4015

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Air quality in a conference room with tobacco smoking ventilated with mixed or displacement ventilation

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AIR QUALITY IN A CONFERENCE ROOM WITH TOBACCO SMOKING VENTILATED WITH MIXED OR DISPLACEMENT VENTILATION

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Introduction

The thermal climate and the air quality are two of the most important factors in indoor climate which are affected by mechanical ventilation.

The thermal climate has been investigated in many years. The influence of different thermal parameters on a persons comfort is known and it is possible to calculate draught risk using P.O. Fangers draught risk model. Thus it is possible to quantify demands on air velocity and temperature to get acceptable thermal conditions. The development and practical experiences make it possible to design ventilation systems meeting those requirements.

Hundreds of unknown contaminants in the indoor air might occur. In what way they affect persons is still unknown. Therefore it is impossible to quantify general demands to air quality. Exsisting standards for ventilation recommend air exchange rates for different types of rooms or minimum outdoor air rates pr. person in order to obtain an acceptable air quality. But such design rules do not consider the influence of different ventilation systems such as mixed or displacement ventilation.

Purpose

Different investigations point tobacco smoke out as one of the decisive contaminants in non industrial environments. This investigation was carried out to determine the influence of different types of ventilation systems on the air quality in a room with tobacco smoking.

The purpose of the measurements was to decide, whether a decisive difference in air quality using mixed ventilation or displacement ventilation could be stated. The possibilities for subdivision of the room in a smoker and a non-smoker zone were tested and the measurements should determine how much the non-smokers would be exposed to tobacco smoke.

In another investigation with tobacco smoking and 2 persons using the room with normal activity no significant difference in air quality was found between displacement and mixed ventilation. Our own experiences (confirmed by this investigation) prove, that persons even with low activity disorganize the thermal stratification and cause increased mixing of air.

To decide the difference between the two types of ventilation without the influence of human activity, the experiments were performed using manikins to simulate the thermal loads of persons. In practice the difference will be less evident due to the increased mixing by human activity.

Air Quality

To describe a ventilation systems influence on the air quality, two different physical quantities are used: a) ventilation efficiency and b) age-of-air and air-exchange efficiency.

Ventilation efficiency

Ventilation efficiency expresses the concentration of a pollution related to the total air flow and the pollution source intensity. Ventilation efficiency can be used to describe the air quality in one point of the room or can be calculated as an average ventilation efficiency for a part of the room (e.g. the occupied zone) or the whole room.

Under steady conditions the concentration of a pollution in the extract is

(1) $C_{ex} = S / Q_v$

C_{ex} - concentration in extract

S - pollution source intensity

Q_v - total air flow

C_p - concentration in a point p

Local ventilation efficiency ε_l

(2) $\varepsilon_l = (S/Q_v) / C_p$

(3) $\varepsilon_l = C_{ex} / C_p$

Thus the local ventilation efficiency can be measured without knowing the pollution source intensity.

In a room with perfect mixing ventilation, the air quality in each point of the room and in the extract is the same. The local ventilation efficiency in all points of the room is $\varepsilon_l = 1$. Ventilation efficiency can be interpreted as the improvement of air quality compared with mixed ventilation.

The local ventilation efficiency in different points depends on the spreading of the pollution in the room and therefore (without using perfect mixed ventilation) on the location of the pollution sources.

The ventilation efficiency is not a characteristic of a ventilation system alone, but is only defined if a pollution can be stated. Different locations of the same pollution source can result in different ventilation efficiencies (not only in different points but also the average ventilation efficiency for the whole room).

Age-of-air and air-exchange efficiency

The age-of-air in a point is defined as the average age (time from entering the room) of all air particles coming through this point. As ventilation efficiency the age of air can be used locally or as an average for parts of the room. The air-exchange efficiency for the whole room is the local age-of-air in extract divided by twice the room-average age of air. The local age of air in extract is the reziproke of the air exchange rate (airflow divided by roomvolume).

Age-of-air and air-exchange efficiency describe the air flow in the room and is a characteritic of the room and the ventilation system alone. They can be used without any determined pollution in the room. Normally a better air

quality will be stated in points with a lower age-of-air. if the air is polluted everywhere in the room. But if the pollution source is located in a few points of the room and especially if the pollution is bound to thermal loads, air-exchange efficiency and age-of-air can not describe the air quality sufficiently.

Mixed Ventilation

In traditional mixed ventilation systems using nozzles or grilles placed at one side of the room, the air enters the room with high impulse and inlet velocity. This creates an air flow with perfect mixing of air in the whole room. So all contaminants are spread over the room and the air quality is the same in all points of the room and in the extract. In rooms with perfect mixing the local ventilation efficiency in all points is $\varepsilon_l = 1$.

Such systems can not meet the requirements to thermal climate in rooms with high thermal loads (> 30 W/m²). The air distribution systems have to be designed with several ceiling mounted diffusers located in the whole room. This causes lower inlet velocities and shorter air throws and the mixing of air between different parts of the rooms is considerable reduced. The age-of-air will still be the same in all points of the room, but the air now comes from different air inlets. The local ventilation efficiency can differ from one point to another, even if the air exchange efficiency is the same in the whole room (and even the same as with perfect mixing).

