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Indoor climate, psychosocial work environment and symptoms in open-plan offices

Abstract To study the indoor climate, the psychosocial work environment and occupants' symptoms in offices a cross-sectional questionnaire survey was made in 11 naturally and 11 mechanically ventilated office buildings. Nine of the buildings had mainly cellular offices; five of the buildings had mainly open-plan offices, whereas eight buildings had a mixture of cellular, multi-person and open-plan offices. A total of 2301 occupants, corresponding to a response rate of 72%, completed a retrospective questionnaire. The questionnaire comprised questions concerning environmental perceptions, mucous membrane irritation, skin irritation, central nervous system (CNS) symptoms and psychosocial factors. Occupants in open-plan offices are more likely to perceive thermal discomfort, poor air quality and noise and they more frequently complain about CNS and mucous membrane symptoms than occupants in multi-person and cellular offices. The association between psychosocial factors and office size was weak. Open-plan offices may not be suited for all job types.

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Key words: Open-plan office; Sick building syndrome symptoms; Psychosocial work environment; Indoor air quality; Questionnaire study; Indoor environment.

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Practical Implication
Open-plan offices may be a risk factor for adverse environmental perceptions and symptoms.

Introduction

One of the first buildings with open office space was designed by Frank Lloyd Wright in 1904 (Sundstrom, 1986) in the US. The office had the traditional classroom design with tables in rows and became soon widely used in office buildings. However, this office type was mainly for the clerical workers whereas managers had their own private office. The landscape office or 'Burolandschaft' which originated in Germany became very popular in the 1960s (Sundstrom, 1986). The original landscape office was an entirely open space without private offices even for managers. The work places were arranged in small groups for convenient work flow and communication and the traditional classroom design was given up. Even though the first German offices had no partition walls between the different work groups or work places the characteristic features of the landscape office soon became the semi-high partitions in the office design. However, many companies began to adopt the idea of open offices due to the lower cost rather than the organization of work and facilitation of internal communication. The open office required fewer square meters per person and were easier to maintain and rebuild (Brennan et al., 2002). In the 1970s and the beginning of the 1980s reports on people's problems regarding lack of privacy and noise from colleagues started to emerge (Hedge, 1982), and by the 1980s architects began to use private offices again in combination with the open-plan office (Sundstrom, 1986).

The Danish trend had somewhat followed the trend in the US. Yet, due to energy regulation, the typical new building in the 1990s was naturally ventilated with cellular offices and small windows. Within the last 10 years more and more private companies and public institutions in Denmark have replaced the cellular offices with open-plan offices. The idea has been that the physical design should support the modern office work with a high degree of knowledge sharing among the employees working in project groups with a constant demand for flexible physical facilities.

In many ways we are now back to the original idea of the landscape office.

In the behavioral literature there are two basic approaches that describe employees' reaction to work in open-plan offices: a social relation approach and a sociotechnical approach (Oldham and Brass, 1979). In the social relation approach the absence of walls in the open space will facilitate social relationships among employees, decrease interpersonal problems, increase supervision and feedback from colleagues and facilitate more intra- and interdepartmental interaction. Changes in these variables will therefore increase workers' motivation and job satisfaction and in the end increase performance. The sociotechnical approach states that the absence of walls and partitions will decrease privacy and reduce workers' experience of autonomy as the absence of physical boundaries will increase the likelihood that coworkers and leaders will interfere with the workers' discretion and freedom to work. The lack of private space will also decrease feedback from supervisors and coworkers as the confidential conversation is less likely to happen in the open space. In the sociotechnical approach the open-plan office will therefore decrease workers' motivation, job satisfaction and performance. Oldham and Brass (1979) tested the two hypotheses in an intervention study and found that there was support for the sociotechnical approach in accordance with other studies (Brennan et al., 2002; Brookes, 1972; Hedge, 1982; Sundstrom et al., 1982a, 1994).

More and more studies in the international literature report about problems in open-plan offices. De Croon et al. (2005) made a review on the effects of open-plan offices on job demands, job resources, well-being and performance compared with cellular offices. There was strong evidence that working in open-plan offices reduces workers' perception of privacy and job satisfaction. There was some evidence that working in open-plan offices can intensify the cognitive work load and worsen interpersonal relations. Most of the literature on open-plan offices has been from the social and behavioral sciences (Brennan et al., 2002; De Croon et al., 2005; Oldham and Brass, 1979; Sundstrom et al., 1982a,b) or more technical studies on noise (Hongisto et al., 2004). In the traditional indoor climate literature very few researchers have focused on open-plan offices. In the review by Mendell (1993) only seven of 32 reviewed studies included number of occupants in the space and of the seven studies, five found that more occupants in the space were associated with higher prevalence of symptoms. Hedge (1982) included questions about the physical environment in his study of people's attitude toward open-plan offices and found that more than half of the workers complained about the physical environment. In a new study Chao et al. (2003) found that the number of workers per office was positively associated with CNS and upper respiratory symptoms.

