Standards for Ventilation, IAQ, and Thermal Comfort

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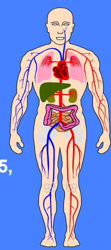


EVALUATION OF THE INDOOR ENVIRONMENT

- DESIGN LEVEL
- COMMISSIONING
- TESTING
- COMPLAINTS

INDOOR ENVIRONMENT

- THERMAL
- AIR QUALITY
- ACOUSTIC
- LIGHT

THERMAL ENVIRONMENT

- ISO EN 11399 Principles and application of international standards
- ISO EN 13731 Definitions, symbols and units
- ISO EN 7730 Moderate thermal environments: determination of PMV and PPD indices and specification of the conditions for thermal comfort.
- ISO EN 7933 Hot environments: analytical determination and interpretation of thermal stress using calculation of required sweat rate
- ISO EN 7243 Hot environments: estimation of the heat stress on working man, based on the WBGT index (wet bulb globe temperature)
- ISO TR 11079 Evaluation of cold environments: determination of required clothing insulation (IREQ)
- ISO EN 8996 Determination of metabolic rate
- ISO EN 9920 Estimation of the thermal insulation and evaporative resistance of a clothing ensemble
- ISO EN 7726 Instruments and methods for measuring physical quantities (under revision)
- ISO EN 10551 Assessment of the influence of the thermal environment using subjective judgement scales.
- ISO 9886 Evaluation of thermal strain by physiological measurements
- ISO DIS 12894 Medical supervision of individuals exposed to extreme hot or cold environments
- ISO CD 14415 Application of international standards for people with special requirements
- ISO NP 13732 Method for the assessment of human responses to contact with surfaces
  - Part 1 Hot surfaces
  - Part 2 Moderate surfaces
  - Part 3 Cold surfaces
- ISO NP 15265 Risk of stress or discomfort in thermal working environments
- ISO/NP 14505 Evaluation of the thermal environment in vehicles

ISO EN 7730rev

- 1 Scope
- The purpose of this International Standard is
  - • to present a method for predicting the general thermal sensation and the degree of discomfort (thermal dissatisfaction) of people exposed to moderate thermal environments.
  - • to specify acceptable thermal environmental conditions for general and local thermal comfort

ISO EN 7730rev

- The International Standard applies to healthy men and women. The standard applies to people exposed to indoor environments where the aim is to attain thermal comfort, or indoor environments where moderate deviations from comfort occur.
- In extreme thermal environments other International Standards apply (ISO 7243, ISO 7933, ISO TR 11079)
- Deviations may occur for sick and disabled people (ISO TS 14415.

ISO EN 7730rev

- The present International Standard may be used in the design of new environments or in assessing existing ones.
- The standard has been prepared for working environments but can be applied to any kind of environment.
- In non-conditioned spaces ethnic and national-geographic deviations may occur.

MODERATE THERMAL ENVIRONMENT

- **ISO EN 7730 Moderate thermal environments: determination of PMV and PPD indices and specification of the conditions for thermal comfort.**
- **ASHRAE 55-92R Thermal environment conditions for human occupancy.**

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

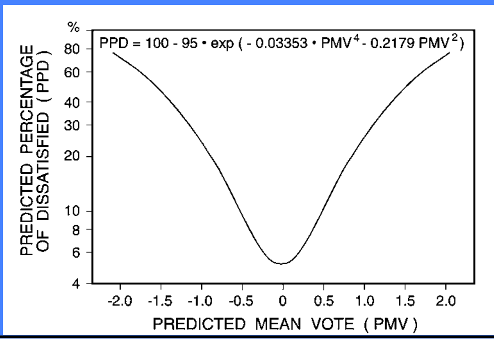
GENERAL THERMAL COMFORT

- **ISO EN 7730**
- **PMV-PPD index**
- **OPERATIVE TEMPERATURE**
- **HUMIDITY**

PMV-index

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

GENERAL THERMAL COMFORT



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.

GENERAL THERMAL COMFORT

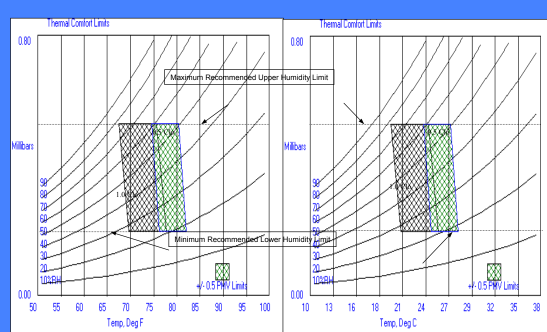
Category	*Thermal state of the body as a whole*	
	PPD %	Predicted Mean Vote
A	< 6	-0.2 < PMV < + 0.2
B	< 10	-0.5 < PMV < + 0.5
C	< 15	0.7 < PMV < + 0.7