The air quality is not affected by the location of extract in rooms with perfect mixed ventilation. Neither does the extract location affect the air velocities in the occupied zone. Thus the location of the extract is often neglected in the design phase.

This investigation proves, that the extract location might affect the air quality in rooms with ceiling mounted diffusers, and the extract should not be neglected in the design of the air distribution system.

Displacement Ventilation

The principle of displacement ventilation is based on three types of air flow. The cold air is supplied to the room close to the floor and disperes over the whole room at floor level. Heat sources create a vertical thermal air flow (plumes) which transports air and pollutions from the occupied zone to the ceiling with increasing flow with the height. In the upper part of the room the vertical flow caused by thermal plumes is larger than the extract flow and so the exceeding flow recirculates in a zone coming down to a height, where the air flow in thermal plumes is equal to the extract air flow. This zone is called the "polluted zone". The flow in the polluted zone is affected by the thermal plumes and the location of the extract, which have a decisive influence on the spreading of pollutions in this zone.

Compared with mixed ventilation, the velocities in most parts of the room are much lower. Therefore location and thermal characteristics of pollution sources affect the air quality much more than in rooms with mixed ventilation. Many contaminants are bound to thermal loads (such as tobacco smoke and human bioeffluenter) and they are transportated quickly away from the breathing zone up to the polluted zone. If the boundary front between the polluted zone and the clean zone is clearly above the occupied zone, the air

quality in the breathing zone will be better than with mixed ventilation and the ventilation efficiency will be $\varepsilon_1 = 1$.

If the breathing zone is located in the polluted zone, the air quality in the breathing zone might vary depending on the kind af pollution and the design of the ventilation system. The air quality can still be better than with mixed ventilation, but it can also be worse, as the measurements indicate.

Many full-scale tests in rooms with 2.5 to 3.0 m height and with persons and e.g. PC's as thermal loads show, that the airflow must be about 0.020-0.025 m^3/s (75-90 m^3/h) for each 100 W thermal load, if the boundary front should be at about 1.8 m height. This implies, that the temperature difference between supply and extract air will not exceed about 4 K . Compared with mixed ventilation, where temperature differences up to 10 K are usual, displacement ventilation requieres much higher air flow for cooling, if a high boundary front shall garantee the advantages of better air quality in the clean zone.

Test room and conditions

All experiments were performed in the same room as shown in fig. 1. The test room had a low heat accumulation and all measurements were carried out under steady thermal conditions.

Supply and extract air flow were equal in all experiments. The leakage and infiltration with the surrounding room was less than 0.01 m^3/s (35 m^3/h).

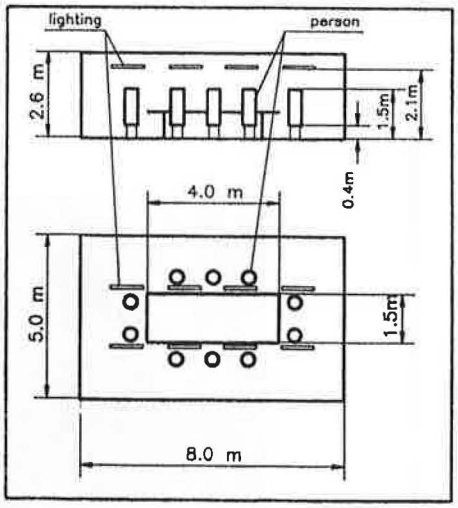


Fig. 1 : Test Room

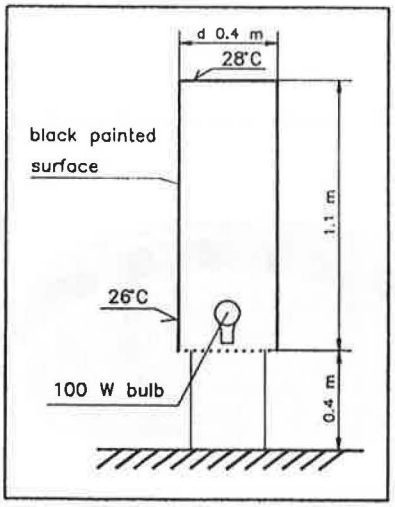


Fig. 2 : Person (Manikin)

The room was designed as a conference room for 10 persons. The persons were simulated with black painted steel cylinder as shown in fig. 2, heated with a 100 W bulb. The surface area was 1.65 m^2. At an air temperature of about 21-22°C the surface temperature was between 26°C (bottom) and 28°C (top).

Heat Loads (in all experiments) :	Persons: 10 x 100 W	= 1000 W
	Lighting: 8 x 36 W	= 288 W
	Total Heat Load :	1288 W

Supply air terminal devices

The air terminal devices were dimensioned due to following conditions:

1) Maximum air velocity in occupied zone 0.2 m/s
2) Minimum inlet velocity (in slot) 1.5 m/s
3) Maximum sound power level 35 db(A)
4) Near zone (displacement ventilation) 1.5 m

Mixed ventilation

The experiments were performed with perforated ceiling mounted diffusor with 20 mm slot, type Lindab-Riscanco UFO-N or UFO P.