Many indoor climate investigations have failed to find the causes of employees' symptoms even though a substantial number of physical, chemical and biological measurements have been performed to explain the symptoms. It has therefore often been stated that the lack of a clear association between the objective measurements and the symptoms is due to psychological or psychosocial factors (Lahtinen et al., 1998). However, in the literature review on sick building syndrome symptoms and psychosocial factors by Lahtinen et al. (1998), it was concluded that relatively few investigations on indoor air have actually included psychosocial factors.

The purpose of the investigation was to study the indoor climate, the psychosocial work environment and occupants' symptoms in different office environments including cellular offices, multi-person offices and open-plan offices. The research question of interest was: Is the indoor climate and the psychosocial work environment in open-plan offices different from that in multi-person and cellular offices? The hypothesis was that the indoor climate may be worse in the open-plan offices than in the other types of offices. It was interesting to study whether the sociotechnical approach or the social relation approach was supported by the present study. The study was performed parallel to a study looking at symptoms and the ability of dust to induce an inflammatory reaction in a bioassay (Allermann et al., 2005).

Material and methods

A cross-sectional questionnaire survey was made in 11 naturally and 11 mechanically ventilated office buildings. Both buildings with cellular, multi-person and open-plan offices were studied. In each building 100–300 occupants completed a retrospective questionnaire on environmental perceptions, symptoms and psychosocial factors looking back at the last 4 weeks. A building checklist was used to characterize the offices regarding number of workplaces, ventilation in offices, building materials, etc. To be able to relate data from the offices with the questionnaire survey, the questionnaire was handed out to each respondent by the research team. The study was performed from November to December 2001.

Buildings and study population

The Central Business Register in Denmark provided a list of private companies and public institutions with more than 200 employees in the Copenhagen area. From this list of 576 companies and institutions 141 were randomly selected and invited to participate in the study. Furthermore, 14 companies were contacted through their occupational health service. The first 20 companies which responded to the request were

selected for the study. Nine of the buildings had mainly cellular offices; five of the buildings had mainly open-plan offices, whereas eight buildings had a mixture of cellular, multi-person and open-plan offices. In general, most of the open-plan offices were equipped with mechanical ventilation and most cellular offices had natural ventilation. Half of the buildings were from the private sector while the other half consisted of public or governmental buildings. The work places involved in the study comprised: two research institutes, eight ministries or governmental institutions, three IT-companies, two consulting engineers companies/building contractors, one production company, one consumer retail company and three financial or insurance companies. The recruitment of buildings was not based on any prior knowledge about the indoor climate or the psychosocial work environment in the buildings.

The study population was office workers, who spend most of their time in the offices. A total of 3200 occupants from 22 different office buildings within the 20 companies were selected for the study.

Questionnaire

The questionnaire comprised questions concerning perceptions of environmental factors, irritation of the mucous membrane, skin irritation, CNS symptoms, and psychosocial risk factors such as: demands at work, job control, motivation, social support, quality of leadership, insecurity at work, and health and well-being (job satisfaction, self-rated health, mental health, vitality, and work satisfaction). The indoor environmental perceptions and symptoms were assessed on four category frequency scales using a questionnaire that had been validated in another study (Brauer, 2005). The psychosocial work environment was assessed using the Copenhagen Psychosocial Questionnaire (Kristensen et al., 2002), which is a validated questionnaire with index scales. In general the items had five to six response options.

Results

The response rate of the questionnaire survey was 72% for the total population ranging from 62% to 92% for the single companies, which is quite an acceptable rate. The occupants in the 22 office buildings were divided into five groups according to the size of their office: cellular offices comprising one and two occupants, multi-person offices comprising three to six occupants, open-plan offices comprising 7–28 occupants, and open-plan offices with more than 28 occupants. The two groups of open-plan offices were made so that the number of occupants was approximately the same in the two groups. The frequency distribution of sex and socioeconomic status of the occupants in the five groups of offices is given in Table 1. The different socioeconomic groups are represented in all office types, but there is a socioeconomic trend as the number of occupants with lower socioeconomic status increases with office size.

The prevalence of occupants with adverse perceptions of the indoor environment and symptoms occurring 'daily' or 'several times a week' is shown in Tables 2 and 3. The gamma tests for association between the office size and the environmental perceptions or the symptoms were based on the categorical data with four response options. Included in the tables is also the result of logistic regression of the associations where the models have been adjusted for sex, age, and socioeconomic status. For most of the environmental perceptions the prevalence of complaints was increasing with number of occupants in the space even when adjusting for the demographic variables. In general, the perception of *dry air*, *stuffy air* and being bothered by *dust and debris* were more prevalent in all types of offices, Table 2. The most dominating complaints in the open-plan offices were the occupants' perception of *dry air*, *stuffy air* and *noise in the room* (Table 2). The gamma coefficient was high for the perception of *too high temperature*, *varying temperature*, *cramped space* and particularly *noise in the room*, which indicates a strong association with office size. Approximately 10 times as many occupants complained about noise in the large open-plan offices compared with the occupants in the cellular offices, and about 2–3 times as many occupants in the large open-plan offices complained about the thermal discomfort compared with the occupants in the cellular offices.