GENERAL THERMAL COMFORT

Type of Building/Space	Clothing		Activity met	Category	Operative Temperature	
	Cooling Season (Summer) clo	Heating Season (Winter) clo			Cooling Season (Summer) °C	Heating Season (Winter) °C
Office	0.5	1.0	1.2	A	24.5 ± 0.5	22.0 ± 1.0
				B	24.5 ± 1.5	22.0 ± 2.0
				C	24.5 ± 2.5	22.0 ± 3.0
Cafeteria/ Restaurant	0.5	1.0	1.4	A	23.5 ± 1.0	20.0 ± 1.0
				B	23.5± 2.0	20.0 ± 2.5
				C	23.5 ± 2.5	20.0 ± 3.5
Department Store	0.5	1.0	1.6	A	23.0 ± 1.0	19.0 ± 1.5
				B	23.0 ± 2.0	19.0 ± 3.0
				C	23.0 ± 3.0	19.0 ± 4.0

GENERAL THERMAL COMFORT

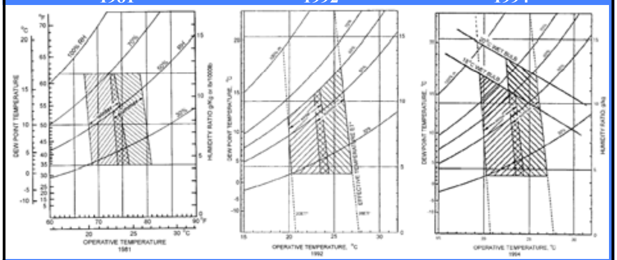
- HUMIDITY
  - Low humidity, eye irritation, skin dryness
  - High humidity, wettedness
  - Combined with perception of air quality



Humidity limits according to ASHRAE-55

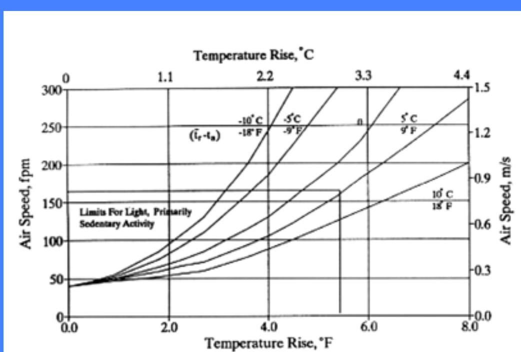
2000 ???

1981 1992 1994



GENERAL THERMAL COMFORT

- AIR VELOCITY
  - Preferred air velocity at increased temperature
  - Direction of air velocity
  - Large individual differences
  - Personal control (fans, windows)



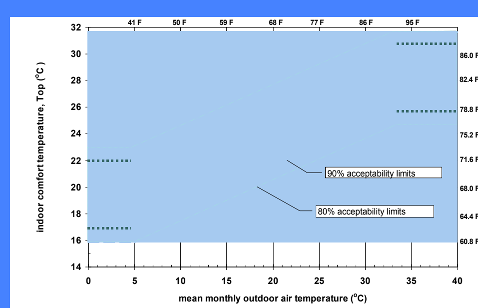
ADAPTATION

- Behavioural
  - Clothing, activity, posture
- Psychological
  - Expectations

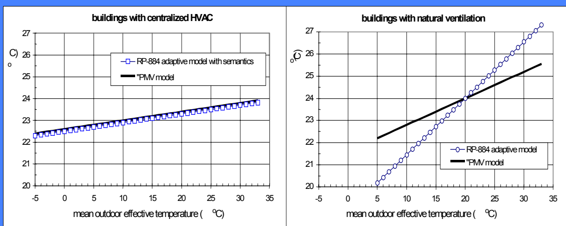
ADAPTATION

- The following text can be found in ASHRAE Handbook 1936, Chapter 3:
  - *"It should be kept in mind that southern people, with their more sluggish heat production and lack of adaptability, will demand a comfort zone several degrees higher than those given here for the more active people of northern climates"*

Adaptation ASHRAE 55-93R



FIELD STUDIES
Adaptation



ADAPTATION

- In determining the acceptable range of operative temperature from sec 4 to 6, a clo-value that correspond to the local clothing habits and climate shall be used.
- In warm or cold environments there may often be an influence of adaptation. Other forms of adaptation, than clothing, like body posture and decreased activity, which are difficult to quantify, may result in acceptance of higher indoor temperatures.
- People used to working and living in warm climates can more easily accept and maintain a higher work performance in hot environments than people from colder climates.
- Extended acceptable environments as given in Section 6 and Annex A may be applied for natural ventilated building and houses in warm areas. In this case it may be designed for higher PMV-values.

Non-steady thermal environments

- **Temperature cycles**
- **Temperature drifts or ramps**
- **Transients**

Non-steady thermal environments

- **Temperature cycles**
  - Temperature cycles may occur due to the control of the temperature in a space. If the peak to peak variation is less than 1 K, there will be no influence on the comfort and the recommendations for steady state may be used. Higher peak variations may decrease comfort.

Non-steady thermal environments

- **Temperature drifts or ramps**
  - If the rate of temperature change for drift or ramps are lower than 2.0 K per hour, the methods for steady state variation apply.