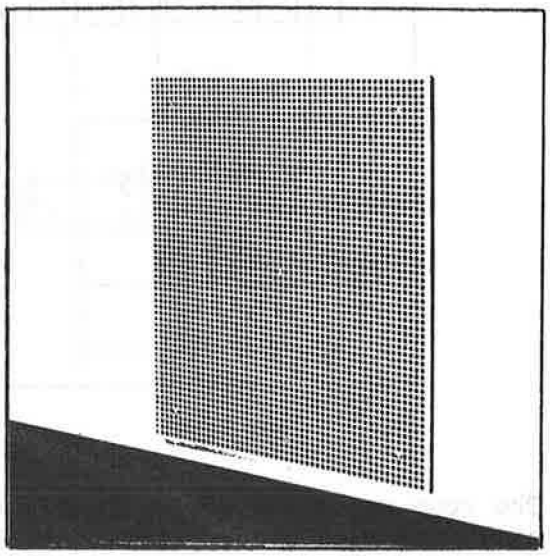
Air flow 0.139 m^3/s (500 m^3/h): 2 UFO-N 315
square diffusor a x b = 600 x 600 mm
duct size d = 315 mm
inlet velocity (slot) v = 1.5 m/s

Air flow 0.278 m^3/s (1000 m^3/h): 4 UFO-N 250
circular diffusor D = 460 mm
duct size d = 250 mm
inlet velocity v = 2.0 m/s

Displacement Ventilation
(all experiments) 4 COMDIF CDV-600 (Lindab-Riscanco)

This outlet is flat mounted in the wall with perforated front area, sized 540 mm x 580 mm. The outlet has high induction with 180° spreading of air.

UFO-N



COMDIF CDV-600

Measurements

Experiments with cigarette smoke

The experiments were carried out with real cigarettes and the smoke concentration was determined by carbon-monoxid (CO) measurements.

12 cigarettes were lit at a time and then burning in about 15 minutes without any inhalation. The next 12 cigarettes were lit by a person entering the room for about 2 minutes, avoiding unnescessary movements to minimize disturbance. Changing of cigarettes was repeated until steady conditions in the CO-concentrations were obtained. The dotted marks in the diagrams on page 6 - 9 indicate lighting and changing of the cigarettes. The last mark indicates, when smoke production by the last cigarretes stopped.

The results prove, that the CO-production by the cigarettes differs very little in the 7 experiments. The concentration in extract was about 3 ppm with a flow of 0.278 m^3/h (1000 m^3/h) and about 6 ppm with a flow of 0.139 m^3/h (500 m^3/h).

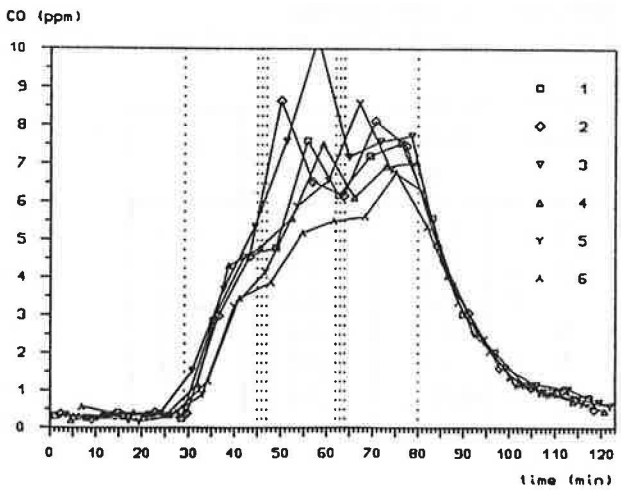
No.	Type	Flow m^3/s	Flow m^3/h	Extract location	Contaminant	Cextract ppm
1	mixed	0.139	500	corner	cigarettesmoke	6.20
2	displacement	0.139	500	center	"	5.40
3	displacement	0.139	500	corner	"	5.75
4	displacement	0.278	1000	center	"	3.18
5	displacement	0.278	1000	corner	"	3.26
6	mixed	0.278	1000	center	"	2.95
7	mixed	0.278	1000	corner	"	3.17
8	displacement	0.139	500	corner	SF_6 tracergas	

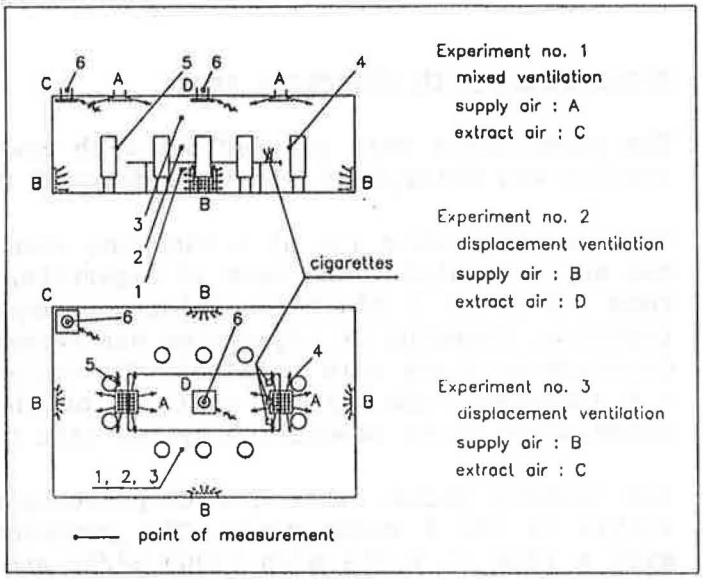
Experiment no. 1

Mixed ventialation
Extract in the corner
Flow : 0.139 m^3/s (500 m^3/h)
Heat Load: 1288 W

