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<u>running head</u>: Office Worker Symptoms and Mechanical Ventilation

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ABSTRACT

Background. European epidemiologic studies have found health symptoms in office workers to be consistently increased in air-conditioned buildings relative to naturally ventilated buildings. Because this had not been studied in the U.S., the California Healthy Building Study assessed the relationship of ventilation system type to office worker symptoms in a set of U.S. buildings selected without regard to worker complaints.

Methods. Questionnaire data, building information, and environmental measures were collected from spaces within 12 public office buildings having one of three ventilation types: natural ventilation (NV), mechanical ventilation without air-conditioning (MV), and mechanical ventilation with air-conditioning (AC). Multiple logistic regression was used to assess relations between ventilation type and work-related symptoms, adjusting for potential confounding by building, job, and personal factors.

Results. 880 completed questionnaires (response rate 85%) were received. Overall prevalences of four work-related symptoms were greater than 20%. Higher adjusted prevalences of several work-related symptoms were associated with both MV and AC, relative to NV. The highest adjusted prevalence odds ratios were found for dry or itchy skin [MV, 5.8 (95% confidence interval=1.5-22); AC, 5.6 (1.6-20)] and tight chest or difficulty breathing [MV, 3.6 (0.9-15); AC, 4.3 (1.1-16)]. Available evidence suggests that reporting bias is unlikely to explain these findings. Symptom prevalence was not associated with specific environmental measurements made.

Conclusions. This study provides further evidence that work-related symptoms among office workers are common, even in buildings not considered to be "problem" buildings, and are increased in association with unidentified factors in some mechanically ventilated or air-conditioned buildings. Research to identify these factors should include assessment of contaminants emitted by ventilation systems.

keywords: sick building syndrome, indoor environment, indoor air quality

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INTRODUCTION

Outbreaks of building-related illness in offices, involving either infectious disease (e.g., Legionnaires disease), hypersensitivity disease (e.g., hypersensitivity pneumonitis), or exposures to recognized pollutants (e.g., carbon monoxide), have been well documented (1). More common, though, are apparent outbreaks of illness within office buildings for which neither an environmental cause nor a recognized disease can be identified. Mostly reported within the last 20 years, these episodes are generally called Sick Building Syndrome (SBS) (2).

SBS is characterized by widespread complaints of nonspecific symptoms (e.g., mucus membrane irritation, upper respiratory problems, shortness of breath, skin irritation, headache, and fatigue), but no clinical signs or laboratory abnormalities (1). Although poor indoor air quality often has been suspected as a cause of these episodes, investigations generally have not identified contaminants at levels above existing health standards, or conditions outside acceptable ranges for thermal comfort parameters. Early SBS episodes often were attributed to "mass hysteria," but the chronic health complaints involved do not fit existing diagnostic criteria for mass psychogenic illness (1).

Early studies of SBS were limited to investigations of single buildings with persistent worker complaints. Interpretation of the data was difficult because of possible over-reporting by worried workers, and because of lack of comparison data. More recently, a number of epidemiologic studies in Europe have examined symptom prevalence within multiple office buildings of different ventilation types chosen without regard to worker complaints (3-10). In these studies, higher symptom prevalence has not been associated with specific measured contaminants at levels above existing health standards. Without exception, however, these studies found higher symptom prevalence among workers in air-conditioned buildings than among those in naturally ventilated buildings (3-9). Humidification of the indoor air was not necessary for this higher prevalence. Findings for mechanical ventilation systems <u>without</u> air-conditioning have been inconsistent (1,10-12). None of these studies attempted to assess the role of potential reporting bias related to air-conditioning.

The relationships of worker symptoms to building ventilation type has not been studied previously within the U.S. To make an initial assessment of these and other relationships, we studied workers in 12 California office buildings selected without regard to complaint status. In particular, we were interested in investigating associations of work-related symptoms with mechanical ventilation and with air-conditioning, after adjustment for potential confounding by personal, job-related, and workspace factors, and with assessments of potential reporting bias. Study objectives, design, and methods have been reported previously in detail (13).