Non-steady thermal environments

- **Transients**
- In general the following statements regarding transients can be made:
  - **A step-change of operative temperature is felt instantaneously.**
  - **After an up-step in operative temperature the new steady-state thermal sensation is experienced immediately, i. e. the PMV-PPD can be used to predict the comfort.**
  - **After a down-step in operative temperature the thermal sensation drops to a level cooler than the later steady-state sensation (in approx.. 30 min.), i. e. the PMV-PPD predicts tow high values the first 30 min.**

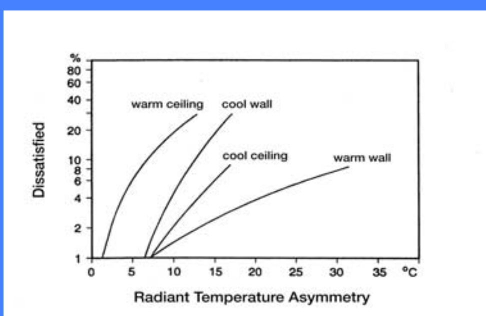
LOCAL THERMAL DISCOMFORT

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

LOCAL THERMAL COMFORT

Draught Rate, DR %	*Vertical Air Temp. difference %*	*Warm or Cool Floor %*	*Radiant Temperature Asymmetry %*
<15	< 3	< 10	< 5
<20	< 5	< 10	< 5
<25	< 10	< 15	< 10

RADIANT TEMPERATURE ASYMMETRY



LOCAL THERMAL COMFORT

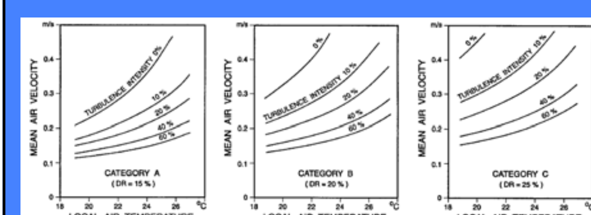
Radiant temperature asymmetry K			
Warm ceiling	Cool ceiling	Cool wall	Warm wall
< 5	< 14	< 10	< 23
< 5	< 14	< 10	< 23
< 7	< 18	< 13	< 35

DRAUGHT

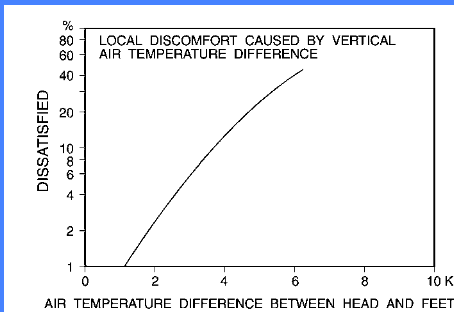
- DRAUGHT RATING, DR
- MEAN AIR VELOCITY
- TURBULENCE
- AIR TEMPERATURE

DR= $(34-t_a)(v-0.05)^{0.62}(0.37 \text{ v Tu} + 3.14)$

DRAUGHT



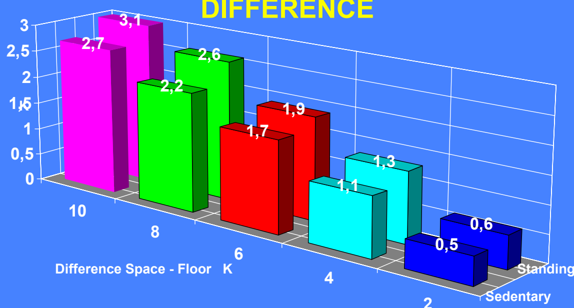
VERTICAL AIR TEMPERATURE DIFFERENCE



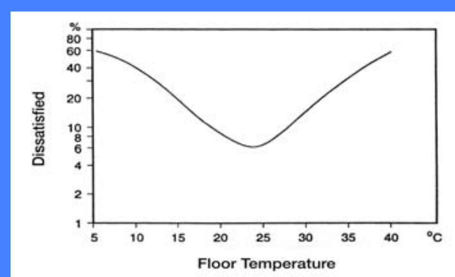
VERTICAL AIR TEMPERATURE DIFFERENCE

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

VERTICAL AIR TEMPERATURE DIFFERENCE



FLOOR TEMPERATURE



FLOOR TEMPERATURE

Category	*Floor surface temperature °C*
A	19 - 29
B	19 - 29
C	17 - 31

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**

VENTILATION AND IAQ STANDARDS OR GUIDELINES

- CR1752
- ASHRAE 62.1
- ASHRAE 62.2
- ISO/TC205 WG4

CEN TC156 Ventilation for Buildings

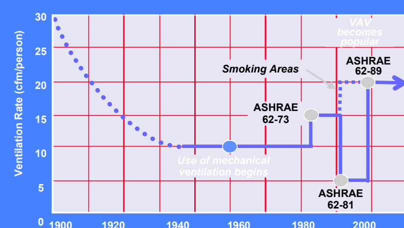
- **CR 12792** Symbols, units and terminology
- **prEN 13465** Residential ventilation- Simplified calculation method
- **CR 1752** Design criteria for the indoor environment
  - Thermal, PMV-PPD, Different classes
  - IAQ, ventilation, health, comfort
  - Acoustic

VENTILATION

- COMFORT
- HEALTH

Ventilation Rate History

Office spaces...



