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Influence of Type of Ventilation and Outdoor Airflow Rate on the Prevalence of SBS Symptoms

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ABSTRACT

As part of the Office Illness Project of Northern Sweden, the influence of type of ventilation and outdoor airflow rates on sick building syndrome (SBS) symptoms is analyzed. Measured mean ventilation rates are higher than newly adopted or proposed standards or guidelines (ASHRAE 1989; NKB 1991). Low outdoor airflow rates correlate strongly with high prevalences of general symptoms but not so strongly with mucous membrane and skin symptoms. The sensation of "dry air" is strongly correlated with symptoms and outdoor airflow rates but not with humidity. To reduce general symptoms, it seems likely that ventilation rates have to be raised.

INTRODUCTION

Requirements for airflow rates for building ventilation have varied over the years. After Yaglou's studies (Yaglou et al. 1936) in the 1920s and 1930s, the view of ventilation requirement levels was largely unchanged for a long time. The typical minimum value for general office spaces was 7.5 L/s of ventilation air per person, as recommended by ASHRAE (1977). As a result of the energy conservation debate in the 1970s, requirements in nonsmoking areas were reduced to minimum values of 2.5 (ASHRAE 1981) and 4 L/s per person (NKB, Nordic Committee on Building Regulations 1981). For smoking areas, the minimum value was 10 L/s per person in both standards. The increased interest in clean air during the last decade, due to problems with, for example, radon, formaldehyde, and sick building syndrome, has resulted in revised requirements with raised minimum values of 10 L/s (ASHRAE 1989) and about 11 L/s per person (NKB 1991) for office spaces. The ASHRAE standard has the same requirements regardless of smoking as opposed to the NKB guideline, where 20 L/s per person is recommended for areas where smoking is allowed.

Ventilation standards have, historically, been based on the assumption that man himself is the main source of indoor pollution, mainly body odors. The classic measure of air quality has been the extent to which odor is perceived as acceptable by visitors directly on entry into the premises. This measure was used by Yaglou and has in recent years been developed by Fanger (1988). In addition, Fanger has quantified the sensory load of pollution sources other than persons, expressed as person equivalents, which include building materials, fixtures, fittings, furnishings, and furniture. They are commonly the dominant odor sources indoors. Fanger has proposed that in existing buildings that have a large sensory pollution load, the ventilation requirement might have to be 50 L/s per person and in buildings with a low pollution load, 14 L/s per person, corresponding to approximately 20% dissatisfied (Fanger 1988).

Although inadequate ventilation is a common denominator in buildings with sick building syndrome (SBS) (NIOSH 1987; Valbjörn et al. 1990), measurements of airflow rates are scarce in major studies of problem buildings. More commonly, the prevalence of SBS symptoms has been studied with reference to the type of ventilation or air-conditioning system used. Typically, high prevalence of the syndrome has been associated with modern air-conditioning systems (Valbjörn and Skov 1987; Hedge et al. 1989) and low prevalence with naturally ventilated buildings.

In a major office complex, however, Jaakola et al. (1988) have found a significant correlation between the outdoor airflow rate and the incidence of SBS symptoms when the airflow was less than 5 L/s per person. Their conclusion was that the airflow rate should not be less than 10 L/s per person.

The focus of this paper is to demonstrate the association in office buildings between ventilation characteristics and outdoor air rates on the one hand and the prevalence of sick building symptoms on the other hand. The report is a part of the Office Illness Project of Northern Sweden (Stenberg et al. 1990a, b; Sundell et al. 1990; Sandström et al. 1990).

MATERIALS AND METHODS

A total of 5,986 office workers were selected from all office employees in workplaces with more than 10 office workers in the county of Västerbotten in northern Sweden. A tested and validated questionnaire on demographic factors, work characteristics, perceptions of physical climate and psychosocial factors, symptoms, and building characteristics at work and home were used (Stenberg et al. 1990a). The questionnaire return rate was 95.7%. After excluding 13% of the respondents, because they spent less than half their work time in the office, were absent from work during the study period, etc., 4,943 office workers remained in the questionnaire study.

Investigations of indoor climate and measurements of ventilation were carried out in offices of 540 persons in 160 of about

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210 buildings. In the buildings investigated, 3,926 of the persons in the study worked. Of these, 2,649 worked in offices for one or two persons, and measurements were made in the buildings of 2,586 of these persons.