MATERIALS AND METHODS

Study Design and Population

We studied workers within public office buildings of three different ventilation types, within 3 counties in the San Francisco Bay Area of California, between June and September of 1990. A list was assembled of city- and county-owned office buildings which had more than 10,000 square feet of office space; at least 45 full-time office workers (including at least 10 clerical workers); no unusual pollutant sources (e.g., vehicle repair, laboratories); no ongoing major renovations; no large-scale occupant relocations; and one of three types of ventilation:

* NATURAL VENTILATION: natural ventilation only, with operable windows;
* MECHANICAL VENTILATION: mechanical supply and exhaust ventilation with no air-conditioning and no humidification, and with operable windows; and
* AIR-CONDITIONING: mechanical supply and exhaust ventilation with air-conditioning and no humidification, and with sealed windows.

Jails, hospitals, police stations, and fire stations were excluded from the list. One eligible building contained two large spaces with different types of ventilation that were essentially isolated from each other and from the rest of the building with respect to their ventilation. We treated these as spaces from separate buildings (see Table 1).

We obtained permission to study workers in three of four eligible naturally ventilated buildings, in three of four eligible mechanically ventilated buildings, and in six of eleven eligible air-conditioned buildings. No reason for denying access was given for the naturally or mechanically ventilated buildings. Reasons given for refusals in the five air-conditioned buildings were, for four, serious worker/management tensions about health and comfort in the building, and for one, insufficient occupant time for questionnaire completion. We studied workers in the 12 buildings to which we were granted access (see Table 1). Smoking within all these buildings was prohibited except in small designated areas not linked by the ventilation systems to the rest of the buildings.

Workers in any building may worry about indoor air quality, but in some buildings worry about apparent building-related health problems becomes almost universal. Formal criteria for recognizing such buildings have not been defined. We refer to these buildings, following Cone and Hodgson (14), as "problem" buildings. We neither sought nor excluded problem buildings, but because symptom reports from such buildings may be affected by unusual levels of occupant concern, our analysis plan included adjustment for problem building status. Only one of our study buildings, an air-conditioned building, was found to be a classic problem building, with a history of persistent occupant health complaints and unsuccessful health investigations since initial building occupancy.

Within each building, we studied only workers from specific spaces rather than from the entire building. Study spaces were selected to make the physical working environments assessed within different buildings as similar as possible. Large open office areas were selected where available, along with any adjoining enclosed offices. Where this was not possible, smaller spaces within a building, containing an overall total of at least 45 workers, were combined.

We considered all workers in the study spaces eligible for participation except those who had worked in the building less than three months, those who generally worked in the building less than 20 hours per week, and those who were absent from the office for one week or more during our study period.

Information about buildings was obtained from records, by physical inspection, and from interviews with building management and engineering staff. Indoor and outdoor measurements were made of temperature and relative humidity, and concentrations of carbon dioxide, carbon monoxide, total volatile organic compounds (VOCs), specific VOCs, and culturable airborne fungi and bacteria (13). Measurements were taken during the week before questionnaire completion, at one to three locations within each study space selected to represent the environment of most workers in that space; however, some microbiological sampling was performed at a later time, and because microbiological measurements were ultimately not available for all study spaces, a median value from available measurements was used for each building.

Questionnaire

We used a modified version of a self-administered questionnaire (13) from a study of several U.S. Government buildings in Washington, D.C. (15). The questionnaire asked about the frequency of 15 symptoms occurring at work, during the previous week and also during the previous year, and whether each symptom changed when the respondent was not at work. Other questions assessed various health, demographic, psycho-social, and work-related parameters. Questionnaires were distributed to all workers in each selected space at the beginning of a work week. Workers who did not return questionnaires were recontacted up to three times by phone before being considered non-respondents.

Analytical Methods

Analyses were performed using mainframe statistical packages. For these analyses, we defined a work-related symptom as one which occurred often or always when at work the previous year, and which also improved when away from work. Seven symptom groups were formed by combining related symptoms. Reporting of at least one work-related symptom within a symptom group constituted a positive response for that group. Six of these groups (eye, nose, or throat symptoms; chest tightness or difficulty breathing; chills or fever; fatigue or sleepiness; headache; and dry or itchy skin) were formed from 11 symptoms previously reported to be related to indoor air factors and ventilation type.