Standard 62 Definitions:

What is "Acceptable IAQ"?

- **Standard 62-1989**: "Air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction."
- **Standard 62R**: "Air in an occupied space toward which a substantial majority of occupants express no dissatisfaction and in which there are not likely to be known contaminants at concentrations leading to exposures that pose a significant health risk."

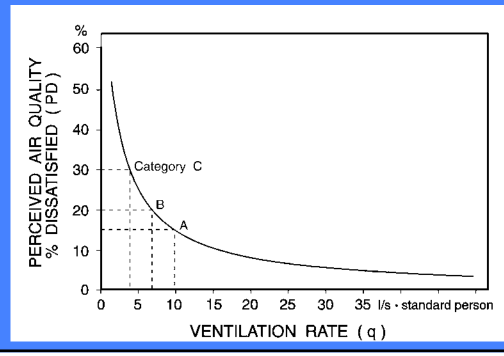
TWO PATHWAYS

- Ventilation Rate Procedure
  - Prescriptively Based
  - Rates by Space Type
  - Equipment Requirements
  - 8-10 l/s/p
- Indoor Air Quality Procedure
  - Performance Based
  - Concentration Targets
  - Occupant Acceptability
  - Air Cleaning Allowed

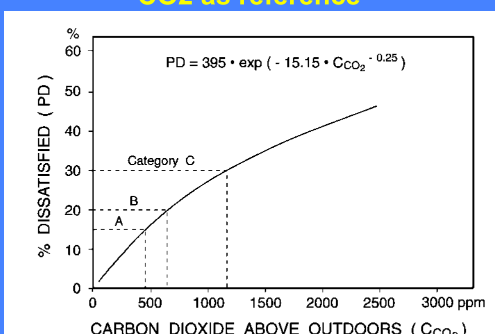
INDOOR CONTAMINANTS

- People and their activity (smoking)
- Building
- Furnishing
- HVAC system
- Outdoor

Perceived air quality



CO2 as reference



What about CO_2?

CO_2: The Great Misconception

- CO_2 is not a dangerous pollutant at levels found in non-industrial buildings
- CO_2 cannot be used to accurately determine space ventilation rates
- CO_2 is not a reliable indicator of acceptable indoor air quality
- CO_2 at 1000 ppm is not a requirement of Standard 62-1989

Required ventilation rate for smoking

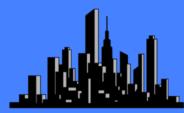
	Un-adapted (m³/cig)	Adapted (m³/cig)
Non-smokers	160	110
Smokers	40	30

Required ventilation rate for smoking

Standard	Class	Required ventilation l/s · person			
		no smoker	20 % smoker	40 % smoker	100% smoker
CR1752	A B C	10 7 4	20 14 8	30 21 12	30 21 12

Possible Revised Ventilation Rate Procedure (from 62R)

People Component | Building Component



Design Outdoor Air Ventilation Rate

DVR = RpPd + RsSd + RbAb

Minimum l/s/Person

Number of People

Ventilation per Smoker

Number of Smokers

Building Area

Minimum l/s/m²

Analytical procedure

The required ventilation rate is calculated as:

$$Q = \frac{G}{(C_i - C_o) \cdot E_v} \qquad \text{l/s}$$

where G = Total emission rate mg/s

C_i = Concentration limit mg/l

C_o = Concentration in outside air mg/l

E_v = Ventilation effectiveness

DESIGN VENTILATION RATES

Standard	Category	Required ventilation rate in office l/s Person			
		No smokers	20% Smokers	40% Smokers	100% Smokers
CR1752	A B C	10 7 4	20 14 8	30 21 12	30 21 12
CIBSE		8	16	24	43
DIN1946		17	22	22	22
ASHRAE 62-89		10	10	10	10

DESIGN VENTILATION RATES

Standard	Class	Required ventilation l/s · person			
		no smoker	20 % smoker	40 % smoker	100% smoker
perENV1752 (96)	A B C	10 7 4	20 14 8	30 21 12	30 21 12
ASHRAE 62-89R	Adapted Unadapted	3 5	6 8	17 25	25 33
ASHRAE 62-89		10	10	10	30
NKB-61 (91)		7	20	20	20
CIBSE-Guide A (new 93)		8	16	24	43

DESIGN VENTILATION RATES

Standards	Room	Occupancy	Only People			STANDARD-calculation		
		Person/m²	l/s m²			l/s m²		
Class			A	B	C	A	B	C
CR1752	Single office	0.1	1.0	0.7	0.4	2.0	1.4	0.8
DIN 1946 (94)							1.1	
ASHRAE 62 (rev) ASHRAE 62-89							0.65 1.0	
NKB-61 (91)							1.05	
CIBSE-Guide A (rev.93)							0.8	