Table 1 Frequency distribution of number of occupants (*n*), their sex and socioeconomic status

				Socioeconomic status (%)			
Size of office (*n*)	Median (*n*)	Total (*n*)	Women (%)	Secretary, clerk, trainee, student	Technician, controller, academic, consultant	Project leader, senior consultant	Director, head of department, manager
1	1	784	45	15	29	32	24
2	2	421	57	27	50	17	5
3–6	4	381	48	32	51	12	5
7–28	23	365	46	36	41	14	8
>28	52	350	53	47	29	17	7
Total	2	2301	49	28	39	21	12

Table 2 Prevalence (%) of adverse environmental perceptions in various office types

Environmental perception	Office size (number of occupants)					Gamma coefficient, *P*-value	Logistic regression[a] *P*-value
	1	2	3–6	7–28	>28		
Draught	9	10	12	26	18	0.23***	***
Too high temperature	11	10	21	23	34	0.36***	***
Varying temperature	8	14	17	28	25	0.35***	***
Too low temperature	6	10	14	17	17	0.25***	***
Stuffy air	21	29	36	42	54	0.28***	***
Dry air	19	25	31	39	50	0.28***	***
Unpleasant odor	7	8	9	12	17	0.22***	***
Static electricity	4	7	5	9	9	0.12***	*
Tobacco smoke (ETS)	10	16	9	6	16	NS	***
Noise in the room	6	15	28	42	60	0.62***	***
Noise, adjacent spaces	9	14	12	12	10	−0.11***	***
Noise, outdoors	14	16	18	8	6	−0.12***	***
Inadequate lighting	9	13	15	20	23	0.26***	***
Reflections	11	13	15	21	26	0.22***	***
Dust and debris	20	27	22	14	26	NS	***
Cold feet	4	7	6	11	10	0.21***	***
Cramped space	5	15	21	11	32	0.37***	***

[a]Adjusted for sex, age and socioeconomic status.
NS: $P > 0.05$; *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

The prevalence of mucous membrane irritation and CNS symptoms increased with office size, whereas the airways symptoms were low in all types of offices and most of them were not significantly related to office size when adjusting for the demographic variables (Table 3). In the large open-plan offices the prevalence of mucous membrane symptoms was 2–3 times higher than in the cellular offices. For *fatigue* and *headache* there were three times higher prevalence of symptoms among occupants in the large open-plan offices than in the cellular offices. Also, the symptom *difficulty in concentration* was more pronounced in open-plan offices as eight times more occupants were bothered by the symptom than in cellular offices.

The assessment of psychosocial work environment is shown in Table 4. The mean level of the different psychosocial dimensions was very similar to the mean values for companies in Denmark (Kristensen et al., 2002). The analyses showed that the psychosocial factors *job control* and *quality of leadership* decreased with increasing office size. The dimension *quantitative demands* had a slight U-shape relation with office size. Also, the dimensions *insecurity at work* and *job satisfaction* were significantly associated with office size; however, *insecurity at work* was inversely U-shaped related to office size. Health symptoms did not differ in the different office types. The low Spearman correlation and the little difference in scale

Table 3 Prevalence (%) of mucous membrane irritation, airway symptoms, skin symptoms and central nervous system symptoms in various office types

Symptom	Office size (number of occupants)					Gamma coefficient *P*-value	Logistic regression[a] *P*-value
	1	2	36	728	>28		
Eye irritation	10	15	12	18	27	0.20***	***
Nose irritation	9	12	10	14	18	0.16***	***
Running or blocked nose	10	12	12	14	14	0.12***	NS
Throat irritation	7	8	9	12	14	0.20***	***
Hoarseness	2	5	3	4	4	0.09*	NS
Cough	7	9	7	8	9	0.11***	NS
Wheezing	7	5	5	7	9	NS	NS
Difficulties in breathing	5	5	4	8	10	0.18**	**
Skin irritation, hands/arms	14	21	21	22	21	0.11***	NS
Facial skin irritation	6	8	8	10	11	0.10**	NS
Fatigue	8	12	12	17	21	0.17***	***
Headache	10	14	13	19	25	0.15***	***
Difficulties in concentrating	2	6	6	8	16	0.25***	***
Dizziness	10	12	14	10	14	NS	NS

[a]Adjusted for gender, age and socioeconomic status.
NS: $P > 0.05$; *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

Table 4 Psychosocial dimensions in various office types scored on scales from 0 to 100

Number of items in brackets	Office size (number of occupants)					Spearman correlation *P*-value	ANOVA/regression analysis[a]
	1	2	3–6	7–28	>28		
Quantitative demands (3)	53.8 (17.6)	48.0 (16.2)	48.5 (16.6)	51.7 (17.5)	50.3 (16.4)	−0.07**	***
Emotional demands (3)	33.3 (20.3)	28.5 (19.9)	28.0 (19.9)	30.1 (18.9)	29.0 (19.6)	−0.08***	NS
Job control (6)	67.8 (15.8)	66.2 (14.6)	62.3 (15.1)	64.4 (14.6)	63.0 (17.5)	−0.11***	**
Motivation (4)	69.3 (15.8)	65.3 (17.0)	63.9 (16.2)	66.5 (15.6)	65.9 (17.4)	−0.08***	NS
Quality of leadership (4)	58.1 (17.4)	57.1 (16.9)	54.7 (17.6)	54.6 (18.0)	53.5 (17.9)	−0.09***	***
Social support (6)	55.9 (13.9)	57.5 (14.8)	57.7 (13.6)	56.4 (13.7)	57.1 (14.1)	NS	NS
Insecurity at work (4)	12.1 (21.2)	15.9 (25.3)	14.9 (24.2)	13.6 (23.2)	12.9 (23.7)	NS	*
Job satisfaction (4)	52.6 (11.7)	50.5 (11.5)	49.1 (12.2)	50.2 (12.1)	47.9 (12.5)	−0.14***	***
General health (1)	69.8 (19.0)	68.2 (20.1)	68.8 (18.3)	69.6 (18.8)	68.5 (18.3)	NS	NS
Mental health (5)	78.8 (13.9)	78.6 (15.2)	79.7 (13.1)	79.5 (14.2)	79.8 (12.9)	NS	NS
Vitality (4)	67.1 (18.2)	65.8 (18.5)	65.5 (18.3)	65.8 (18.1)	64.3 (17.6)	−0.06 **	NS