One group ("non-indoor air-related" symptoms) was formed from three symptoms not previously reported to be associated with indoor air factors or ventilation type -- toothache, earache, and pain in neck or shoulder. These three symptoms were included to assess symptom over-reporting, under the assumption that actual prevalence of these symptoms should not differ by ventilation type. Increased reporting of these symptoms in association with a building or ventilation type would thus suggest general symptom over-reporting.

Differences in environmental measures between ventilation types were assessed by the Wilcoxon rank sum test, using means or medians of measured values within each space (or each building, for microbiological measures). Analyses used some parameters as measured, and several calculated parameters, such as the difference between indoor and outdoor carbon dioxide concentrations, and a thermal comfort index based on real-time temperature and humidity data. This index, based on a thermal comfort model (16) and an assumed typical indoor air velocity, estimates "predicted percent (of workers) dissatisfied" with thermal comfort (ppd); the parameter used in the analysis was the number of hours in the week when ppd was greater than 10 (13).

Other analyses assessed relationships between work-related symptom prevalence (for the seven symptom groups) and building ventilation categories, using the naturally ventilated buildings as a reference category. Odds ratios (ORs) were used as the measure of effect for both crude analyses (unadjusted for potential confounders) and adjusted analyses (adjusting for a number of personal, psychosocial, job, and workspace characteristics).

Crude ORs for associations between work-related symptoms and ventilation type were calculated, along with 95% confidence intervals using the method of Woolf (17).

For each symptom, adjusted ORs for mechanical ventilation and for air-conditioning were estimated in an unconditional logistic regression model. Each model contained a dichotomous dependent variable for the symptom, independent terms for the two ventilation categories (using naturally ventilated buildings as a reference level), and additional covariates.

Construction of the seven symptom models began with inclusion of covariates representing five personal, three psychosocial, five job, and nine workspace variables found to be related to symptom reporting in previous studies, or in bivariate analyses here. These variables included personal factors (gender, age, race, education, smoking), psychosocial factors (working in a problem building, job stress, job dissatisfaction), job factors (job type, hours per week in building, use of carbonless copy paper, use of photocopiers, and use of computers) and workspace factors (sharing of workspace with other workers, cloth partitions, carpets, new carpets, new walls, new paint, distance from a window, ability to see out a window, and amount of natural light). Missing values of any covariate for a respondent were imputed by assigning the modal values for the covariate within the respondent's building (18). Retaining a group of core variables (ventilation type, personal and psychosocial factors, and job type) in all models, other covariates which did not contribute significantly ($p<0.05$) to the model were sequentially removed.

Each environmental parameter, categorized into quartiles, was then added individually to the reduced models and checked for significant ($p<0.05$) contribution. For comparison, these parameters also were added to an additional set of models, differing only in the definition of work-related symptoms as those having occurred on three or more days during the week of the actual environmental measurements, and also having improved away from work.

RESULTS

The response rate among eligible workers was 85% overall, with 880 completed questionnaires received. Building-specific response rates (shown in Table 1) ranged from 76% to 97%. The most common reason provided for worker nonparticipation was lack of time.

Information about study participants is provided in Table 2. Participants were predominantly female (71.1%) and the most common job category was clerical workers (43.6%). Only 18% overall were current smokers.

Table 3 shows the crude prevalence of work-related symptoms and symptom groups for the total study population. Among the symptom groups, prevalence of eye, nose, or throat symptoms was the highest (40.3%) and prevalence of chills or fever the lowest (4.5%). Prevalence of four specific work-related symptoms was greater than 20%: fatigue, stuffy nose, sleepiness, and eye problems. Of the non-indoor air-related symptoms, only shoulder pain or numbness was reported at a substantial level as a work-related symptom.

