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Efficiency of general ventilation on working area of convective contamination source

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EFFICIENCY OF GENERAL VENTILATION ON WORKING AREA OF CONVECTIVE CONTAMINATION SOURCE

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Abstract

This document purposes to provide a better understanding of general ventilation system performance on work places for industrial premises. The relationship between ventilation efficiency and air change efficiency in whole space and in local points is illustrated as well.

The studies were carried out in a full scale laboratory hall (27*16*9 m^3) with three different types of general ventilation systems that were driven at half and full power. In all of these six conditions air change efficiency and age distribution were determined by using tracer gas techniques and the test worker's exposure was monitored on all four positions around the work table as well. The work procedure simulated was hand welding (MIG) representing thermal active contamination sources.

The supply air systems and room air flow patterns created were as following: 1) mixing ventilation with horizontal wall jets creating cycling roller type air flow, 2) mixing ventilation with wall jets targeted on the source creating two direction deflected air flow, 3) with low impulse fed supply air at floor level creating a displacing flow.

Summary of the results show that the exposures between the studied conditions varied in the range of twenty. The position of the worker within the air flow pattern has a slightly greater effect on exposure than the supply air distributions does. This is especially the case with the source targeted air flow. The cycling air flow pattern gives the most stable and undisturbed, nonventilated type concentration field. In this case only doubled air flow caused increased exposure. The displacement ventilation systems give the slightly lowest average exposure in the vicinity of the convection contamination source. The most important fact is to create the correct air flow pattern at work places to transport contaminations as efficiently as possible away from the occupation zone.

1 Introduction

The purpose of ventilation is to remove contamination generated in a space as efficiently as possible. In assuming the ventilation efficiency the most important reference point is the breathing zone of the occupant. The contamination concentration of the breathing zone must not exeed the threshold limit value of the contamination.

The ventilation designer should be aware of the facts effecting the exposure of workers. The air change in a certain point is expressed by the local age. This tells how rapidly the room air is removed from the point by clean supply air. The air quality also depends on the characteristics of the source and the contamination. This is important to recognize especially when occupation is in the vicinity of the source. The third important factor is the behaviour of the worker and his position in regard to the source.

The distribution of air and contamination is the same if complete mixing takes place and the source of the contamination is dynamically passive and homogeneous. Thus the local equilibrium concentration can be given by the mean age of the air at the point in question. Neither of the above assumptions are entirely complied with in practice.

The quantifying of a ventilation system's function has to include the characteristics of the whole space and the local points. To realize the significancy of the room air flow on ventilation performance the air change characteristics in the whole space and local points have to be determined as well. There is no generally applicable quantitative relationship between local concentration and the contamination's or air's local mean age.

The definitions of ventilation efficiency used, are as follows /1/ and /2/:

- The specific flow, **n**, which states the magnitude of supply air flow

$$\mathbf{n} = \mathbf{q} / \mathbf{V} \qquad [\ m^3/h \ /\ m^3 \text{ or } 1/h] \qquad (1)$$

where

q is the supply air flow, [m^3/h]

V the volyme of the space, [m^3].

- The air change efficiency, ε_a , which states how quickly the air in the space is changed in relation to the quickest possible air change in theory.

$$\varepsilon_a = \tau_n / 2\langle\tau\rangle * 100\% \qquad [\ \%\ ] \qquad (2)$$

where

τ_n is the nominal time constant of the ventilation system, [h]

$\langle\tau\rangle$ the mean age of the air in the space, [h].

- The local air change index, ε_i, states the local average air age at an arbitrary point p in relation to the nominal time constant of the system.

$$\varepsilon_i = \tau_n / \tau_p * 100 \qquad [\ \%\ ] \qquad (3)$$

where

τ_p is the local average age of the air at a point p, [h].

- The average ventilation efficiency, $\langle\varepsilon\rangle^C$, states the average concentration in the space as a whole in relation to the concentration in the exhaust air.

$$\langle\varepsilon\rangle^C = C_e(\infty) / \langle C(\infty)\rangle * 100 \qquad [\ \%\ ] \qquad (4)$$

where

$C_e(\infty)$ is the concentration in the exhaust air, [mg/m^3]

$\langle C(\infty)\rangle$ the average concentration in the space, [mg/m^3].

