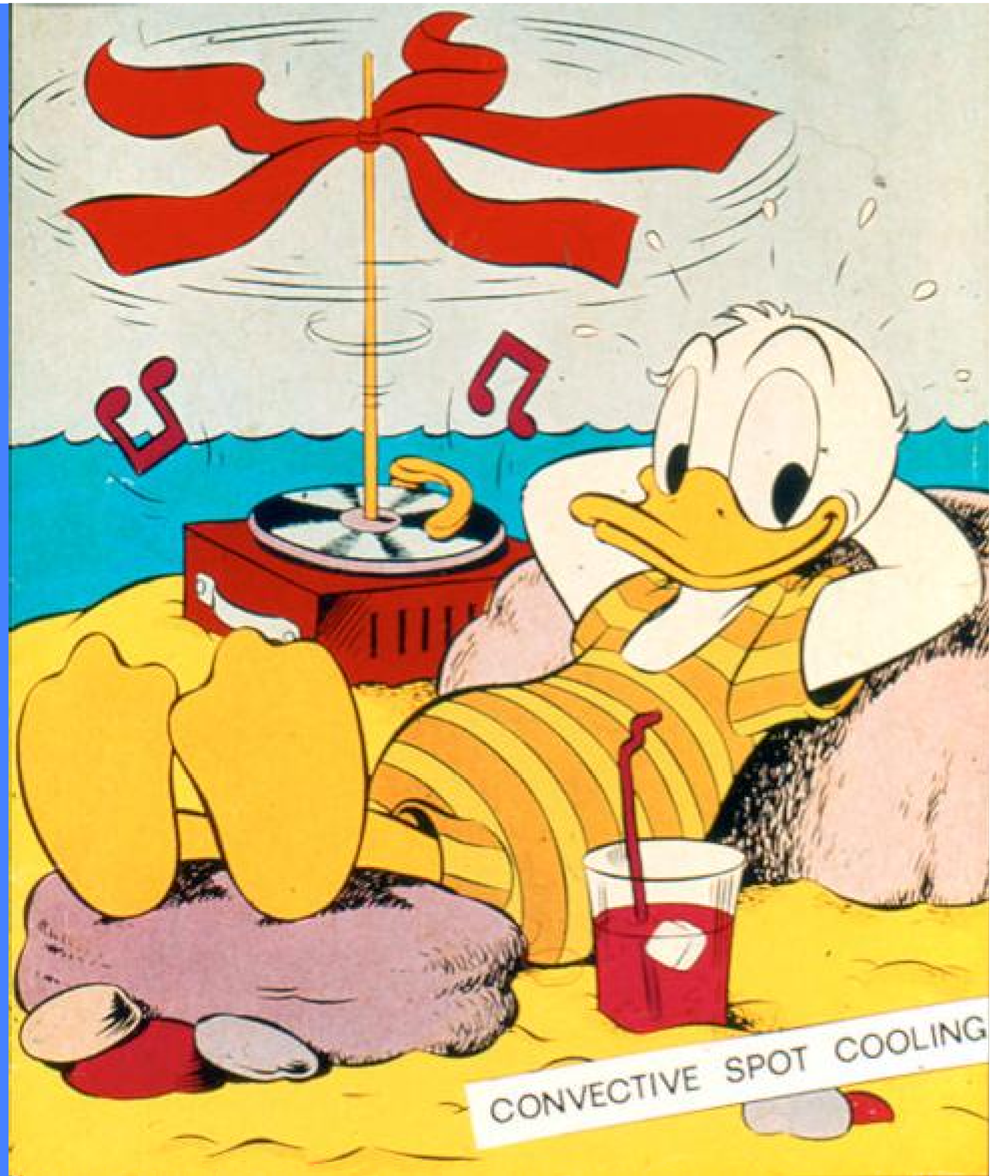
- 10 % decrease in dissatisfied will increase the performance with 1,5 %

