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RELATIONSHIP OF SBS-SYMPTOMS AND VENTILATION SYSTEM TYPE IN OFFICE BUILDINGS

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ABSTRACT
This paper provides a summary of current knowledge about the associations of ventilation system types in office buildings with sick building syndrome symptoms. Most studies completed to date indicate that relative to natural ventilation, air conditioning, with or without humidification, was consistently associated with a statistically significant increase in the prevalence of one or more SBS symptoms, by approximately 30% to 200%. In two of three analyses from a single study (assessments), symptom prevalences were also significantly higher in air-conditioned buildings than in buildings with simple mechanical ventilation and no humidification. The available data also suggest, with less consistency, an increase in risk of symptoms with simple mechanical ventilation relative to natural ventilation. The statistically significant associations of mechanical ventilation and air conditioning with SBS symptoms are much more frequent than expected from chance and also not likely to be a consequence of confounding by several potential personal, job, or building-related confounders. Multiple deficiencies in HVAC system design, construction, operation, or maintenance, including some of which cause pollutant emissions from HVAC systems, may contribute to the increases in symptom prevalences but other possible reasons remain unclear.

INDEX TERMS
HVAC, Sick building syndrome, Ventilation system type, Review article

INTRODUCTION
The primary objectives of this paper is to synthesize available literature on the associations of ventilation system types in office buildings with sick building syndrome symptoms and to evaluate potential explanations for the associations. This paper is based on the review by (Seppänen and Fisk, 2001).

In many studies, prevalence of sick building syndrome symptoms have been associated with characteristics of buildings and ventilation systems. One of the most important factors affecting indoor air quality is how the building is heated, ventilated and air-conditioned. In many cases, particularly in office buildings, these functions are integrated in one system. In this paper these systems are called HVAC systems (heating, ventilating and air-conditioning systems).

Studies of the associations of ventilation system types or features with health and perception outcomes have primarily been performed in buildings several years after construction, and risk factors could differ in new buildings. Most studies have been cross-sectional, with data on health (or perception) outcomes, ventilation system characteristics, and other relevant factors collected in multiple buildings and these data analyzed statistically to determine the

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strength and uncertainty in the associations of health outcomes with the type of HVAC system. A weakness of this study design is that many factors other than ventilation system type vary among the buildings and may influence the health outcomes, confounding the association of HVAC system type with the health outcome. The better cross-sectional studies control for many potential confounding factors in the study design or data analyses. Unfortunately, some studies have controlled for few or no confounding factors in statistical analyses. Another inherent weakness of cross-sectional studies is that occupants with substantial adverse health effects from exposures in a building may more frequently be absent or quit working in the building. For these reasons, cross sectional studies can find statistical associations but, without other supporting findings, such studies cannot confirm causal relationships.

APPROACH

General approach

The overall approach was to identify relevant papers for review, to set criteria for studies to be included, to analyze the available information from studies meeting the inclusion criteria and process the results into a common format, and finally to draw conclusions.

Study inclusion criteria

The review included only studies of office buildings, although some information is available from schools, residences, etc. Most of the studies have used SBS symptoms as the outcome, and we excluded other outcomes from the review. We also excluded studies that did not perform a statistical test to determine if there were statistically significant differences in symptoms between occupants of buildings with different HVAC types.

The power of a cross-sectional study increases with the number of study buildings or study spaces with different HVAC systems, and also with the number of occupants included in the study. Increased power reduces effects of random error, but does not reduce systematic bias. For this review, we excluded from consideration any cross-sectional study with less than two buildings in any included HVAC-type category. We also excluded studies primarily containing complaint buildings, because we suspected that the widespread concerns about health in complaint buildings could decrease the validity of self-reported symptoms.

Some published experimental studies involved movement of subjects from building to building or with replacement of HVAC systems, with analyses of the changes in symptom prevalences within subjects. Some potential confounding is eliminated by within-subject analyses; for example by personal and job-related factors, which are unchanged during the experiment. However, there is still a possibility of confounding by many parameters which may have varied among the experimental periods, such as building characteristics, indoor temperature, outdoor conditions or job stress. We considered these sources of potential bias so significant that we excluded from our review any studies with movement of the study population between buildings or with replacement of HVAC systems. Another weakness of these studies is that occupants' awareness of the HVAC and environmental changes may have influenced their symptom reporting on questionnaires.

All studies that fulfilled the criteria described above were included in our review whether or not statistically significant associations were reported.

RESULTS

Tables 1 and 2 summarize the major features and findings of studies included in this review. A study may have performed multiple analyses (called assessments) between different groups of HVAC types or analyzed different subsets of study data (e.g. a natural ventilation group was compared with air conditioning group and also with a simple mechanical group). Each assessment is presented on an individual row in Table 1 or 2.