The supply and/or the exhaust airflow or the air exchange rate were measured once in each room. In 120 of the 160 buildings, 2 to 23 rooms were measured. Offices for one or two persons were measured in 128 buildings, and in 80 of these buildings, 2 to 23 rooms were measured. Measurements were carried out as specified by the Nordic Ventilation Group (NVG 1982). Calibrated hot-wire instruments and IR instruments were used. As a tracer gas (for the decay method), nitrous oxide was chosen. Doors and windows were closed during measurements. The recirculation air rate as well as leakage of exhaust air into the supply air were measured with tracer gas. Temperature and humidity were measured at three heights in the workplace (0.1 m and 1.1 m above the floor and 0.1 m below the ceiling) and in the supply air. Measurements and inspections were made from January to April. The mean outdoor temperature was 2°C with small variations. For more details about the total study, see Stenberg (1990a, b), Sundell (1990), and Sandström et al. (1990).

Symptoms were divided into three groups: General symptoms include "fatigue," "feeling heavy-headed," "headache," "nausea/dizziness," and "difficulties concentrating." Mucous membrane symptoms include "itching, burning, or irritation of the eyes," "irritated, stuffy, or runny nose," "hoarse or dry throat," and "cough." Skin symptoms include "dry facial skin," "flushed facial skin," and "itchy, stinging, tight, or burning sensations in facial skin." In the questionnaire, answers were to be given in one of three categories: "Yes, often (every week)," "Yes, sometimes," or "No, never." Cases in the analysis are persons who have answered "Yes, often" to at least one of the symptoms.

In the analysis, buildings are weighed by the number of persons working in them. The data were analyzed using standard statistical packages. The significance level chosen is $p < 0.01$. Significant associations are denoted "*" and nonsignificant ones "ns." In some instances, the odds ratio (OR) is calculated. The odds ratio is the ratio of the odds of exposure among the cases to that among the controls (with OR = 1).

RESULTS

Three percent of the 160 office buildings had "natural" ventilation and three percent mechanical exhaust only. The rest (94%) had mechanical exhaust and supply systems, with heat exchangers in 59%. Recirculation of air was used in 30% of the buildings. Twenty-three percent of the systems were operated 24 hours a day. The rest had a median of 11 operating hours during weekdays. During holidays, 71% of the systems were shut off. Some characteristics of ventilation are given in Table 1. The mean outdoor air rate was about 17 L/s per person with large differences between different types of systems.

A subgroup of buildings was formed after stratification with regard to size of offices (one/two-person offices included), size of study population in the building (> 20 men or women), and number of measured rooms in the building (≥ 2). Larger offices, such as open-plan offices, are not included in this subgroup, as they differ from smaller offices in a way that would hide the influence of the ventilation parameters under study. The subgroup was stratified with regard to sex. The 22 buildings assessed for men and the 19 for women have the following characteristics: the majority were public service buildings with one to six floors. The mean number of years since construction or renovation was nine (SD 7). In this subgroup of buildings, none had natural ventilation and only one had mechanical exhaust (see Table 2). The mean operating hours for the ventilation were 15 hours during weekdays.

Studies of the variation in room airflow rates within and between buildings show that the interbuilding variation by far exceeds the intrabuilding variation.

TABLE 1
Room Ventilation Characteristics for Measured Office Buildings (e = exhaust, s = supply, x = heat exchanger)

Type of ventilation	Supply air l/s,p mean	Supply air l/s,p SD	Outdoor air l/s,p mean	Outdoor air l/s,p SD	Buildings measured n	Rooms measured n
Natural	4.6	2.1	4.6	2.1	5	10
Mechanical e.	8.6	7.5	8.6	7.5	6	19
Mech. e-s	23.5	20.0	14.7	11.2	52	187
Mech. e-s-x	21.1	14.2	18.9	13.9	97	320
Total pop.	21.8	16.5	16.9	13.0	160	540

TABLE 2
Outdoor Airflow Rates to Rooms and Type of Ventilation in the Subgroup of Office Buildings with ≥ 20 Men or Women Working in One/Two-Person Offices (e = exhaust, s = supply, x = heat exchanger)

Type of ventilation	Outdoor air l/s,p mean men	Outdoor air l/s,p mean women	Buildings n men	Buildings n women	Rooms n men	Rooms n women
Natural	-	-	0	0	0	0
Mechanical e.	-	8.1	0	1	0	23
Mech. e-s	14.6	12.8	7	9	211	277
Mech. e-s-x	18.8	13.2	15	9	419	321