LOCAL THERMAL DISCOMFORT

- FLOOR SURFACE TEMPERATURE
- VERTICAL AIR TEMPERATURE DIFFERENCE
- DRAUGHT
- RADIANT TEMPERATUR ASYMMETRI

DRAUGHT

- MEAN AIR VELOCITY
- TURBULENCE
- AIR TEMPERATURE

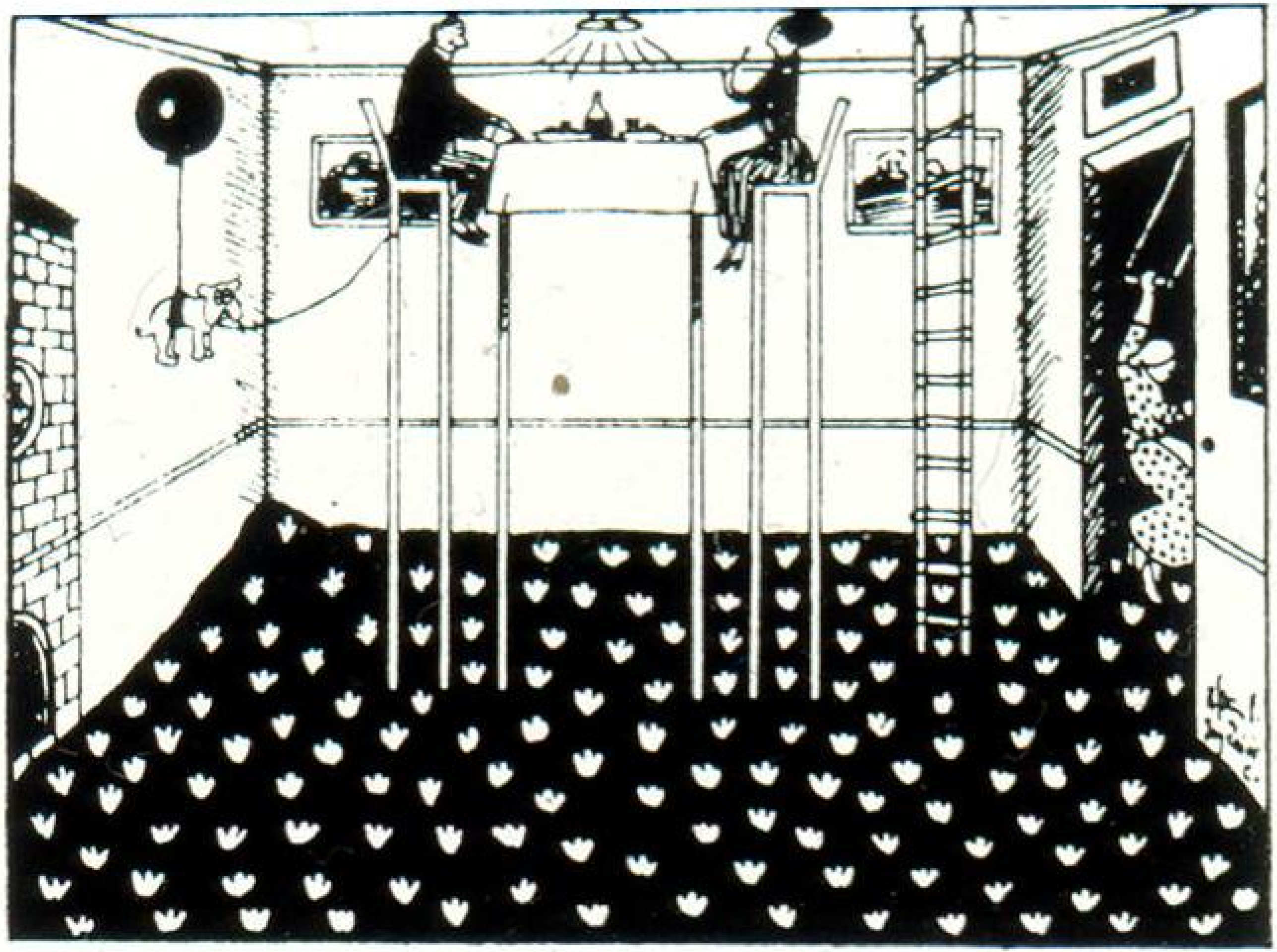


DRAUGHT RATING, DR= (34-ta)(v-0.05)0.62(0.37 v Tu + 3.14)

