

iche International Centre for Indoor Environment and Energy

Indoor Air Quality and Thermal Comfort in



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COMFORT-PRODUCTIVITY Building costs

People 100

Maintenance 10

Financing 10

Energy 1

Achieving Excellence in Indoor Environmental Quality

Physical factors

- Thermal Comfort
- Air quality (ventilation)
- Noise-Acoustic
- Illumination

Personal factors

- Activity
- Clothing
- Adaptation
- Expectation
- Exposure time

Energy Efficient Technologies

Indoor air quality

- Reduce loads (pollution sources)
- Natural ventilation
- Air distribution (contaminant removal) effectiveness
 - » Personal ventilation
- Air cleaning

Thermal comfort

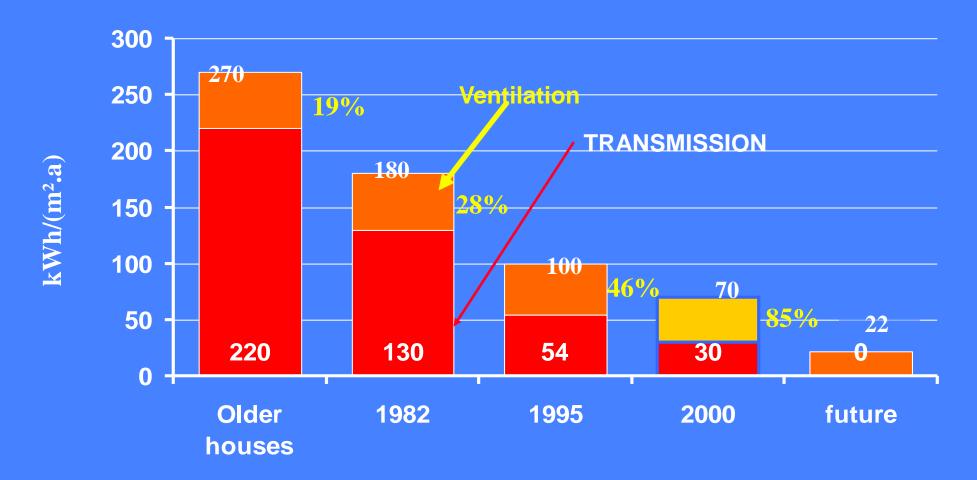
- Reduce loads (building shell, solar screen, internal loads)
- Low Temperatur Heating- and High Temperature Cooling Systems
- Use of building mass (Thermo-Active-Building-Systems (TABS))
- Drifting temperatures

MINIMIZE

Primary Energy Use Indoor Environmental Quality

WILL NOT WORK WITH ZERO ENERGY BUILDINGS

Low energy buildings will be standard!



Required energy for heating in residential buildings kWh / (m² . a)

STANDARDS

- 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
- ASHRAE 62.1 and 62.2 -2004
 - Ventilation and indoor air quality
- CR 1752
 - Ventilation of buildings-Design criteria for the indoor environment
- EN 13779
 - Ventilation for non-residential buildings performance requirements for ventilation and room-conditioning systems

EN15251 (CEN TC156 WG12)

Indoor environmental input parameters for design and assessment of energy performance of buildings- addressing indoor air quality, thermal environment, lighting and acoustics

CRITERIA FOR LIGHTING

Table D.1 - Examples of design illumination levels for some buildings and spaces from EN 12464-1. For information purposes the UGR and Ra are also presented.

Type of building	Space	Maintained luminance, $\hat{\mathbf{E}}_{m}$, at working areas, lx	UGR	Ra	Remarks
Office buildings	Single offices	500	19	80	at 0,8 m
	Open plan offices	500	19	80	at 0,8 m
	Conference rooms	500	19	80	at 0,8 m
Educational buildings	Classrooms	300	19	80	at 0,8 m
	Classrooms for adult education	500	19	80	at 0,8 m
	Lecture hall	500	19	80	at 0,8 m