Association of HVAC system types with SBS symptoms

Table 1 presents the assessments comparing symptoms among occupants of air-conditioned buildings with those in naturally-ventilated or simple-mechanically-ventilated buildings. Table 2 presents the assessments comparing symptoms associated with simple mechanical ventilation to symptoms associated with natural ventilation. Tables 1 and 2 provide the following data: a) the number of symptoms or symptom groups in the analyses; b) the number of symptoms that were statistically significantly associated with HVAC system type; and c) when available, the range of relative risks or odds ratios for statistically-significant associations. Additionally, the presence or absence of statistically-significant associations of HVAC system types with outcomes is illustrated graphically within the tables using an adaptation of the format of (Mendell, 1993). HVAC system types are indicated by circles located in the appropriate columns. When the type of humidification was uncertain or included multiple types, the circle was replaced with a horizontal bar extending across the applicable columns. Within these tables, shading of a circle or horizontal bar (relative to no shading), indicates that the study found a statistically-significant increase in prevalence of one or more symptoms among occupants with that HVAC system type relative to buildings with the reference-type of HVAC. Unshaded circles at both ends of a connecting line indicate that the subjects served by different types of HVAC systems did not have significantly different symptom prevalences. The numbers adjacent to the circles denote the number of buildings in the assessment with that type of HVAC system. Blank spaces in the tables indicate that the information was not reported.

Referring to Table 1, 16 of 17 assessments found a statistically significant increase in the prevalence of one or more symptoms with air conditioning relative to natural ventilation. Nine of these assessments controlled for two or more types of confounding factors, and eight of the nine found a significant increase in symptoms with air conditioning. Two of three assessments found a statistically significant increase in the prevalence of symptoms with air conditioning relative to simple mechanical ventilation without air conditioning; however, no significant increase in symptom prevalences was found in the assessment with the largest number of buildings. Air conditioning with or without humidification was associated with significant increases in symptom prevalences. The studies provided minimal information to assess the hypothesized increase in risks with various types of humidification. In 12 of 20 assessments, air conditioning was associated with a significant increase in the prevalence of a majority of the symptoms or symptom groups. Most of the relative risks or odds ratios were between 1.3 and 3.0, indicating roughly up to 30% to 200% increases in symptom prevalences in the air conditioned buildings.

The results of the nine assessments that did not involve air conditioned buildings are provided in Table 2. In five of seven assessments that compared simple mechanical ventilation to natural ventilation or to sets of buildings with both natural and exhaust ventilation, prevalences of one or more symptoms were statistically-significantly higher with simple mechanical ventilation. The study with the largest number of buildings (Sundell et al., 1994) did not find a significantly higher symptom prevalence with simple mechanical ventilation;

Table 1. Comparison of SBS symptom prevalences with and without air conditioning.

Reference		Study and Building Characteristics					Ventilation System Type								Results	
								Mechanical Without AC			Air Conditioning					
First Author	Year	Controlled confounders#	No of respondents in comparison	Sealed or openable windows*	Smoking	Recirculation *	Natural Ventilation	Mechanical exhaust	Simple mechanical, no humidification	Simple mechanical with humidification	No Humidification	Steam Hum.**	Evaporative Hum.	Spray Hum.	Number of Symptoms with signicantly higher prevalences in assessment^^	Range of risk ratio or (odds ratio) for outcomes
Jaakkola	95	P,W,B	868	O		Y/N	7 ○				● 9				2 of 14 S	1.5-2.6
Mendell	96	P,W	710	S	N	Y	3 ○				● 6				6 of 7 S	1.6-5.4
Burge^	87	none	1459	S/O			11 ○				● 10				10 of 10 S	(1.3-2.1)
Harrison^	87	none	1044	S		Y/N	8 ○				● 6				6 of 6 S	(1.7-2.9)
Zweers	92	P,W,B	2806	S/O	Y		21 ○				●				5 gr. of S	1.5-1.7
Jaakkola	95	P,W,B	335	O		Y	7 ○					● 2			3 of 14 S	(1.9-2.5)
Burge^	87	none	863	S/O			11 ○					● 4			8 of 10 S	(1.3-2.1)
Zweers	92	P,W,B	3573	S/O	Y		21 ○					●			5 of 5 gr. of S	1.3-1.9
Jaakkola	95	P,W,B	559	O		Y/N	7 ○						● 3		3 of 14 S	(2.0-2.7)
Teeuw	94	none	927	S/O		Y/N	7 ○						● 7		5 of 8 S	1.4-2
Burge^	87	none	1991	S/O			11 ○						▬	▬ 15	10 of 10 S	(1.4-2.2)
Finnegan^	87	none	787	S	Y	Y/N	3 ○						▬	▬ 3	6 of 11 S	(2.5-4.8)
Harrison^	87	none	2080	S		Y/N	8 ○						▬	▬ 13	5 of 6 S	(2.1-3.2)
Hedge^	84	none	1214				2 ○						▬	▬ 2	2 of 2 S	(2.7-3.0)
Zweers	92	P,W,B	3846	S/O	Y		21 ○							●	5 of 5 gr. of S	1.5-2.1
Brasche	99	P,W					○				▬	▬	▬	▬	3 of 7 S	(1.4-1.4)
Hawkins	91	P	255		N	Y	6 ○					▭	▭	▭ 6	S score	
Jaakkola	95	P,W,B	1828	O		Y/N			18 ○		● 9				2 of 14 S	(1.3-1.7)
Jaakkola	95	P,W,B	1295	O		Y/N			18 ○			● 2			1 of 14 S	(1.8-1.8)
Jaakkola	95	P,W,B	1519	O		Y/N			18 ○				○ 3			