- The (local) ventilation index, ε_p, states the local concentration in relation to the concentration in the exhaust air.

$$\varepsilon_p = C_e(\infty) / C_p(\infty) * 100 \qquad [\ \%\ ] \qquad (5)$$

where

$C_p(\infty)$ is the equilibrium concentration at an arbitrary point p in the space, [mg/m^3].

This document discusses the interaction of the air distribution system, the air flow rate and the dynamical convection function of the source in terms of the ventilation efficiency and the air change efficiency.

3 Laboratory experiments

The laboratory studies were carried out in the autumn of 1989 in the laboratory hall of the department of building technology at the Royal Institute of Technology in Stockholm in co-operation with Air-Ix Consulting Engineers.

3.1 Laboratory space

The entire net volume of the hall is approx. 3 300 m^3. The test area was located in the centre of the hall floor, see Appendix 1. At the eastern end of the laboratory hall exists a balcony at a height of three meters and with the depth of 9 m. The area underneath the balcony is closed on all sides. The free floor area is about 18*16 m^2.

3.2 Ventilation installation in laboratory and system classification

The laboratory hall was equipped with supply air terminal devices consisting of both mixing and displacing ventilation systems. The terminal devices are located on the northern wall. These devices include: four wall jets, type BVAA Φ 400 (made by Fläkt), for the mixing room air flow at a height of seven meters and three low impulse devices, type GKF Φ 500 (made by Stratos), for the displacing room air flow at just above floor level. The air flow rates of the ventilation installation are 1,5 m^3/s at half power and 2,75 m^3/s at full power the corresponding specific flow rates are 1,6 and 3,0 1/h that equals 3,5 and 6,4 $dm^3/s,m^2$. The air leakage of the hall varies between 5 - 15 % depending on the type of ventilation system used. See also Appendixes 1 and 2.

The ventilation systems used in the tests can be classified at a number of different levels. From the point of view of the whole space the two main functions are mixing and displacing. In mixing system room air velocities are higher and background concentrations equal. This is not the case however with *displacing flow* systems as room air velocities are lower and the background concentrations are vertically unequal. These two systems can be classified by fluid dynamics with Archimedes number, Ar, that is the ratio of thermal forces to inertial forces. When $Ar > 1$ the system will be classified as displacing and when the Archimedes number drops clearly below 1 the system will be classified as mixing according to the findings of Tapola and Koivula /3/. In these tests the Archimedes number in the mixing systems varied between 0,01 - 0,1 and in the displacing systems between 10 - 100.

In mixing systems the supply air jets and their direction have a remarkable effect on the concentration fields in the room air flow pattern. Therefore two types of mixing ventilation room flows were applied. The first of these was arranged in such a way that the wall jets were targeted on the floor either side of the source. In this case the primary jets were being deflected towards the jet wall and the opposite wall. So in fact the core jets did not hit the work place or the source but the room air flow pattern was directed diagonally parallel with the jets. This type of mixing room flow is termed here *source targeted flow*. The other mixing ventilation flow is called *cycling flow*. In this case the four wall jets were directed horizontally towards the opposite wall where the jet turned down and returned along the floor. Thus the room air flow pattern is cycling around a vertical axis of the space roller type. In the vicinity of the work place the room air flow is very slow and is directed diagonally towards the devices.

In the mixing flow conditions the temperature between the occupation zone air and the supply air varied from -2 ... +3 °C and in the displacing flow conditions +0,5 ... +3 °C.

The conclusion of the ventilation conditions studied that were in total six, is as follows. Two mixing flows: *cycling flow* and *source targeted flow* and one *displacing flow* and all of these three were driven at *half* and *full* supply air flow. Fig. 1 illustrates the studied room air flow conditions.