Figure 1 shows crude prevalence of work-related symptom groups (hereafter called symptoms) by ventilation type. Symptom prevalences were generally lowest within naturally ventilated buildings and highest within air-conditioned buildings. Prevalences of non-indoor air-related symptoms, however, were similar in all ventilation types. The range of building prevalence values for each symptom (indicated in Figure 1) was greatest in air-conditioned buildings, and least in naturally ventilated buildings. Although the lower ends of symptom prevalence ranges were similar among ventilation types, the upper ends of ranges were consistently higher for mechanically ventilated and air-conditioned buildings.

All environmental contaminant measurements in study spaces were below any existing health standards or guidelines. Some environmental measurements differed between ventilation categories, as shown in Table 4. Air-conditioned buildings had the least predicted thermal discomfort, and mechanically ventilated buildings the most. Air-conditioned buildings had the highest concentrations of carbon dioxide and the largest differences between indoor and outdoor carbon dioxide concentrations; mechanically ventilated buildings had the lowest values for both. Air-conditioned buildings had the lowest concentrations of viable airborne fungi, and naturally ventilated buildings had the highest. The high mean and variability for total VOCs in air-conditioned buildings was explained by wet-process photocopiers or plotters in three of eleven air-conditioned spaces. The problem building had low to average levels of all measured contaminants (not shown).

Table 5 shows crude ORs for seven work-related symptoms, for workers in mechanically ventilated and in air-conditioned buildings relative to naturally ventilated buildings. For both mechanically ventilated and air-conditioned buildings, some elevation in crude ORs was apparent for all symptoms hypothesized to be related to indoor air, although ORs were consistently highest in the air-conditioned buildings. Symptoms with the highest ORs within both these ventilation types were dry or itchy skin, followed by chest tightness or difficulty breathing, and chills or fever. Eye, nose, or throat symptoms, fatigue or sleepiness, and headache were also somewhat elevated for both these ventilation types. No elevations were seen for non-indoor air-related symptoms. Exploratory exclusion of data from the problem air-conditioned building produced ORs in air-conditioned buildings similar to those in mechanically ventilated buildings.

Adjusted ORs from the regression models are also shown in Table 5. No terms for environmental measures were included in the final models, as none contributed significantly. (This was also true for the alternate set of models based on symptoms experienced during the previous week.)

Adjusted ORs were similar within the mechanically ventilated and air-conditioned buildings, with the highest ORs in both building groups again associated with skin symptoms, chest tightness or difficulty breathing, and chills or fever. In both groups, there was some elevation for fatigue or sleepiness, less for eye, nose, or throat symptoms, and none for headache. Non-indoor air-related symptoms showed little increase.

DISCUSSION

This study found higher prevalences of a number of work-related symptoms among workers in 12 California office buildings with mechanical supply and exhaust ventilation, with or without air-conditioning. The presence or lack of operable windows did not explain these findings, because the mechanically ventilated buildings without air-conditioning had operable windows. Humidification systems were not present in any of the study buildings. Measured environmental parameters did not explain these differences.

Most symptom increases with ventilation type in this study (except for headaches) persisted after adjustment in a multivariate model. Some adjusted ORs within both mechanically ventilated and air-conditioned buildings were striking: for skin symptoms, 5.8 and 5.6; for tight chest or difficulty breathing, 3.6 and 4.3. Without adjustment for problem building status, symptom ORs for air-conditioned buildings would have been 25-50% higher than for mechanically ventilated buildings.

Comparable data from other studies are limited, because most studies did not use equally specific ventilation categories, and those which did reported only unadjusted findings (3,9). Available data are particularly limited for comparisons with the mechanically ventilated buildings in this study (e.g., buildings with mechanical ventilation supply and exhaust without air-conditioning or humidification); such data were available only from reanalysis (19, p. 86) of data from one previous study (10). Our unadjusted findings are generally within the range of comparable European studies, except that ORs for skin symptoms in this study were higher.