rettet

Point	Height m	Conc. ppm	ε_1
1	0.6	7.13	0.87
2	1.2	7.38	0.84
3	2.0	8.08	0.77
4	1.2	6.90	0.90
5	1.2	7.33	0.85
6	extr.	6.20	-

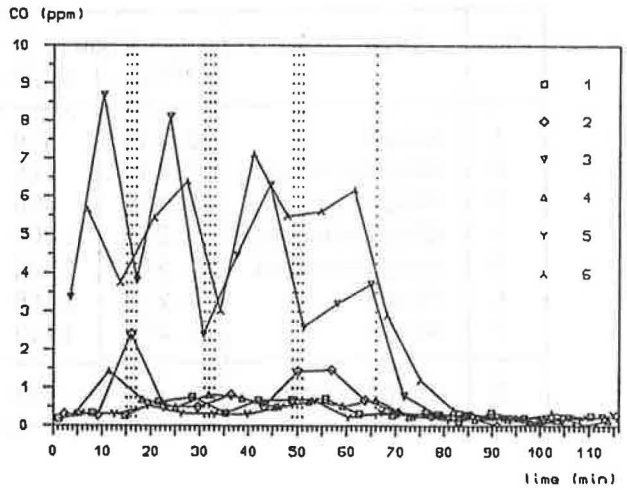




Experiment no. 2

Displacement ventilation
Extract in the room center
Flow : 0.139 m^3/s (500 m^3/h)

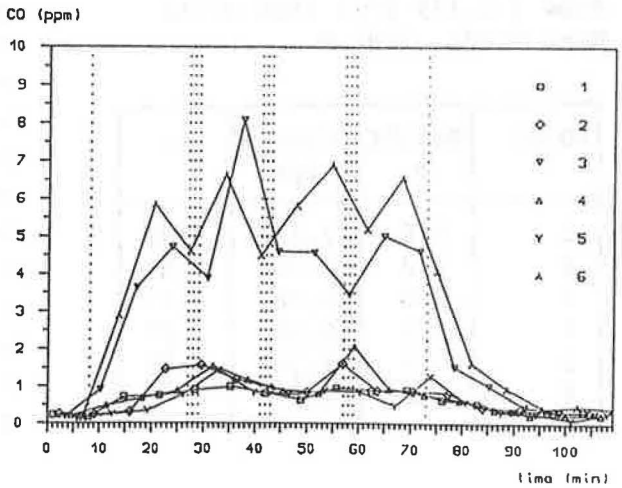
Point	Height m	Conc. ppm	ε_1
1 □	0.6	0.49	11.0
2 ◇	1.2	0.89	6.1
3 ▽	2.0	4.66	1.2
4 △	1.2	0.68	7.9
5 Y	1.2	0.39	14.0
6 ⅄	extr.	5.4	-



Experiment no. 3

Displacement ventilation
Extract in the corner
Flow : 0.139 m^3/s (500 m^3/h)

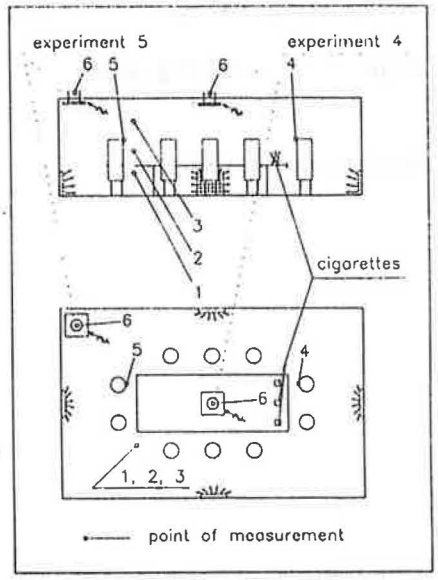
Point	Height m	Conc. ppm	ε_1
1 □	0.6	0.86	6.7
2 ◇	1.2	1.17	4.9
3 ▽	2.0	4.86	1.2
4 △	1.2	1.13	5.1
5 Y	1.2	0.91	6.3
6 ⅄	extr.	5.75	-