DESIGN VENTILATION RATES

Standards	Room	Occupancy	Only People			STANDARD-calculation			20 % Smokers		
		Person/m²	l/s m²			l/s m²			l/s m²		
Class			A	B	C	A	B	C	A	B	C
prENV 1752	Landscaped office	0.07	0.7	0.5	0.3	1.7	1.2	0.7	2.4	1.7	1.0
DIN 1946							1.7			1.7	
ASHRAE 62 (rev.96) ASHRAE 62-89							0.56 0.7			1.1 (1.6) 0.7	
NKB-61 (91)							0.95			1.4	
CIBSE-Guide A (rev.93)							0.56			1.1	

DESIGN VENTILATION RATES

Standards	Room	Occupancy	Only People			STANDARD-calculation			20 % Smokers		
		Person/m²	l/s m²			l/s m²			l/s m²		
Class			A	B	C	A	B	C	A	B	C
prENV 1752	Conference room	0.5	5.0	3.5	2.0	6.0	4.2	2.4	1.0	7.8	4.4
DIN 1946							2.8 - 5.4			5.4	
ASHRAE 62 (rev.96) ASHRAE 62-89							1.5 (4.0) 5.0			4.4 (8.2) 5.0	
NKB-61 (91)							3.5			10.0	
CIBSE-Guide A (rev.93)							4.0			8.0	

DESIGN VENTILATION RATES

Standards	Room	Occupancy	Only People			STANDARD-calculation		
		Person/m²	l/s m²			l/s m²		
Class			A	B	C	A	B	C
prENV 1752	Class room	0.5	5.0	3.5	2.0	6.0	4.2	2.4
DIN 1946							4.2	
ASHRAE 62 (rev.96) ASHRAE 62-89							2.1 (4.6) 4.0	
NKB-61 (91)							3.5	
CIBSE-Guide A (rev. 93)							4.0	

SUMMARY

- General agreement on standards for thermal comfort (ASHRAE, ISO, CEN)
- Need for more knowledge on Indoor Air Quality and Ventilation
- Sources like people, activity, building, HVAC-systems and outdoor air must be taken into account.
- Influence of sources like people and smoking is available
- More information is needed on sources like buildings and HVAC systems.
- Relation between contaminant concentration and health effect is needed

Minimum requirements

- Operative temperature range for mainly sedentary people
  - Winter 20 - 24 °C
  - Summer 23 - 26 °C
- Heating systems should be dimensioned for 20 °C
- Cooling system should be dimensioned for 26 °C
- Ventilation systems should be dimensioned for 10 l/s/person
- Personal and individual room control is important

Pollution source control and ventilation improve health, comfort and productivity

(www.ie.dtu.dk)

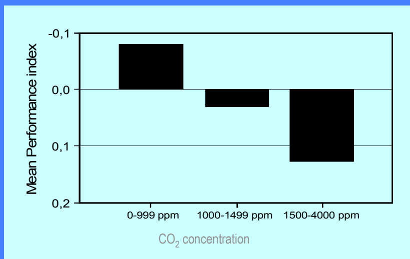
Background

- Poor data on direct effects of air pollution on human performance in offices

⇩

- Three independent s Three independent studies were carried out at the International Centre for Indoor Environment and Energy in 1998 and 1999 tudies were carried out at the International Centre for Indoor Environment and Energy in 1998 and 1999

Diagnostic tests in schools



Source: Myhrvold et al. (1996)

Air-conditioning has had a well documented positive effect on productivity and economic growth in warm climates

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)

Sick Building Syndrome:

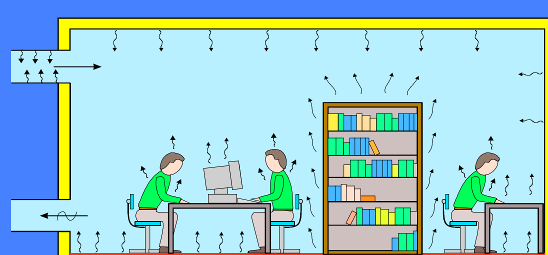
- **irritation of eyes and nose**
- **headache**
- **fatigue**
-
-

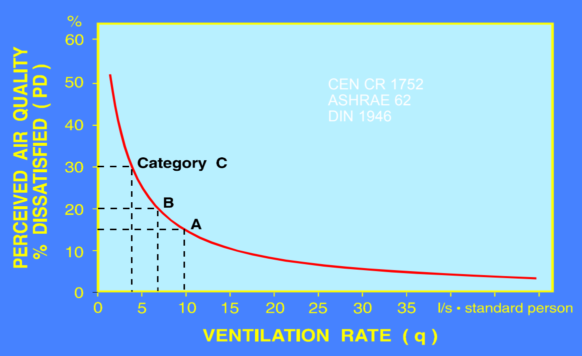
In typical office buildings

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

even though existing ventilation standards are met.