Daylight factor, 2-5%, Ra colour rendering index

Table E.1 - Examples of design A-weighted sound pressure level

Building	Type of space	Sound pres	Sound pressure level [dB(A)]		
		Typical range	Default design value		
Residential	Living room	25 to 40	32		
	Bed room	20 to 35	26		
Child care institutions	Nursery schools	30 to 45	40		
	Day nurseries	30 to 45	40		
Places of assembly	Auditoriums	30 to 35	33		
	Libraries	28 to 35	30		
	Cinemas	30 to 35	33		
	Court rooms	30 to 40	35		
	Museums	28 to 35	30		
Commercial	Retail shops	35 to 50	40		
	Department stores	40 to 50	45		
	Supermarkets	40 to 50	45		
	Computer rooms, large	40 to 60	50		
	Computer rooms, small	40 to 50	45		
Hospitals	Corridors	35 to 45	40		
	Operating theatres	30 to 48	40		
	Wards	25 to 35	30		
	Bedrooms night-time	20 to 35	30		
	Bedrooms daytime	25 to 40	30		
Hotels	Lobbies	35 to 45	40		
	Reception rooms	35 to 45	40		
	Hotel rooms (during night-time)	25 to 35	30		
	Hotel rooms (during daytime)	30 to 40	35		
Offices	Small offices	30 to 40	35		
	Conference rooms	30 to 40	35		
	Landscaped offices	35 to 45	40		
	Office cubicles	35 to 45	40		

Indoor System Noise Criteria

Noise from **outside** by natural ventilation?

Categories

Category	Explanation
	High level of expectation and is recommended for spaces occupied by very sensitive and fragile persons with special requirements like handicapped, sick, very young children and elderly persons
II	Normal level of expectation and should be used for new buildings and renovations
III	An acceptable, moderate level of expectation and may be used for existing buildings
IV .	Values outside the criteria for the above categories. This category should only be accepted for a limited part of the year

Recommended categories for design of mechanical heated and cooled buildings

Cate gory	Therma	I state of the body as a whole		Local therm	al discomfort			
	PPD %	Predicted Mean Vote	Draught Rate, DR %	Vertical air tempe- rature difference %	Warm or cool floor %	Radiant Tempe- rature Asymmetry %		
I	< 6	-0.2 < PMV < + 0.2	<10	< 3	< 10	< 5		
II	< 10	-0.5 < PMV < + 0.5	<20	< 5	< 10	< 5		
Ш	< 15	-0.7 < PMV < + 0.7	<30	< 10	< 15	< 10		
IV	> 15	PMV<-0.7; or 0,7 <pmv< th=""><th>>30</th><th></th><th></th><th></th></pmv<>	>30					

Temperature ranges for hourly calculation of cooling and heating energy in three categories of indoor environment

Type of building/ space	Category	Operative Temperature for Energy Calculations °C		
Offices and spaces with similar activity (single		Heating (winter season), ~ 1,0 clo	Cooling (summer season), ~ 0,5 clo	
offices, open plan offices, conference rooms,	I	21,0 - 23,0	23,5 - 25,5	
auditorium, cafeteria, restaurants, class rooms,	II	20,0 - 24,0	23,0 - 26,0	
Sedentary activity ~1,2 met	III	19,0 – 25,0	22,0 - 27,0	