Data are mean scores in each office type with standard deviations in brackets.
[a]ANOVA except for 'insecurity at work' and 'general health' where logistic regression were applied as the scales had only five values.
NS: $P > 0.05$; *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

value between office types (< 5 points) indicate that even when the multi-variate analyses were significant, the psychosocial factors had only a weak association with office size.

To further analyze the found association between office size and the indoor climate the logistic regression models in Tables 2 and 3 were adjusted for the psychosocial risk factors. The following psychosocial factors were included in the models: quantitative demands, emotional demands, job control, motivation, quality of leadership, and social support. The analysis was made for all models; however, only models which showed a significant association in Tables 2 and 3 were included in Tables 5 and 6. Furthermore the models with environmental tobacco smoke (ETS), static electricity, noise from adjacent spaces, and noise from outdoor are not shown, as these parameters had only weak association with office size or showed a reverse relation to office size (Table 2).

Adjusting for psychosocial risk factors had very little effect on the perception models (Table 5). The estimate of the odds ratio did hardly change and if anything there was a tendency that the odds ratios increased after adjustment for psychosocial factors. The psychosocial factors can therefore not explain the found associations between environmental perceptions and office size (Table 5). A similar result was found for the symptoms model. Adjusting for psychosocial factors had no effect on the found association between symptoms and office size (Table 6).

Included in Tables 5 and 6 are also logistic regression models adjusting for type of ventilation (natural or mechanical), as ventilation type in numerous studies has been shown to affect the prevalence of perceptions and symptoms (Mendell and Smith, 1990). Adjusting for ventilation type did not change the significant findings for the effect of office size on complaints and symptoms (Tables 5 and 6), as the estimated odds ratios did not change.

Discussion

In general, the prevalence of environmental complains from the present study were very similar to the prevalence found in another Danish study using the same questionnaire among 3492 occupants in 41 buildings including offices, schools and hospitals (Brauer and Mikkelsen, 2002). The data from the present study differed from the study in the 41 buildings in the way that more occupants in the present study complained about *stuffy air* and fewer occupants complained about *environmental tobacco smoke*, *static electricity*, *noise in the room* and *noise from adjacent spaces*. The difference in noise complaints can be due to the fact that nine schools were included in the previous study of 41 buildings.

The environmental perceptions were significantly related to office size in the present study and all except ETS, *dust* and *debris*, *noise from outdoor* and *noise from adjacent spaces* increased with increasing office size (Tables 2 and 5). The perceptions of noise from adjacent spaces and noise from outdoor had negative association with office size. When occupants are annoyed by the noise in the room they are not in general bothered by the noise from the surroundings and this has been confirmed in other studies (Ayr et al., 2001; Sundstrom et al., 1994).

Noise in the room was the most prevalent complain in the open-plan offices and noise had the strongest association with office size (Tables 2 and 5). It is remarkable that 60% of the occupants complained about noise in the very large open-plan offices compared with only 6% in the cellular offices. Several studies have found similar results. In the review by Sundstrom (1986) five of 10 intervention studies found an increase in noise problems when changing office to an open space layout, whereas only one study found a decrease in noise problems after the change. Sundstrom et al. (1994) have performed a study of different

Table 5 Environmental perceptions vs. office size. Logistic regression models adjusting for sociodemographic variables, psychosocial risk factors and ventilation type