TABLE 3

Odds Ratios (and 95% Confidence Interval) for General, Mucous Membrane, and Skin Symptoms for Men and Women Working in One/Two-Person Offices as a Function of Type of Ventilation System (e = exhaust, s = supply, x = heat exchanger)

	Type of ventilation			
	Natural	Mech. e.	Mech. e-s	Mech.e-s-x
Men				
No. persons	20	30	478	758
Gen. sym.	1.00 (0.3-3.2)	0.61 (0.2-1.9)	1.04 (0.78-1.40)	1
Mucous.m.s	1.43 (0.4-4.7)	0.63 (0.2-2.2)	1.27 (0.92-1.8)	1
Skin sym.	2.42 (0.66-8.0)	1.08 (0.3-3.8)	0.86 (0.56-1.32)	1
Women				
No. persons	23	68	510	762
Gen.sym.	1.13 (0.4-2.8)	0.96 (0.55-1.7)	0.70 (0.54-0.89)	1
Mucous.m.s.	1.11 (0.4-2.9)	1.13 (0.64-2.0)	0.75 (0.58-0.98)	1
Skin sym.	1.61 (0.6-4.1)	1.25 (0.70-2.2)	0.96 (0.73-1.25)	1

TABLE 4

Correlation between the Prevalence of Specific Symptom Groups and the Outdoor Airflow Rate for Workers in a One/Two-Person Office (Linear Regression)

Group 1: ≥ 1 room measured.
Group 2: ≥ 2 rooms measured.
Group 3: ≥ 2 rooms measured, ≥ 20 occupants in the building.

	Buildings n	Persons n	Symptoms General	Mucous m	Skin
			Correlation coefficients		
Men					
Group 1	105	1240	-0.14 *	-0.13 *	-0.09 *
Group 2	69	1052	-0.22 *	-0.13 *	-0.08 *
Group 3	22	656	-0.46 *	-0.05 ns	-0.38 *
Women					
Group 1	119	1346	-0.15 *	0.03 ns	0.06 ns
Group 2	75	1181	-0.24 *	-0.13 *	0.01 ns
Group 3	19	621	-0.39 *	-0.31 *	-0.10 *

Type of Ventilation vs. Symptoms

The odds ratios for having symptoms as a function of type of ventilation are given in Table 3. The table is based on the 2,649 office workers working in one/two-person offices. There is no conclusive trend in these associations. Women, but not men, seemingly display fewer general and mucous membrane symptoms in buildings with mechanical exhaust and supply systems without heat exchangers.

Outdoor Airflow Rate vs. Symptoms

With linear regression, the association between the outdoor airflow rate and the prevalence of different types of symptoms has been analyzed. The results are given in Table 4 for different subgroups of buildings. Figures 1 through 3 show the linear regression lines for buildings with more than 20 occupants (Group 3 in Table 5).

Some Environmental Perceptions vs. Outdoor Airflow Rate The relationships between the environmental perceptions of "dry air" and "noise" and the outdoor airflow rate as a result of linear regression are given in Figures 4 and 5. The relationships shown are statistically significant.

"Dry Air" vs. Temperature and RH The sensation of "dry air" is commonly found in investigations of suspected sick buildings. The prevalence and odds ratios for reporting symptoms when answering "Yes, often" with regard to the sensation of "dry air" are given in Table 5. Figures 5 and 6 give the relationships (linear regression) between this sensation, the relative humidity, and the outdoor airflow rate.

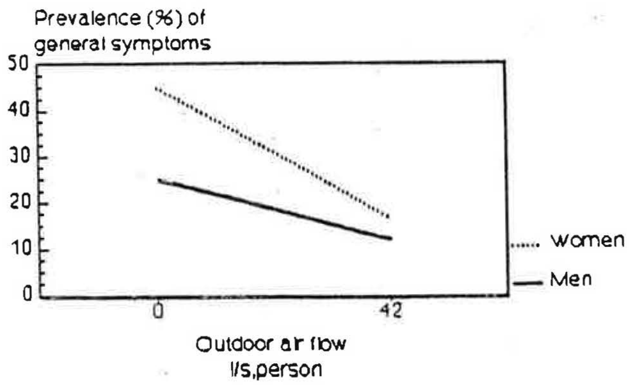

Figure 1 Prevalence of general symptoms as a function of the outdoor airflow rate. Group 3 in Table 4. Corr: women −0.39, men −0.46*.*