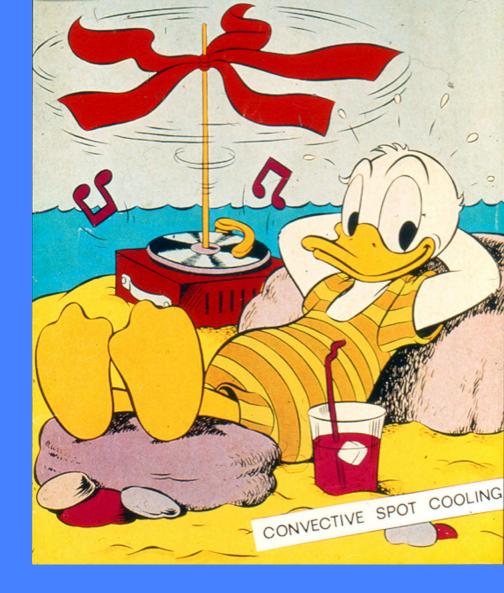
LOCAL THERMAL DISCOMFORT

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



DRAUGHT

- MEAN AIR VELOCITY
- TURBULENCE
- AIR TEMPERATURE



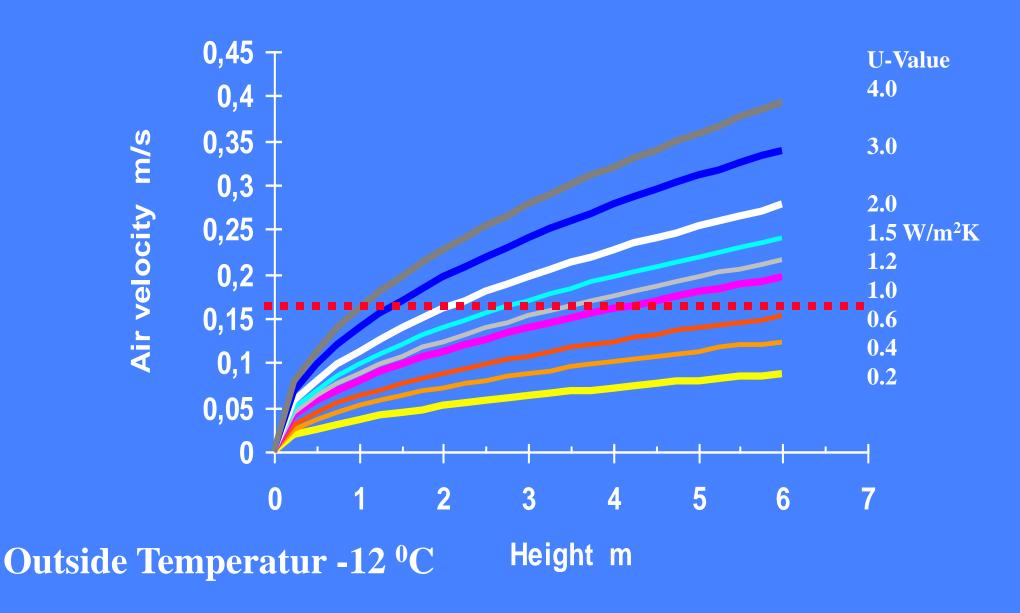
DRAUGHT RATING, DR= (34-ta)(v-0.05)0.62(0.37 v Tu + 3.14)



Calculated values for the air movement at the floor (Heiselberg 1994) for two-dimensional (Window- = Room width)

Parameter	Distance from cold surface	Formular	Unit
Min. Air	x		°C
temperature at the		$t_{min} = t_{Raum} - (0.30 - 0.034 * X)(t_{Raum} - 0.034 * X)$	
floor		t _{Fläche})	
	x<0.4 m	$v_{\text{max}} = 0.055 \cdot \left(t_{\text{Raum}} - t_{\text{Fläche}} \cdot h \right)^{0.5}$	m/s
Max. air velocity			
at the floor	0,4 <x< 2,0<="" td=""><td>$v_{\text{max}} = \frac{0.095}{X + 1.32} (t_{Raum} - t_{Fläche} \cdot h)^{0.5}$</td><td>m/s</td></x<>	$v_{\text{max}} = \frac{0.095}{X + 1.32} (t_{Raum} - t_{Fläche} \cdot h)^{0.5}$	m/s
	2,0 <x< td=""><td>$v_{\text{max}} = 0.028 \left(t_{Raum} - t_{Fläche} \cdot h \right)^{0.5}$</td><td>m/s</td></x<>	$v_{\text{max}} = 0.028 \left(t_{Raum} - t_{Fläche} \cdot h \right)^{0.5}$	m/s