Displacement ventilation

Flow : 0.278 m^3/h
1000 m^3/h

Heat load : 1288 W

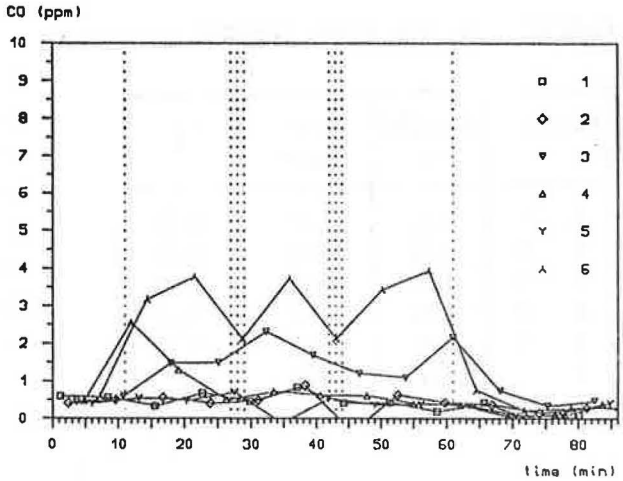


Experiment no. 4

Extract in the room center

Point	Height m	Conc. ppm	ε_1
1 □	0.6	*	> 4 *
2 ◇	1.2	*	> 4 *
3 ▽	2.0	1.63	2 *
4 △	1.5	*	> 4 *
5 ⊤	1.5	*	> 4 *
6 ⊥	extr.	3.18	-

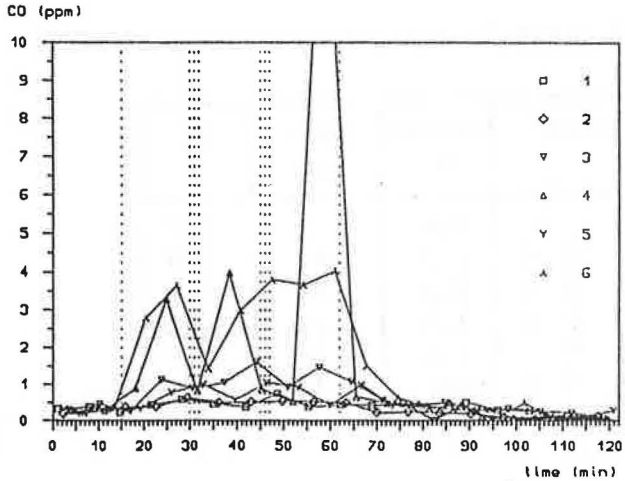
* Calculation impossible due to high background concentration



Experiment no. 5

Extract in the corner

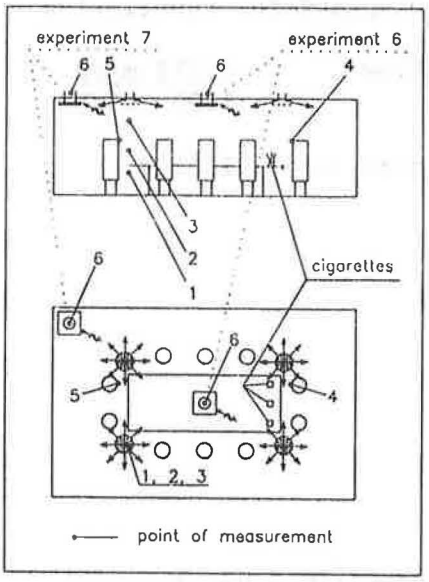
Point	Height m	Conc. ppm	ε_1
1 □	0.6	0.51	6.4
2 ◇	1.2	0.54	6.0
3 ▽	2.0	1.17	2.8
4 △	1.5	3.63	0.9
5 ⊤	1.5	0.82	4.0
6 ⊥	extr.	3.26	-