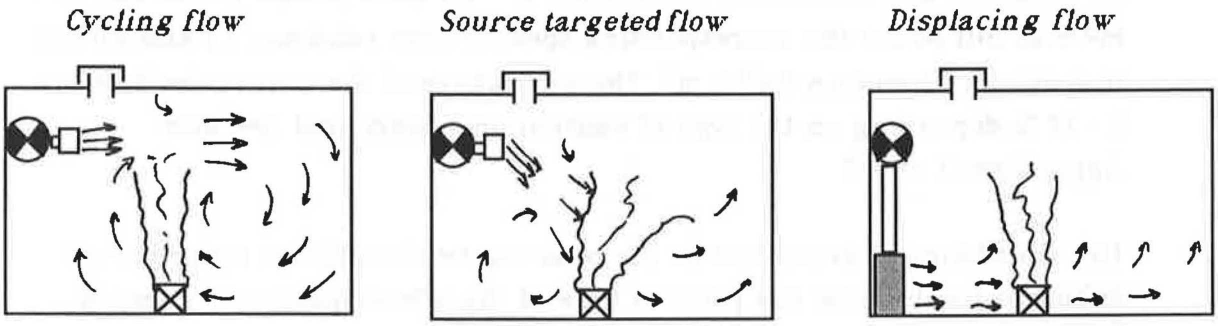


Fig. 1 The studied room air flow patterns

3.3 Contamination source and work procedure

In laboratory studies a dynamically active hot source that created a vigorous natural convection flow was used. According to the extent and size of the source it can be characterized as a point source. The work procedure was hand welding (MIG) with the electrical power of approx. 5,0 kW. The welding trials took place on a work table with a height of 0,68 m and a lattice surface area of 0,62*0,46 m^2. The H-shaped welding steel test-pieces were placed at the centre of the table and were 0,25*0,075*0,05 m^3 in initial size and 2,8 kg in initial weight. The same welding procedure took place under each six different ventilation conditions. The welder was seated on all four sides of the table in his ergonomic posture. See also Appendix 2. The distance from the welding electrode to the welder's breathing zone was vertically 0,42 m and horizontally 0,41 m.

3.4 Methods of measurements

The welding fume concentration was measured with sample filters. The sample air was sucked through the welding mask by a sample pump. In order to achieve reliable sample concentrations welding times varied between 10 and 45 minutes. During each trial the fume concentration of the exhaust air and the active welding time was recorded. At the same time the temperature field around the work place as well as supply and exhaust air temperatures were recorded with thermo-elements and a datalogger. The purpose of temperature measurements was to control that the temperatures keep constant.

The age distribution of the room air and the air change efficiency was measured in each ventilation condition without the active source. The tracer gas system used is described in Appendix 3. The room air velocities in the work place were measured with a low velocity thermal anemometer in each ventilation condition without the active source.

4 Results

4.1 Room air velocities

The room air velocities caused by mechanical ventilation were measured at the heights of 0,65, 1,15 and 1,65 m, in the source line. The mean velocities and the turbulence grade are determined for the six ventilation conditions that are the three room air flow patterns at half and full fan speed. The results are in table 1.

Table 1. Room air velocities and turbulence grades

Room flow pattern	Mixing ventilation				Displacement v.		*Mean*	*σ*
	Cycling flow		Source targ. flow		Displacing flow			
n [1/h]	1,6	3,0	1,6	3,0	1,6	3,0		
v [cm/s]	4		19		8		*10*	*8*
v [cm/s]		10		36		15	*20*	*14*
Tu [%]	31		34		14		*26*	*11*
Tu [%]		34		37		19	*30*	*10*

4.2 Air change efficiency and local air change index

The local air change indexes are determined from the age of the air just behind the work place on the height of the worker's breathing zone. The air change efficiency values for the whole installation and local air change indexes for all six ventilation conditions are in table 2.

Table 2. Air change efficiency and local air change index

Room flow pattern	Mixing ventilation				Displacement ventilation	
	Cycling flow		Source targ. flow		Displacing flow	
n [1/h]	1,6	3,0	1,6	3,0	1,6	3,0
ε_a [%]	50	49	50	52	68	67
ε_i [%]	100	100	95	110	410	330

4.3 Local ventilation index

The local ventilation indexes are determined in all six ventilation conditions and in all four sitting positions around the work table (P 1, P 2, P 3, P 4). The breathing zone and the exhaust air concentrations have been converted to correspond equally to 100 % welding time.