DOWN DRAUGHT



RADIANT TEMPERATURE ASYMMETRY

• HEATED CEILING: < 5 °C

• COOLED CEILING: < 14 °C

• WARM WALL: < 23 °C

• COOL WALL: <10 °C

UNIFORMITY OF OPERATIVE TEMPERATURE DISTRIBUTION

• t_{o,warm} - t_{o,cold} < 4 K

• $t_{o,warm}$ - $t_{o,cold}$ ~ 1,0 x U_w

 \cdot U_w < 4 W/m²K

RADIANT TEMPERATURE ASYMMETRY

•
$$t_{pr,warm}$$
 - $t_{pr,cold}$ ~ 4,0 x U_{w}

 $\cdot U_{\rm w} < 2.5 \,{\rm W/m^2 K}$

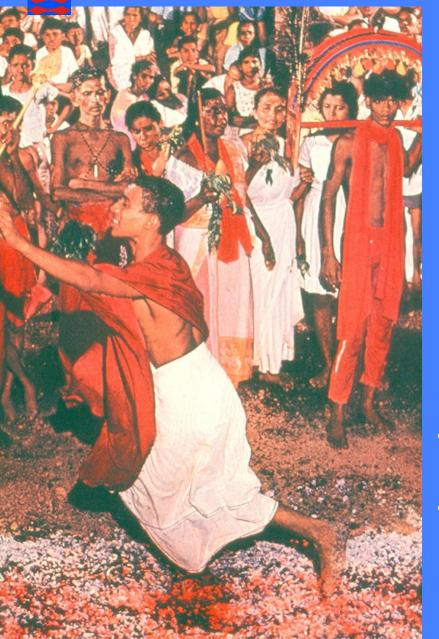
THERMAL COMFORT

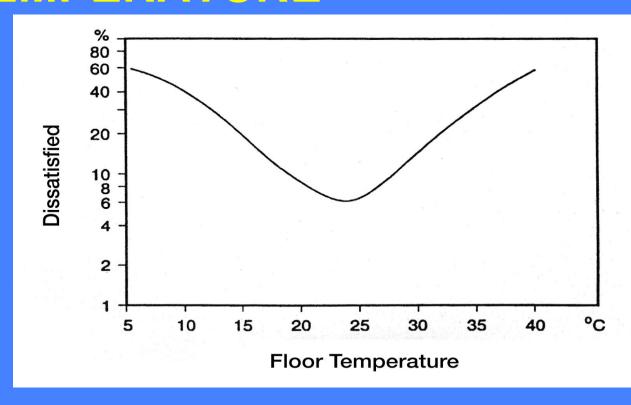
- VERTICAL AIR TEMPERATURE DIFFERENCE
 ∆ t_a BETWEEN HEAD AND FEET:
 - < 3 °C (ISO EN 7730)
- SEATED PERSON:
 1.1 m and 0.1 m above floor level

Abbildung 3 50 W/m² Leistung VERTIKALE LUFTTEMPERATURUNTERSCHIEDE BEI VERSCHIEDENEN HEIZSYSTEMEN 80 W/m² Leistung Zwei-lagig Zwei-lagig Ein-lagig Zwei-lagig Heizkörper Rückwand Heizkörper Seitenwand Heizkörper Brüstung Heizkörper Brüstung 2,70 2,70 2,70 2,62 2,62 2,62 2,62 Raumhohe in m 1,50 E 1,80 E 1,80 1,80 Raumhöhe in m Raumhöhe in Raumhôhe in 1,50 1,50 0,75 0,75 0.75 0,75 0,08 0,08 0,08 0,08 24 22 26 24 22 24 26 24 26 22 Raumtemperatur Raumtemperatur Raumtemperatur Raumtemperatur Warmluft Rückwand Deckenheizung Warmluft Außenwand Fußbodenheizung 2,70 2,70 2,70 2,70 2,62 2,62 2,62 Roumhôhe in m 1'22 1,80 Raumhōhe in m Raumhöhe in Raumhöhe in 1,50 1,50 0,75 0,75 0,75 0,75 0,08 0,08 0,08 0,08 28 26 26 26 24 20 22 24 26 20 22 24 28 30 20 24 Raumtemperatur Raumtemperatur Raumtemperatur Raumtemperatur