RADIANT TEMPERATURE ASYMMETRY

- **HEATED CEILING:** < 5 °C
- **COOLED CEILING:** < 14 °C
- **WARM WALL:** < 23 °C
- **COOL WALL:** <10 °C

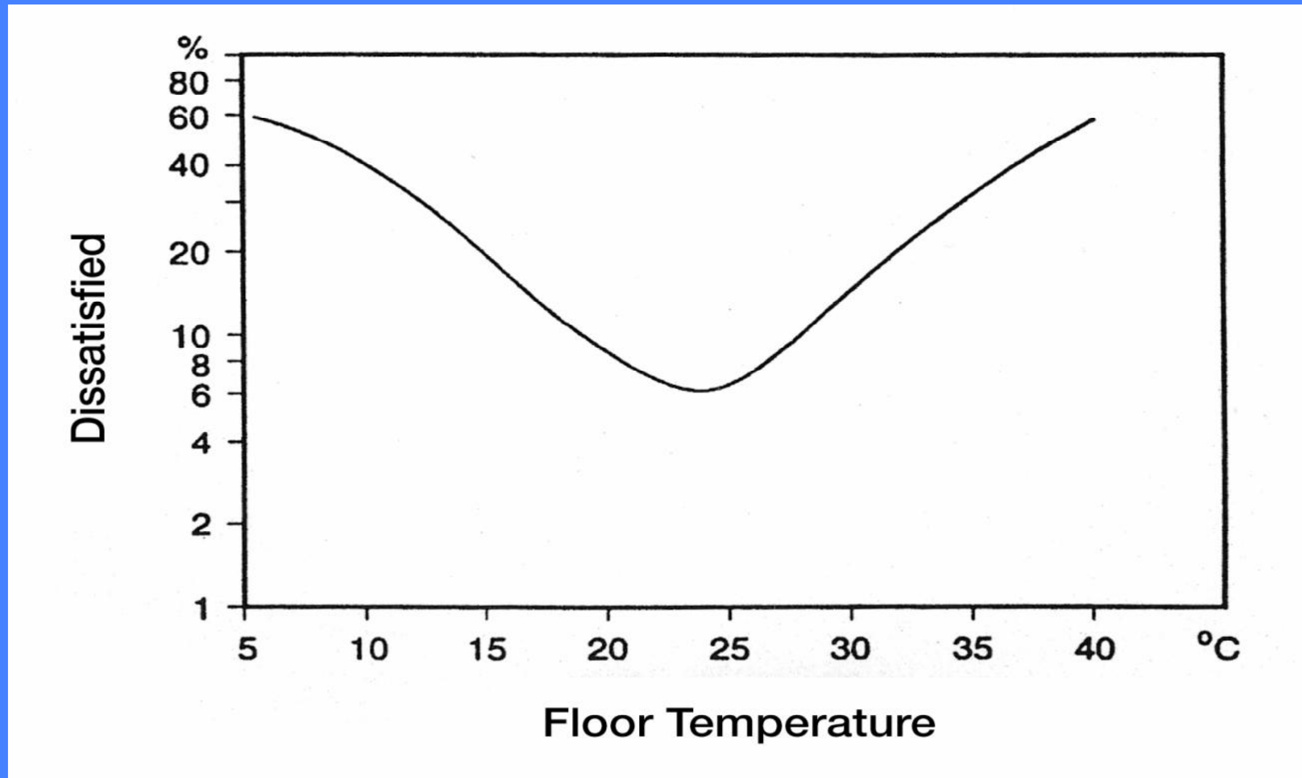
Vertical air temperature difference



The coal shortage 1917
By occupiing the space near the ceiling the heat will be fully utilized- the redundant floor can then be used for growing potatoes. R. Storm. P.

Category	*Vertical air temp. diff. K*
A	< 2
B	< 3
C	< 4

FLOOR TEMPERATURE



- SEATED/STANDING PERSONS:
  19 °C < t_s < 29 °C
- BY HIGHER ACTIVITY LEVELS A LOWER FLOOR TEMPERATURE IS ACCEPTABLE

Directive of the European Parliament and of the Council on the energy performance of buildings

The energy performance of buildings should be ***calculated on the basis of a methodology***, which ***may be differentiated at regional level***, that includes, in addition to thermal insulation other factors that play an increasingly important role such as heating and air-conditioning installations, application of renewable energy sources and design of the building.