Table 3. Local ventilation indexes of the worker's breathing zone, ε_p [%]

Room flow pattern	Mixing ventilation				Displacement v.		*Mean*	*σ*
	Cycling flow		Source targ. flow		Displacing flow			
n [1/h]	1,6	3,0	1,6	3,0	1,6	3,0		
Worker's position								
P 1	135		65		95		*98*	*35*
P 1		140		35		180	*118*	*75*
P 2	160		30		120		*103*	*67*
P 2		120		15		55	*63*	*53*
P 3	150		85		120		*118*	*33*
P 3		180		310		270	253	67
P 4	175		90		150		*138*	*44*
P 4		105		130		270	*168*	*89*
mean	**155**	**135**	**65**	**120**	**120**	**195**	**132**	
σ	17	32	27	135	22	102		
			+ LE		+ LE			
P 2			750		870			

+LE: general ventilation type mentioned above reinforced with local exhaust

5 Discussion

The purpose of general ventilation is to create a favourable room air flow pattern to control exposure in industrial working premises. By creating the correct microclimate at the work place it is able to minimize the exposure. The facts to be concidered in designing are the flow pattern between the source and the breathing zone as well as the flow field induced by the source and the jets and their interaction.

The position of the worker seems to have the more importance the higher air velocities exist at the work place. At the highest the ratio of the highest and lowest exposure between worker positions is over twenty (310%/15%).

The ratio between the highest and lowest mean indexes is four (253%/63%). The corresponding ratios between ventilation conditions are eleven (160%/15%) and three (195%/65%). The effect of worker's position seems to be a little more significant than the effect of ventilation in these test cases. In the system comparision the displacing flow seems to be the most efficient one when thermal active sources are present (the average values of the system mean indexes are: 145%, 95% and 160%).

At the work place in the vicinity of the hot source the less disturbing the room air flow the better the air quality achieved. This kind of undisturbed flow pattern can be installed in certain areas in the hall with the cycling and displacing flow patterns. In the case of high impulse wall jets the convection flow spreads out causing increased worker exposure. The displacing flow gives a decreasing exposure with an increased air flow rate whereas higher flow rates in the cycling flow cause higher exposure.

The research will be continued in the spring of 1990 with a solvent bath representing a thermal passive source. The computational verification of convection flows in ventilated spaces is being considered to carry out for the near future.

The clear fact is of course that the local exhaust system is necessary in the hand held work procedures like welding. But the differences between the studied cases were so significant that they should be taken into consideration in the practical general ventilation system selection and in the supply air flow dimensioning.