	Office size (number of occupants)	Odds ratio, controlled for gender, age and socioeconomic status	Odds ratio, controlled for gender, age, socioeconomic status and psychosocial risk factors	Odds ratio, controlled for gender, age, socioeconomic status and ventilation type
Draught	2 vs. 1	1.21 (0.93–1.58)	1.29 (0.96–1.73)	1.12 (0.85–1.47)
	3–6 vs. 1	**1.68 (1.28–2.21)**	**1.76 (1.31–2.36)**	**1.68 (1.28–2.20)**
	7–28 vs. 1	**2.87 (2.21–3.74)**	**2.85 (2.15–3.78)**	**3.58 (2.70–4.76)**
	>28 vs. 1	**1.83 (1.39–2.40)**	**1.87 (1.40–2.51)**	**2.42 (1.79–3.27)**
Too high temperature	2 vs. 1	**1.32 (1.02–1.71)**	**1.36 (1.03–1.81)**	**1.34 (1.03–1.74)**
	3–6 vs. 1	**2.20 (1.70–2.86)**	**2.39 (1.81–3.16)**	**2.21 (1.70–2.86)**
	7–28 vs. 1	**3.28 (2.53–4.25)**	**3.40 (2.58–4.47)**	**3.18 (2.42–4.17)**
	>28 vs. 1	**4.70 (3.62–6.10)**	**4.98 (3.77–6.58)**	**4.50 (3.39–5.97)**
Varying temperature	2 vs. 1	**1.81 (1.41–2.33)**	**1.84 (1.40–2.42)**	**1.78 (1.38–2.30)**
	3–6 vs. 1	**2.24 (1.72–2.90)**	**2.39 (1.81–3.16)**	**2.23 (1.72–2.90)**
	7–28 vs. 1	**4.88 (3.77–6.33)**	**4.86 (3.69–6.40)**	**5.07 (3.86–6.67)**
	>28 vs. 1	**3.38 (2.60–4.39)**	**3.47 (2.62–4.59)**	**3.55 (2.67–4.72)**
Too low temperature	2 vs. 1	**1.37 (1.05–1.79)**	**1.35 (1.02–1.79)**	**1.35 (1.03–1.76)**
	3–6 vs. 1	**1.79 (1.36–2.34)**	**1.76 (1.32–2.35)**	**1.78 (1.36–2.33)**
	7–28 vs. 1	**3.06 (2.35–4.00)**	**2.90 (2.19–3.85)**	**3.20 (2.42–4.23)**
	>28 vs. 1	**2.18 (1.66–2.86)**	**2.20 (1.65–2.93)**	**2.30 (1.72–3.09)**
Stuffy air	2 vs. 1	**1.53 (1.21–1.94)**	**1.58 (1.22–2.04)**	**1.50 (1.18–1.90)**
	3–6 vs. 1	**1.87 (1.47–2.39)**	**1.86 (1.43–2.42)**	**1.86 (1.46–2.38)**
	7–28 vs. 1	**2.37 (1.85–3.02)**	**2.28 (1.76–2.96)**	**2.49 (1.93–3.23)**
	>28 vs. 1	**3.81 (2.97–4.89)**	**3.75 (2.87–4.90)**	**4.07 (3.11–5.34)**
Dry air	2 vs. 1	**1.39 (1.09–1.76)**	**1.41 (1.09–1.84)**	**1.40 (1.10–1.79)**
	3–6 vs. 1	**1.64 (1.28–2.10)**	**1.66 (1.27–2.18)**	**1.64 (1.28–2.11)**
	7–28 vs. 1	**2.40 (1.87–3.08)**	**2.31 (1.77–3.01)**	**2.33 (1.79–3.02)**
	>28 vs. 1	**3.62 (2.81–4.67)**	**3.66 (2.79–4.81)**	**3.48 (2.65–4.58)**
Unpleasant odor	2 vs. 1	1.23 (0.91–1.66)	**1.42 (1.03–1.97)**	**1.25 (0.93–1.69)**
	3–6 vs. 1	**1.53 (1.13–2.07)**	**1.59 (1.14–2.21)**	**1.53 (1.13–2.08)**
	7–28 vs. 1	**1.86 (1.39–2.50)**	**1.97 (1.43–2.71)**	**1.80 (1.32–2.46)**
	>28 vs. 1	**2.26 (1.68–3.03)**	**2.23 (1.62–3.06)**	**2.16 (1.57–2.96)**
Noise in the room	2 vs. 1	**2.78 (2.09–3.71)**	**3.21 (2.35–4.39)**	**2.64 (1.98–3.53)**
	3–6 vs. 1	**6.25 (4.70–8.32)**	**6.35 (4.66–8.65)**	**6.25 (4.69–8.32)**
	7–28 vs. 1	**13.57 (10.19–18.08)**	**14.24 (10.46–19.39)**	**15.49 (11.39–21.05)**
	>28 vs. 1	**26.09 (19.35–35.20)**	**28.11 (20.35–38.83)**	**30.78 (22.17–42.74)**
Inadequate lighting	2 vs. 1	**1.38 (1.03–1.84)**	**1.58 (1.15–2.16)**	**1.37 (1.02–1.83)**
	3–6 vs. 1	**1.60 (1.19–2.15)**	**1.65 (1.20–2.28)**	**1.59 (1.18–2.14)**
	7–28 vs. 1	**2.29 (1.72–3.04)**	**2.37 (1.75–3.22)**	**2.33 (1.72–3.16)**
	>28 vs. 1	**3.30 (2.49–4.38)**	**3.57 (2.63–4.84)**	**3.39 (2.49–4.62)**
Reflections	2 vs. 1	1.24 (0.95–1.61)	**1.36 (1.02–1.81)**	**1.35 (1.03–1.77)**
	3–6 vs. 1	**1.73 (1.32–2.26)**	**1.90 (1.42–2.54)**	**1.76 (1.34–2.30)**
	7–28 vs. 1	**2.45 (1.89–3.19)**	**2.64 (2.00–3.50)**	**2.02 (1.54–2.67)**
	>28 vs. 1	**2.30 (1.76–3.00)**	**2.34 (1.76–3.12)**	**1.81 (1.36–2.41)**
Dust and debris	2 vs. 1	**1.42 (1.11–1.80)**	**1.57 (1.21–2.04)**	**1.33 (1.04–1.70)**
	3–6 vs. 1	1.05 (0.81–1.35)	1.03 (0.78–1.36)	1.04 (0.81–1.34)
	7–28 vs. 1	**0.65 (0.50–0.85)**	0.69 (0.52–0.92)	0.77 (0.58–1.02)
	>28 vs. 1	1.18 (0.91–1.53)	1.24 (0.94–1.64)	**1.47 (1.11–1.94)**
Cold feet	2 vs. 1	1.37 (0.98–1.93)	1.41 (0.98–2.04)	1.35 (0.96–1.90)
	3–6 vs. 1	1.23 (0.86–1.77)	1.29 (0.88–1.91)	1.23 (0.85–1.77)
	7–28 vs. 1	**2.86 (2.07–3.94)**	**2.68 (1.90–3.78)**	**3.00 (2.13–4.23)**
	>28 vs. 1	**1.64 (1.16–2.32)**	**1.72 (1.19–2.48)**	**1.75 (1.19–2.55)**
Cramped space	2 vs. 1	**2.91 (2.04–4.15)**	**2.87 (1.94–4.24)**	**2.81 (1.96–4.02)**
	3–6 vs. 1	**4.38 (3.09–6.21)**	**4.35 (2.97–6.36)**	**4.35 (3.07–6.17)**
	7–28 vs. 1	**2.31 (1.59–3.37)**	**2.15 (1.44–3.23)**	**2.49 (1.68–3.70)**
	>28 vs. 1	**6.39 (4.54–8.99)**	**6.19 (4.28–8.95)**	**7.03 (4.84–10.22**)