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FLOOR TEMPERATURE

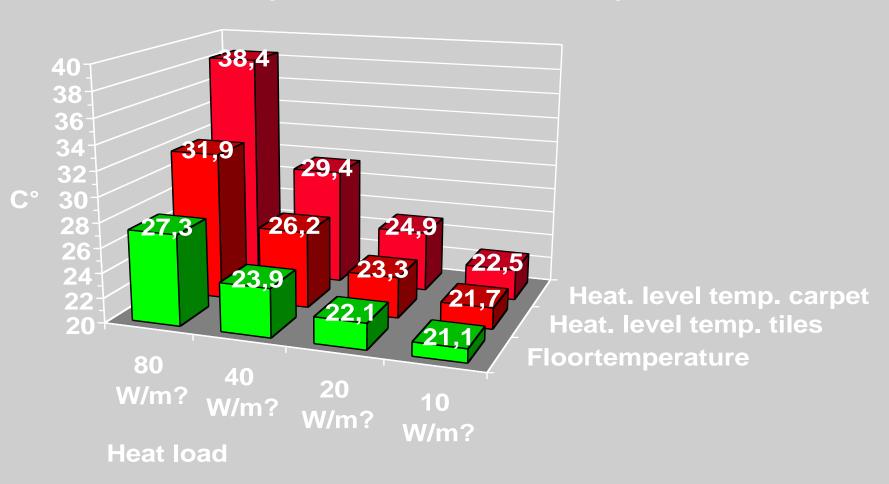




- SEATED/STANDING PERSONS: 19 °C < t < 29 °C
- BY HIGHER ACTIVITY LEVELS A LOWER FLOOR TEMPERATURE IS ACCEPTABLE

SELF CONTROL

Floortemperature at 20 °C Roomtemperature



FLOOR TEMPERATURE

Floor construction on concrete	Optimum floor temperature		Recommended floor temperature range °C	
	1 min. °C	10 min. °C	1 min. 10% dissatisfied	10 min. 15% dissatisfied
Wilton-carpet Needled felt sheet	21	24.5	12-30.5	21-28
	23	25	15.5-31	22.5-28
5 mm cork Wooden floor PVC-sheet with felt underlay	24	26	17-31	23-28
	26.5	25.5	22-31.5	23-28
	28	27	24.5-32	25.5-28
Painted concrete floor	30	28.5	27.5-32.5	27.5-29
Concrete floor	28.5	27	24.6-32.0	26-28.5
Marble	30	29	27.5-32.5	28-29.5

CONTROL OF ROOM TEMPERATURE

- Drifting temperature
 - OK within the comfort range
- Air temperature Operative temperature
 - Less difference in zero energy buildings
- Individual room control
 - May be less important for energy use
 - Still important for thermal comfort (bed room, living room)

Concept for calculation of design ventilation rate

People Component

Building Component

Breathing Zone Outdoor Airflow

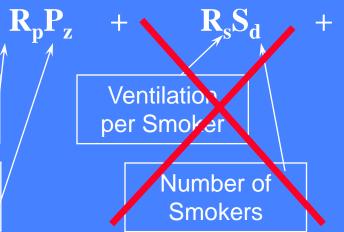


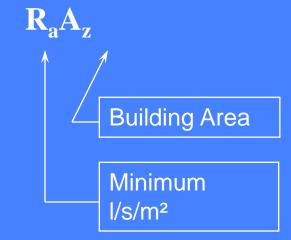


 V_{bz} = $R_p P$ Minimum

I/s/Person

Number of
People





Breathing zone outdoor airflow (V_{bz}),

•
$$V_{bz} = R_{pP}P_z + R_{aA}A_z$$

where:

•

- $-A_z = Zone floor area: the net occupiable floor area of the zone m²$
- P_z = Zone population: the largest number of people expected to occupy the zone during typical usage.
- R_{Pp} = Outdoor airflow rate required per person: these values are based on non-adapted (adapted) occupants.
- $-R_{Aa} =$ Outdoor airflow rate required per unit area.

Recommended ventilation rates for non-residential buildings for three categories

Type of building or space	Cate- gory	Per person I/s,person	Per floor area l/s,m²	Per person I/s,person	Per floor area l/s,m²	Per person I/s,person	Per floor area l/s,m²
		Very low poll building, revi		Low polluted revision	building,	Non-low pollubuilding, revi	
Single office	I	5,0	1,5	10,0	2,0	20,0	3,0
	II	3,0	1,0	7,0	1,4	14,0	2,1
	III	2,0	0,6	4,0	0,8	8,0	1,2
Landscaped	I	7,5	1,5	15,0	1,7	30,0	2,7
office	II	4,5	1,0	10,5	1,2	21,0	1,9
	III	3,0	0,6	6,0	0,7	12,0	1,1
Conference	I	1,0	1,5	2,0	6,0	4,0	7,0
room	II	0,6	1,0	1,4	4,2	2,8	4,9
	III	0,4	0,6	0,8	2,4	1,6	2,8