Indoor Pollution Sources



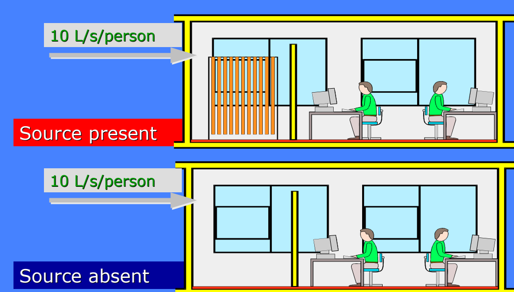


Five independent studies have shown a significant impact of indoor air quality on office productivity.

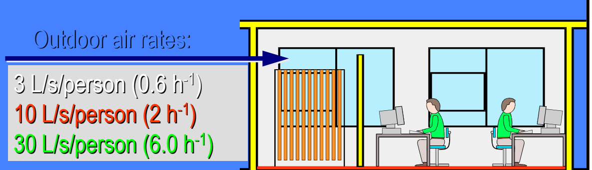
High indoor air quality :

- reduce indoor pollution sources
- increase the ventilation rate

Methods: interventions



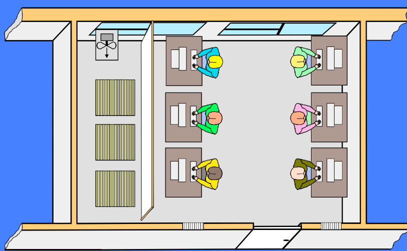
Methods



Pollution s

Samples of a 20-year-old used carpet having size equal to the office floor area

Experimental set-up



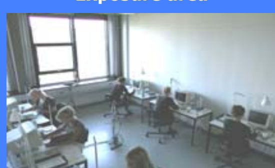
Subjects & procedure

- 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

Methods: exposure office

Behind screen

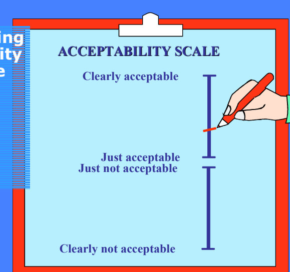
Exposure area



90 female subjects
18-33 years old
students
not atopic

Methods: measurements

- **Air quality: immediate rating of acceptability of air quality upon entering to the office**



Methods: measurements

- **SBS symptoms: marking visual analogue scales during exposure**

Right now I feel as follows:

Nose blocked	Nose clear
Nose dry	Nose running
Throat dry	Throat not dry
Mouth dry	Mouth not dry
Lips dry	Lips not dry
Skin dry	Skin not dry
Hair dry, brittle	Hair not dry
Nails brittle	Nails supple
Eyes dry	Eyes not dry
Eyes smarting	Eyes not smarting
Eyes aching	Eyes not aching
Eyes feel gritty	Eyes not gritty
Severe headache	No headache
Difficult to think	Head clear
Dizzy	Not dizzy
Feeling bad	Feeling good
Tired	Rested
Difficult to concentrate	Easy to concentrate
Depressed	Positive
Alert	Sleepy

Methods: measurements

- **Performance: performing simulated office work during exposure**

- text typing
- arithmetical calculations
- proof-reading

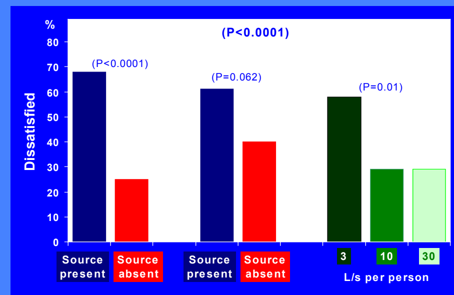
Methods: performance

Subjects performed simulated office work:

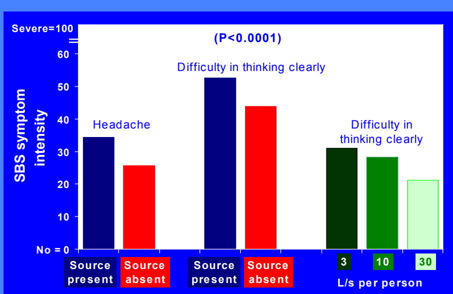
- Text typing
- Proof-reading
- Arithmetical calculations
- Tests of knowledge and recall
- Tests of creativity

→ Estimates of productivity

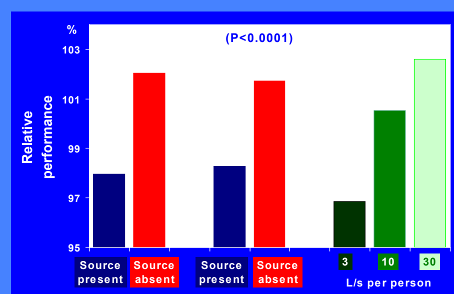
Results: air quality



Results: SBS symptoms



Results: performance

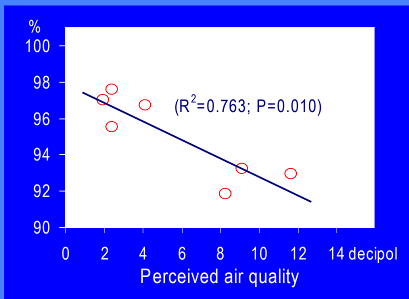


Source control works and pays!