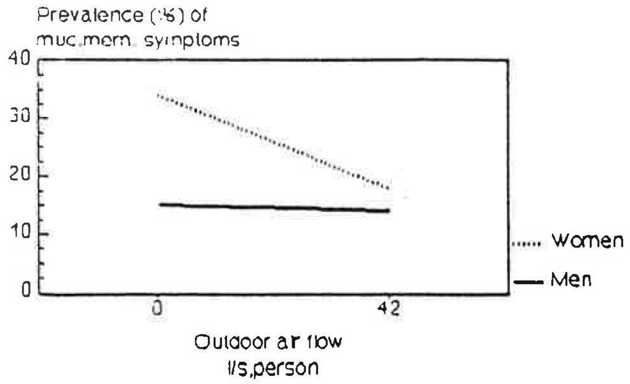

Figure 2 *Prevalence of mucous membrane symptoms as a function of the outdoor airflow rate. Group 3 in Table 4. Corr: women −0.31*, men −0.05 ns.*

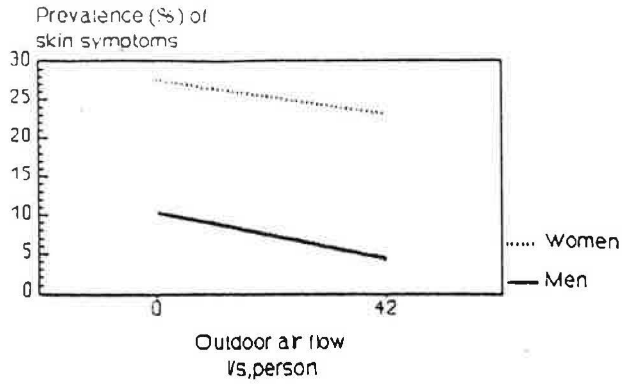

Figure 3 *Prevalence of skin symptoms as a function of the outdoor airflow rate. Group 3 in Table 4. Corr: women −0.10*, men −0.38*.*

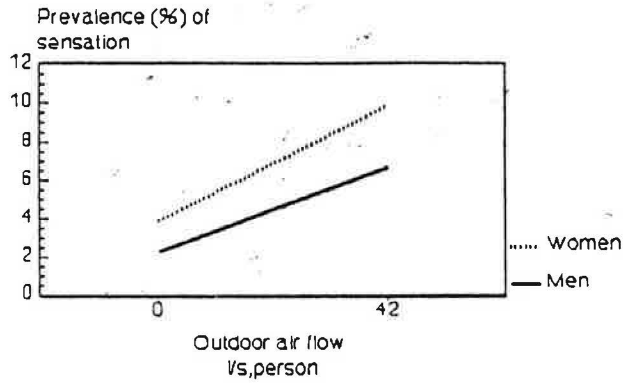

Figure 4 *Sensation of noise as a function of the outdoor airflow rate. Corr: women 0.20*, men 0.28*.*

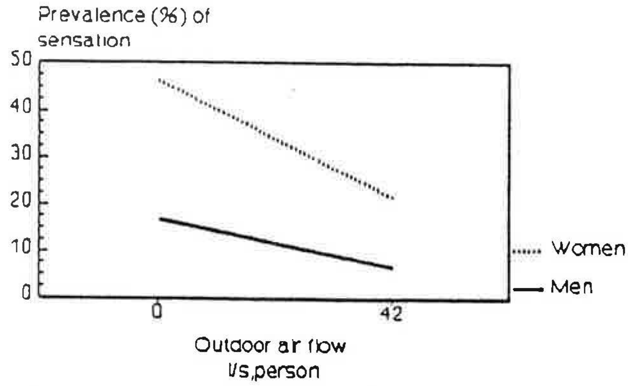

Figure 5 *Sensation of dry air as a function of the outdoor airflow rate. Corr: women −0.39*, men −0.30*.*