Mixed ventilation

Flow : 0.278 m^3/h
1000 m^3/h

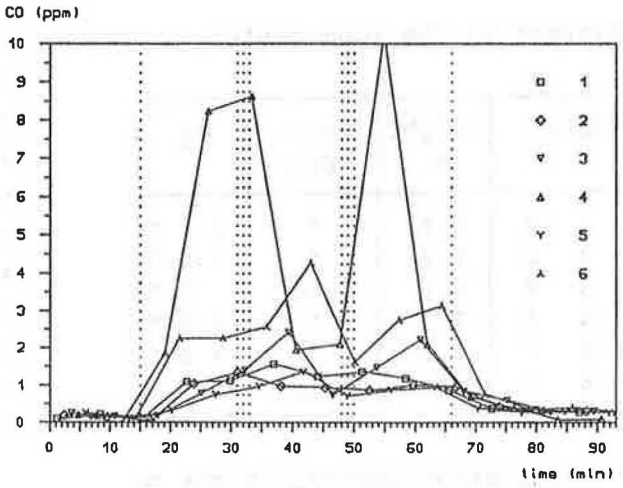
Heat load : 1288 W



Experiment no. 6

Extract in the room center

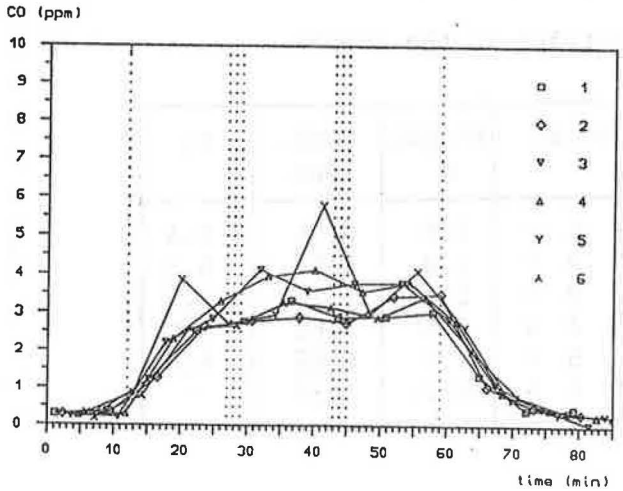
Point		Height m	Conc. ppm	ε_1
1	□	0.6	1.34	2.2
2	◇	1.2	1.03	2.9
3	▽	2.0	1.71	1.7
4	△	1.5	5.50	0.4
5	Y	1.5	0.98	3.0
6	⅄	extr.	2.95	-



Experiment no. 7

Extract in the corner

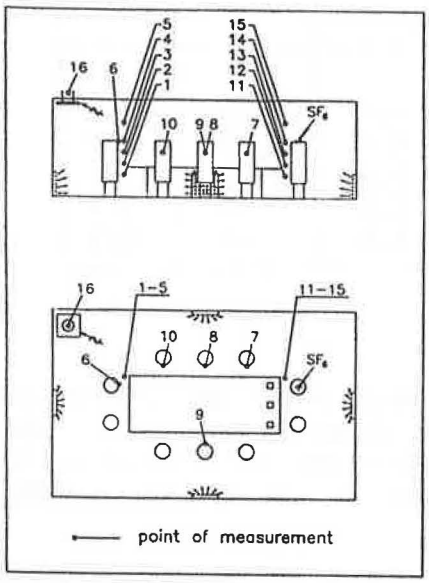
Point		Height m	Conc. ppm	ε_1
1	□	0.6	3.03	1.0
2	◇	1.2	3.46	0.9
3	▽	2.0	3.80	0.8
4	△	1.5	4.03	0.8
5	Y	1.5	4.28	0.7
6	⅄	extr.	3.17	-



Experiment no. 8

Displacement ventilation
Flow : 0.139 m^3/h (500 m^3/h)
Heat Load : 1288 W

(as experiment no. 2)



Point	Height m	Position	Source-distance m	Conc. ppm	ε_1
1	0.6	free	4.0	1.7	13.3
2	0.9	free	4.0	2.0	11.3
3	1.2	free	4.0	6.9	3.3
4	1.5	free	4.0	14.9	1.5
5	2.0	free	4.0	40.5	0.6
6	1.5	person	4.0	5.4	4.2
7	1.2	person	1.0	12.3	1.8
8	1.2	person	2.0	3.8	5.6
9	1.2	person	2.5	3.4	6.7
10	1.2	person	3.0	2.7	8.4
11	0.6	free	0.25	4.5	5.0
12	0.9	free	0.25	5.2	4.3
13	1.2	free	0.25	6.1	3.7
14	1.5	free	0.25	67.1	0.3
15	2.0	free	0.25	77.3	0.3
16	2.6	extract	6.2	22.6	-

In this experiment sulphur hexafluoride (SF_6) tracer gas was used to simulate a pollution . The tracer gas was supplied on the top of one manikin and distributed in the room with the convection flow. The results in the tabel above are measured under steady conditions after about 1 hour with constant SF_6 dosing.

Point 6 represents the breathing zone of one person. Point 4 is at the same level and only 0.25 m from point 6, but is placed free in the room outside the convection flow which surrounds a person. The results in these two-points prove, that the air quality in the breathing zone of a person might be better than in the sourrounding air, because cleaner air from lower levels is drawn up to the breathing zone with the convection flow. In this experiment, the contamination in the breathing zone was only about 35 % compared with the sourrounding air at same level. The concentration in 1.5m height in the convection flow of the person was the same as the concentration in the room in about 1 m height.

The convection flow from persons transports clean air from low levels up to the polluted zone and reduces the concentration of tracer gas in the polluted zone. This explaines the decreasing concentration in the polluted zone from the pollution source to the extract (point 14/15 - 4/5).

Results

Location of extract

Air flow m^3/s m^3/h Air distribution	0.139 500 displacement		0.278 1000 displacement		0.278 1000 mixed	
Extract location Experiment no.	center 2	corner 3	center 4	corner 5	center 6	corner 7
Point of measurement						
1 free	11.0	6.7	>4	6.4	2.2	1.0
2 free	6.1	4.9	>4	6.0	2.9	0.9
3 free	1.2	1.2	>4	2.8	1.7	0.8
4 smoker	7.9	5.1	>4	0.9	0.4	0.8
5 non smoker	14.0	6.3	>4	4.0	3.0	0.7

Tabel 1 : Local ventilation efficiencies ε_1

The location of the extract affects the local ventilation efficience and with it the air quality in all the experiments as shown in tabel 1. A location in the center of the room (above the table close to the pollution-source) results in a better air quality than a location of the extract far away in the corner.

The air flow in the room can be imagined as the superposition of two independent air flows.