95% confidence limits in brackets. Significant results ($P < 0.05$) are in bold face.

interventions among 2391 office employees in 58 office sites. The interventions, in general, involved conversion to a form of open-plan offices with less floor space per occupant and fewer private offices. After the intervention 54% of the participants reported that they were often bothered by noise in the office. Other studies including Ayr et al. (2001), Hedge (1982), and Klitzman and Stellman (1989) have found that workers in open-plan offices are bothered by noise.

We did not ask about the nature of the specific sources of noise, but other studies have shown that especially telephones which keep ringing on vacant workplaces, and other people's conversation are generally the most disturbing noise sources in open-plan

Table 6 Symptoms vs. office size. Logistic regression models adjusting for sociodemographic variables, psychosocial risk factors and ventilation type

	Office size (number of occupants)	Odds ratio, controlled for gender, age and socioeconomic status	Odds ratio, controlled for gender, age, socioeconomic status and psychosocial risk factors	Odds ratio, controlled for gender, age, socioeconomic status and ventilation type
Eye irritation	2 vs. 1	1.18 (0.91–1.53)	1.15 (0.87–1.53)	1.15 (0.88–1.49)
	3–6 vs. 1	1.24 (0.94–1.62)	1.15 (0.86–1.54)	1.23 (0.94–1.61)
	7–28 vs. 1	**1.57 (1.21–2.04)**	**1.61 (1.22–2.13)**	**1.68 (1.27–2.22)**
	>28 vs. 1	**2.52 (1.94–3.27)**	**2.57 (1.94–3.40)**	**2.74 (2.06–3.66)**
Nose irritation	2 vs. 1	1.05 (0.80–1.37)	1.16 (0.86–1.56)	1.03 (0.78–1.36)
	3–6 vs. 1	0.99 (0.740–1.32)	0.99 (0.72–1.36)	0.99 (0.74–1.31)
	7–28 vs. 1	1.27 (0.96–1.67)	**1.36 (1.01–1.83)**	1.32 (0.98–1.77)
	>28 vs. 1	**1.90 (1.45–2.49)**	**2.09 (1.56–2.81)**	**1.99 (1.48–2.69)**
Throat irritation	2 vs. 1	0.93 (0.69–1.25)	1.05 (0.76–1.45)	0.94 (0.69–1.27)
	3–6 vs. 1	1.02 (0.75–1.39)	1.05 (0.75–1.46)	1.02 (0.75–1.39)
	7–28 vs. 1	**1.46 (1.09–1.96)**	**1.55 (1.13–2.13)**	**1.42 (1.04–1.93)**
	>28 vs. 1	**2.05 (1.54–2.73)**	**2.11 (1.55–2.88)**	**1.97 (1.44–2.70)**
Difficulties in breathing	2 vs. 1	0.82 (0.45–1.50)	0.87 (0.45–1.67)	0.80 (0.44–1.48)
	3–6 vs. 1	0.68 (0.35–1.32)	0.65 (0.32–1.34)	0.68 (0.35–1.32)
	7–28 vs. 1	1.66 (0.99–2.78)	1.75 (0.999–3.06)	1.72 (0.99–3.00)
	>28 vs. 1	**1.99 (1.20–3.30)**	**1.93 (1.11–3.34)**	**2.10 (1.19–3.69)**
Fatigue	2 vs. 1	1.02 (0.78–1.34)	1.11 (0.83–1.49)	1.02 (0.78–1.34)
	3–6 vs. 1	1.02 (0.77–1.35)	1.06 (0.79–1.44)	1.02 (0.77–1.34)
	7–28 vs. 1	**1.45 (1.10–1.89)**	**1.44 (1.07–1.93)**	**1.47 (1.10–1.95)**
	>28 vs. 1	**1.80 (1.38–2.36)**	**1.84 (1.38–2.47)**	**1.84 (1.37–2.46)**
Headache	2 vs. 1	0.95 (0.74–1.21)	1.01 (0.78–1.33)	0.93 (0.72–1.19)
	3–6 vs. 1	0.91 (0.71–1.18)	0.90 (0.69–1.19)	0.91 (0.70–1.17)
	7–28 vs. 1	**1.30 (1.01–1.67)**	1.29 (0.99–1.69)	**1.38 (1.06–1.80)**
	>28 vs. 1	**1.70 (1.32–2.20)**	**1.83 (1.39–2.40)**	**1.84 (1.39–2.42)**
Difficulties in concentrating	2 vs. 1	1.28 (0.97–1.71)	1.61 (1.17–2.20)	1.22 (0.92–1.63)
	3–6 vs. 1	1.16 (0.86–1.57)	1.24 (0.89–1.73)	1.15 (0.85–1.56)
	7–28 vs. 1	**1.72 (1.29–2.30)**	**1.80 (1.31–2.47)**	**1.93 (1.42–2.62)**
	>28 vs. 1	**2.99 (2.26–3.97)**	**3.35 (2.46–4.58)**	**3.46 (2.53–4.73)**