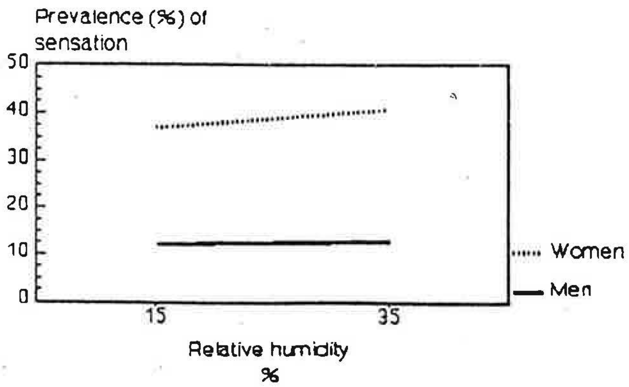

Figure 6 *Sensation of dry air as a function of measured relative humidity. Corr: women 0.06 ns, men 0.01 ns.*

DISCUSSION

Ventilation rates in rooms in office buildings are higher than expected. Few buildings have ventilation rates as low as the newly proposed or adopted standards (ASHRAE 1989; NKB 1991). It appears from this study that the designers of ventilation installations have used rules of thumb regardless of standards, i.e., dimensioned for about 2 ach in office rooms.

There is little in this material to indicate that the type of ventilation is associated with the occurrence of SBS symptoms in general. It should be noted, however, that air-conditioning systems with cooling and humidification, which in other studies have been correlated to high prevalences of symptoms, are sparsely used in Sweden.

From Table 4 and Figures 1 through 3, it can be seen that the prevalence of symptoms tends to be low when outdoor airflows are high or the reverse. The relationship is less pronounced with regard to mucous membrane and skin symptoms when considering both men and women. General symptoms are decidedly associated with the ventilation rate. These results are surprising, since they suggest that increased ventilation and thus reduced pollution levels appear to diminish general symptoms.

Noise is a well-known cause of general symptoms, and high ventilation rates are commonly associated with increased sound levels. Also in this study, the sensation of noise is (as can be seen in Figure 4) strongly associated with the outdoor airflow rate. However, the association between general symptoms and ventilation noise is not dominant enough to disguise the association between general symptoms and ventilation rates.

The sensation of "dry air" is strongly correlated with all types of SBS symptoms. Thus the "dry" sensation might be an important sign of a building's "sickness." The sensation is not correlated with the measured relative humidity nor (not shown) with the absolute humidity or the difference between the absolute humidity indoors and outdoors. The sensation of "dry air" seems not to be an effect of physically dry air but presumably of irritating substances in the air. This is in accordance with the results from chamber studies by Andersen et al. (1982).

From many studies, it is clear that SBS has a multifactorial origin. There is no single causal factor. In the Office Illness Project of Northern Sweden, many different aspects, such as organizational factors, job stress, VDT work, and building and room factors, are being studied. In the preliminary analysis,

TABLE 5
Prevalence, Odds Ratios and 95% Confidence Interval for Reporting General, Mucous Membrane, and Skin Symptoms as a Function of Reported Sensation of "Yes, often" with Regard to "Dry Air" in the Office (4,943 persons in 210 buildings)

	Sensation of "dry air" at the workplace			
	"Never or sometimes"		"Yes often (every week)"	
	Prev. %	OR	Prev. %	OR (95 % Cl)
Men				
Gen. sym.	17.6	1	36.7	2.71 (2.1-3.5)
Mucous.m.s	12.2	1	41.7	5.12 (4.0-6.6)
Skin sym.	7.1	1	21.4	3.55 (2.6-4.8)
Women				
Gen.sym.	25.6	1	48.2	2.70 (2.3-3.2)
Mucous.m.s.	15.3	1	42.2	4.06 (3.4-4.9)
Skin sym.	14.6	1	42.0	4.22 (3.5-5.1)

many factors have been shown to be related to symptom prevalences (Stenberg et al. 1990a, b; Sundell et al. 1990; Sandström et al. 1990). Sex and size of the office are apparently confounders in an analysis of symptoms associated with ventilation rates.

In conclusion, the outdoor airflow rate seems to be important for the prevalence of SBS symptoms. The study indicates that the recommendations given by Fanger are reasonable with regard to symptom reports and discomfort. Since we have assumed linear relationships between symptom prevalence and the outdoor air rates in the report, further analysis of the data is required.

RECOMMENDATIONS

To avoid increasing risks for general symptoms in office buildings, the outdoor airflow rate should not be less than the present mean value in existing buildings of about 15 L/s per person.

Whenever people are complaining of "dry air," the building manager should make sure that the ventilation rate is adequate.

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