Residential buildings

Category	Air change rate 1)			ns, mainly	Exhaust air flow, I/s			
	I/s,m ² (1)	ach	I/s, pers ²⁾ (2)	I/s/m ² (3)	Kitchen (4a)	Bathrooms (4b)	Toilets (4)	
I	0,49	0,7	10	1,4	28	20	14	
II	0,42	0,6	7	1,0	20	15	10	
III	0,35	0,5	4	0,6	14	10	7	

Required ventilation rate

- The total required system ventilation rate is calculated by taking into acount the ventilation effectiveness:
- Total system ventilation rate = V/ϵ_v

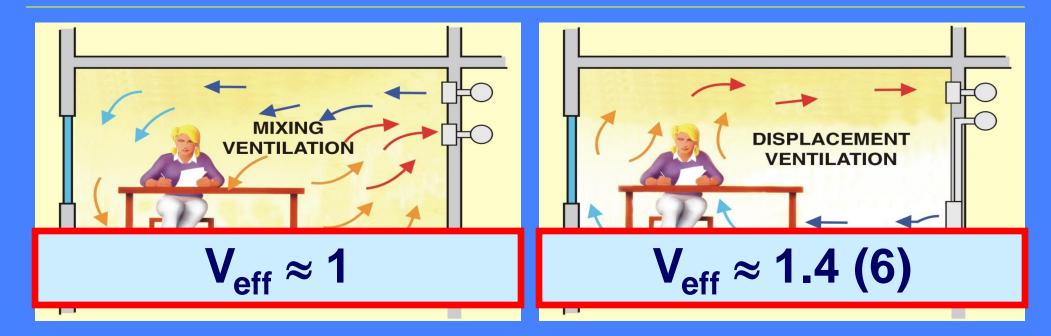
Ventilation effectiveness

$$\varepsilon_{v} = \frac{C_{s} - C_{s}}{C_{i} - C_{s}}$$

where:

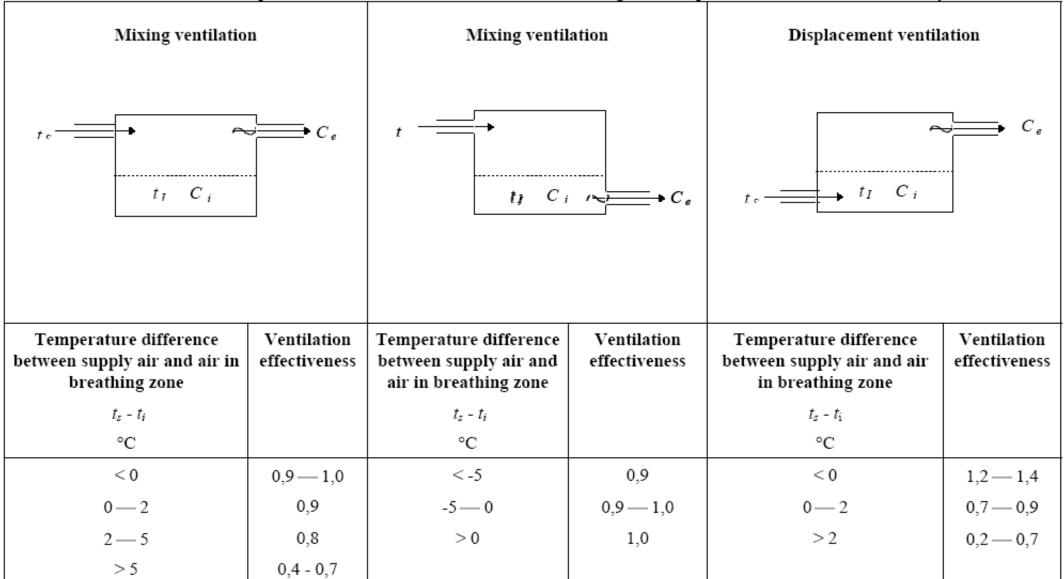
 ε_{v} is the ventilation effectiveness; C_{e} is the pollution concentration in the exhaust air; C_{s} is the pollution concentration in the supply-air; C_{i} is the pollution concentration in the breathing zone.