DIRECTIVE (Art.7)
Energy performance certificate

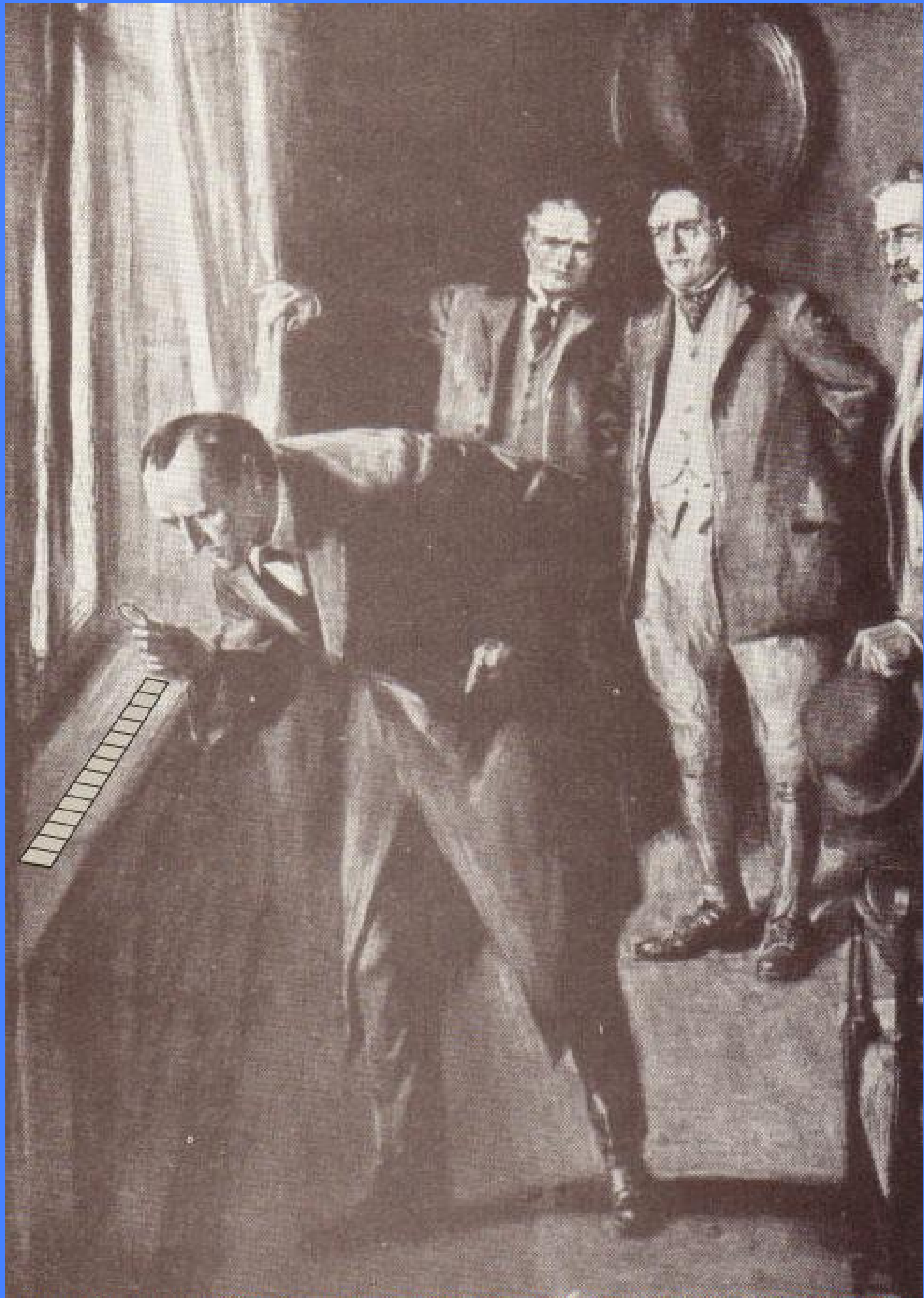
- Member States **shall take measures** to ensure that for buildings with a total useful floor area over 1 000 m2 occupied by public authorities and by institutions providing public services to a large number of persons and therefore frequently visited by these persons an **energy certificate, not older than 10 years, is placed in a prominent place clearly visible to the public.**

- The range of recommended and current indoor temperatures and, when appropriate, other relevant climatic factors **may also be clearly displayed**.

DIRECTIVE (Art.11)

- Moreover, the displaying of officially recommended indoor temperatures, together with the actual measured temperature, should discourage the misuse of heating, air-conditioning and ventilation systems.

- This should contribute to avoiding unnecessary use of energy and to safeguarding comfortable indoor climatic conditions (thermal comfort) in relation to the outside temperature.



INSPECTION

- Boiler and Heating System
- Ventilation System
- Air- (Room) Conditioning System

INSPECTION

- Development of a standard inspection procedure
  - Boilers and heating systems
  - Ventilation systems
  - Cooling systems (Air or Room Conditioning)
- Education of inspectors

INSPECTION

DO IT LIKE THE CARE INDUSTRY

INSPECTION

- Use same concept as for cars:
  - Plug in of PC for download of data
  - Build in sensors
  - No fixed inspection intervals (Months or Distance)
  - Calculation of required inspection
  - Self diagnostic

FUTURE NEEDS FOR HVAC SYSTEMS

- More build in sensors for diagnostic and inspection
- Algorithms for calculation of time for service and inspections
- Running calculation of energy consumption
- More separate measurements of electrical energy use
- Feedback to user regarding energy consumption and indoor environment

FUTURE TRENDS

- Integrated design of building and HVAC systems
- Separation of heating-cooling system from ventilation
- Low-temperature heating and high-temperature cooling
- Use of renewable energy sources (heat pumps, ground heat exchangers, geothermal)
- Reduction of peak loads

OPORTUNITIES FOR THE HVAC INDUSTRY

- **Earlier involvement in the building process**
- **More jobs (energy certificates, inspections, service)**

CONCLUSIONS

- An optimal indoor environment is the most important requirement for a healthy, comfortable and productive working environment
- For each 10 % increase in dissatisfaction the performance will decrease with ~1.5%
- To reduce energy consumption by decreasing the quality of the indoor environment is a bad investment
- An energy certificate make no sense without a certificate for the indoor environment