95% confidence limits in brackets. Significant results ($P < 0.05$) are in bold face.

offices (Banbury and Berry, 2005; Sundstrom et al., 1994). There are several laboratory studies performed on the nature and the effect of irrelevant speech (Banbury and Berry, 1998; Jones et al., 1993). Jones et al. (1993) found that the nature of the noise is crucial for the disruption effect and rather than the noise to be speech-like, their changing state hypothesis argues that the sound has to have a particular variation over time to be disrupting. However, when many people are talking and the sound turns into babble the disruption effect of irrelevant speech is less as the cues to word segmentation becomes inaudible (Jones and Macken, 1995). This is used actively when masking office noise (Loewen and Suedfeld, 1992). Jones and Macken (1995) also showed in the laboratory that subject made less errors in a short-term memory test when exposed to six voices compared with only one or two voices. However, they also argue that the effect of irrelevant speech on complex cognitive task may be different than the serial recall tested in their experiment.

One of the strongest arguments for open-plan offices has been knowledge sharing which should be better supported in the open-plan office environment. In the present study we measured the dimension *social support and feedback* which may be an important characteristic of the construct knowledge sharing. The analysis showed that *social support and feedback* was independent of office size and this do neither support the socio relation approach predicting that the occupants would have increased social support and feedback nor the sociotechnical approach foreseeing that the occupant would have decreased social support and feedback (Oldham and Brass, 1979). Occupants' *motivation* in the present study decreased with office size as predicted by the sociotechnical approach, although the effect was not significant when adjusting for the sociodemographic variables. The study did support the sociotechnical approach on job satisfaction as job satisfaction decreased with increasing office size even though the effect was minor. The present study did not conflict with the sociotechnical approach and supported it weakly at some points.

The main part of the open-plan offices in the present study did not have partition walls between workspaces and in the few offices where the partitions occurred they were very low. This may in some way explain the high prevalence of noise problems in the rooms as partitions and especially high partitions can increase speech privacy (Moreland, 1988) but not necessarily privacy in general (Sundstrom et al., 1982a). Many of the studies in the behavioral science have measured the occupants' perception of privacy rather than noise.

As described by De Croon et al. (2005) there is strong evidence that working in open-plan offices decreases privacy and job satisfaction. Sundstrom et al. (1982b) found that an index formed from the items *noise*, *distraction* and *feeling too close to one's neighbor* was strongly and inversely related to a single-item rating of privacy. The perception of noise plays an essential role for the perception of privacy, although visual privacy is a part of the dimension of privacy (De Croon et al., 2005). Not surprisingly, studies have shown that having a private office is regarded as the best way to facilitate privacy in the office environment (Kupritz, 2003; Sundstrom et al., 1982b), but the studies have also shown that privacy is regarded a bit different by different age groups (Kupritz, 2001) and different job groups (Sundstrom et al., 1982b).

Poor air quality characterized by unpleasant odor and particularly stuffy air was more pronounced in the larger offices than in the cellular offices. It is in general more difficult to ventilate a larger space than a smaller and therefore more difficult to control indoor air quality in open-plan offices. Even if the outdoor air exchange rate is the same in the open-plan office and the cellular office the ventilation effectiveness may be lower in the open-plan office. Some open-plan offices in the present study had displacement ventilation which may have high ventilation effectiveness when operated as designed. However, if the supply air units are blocked by furniture, etc. the displacement flow may be disturbed resulting in lower ventilation effectiveness and poor indoor air quality.