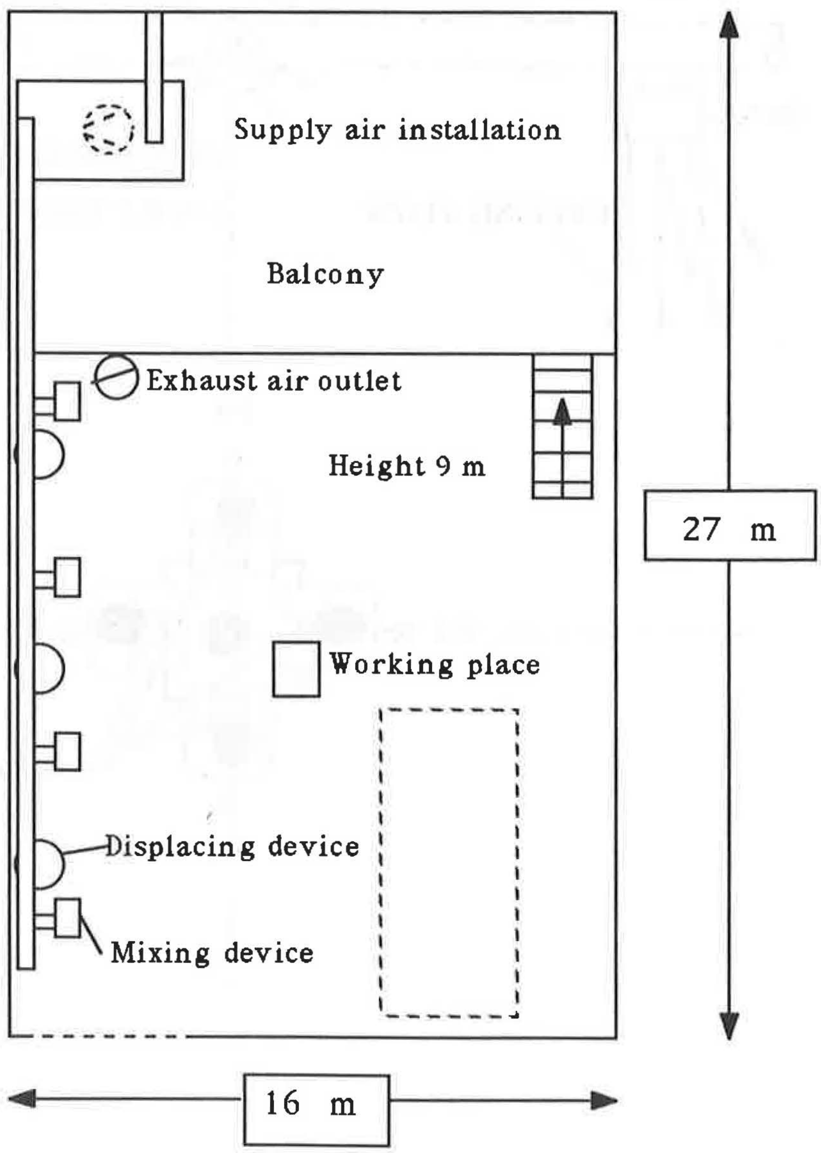
Litterature

/1/ Nordtest method NT VVS 019. Buildings - Ventilation Air: Local Mean Age.

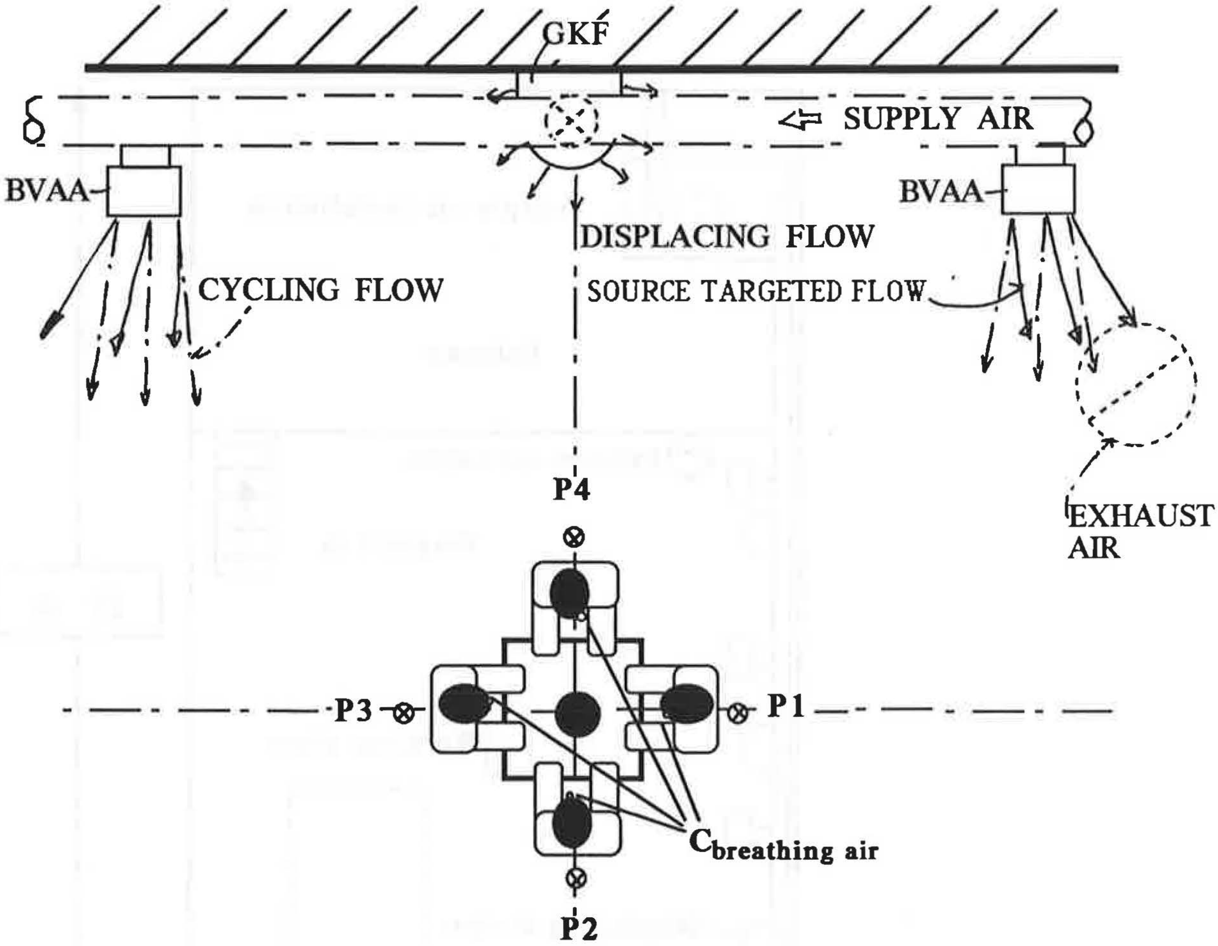
/2/ Nordtest method NT VVS 047. Buildings - Ventilating air: mean age of air.