The prevalence of some work-related symptoms in our overall study population was high: 44% for eye, nose, or throat symptoms, and 33% for fatigue or sleepiness. Symptom prevalences in other cross-sectional office worker surveys have been high (3), including surveys from the U.S. and Canada (20-22). Because prevalence estimates depend heavily on the definitions used, the numbers must be interpreted cautiously. Nevertheless, these findings indicate a potentially widespread problem.

Possible Explanations for Findings.

Clearly ventilation type was not a direct cause of symptoms, yet a factor or factors in <u>some</u> buildings with ventilation systems was associated with increased symptoms. The most likely explanation for our findings would be an association of both ventilation type and symptom prevalence with at least one of the following: poor thermal comfort, lower supply of outside air, or the production or dissemination of contaminants by ventilation systems.

Some studies have found temperature in offices to be related to prevalence of work-related symptoms (20,23,24), although others have not (12). Associations between ventilation type and thermal discomfort has not been reported in other studies (5,25,26). The measure of predicted thermal discomfort in this study did not contribute significantly to prediction of symptom outcomes in the multivariate models.

Supply of less outside air would result in higher concentrations of indoor-produced pollutants, which could elicit symptoms. Assessments of ventilation adequacy, based on carbon dioxide measurements in the study spaces [relative to a suggested standard of 1000 ppm (27)], and on indoor-outdoor differences in carbon dioxide concentration, provided no evidence of inadequate ventilation in mechanically ventilated or air-conditioned study spaces. We also found no association between symptom prevalence and either indoor carbon dioxide concentration or indoor/outdoor differences in concentration. Overall evidence from other studies suggests symptom increases with lower fresh air ventilation rates (11,22,24), although some studies have not found this association (12,21,23,28).

A more tenable hypothesis may be that mechanical ventilation systems are associated with the production or dissemination of biological, chemical, or physical contaminants that are related to occupant illness through as yet uncharacterized mechanisms (3,5,29,30). Previous research has suggested that building ventilation systems may themselves be <u>sources</u> of indoor air contaminants, even in buildings without known health problems. Possible contaminants include microorganisms (1,31,32), VOCs (33), fibers (12), and odors (34), but to date, comparison studies have not associated increases in measured environmental contaminants with ventilation systems. We found greatly decreased concentrations of total viable airborne fungi in air-conditioned buildings, possibly due to the sealed windows and filtered air, but this is a potentially insensitive summary measure.

Most other studies have not found associations in office buildings between increased symptom prevalence and measured airborne contaminants (e.g., specific or total VOCs, carbon dioxide, respirable particles, and viable airborne fungi and bacteria) (1,12,25,28,35). Conventional measurement strategies, however, are limited in scope and may not adequately characterize relevant contaminants, appropriate time periods, or individual worker exposures. Some recent field (12,20,36-38) and chamber (39-43) studies have found relationships between health effects and measured exposures, some below existing standards or guidelines, but these findings have not been consistent and require confirmation. Explanation of SBS may await the development and use of appropriate indoor environmental measurement techniques.

Limits to Interpretation.

This is the first study reported from the U.S. of office workers within buildings of different ventilation types, selected from a defined building population without regard to worker complaints. Because the study included only workers from public office buildings in a limited geographic area, the results cannot be assumed representative of other U.S. office buildings. The generally similar findings from comparable studies elsewhere make generalizations based on our findings plausible, but additional U.S. studies will be necessary.

A number of potential biases may have influenced these findings. Careful enumeration of all eligible buildings minimized bias in selection of buildings, but the high building refusal rate among air-conditioned buildings because of worker complaints may have caused an underestimate of symptom prevalence within air-conditioned buildings in our target population. Selection bias at the individual worker level may also have resulted in an underestimation of actual associations, if workers with building-related health problems either had left work in their buildings or were absent through illness more often than others. The magnitude of this potential bias cannot be assessed in our cross-sectional data. Individual response bias is unlikely to have been substantial, as response rates were high, and similar, within all ventilation types (82% in natural, 84% in mechanical, and 86% in air-conditioned buildings).