The prevalence of occupants complaining about *dry air* ranged from 19% in the cellular offices to 50% in the large open-plan offices. The relative humidity was only measured in about 10 different sites in each of the buildings (Allermann et al., 2005). The mean relative humidity in the measured offices was 33.76 ± 6.44% and there was no difference between the types of offices. It seems that perceived *dry air* is something different from humidity and there is a need to validate this question.

Thermal comfort had a strong association with office size in the present study. All questions regarding thermal comfort – draught, too low temperature, cold feet, and especially too high temperature and varying temperature – were more pronounced in the open-plan offices. Even though the thermal environment has been heavily studied, complaints about thermal comfort together with noise are the most frequent complaints in offices (Jensen et al., 2005). The present study was carried out during November and December and it may be a bit surprising that people complained about *too high temperature* rather than *too low temperature*. This may imply that even more occupants will complain during summertime especially in the open-plan offices without air-conditioning. Furthermore, the architectural trend at the moment goes in the direction of more open-plan offices and more use of glass. Event though the modern windows will reduce radiation from the sun significantly the thermal mass is less in an open-plan office compared with a cellular office due to the absence of walls between workstations. This means that the open-plan office is not as good in absorbing heat from radiation as the cellular office and air temperature may therefore be higher even if all other conditions are the same. In buildings with glass facades it is not always possible to open windows, and the lack of individual control of the indoor environment makes it difficult to create a comfortable environment for all occupants.

The prevalence of symptoms in the present study was very similar to the Danish study of 41 buildings (Brauer and Mikkelsen, 2002), although fewer occupants complained about skin irritations on hand and arms in the present study. Mucous membrane symptoms like eye-, nose- and throat irritation, and CNS symptoms like fatigue, headache and difficulties in concentrating were associated with office size (Table 3), as significantly more occupants complained about the symptoms in the open-plan offices (Table 6). The findings are consistent with the few studies that have included number of workers in the space in their analysis (Chao et al., 2003; Mendell, 1993, 1993).

In a laboratory study of open-plan office noise and raised temperature, Witterseh et al. (2004) found significant effects of raised temperature on mucous membrane irritation, headache and difficulties in concentrating and significant effect of noise on fatigue and difficulty in concentrating. This is in accordance with the present study where the CNS symptoms and mucous membrane symptoms were more prevalent in the open-plan offices than in the cellular offices. However, a prospective study has questioned the causal relationship between perceived indoor environment and symptoms (Brauer, 2005). We have not analyzed the association between perceived indoor environment and symptoms in the present paper as this is a research question of its own and may be addressed in a separate paper.

Many studies have found a higher prevalence of symptoms and complaints in mechanically ventilated buildings than in naturally ventilated buildings (Mendell and Smith, 1990). The open-plan offices in the present study were almost mechanically ventilated whereas the multi-person and cellular offices were more equally distributed between naturally and mechanically ventilated buildings. Adjusting for ventilation type in the logistic regressions did not change the significant effect of office size. In the present study, the size of office was a stronger predictor of symptoms and complains than the type of ventilation.

As one of the few indoor climate investigations, the present study has included questions on the psychosocial work environment (Lahtinen et al., 1998).

The strong dose–response-like association between office size and environmental perceptions and symptoms was not in general seen for the association between office size and the psychosocial factors (Table 4). The levels of the psychosocial factors were very close to the mean values for the population of workers in Denmark (Kristensen et al., 2002) and the differences between office types were small. However, low job control or decision latitude as seen in the open-plan offices compared with cellular offices is a potential risk factor for stress (Kompier, 2003). This is also reflected in the occupants' assessment of job satisfaction which decreased with increasing office size. Other studies have shown that open-plan offices may constitute a potential stress hazard (Evans and Johnson, 2000).

When considering the psychosocial risk factors – *quantitative demands*, *emotional demands*, *job control*, *motivation*, *quality of leadership*, and *social support* and *feedback* – into account in the logistic regressions models, the odds ratio did hardly change (Tables 5 and 6). This means that the psychosocial risk factors cannot explain the found associations between office size and, respectively, the environmental perceptions and symptoms. But it also questions the old hypothesis in the literature that occupants' symptoms and complaints are due to the psychosocial work environment. The present study showed that occupants' perceptions and symptoms were related to office size whereas many of the psychosocial factors were not associated to office size. Similar results were found by Klitzman and Stellman (1989) who found that the workers' assessment of the physical environment is different from their assessment of work load, decision-making latitude and relationship with colleagues.

The present study showed that there is a strong need for improving indoor air quality, thermal comfort and reducing noise in open-plan offices. There is also a strong need to study which type of jobs are suited for open-plan offices. Traditionally, architects, journalists and other jobs where people depend on teamwork and knowledge sharing in the same project have been performed in open-plan offices. However, job types where a high degree of concentrated and individual effort is needed may not be suited for open-plan offices, as such jobs may be particularly sensitive to the distracting effects of noise.

Conclusion and implications

Occupants in open-plan offices are more likely to perceive thermal discomfort, poor air quality and noise and they more frequently complain about CNS and mucous membrane symptoms than occupants in multi-person and cellular offices. The psychosocial factors were only weakly related to office size. Open-plan offices may not be suitable for all job types.

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