/3/ M. Tapola and K. Koivula, Syrjäytysilmanvaihto teollisuustiloissa. (Displacement Ventilation in Industrial Premises) KTM sarja D:173. Helsinki 1989. (In Finnish).

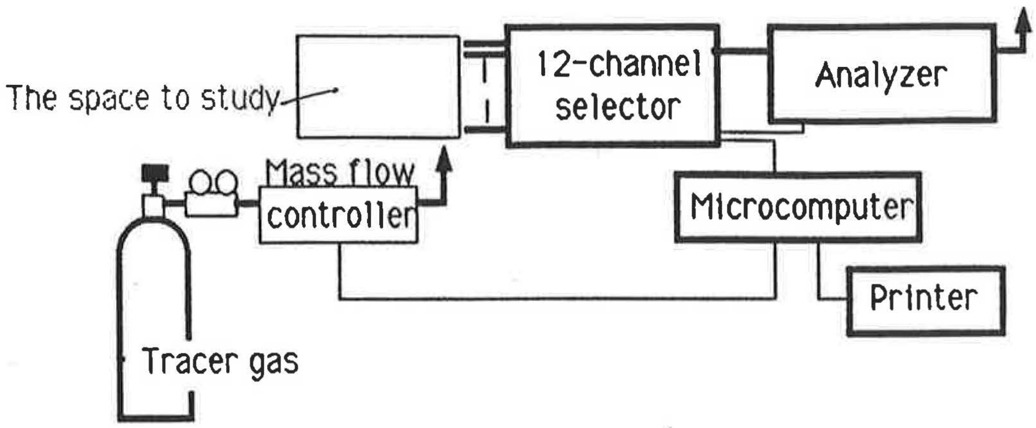
THE PLANE VIEW OF THE LABORATORY HALL



THE TERMINAL DEVICES OF THE SUPPLY AIR SYSTEM
AND WORKER'S POSITIONS



System configuration



Specifications

Microcomputer

* IBM - PC/XT/AT or compatible
  - ☐ expansion slot (full size board)
  - ☐ hi-res graphics adapter and monitor
  - ☐ data acquisition board
  - ☐ serial or parallel port (printer)
* AIR-IX software

Printer

IBM graphic printer compatible

12 channel selector

* sample tubes
* solenoid valves
* pump
* flow control valve
* control unit

Analyzer

* optional (depending on tracer gas) e.g. Binos IR-analyser
  - ☐ meas. gas e.g. N_2O, SF_6
* DC output

Tracer gas system

* tracer gas bottle (not included)
* pressure regulation valve (not included)
* mass flow controller
  - ☐ external control via computer
  - ☐ DC output

Power supply 220 V 50 Hz

Specifications and design subject to change without notice for improvements.