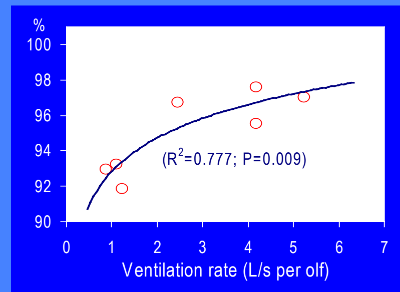
Pettenkofer (1858):

”If there is a pile of manure in a space, do not try to remove the odor by ventilation. Remove the pile of manure.”

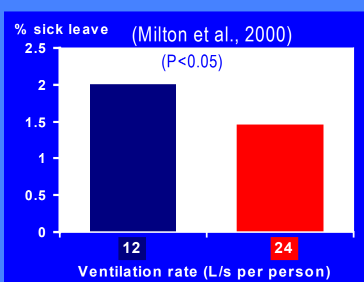
Total productivity



Total productivity



Effects of ventilation on sick absence in offices



Economics of Improving IAQ from mediocre to high:

Improved productivity	~ 5%
Cost	-0,5%
Profit	4,5%

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

Estimated improvement in performance of office work

- 10% less dissatisfied with air quality = 1.1% increase in performance
- Halving pollution load = 1.6% increase in performance
- Doubling ventilation rate = 1.8% increase in performance

Worker salaries vs building energy & maintenance costs

- Salaries/energy costs = 25-100
- Salaries/maintenance costs = 25-100

source: Woods & Jamerson (1989)

⇩

High air quality pays
gains >>> costs

Empirical findings

- Net savings (due to decreased short-term sick leave) following increase of ventilation from 12 to 24 L/s per person are estimated to $400/year/employee ($22.8 billion/year nationally)

⇩

German conditions:
DEM 920/employee/year
DEM 16 billion/year nationally*

*$100=DEM 230
population ratio=Germany 81 mil/US 265mil

Source: Milton et al. (2000)

Potential annual savings from changes in building factors (U.S. data):

- infectious diseases - $6-$19 billion;
- allergies and asthma - $1-$4 billion;
- acute sick-building (SBS) health problems - $10-$20 billion;
- direct impact of indoor environment on worker performance (unrelated to health) - $12-$125 billion.

⇩

Total: $30-$170 billion
German conditions: DEM 21-120 billion

Source: Fisk & Rosenfeld (1997)

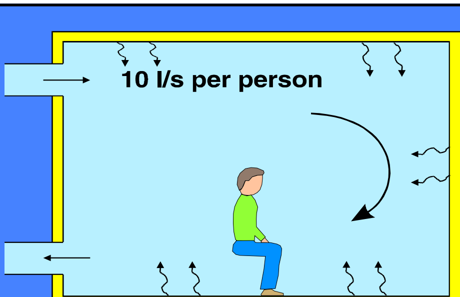
Benefits vs costs of improving IAQ (U.S. data):

- 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)

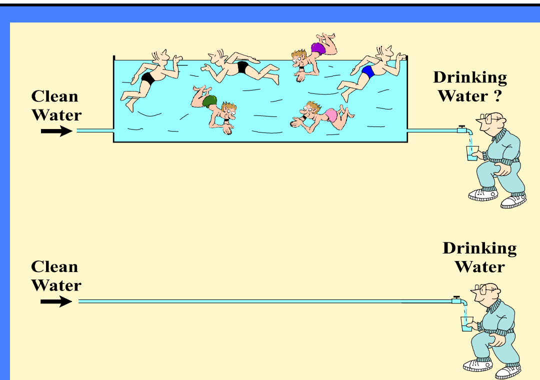
⇩

Pay-back time = 1.4 years
German conditions: similar

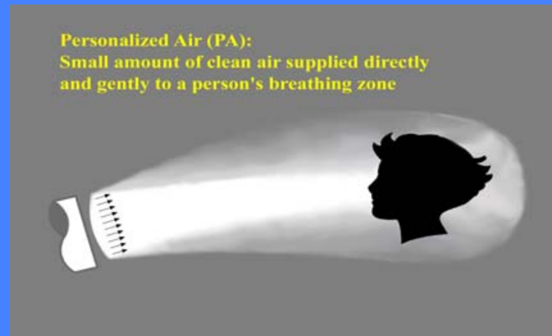
Source: Dorgan et al. (1998)



Only 0.1 L/s per person or 1% is consumed,
99% is wasted!



Why not serve clean air directly to people?