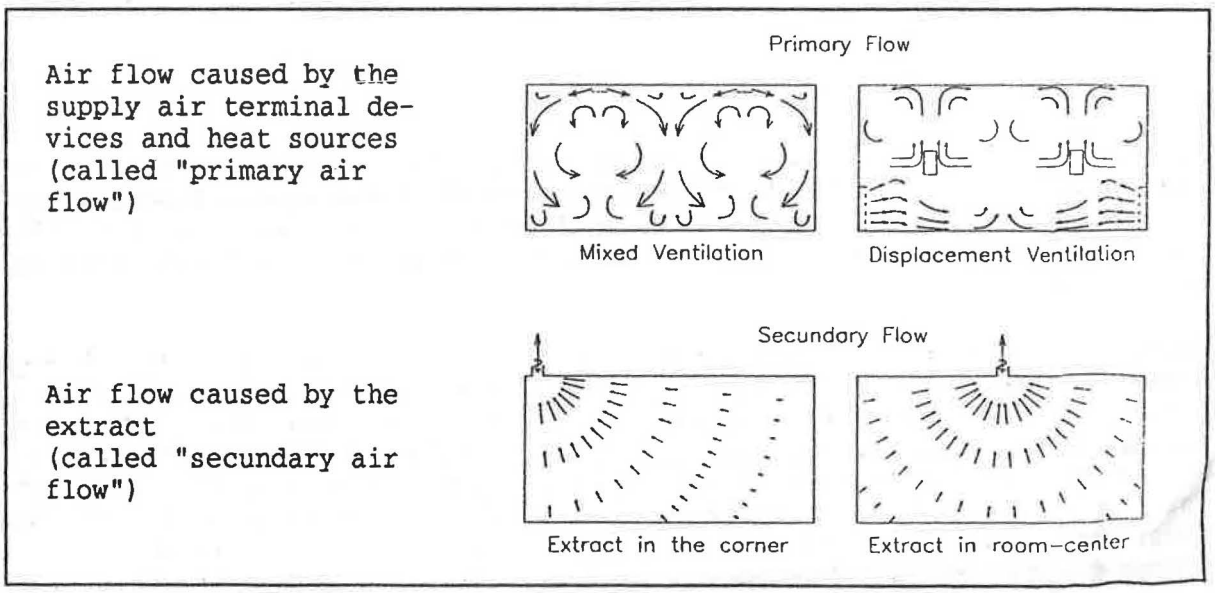


Fig. 3 : Primary and Secundary Flow

The imagination of a pollution source located only in the secundary air flow illustrates the influence of the extract location on the spreading of contaminants in the room.

Mixed Ventilation

The results of experiments 1 and 7 (extract in the corner) indicate a nearly perfect mixing of air (and cigarette smoke). The local ventilation efficiencies are (a little) less than 1 and this can be caused by a minor short circuit between supply and extract devices.

In experiment no. 6 (extract in the center) the local ventilation efficiencies in the left side of the room (non-smokers) vary between 1.7 and 3.0. This proves, that the cigarette smoke is not spread completly over the whole room.

Displacement Ventilation

a) Boundary front between clean and polluted zone

The experiments indicate, that the height of the boundary front between the clean zone and the polluted zone is unaffected by the location of the extract, if the extract is placed in the ceiling.

The height of the boundary front was determined by observing the smoke distribution in the polluted zone, when smoke was supplied to the room direct under the ceiling (using a smoke machine).

Total air flow		Air flow pr. person		Height of boundary front
m^3/s	m^3/h	m^3/s	m^3/h	m
0.139	500	0.014	50	1.3
0.278	1000	0.028	100	1.6 - 1.8