Some potential confounding factors were minimized in the study design and others controlled in the analysis. In theory, other confounders not considered here could explain our findings; however, to do so these would have to be strongly related to both symptoms and ventilation type. Building size and building age might be such factors, but neither factor was found to be related to symptoms in bivariate analyses. Another potential confounding factor in this study is worker concern about health effects of indoor air quality: concerns associated more with a particular ventilation type might have inflated estimates of symptom prevalence for workers within that ventilation type. Current studies of SBS, lacking objective health measures, are very susceptible to such over-reporting bias.

In this study it was possible to assess over-reporting in several ways. First, the OR for non-indoor air-related symptoms was only slightly elevated in mechanical or air-conditioned buildings, although most other symptoms assessed were elevated in these groups. In the problem building, the adjusted OR for non-indoor air-related symptoms was 1.4 (95% CI, 0.8-2.4), suggesting at most moderate over-reporting in the study, even where it was most likely.

Second, the largest increases related to ventilation type were found in skin problems and lower respiratory symptoms, rather than in the symptoms more commonly linked to SBS in the media -- eye, nose, and throat symptoms, fatigue, and headache. Also, symptom increases in our study were equally high within the older mechanically ventilated buildings with operable windows and the newer sealed air-conditioned buildings. Thus, worker concerns based on media reports about specific symptoms in predominantly new, air-conditioned buildings were not a likely explanation for our findings.

Suggested Research.

Findings of this study and of previous European studies suggest a common but potentially preventable health problem among office workers worldwide. Resulting costs, for health care and from losses in time and productivity, may be considerable (44,45). The overall etiology of this problem is likely multifactorial, involving still poorly characterized chemical, biological, physical, and psychosocial factors. Future research to identify specific etiologic exposures or conditions should include assessment of ventilation system-associated risk factors, such as the production of contaminants by some ventilation systems.

Table 1. Descriptive information on study buildings

Ventilation Category	Building Size (sq m)	Number Floors in Building	Year Built	Total No. Eligible Workers	Questionnaires Received	Response Rate
Natural ventilation	3,620	10	1912*	54	41	76%
	2,320	3	1895	35	34	97%
	47,940**	6	1915	69	55	80%
Mechanical ventilation	6,320	2	1955	44	41	93%
	2,320	4	1954	59	50	85%
	47,940**	6	1915	99	79	80%
Air-conditioning	15,890+	9	1978	186	151	81%
	19,510	7	1982	113	96	85%
	8,640	5	1964	106	89	84%
	8,360	4	1964	97	83	86%
	3,620	3	1987	117	111	95%
	8,360	12	1957	53	50	94%
Total				1032	880	85%

* building interior totally rebuilt in 1964
** distinct spaces of 1,300 and 1,020 sq. m. located within a single large building;
+ problem building

Table 2. Distribution of individual characteristics within ventilation categories, and in total population of workers

Variables	Ventilation Category: Natural Ventilation (n=130*)	Ventilation Category: Mechanical Ventilation (n=170*)	Ventilation Category: Air-Conditioning (n=581*)	Total (n=880*)
	%	%	%	%
Gender				
male	35.4	37.7	24.8	28.9
female	64.6	62.3	75.2	71.1
Age in years				
<30	8.0	13.4	10.5	10.7
30-39	24.8	32.3	21.4	24.0
40-49	34.4	30.5	38.4	36.3
>=50	32.8	23.8	29.7	29.0
Job category				
managerial	25.6	12.5	18.2	18.2
professional	3.9	34.5	12.1	15.2
case worker	22.5	0	17.0	14.5
clerical	41.9	47.6	42.8	43.6
technical or other	6.3	5.4	9.9	8.4
Race/ethnicity				
White	37.0	35.5	50.2	45.5
Black	3.9	15.7	19.3	16.3
Asian/Pacific Islander	41.7	30.7	17.3	23.5
Hispanic	11.8	14.5	8.6	10.2
other	5.5	3.6	4.6	4.5
Education (highest degree completed)	41.3	42.8	50.1	47.4
less than bachelor's	36.5	39.2	31.5	33.7
bachelor's degree	22.2	18.1	18.5	18.9
graduate/professional degree				
Smoking status				
not current	89.1	81.3	81.0	82.3
current, 1-10 cigarettes/day	3.1	10.2	9.9	9.0
current, 11-20 cigarettes/day	7.8	8.4	9.0	8.7

* Denominator for each variable may vary due to non-response.