Personalized Ventilation

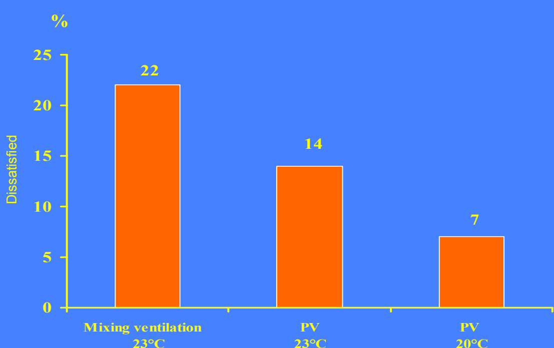
- Office with ventilation rate 15l/s·person; temp = 23°C; RH = 30%
- typical substantial office pollution loa
- 6 workstations equipped with PV
- individual control of location, directio and airflow rate (0-15 l/s) from PV

Experimental design

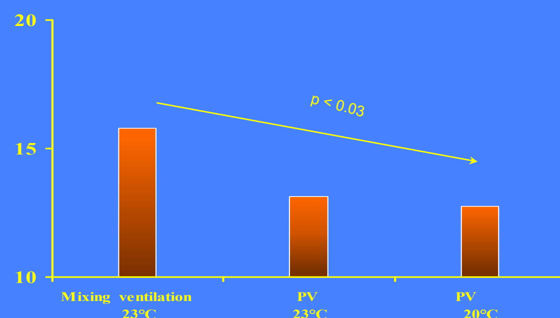
Mixing ventilation 23 °C	PV 23 °C	PV 20 °C

Human subjects

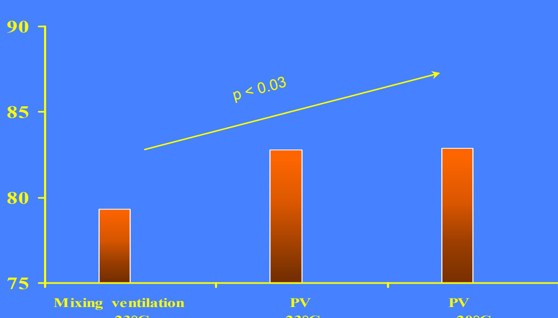
- 30 subject
- groups of 6 subjects
- simulated office work
- 4 hours exposure



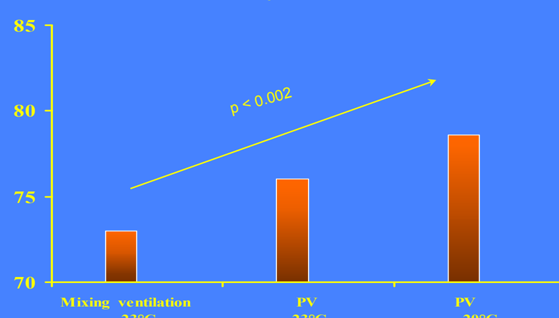
Headache



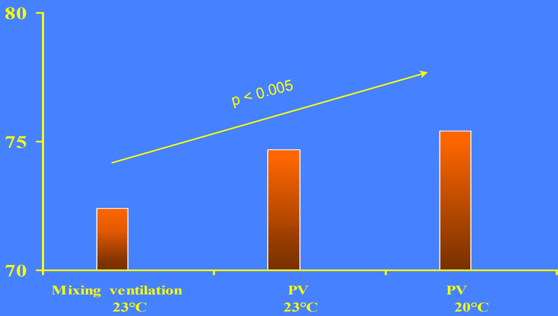
Well being



Ability to think

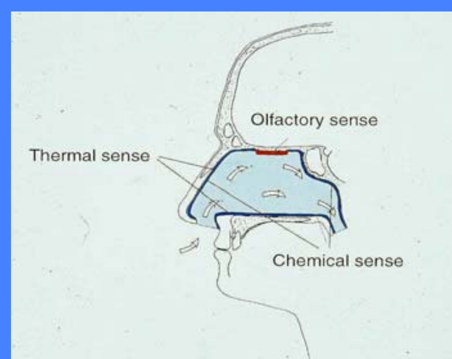


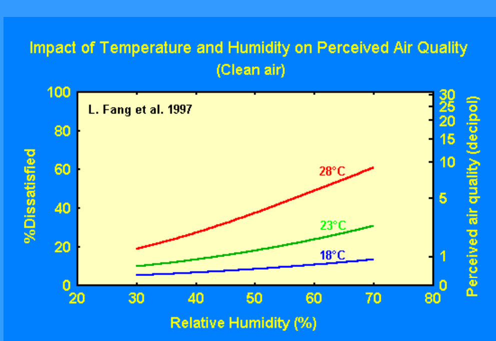
Ability to concentrate



Individual preferences
Positioning of Air Supply

Impact of temperature and humidity on perceived air quality





Conclusions

- Poor air quality affects negatively productivity in offices.
- The present data document the economic benefits of providing indoor air of a higher quality than the minimum prescribed by the present ventilation standards.

Conclusions (contd)

- Measures used to reduce costs of owning and operating buildings can be counter-productive.

- Measures used to improve indoor environmental conditions can be highly cost-effective due to increased productivity and reduced health and comfort complaints.

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