Inhaled Air Quality

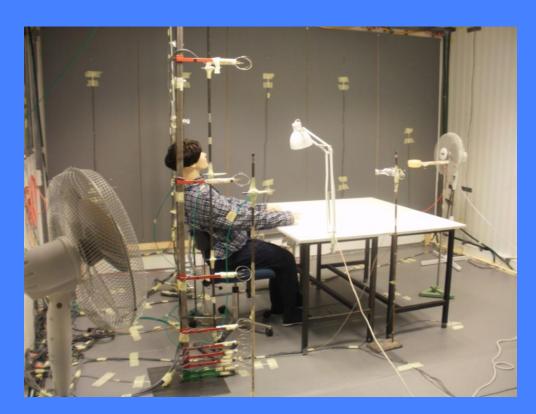


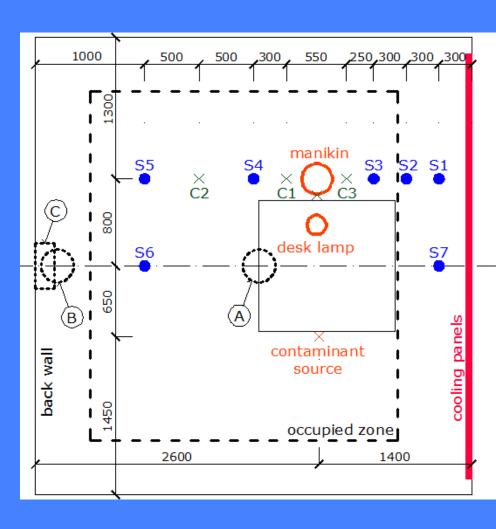
Ventilation effectiveness

Table F.1 — Examples of ventilation effectiveness in the breathing zone of spaces ventilated in different ways