Table 3. Crude prevalence of work-related symptoms in the study population+ of workers

Hypothesized To Be Related to Indoor Air Quality		Hypothesized To Be Unrelated to Indoor Air Quality	
symptoms	prevalence (%)	symptoms	prevalence (%)
Eye, Nose, or Throat Symptoms[1]	**40.3**	**Non-Indoor Air-Related**[1]	**15.3**
runny nose[2]	16.6	earache[2]	2.7
stuffy nose[2]	25.2	toothache[2]	1.0
dry irritated throat[2]	17.7	shoulder pain or numbness[2]	14.1
dry, irritated, or itching eyes[2]	22.0		
Chest Tightness or Difficulty Breathing[1]	**7.5**		
chest tightness[2]	3.7		
difficulty breathing[2]	6.5		
Chills or Fever[1,2]	**4.5**		
Fatigue or Sleepiness[1]	**33.2**		
fatigue/tiredness[2]	25.4		
sleepiness[2]	24.9		
Headache[1,2]	**19.8**		
Dry or Itchy Skin[1,2]	**10.8**		

\+ n=880, but denominator for each symptom may differ due to non-response

[1] symptom used in analysis

[2] symptom assessed in questionnaire

Table 4: Environmental measures within different ventilation categories

Environmental Measure	Ventilation Category: Natural Ventilation mean (s.d.*)	Mechanical Ventilation mean (s.d.)	Air-Conditioning mean (s.d.)	Wilcoxon Rank Sum Test p value
predicted thermal discomfort (hours ppd** > 10%)	8.1 (2.4)	9.9 (2.5)	7.6 (3.7)	0.04
carbon dioxide concentration (ppm***)	417 (41.3)	386 (8.5)	442 (63.9)	0.07
carbon dioxide, inside/outside concentration difference (ppm)	81.0 (35.1)	48.0 (12.2)	111 (72.4)	0.07
total volatile organic compound concentration (ug+/m³)	336 (143)	382 (103)	1220 (1710)	0.28
viable airborne fungi concentration (c.f.u.++/m³)	71.7 (11.5)	58.7 (19.9)	12.2 (4.9)	0.01
viable airborne bacteria concentration (c.f.u./m³)	177 (81.7)	124 (46.8)	175 (67.5)	0.59

* s.d = standard deviation
** p.p.d. = predicted percent dissatisfied
*** p.p.m. = parts per million

\+ ug = micrograms
++ c.f.u. = colony forming units

Table 5. Crude and adjusted odds ratios (OR) and 95% confidence intervals (CI) for work-related symptoms by ventilation category relative to naturally ventilated buildings

	Ventilation Category			
	Mechanical Ventilation		Air-Conditioning	
	Crude	Adjusted	Crude	Adjusted
Work-Related Symptoms	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Eye, nose, or throat symptoms	1.5 (0.9-2.5)	1.7 (0.9-3.0)	2.1 (1.4-3.2)	1.3 (0.7-2.4)
Chest tightness or difficulty breathing	3.0 (0.8-11)	3.6 (0.9-15)	3.9 (1.2-13)	4.3 (1.1-16)
Chills or fever	2.8 (0.6-14)	2.3 (0.4-14)	3.4 (0.8-14)	2.3 (0.5-12)
Fatigue or sleepiness	1.4 (0.8-2.4)	1.9 (1.0-3.6)	1.9 (1.2-3.0)	2.2 (1.2-3.9)
Headache	1.4 (0.7-2.7)	1.0 (0.5-2.2)	1.9 (1.1-3.4)	0.9 (0.4-1.9)
Dry or itchy skin	4.2 (1.2-15)	5.8 (1.5-22)	6.0 (1.9-19)	5.6 (1.6-20)
Non-indoor air-related	0.9 (0.5-1.8)	1.3 (0.6-2.6)	1.1 (0.6-1.8)	1.2 (0.6-2.3)