Tabel 2. : Air flow and height of the boundary front

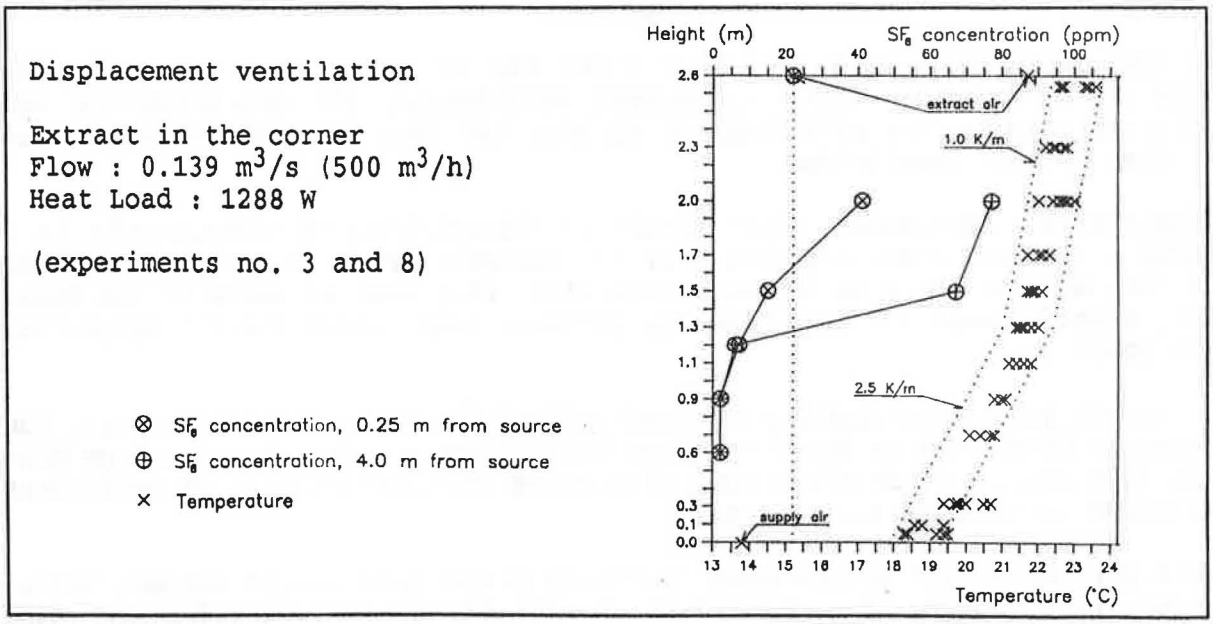


Fig. 4 : Temperature- and concentration gradient

b) Temperature- and concentration gradient

Fig. 4 shows the temperature at different heights, measured at several positions in the room outside the nearzone of the air inlets (experiment 3, displacement ventilation with 0.139 m^3/h (500 m^3/h)) and additionally the concentration of SF_6 at different heights, measured in experiment no. 8.

Especially near the tracer gas source the concentration increases abruptly at a height of 1.3 m and this verifies the visuel determined height of the boundary front.

The temperature gradient up to 1.3 m is about 2.5 K/m and above 1.3 m only about 1.0 K/m. In these experiments the change from the clean zone to the polluted zone is followed by a decreasing of the temperature gradient.

c) Akkumulation of contaminants

Remarkable is the high concentration of SF_6 in the upper part of the room (experiment no. 8). In a distance of 4 m from the pollution source, the concentration at a height of 2.0 m is about twice the concentration in the extract. This indicates a zone in the room, where an akkumulation of contaminants results in higher concentrations than in the extract. The air quality in this zone is worse than it will be with mixed ventilation.

d) Stability of stratification

In the experiments with displacement ventilation the changing of cigarettes obviusly affected the stratification of air. This low activity was sufficient to increase mixing of clean air from lower levels with polluted air from the upper part of the room. The mixing results in decreasing concentrations in 2 m height and increasing concentrations in 0.6 and 1.2 m height. After about 5 minutes the stratification was reorganized as measurements and visuel observations confirm.

Conclusion

In the experiments with cigarette smoke the air quality in the breathing zone was much better with displacement ventilation. The stratification was affected even by low activities of persons and this reduced the advantages of displacement ventilation.

Displacement ventilation might result in akkumulation of contaminants in a badly ventilated zone, especially if the contaminants have a high density or if they are not bound to thermal convection. This zone is close to the boundary front between the clean and the polluted zone, where the air velocities are lowest.

To ensure proper air quality in rooms with different pollution sources, the boundary front must be definite above the breathing zone. This requires high air flow rates, which often even with mixed ventilation will be sufficient to ensure acceptable air quality.

Both with mixed and displacement ventilation the location of extract influences the spreading of contaminants and the air quality considerably. Even with mixed ventilation the spreading of contaminants from one part of the room to another can be reduced with a suitable location of supply and ex-

tract air terminal devices. It is possible to devide a room in a smoker and a non smoker zone and reduce the smoke concentration in the non smoker zone.

Using displacement ventilationc might result in a higher draught risk than mixed ventilation. Close to the air inlets a zone with high velocities and low temperatures (near-zone) can be stated, which normally can not be used for permanent workplaces. The vertical temperature gradient is an additional factor in displacement ventilation, which might cause thermal discomfort.

It is not possible to determine a specific type of ventilation system resulting in a better air quality. Both systems must be evaluated in regard to the suspected pollutions and the individual design (type, number and location of air terminal devices). Besides the differences in thermal comfort have to be considered too.

Systems with low impulse ceiling mounted air terminal devices should be investigated. They might be able to combine some advantages of mixed and displacement ventilation. The ceiling mounted air inlets will reduce vertical temperature gradients and they do not affect the room arrangement in the near-zone. Low inlet velocities reduce mixing and spreading of air over the whole room and it will be possible to obtain high ventilation efficiencies when using suitable locations of extract.

Abstract

The air quality in a conference-room with tobacco smoking was investigated in full-scale tests. The room was ventilated with mixed or displacement ventilation and the tests were performed with different locations of the extract.

In experiments with cigarette smoke as contaminant a higher air quality in the occupied zone was obtained using displacement ventilation. In another experiment with a tracer gas as contaminant areas of low air quality (compared with mixed ventilation) were stated close to the breathing zone.

Both with mixed and displacement ventialtion the location of the extract had a considerable influence on the air quality. Even with mixed ventilation the room could be divided in a smoker and a non smoker zone and the smoke concentration in the non smoker zone could be reduced to about 50 % compared with perfect mixing.