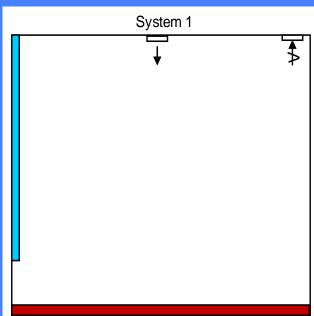


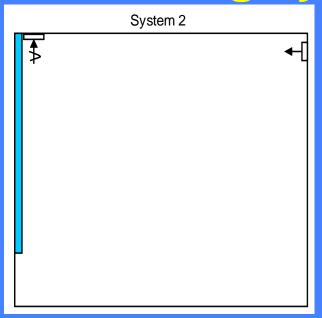
Studies of heating systems

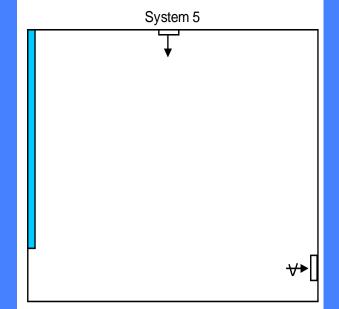


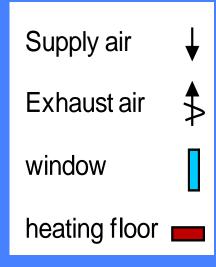


Studies of heating systems

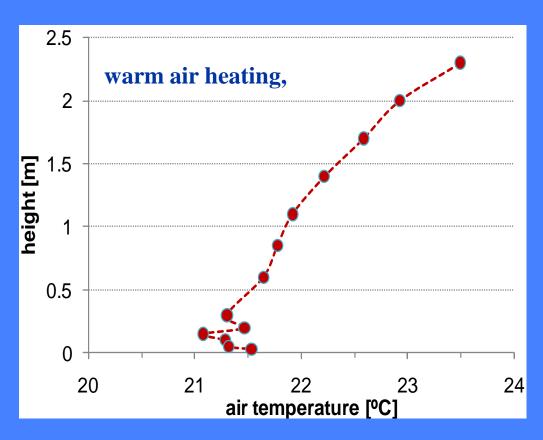


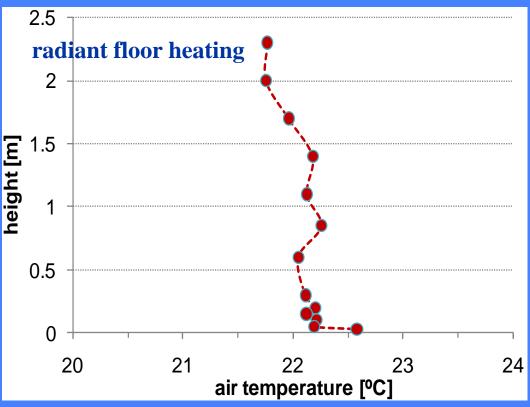






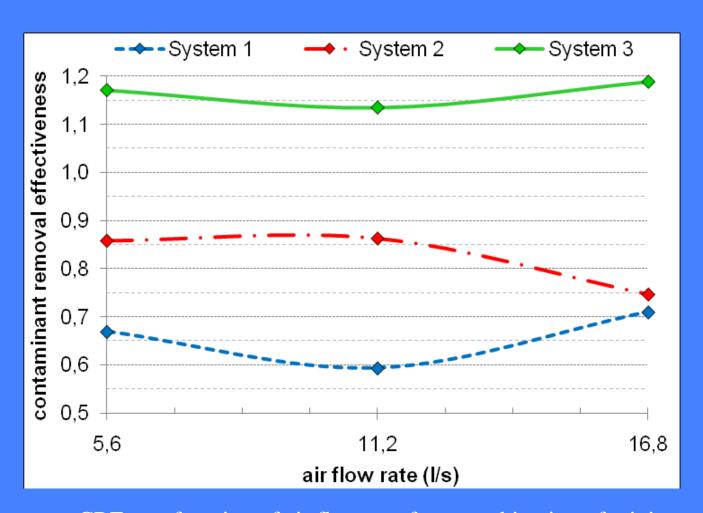
Vertical air temperature profile



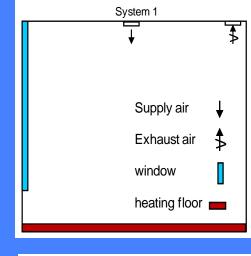


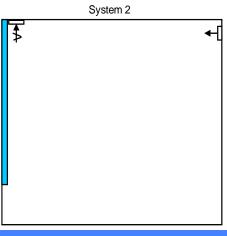
System 1 (ach=0.5 h⁻¹, internal gains=100 W) in the occupied zone

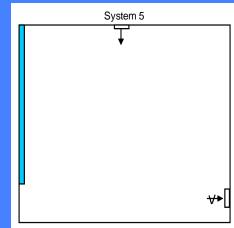
WARM AIR HEATING Contaminat Removal Effectiveness



CRE as a function of air flow rate for a combination of mixing ventilation and warm air heating, with internal gains of 90 W (cases 3, 4 and 7). The curves represent average in the occupied zone







Indoor Air Quality and Thermal Comfort in Zero Energy Buildings

Thermal Comfort

- More uniform conditions (radiant asymmetry, vertical air temperature differences)
- Less draught risk (reduced heat supply, no cold surfaces)
- Less difference between air and operative temperature
- Is individual room control important?
 - » Comfort
 - » Energy

Indoor Air Quality

- Tighter buildings
- Cannot rely on infiltration
- Can you heat with the ventilation system?
 - » Air distribution
 - » Ventilation effectiveness
 - » Individual room control





Indoor Air Quality and Thermal Comfort in Zero Energy Buildings

If an energy efficient measure also improve the indoor environment it will lower health risk and increase productivity and always be cost efficient.





Occupant behaviour and Energy Consumption

- Simulation study:
 - Occupant behaviour can affect energy consumption by more than 300 %
- Literature survey
 - In identical dwellings, the highest energy consumption is typically 2-3 times as high as the lowest
 - Differences as high as 600 % has been observed