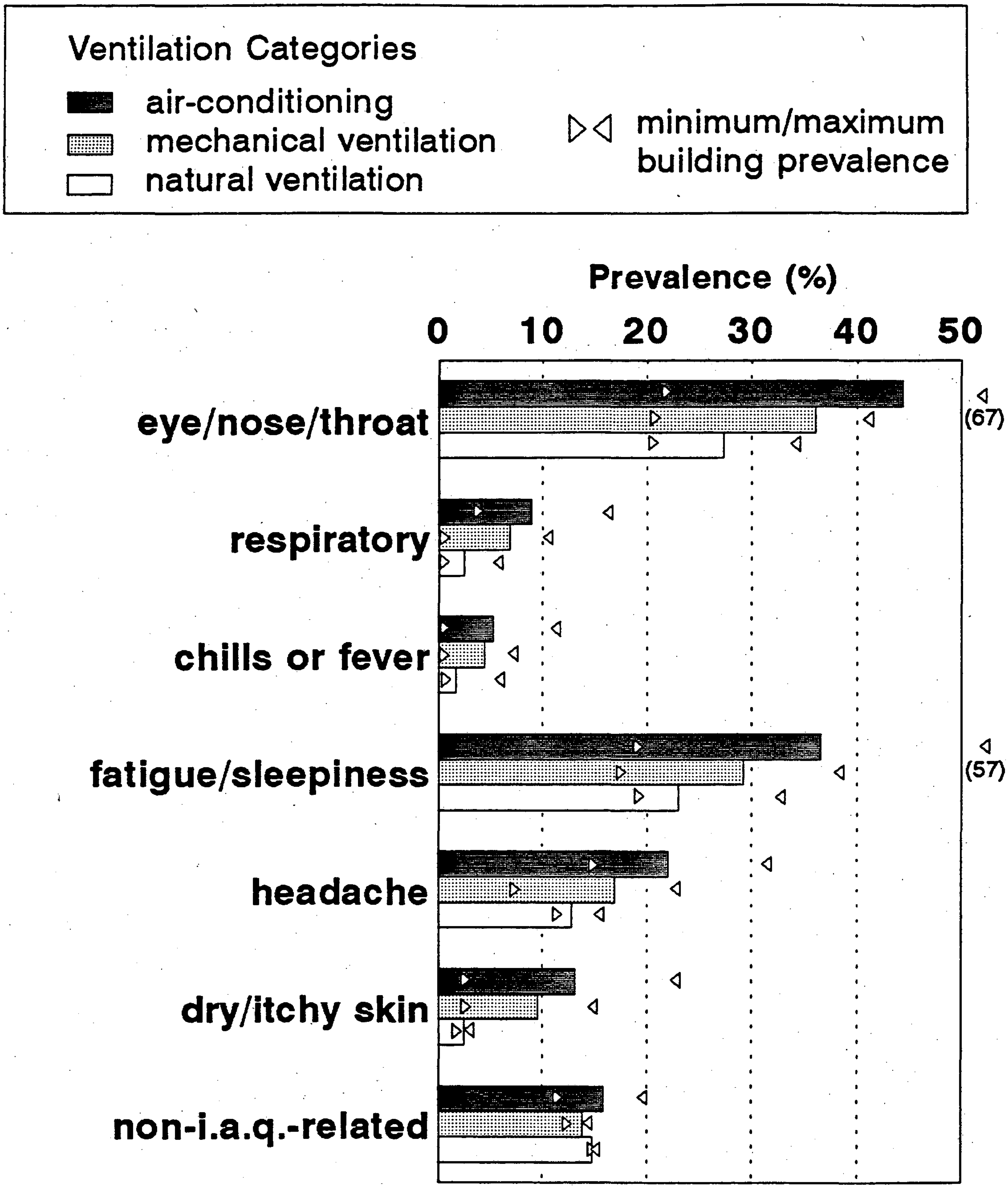

Figure 1. Crude prevalence of work-related symptoms by ventilation category