^ as reanalyzed by Mendell (1990) #P = personal factors, W = work factors, B = building factors
*In mechanically-ventilated buildings **Hum = Humidification ^^ gr = groups

Key: ○—○ / ○—▭ No statistically significant difference in symptoms; ○—● / ○—▬ Statistically significant difference in symptoms

however, only ten of 540 rooms in this study had natural ventilation. In one of the five assessments (Skov et al., 1990) with increased symptoms in buildings with simple mechanical ventilation, two buildings with mechanical ventilation had humidifiers, a possible risk factor. When prevalences were significantly higher with simple mechanical ventilation, the odds ratios or relative risks ranged from 1.4 to 2.3, with one outlier of 6.0. One of these seven assessments had the opposite finding (significantly more symptoms with natural ventilation) and one had no statistically-significant findings. In two other assessments in Table 2, prevalences of symptoms with mechanical exhaust ventilation did not differ significantly from prevalences with natural or simple mechanical ventilation.

Table 2. Comparisons of symptom prevalences among buildings without air conditioning.

Reference		Study and Building Characteristics					Ventilation System Type				Results	
First Author	Year	Controlled confounders#	No of respondents	Sealed (S) or openable (O) windows*	Smoking	Recirculation*	Natural Ventilation	Mechanical exhaust	Simple mechanical	Simple mechanical, with humidification	Symptoms with signicantly higher prevalences in assessment^^	Range of risk ratio or (odds ratio) for outcomes
Jaakkola	95	P,W,B	456	O		N	7	2				
Skov	90	P,W	2369	O		Y/N	9		5		2 of 2 gr. of S	1.4 - 1.8
Jaakkola	95	P,W,B	1460	O		Y/N	7		18		1 of 14 S	2.2
Mendell	96	P,W	300	O	N	Y	3		3		4 of 7 S	1.5 - 5.4
Burge^	87	none	1386	S/O			11		7		3 of 10 S	(0.7- 0.8)
Sundell	94	P,W,B	778	S/O								
Zweers	92	P,W,B	3009	S/O	Y		21				2 gr. of S	1.3 - 1.5
Sundell	94	P,W,B	788									
Zweers	92	P,W,B	2879	S/O	Y		21				4 gr. of S	1.4 - 2.1

^as reanalyzed by Mendell 90 #P = personal factos, W = work factors, B = building factors
*In mechanically-ventilated buildings **Hum = Humidification ^^gr. = group

Key: No statistically significant difference in symptom prevalences; Statistically significant difference in symptom prevalences

The results portrayed in Tables 1 and 2 provide minimal information on the potential additional risks of humidification. Hedge et al. (1989) compared symptom prevalences among three sets of air-conditioned buildings: buildings without humidification, buildings with steam humidification, and buildings with evaporative humidification. The prevalences of five of ten symptoms differed significantly among the three HVAC types; suggesting that humidification type may affect symptom prevalences. For eight of ten symptoms, prevalences were highest with evaporative humidification. The results reported in Table 1 of Zweers et al. (1992), comparing symptom prevalences with simple mechanical ventilation (independently with and without humidification) to symptom prevalences with natural ventilation, also suggest that humidification may be associated with higher prevalences of two out of five symptom groups.

CONCLUSIONS

Relative to natural ventilation, air conditioning with or without humidification was consistently (16 of 17 assessments) associated with a statistically significant increase in the prevalence of one or more SBS symptoms. Prevalences were typically higher by roughly 30% to 200% in the air conditioned buildings. In two of three available assessments (from a single study), symptom prevalences were also significantly higher in air conditioned buildings than in buildings with simple mechanical ventilation and no humidification. The available data also suggest, with less consistency, an increase in risk of symptoms with simple mechanical ventilation relative to natural ventilation. In five of seven assessments, SBS symptom prevalences were higher in buildings with simple mechanical ventilation with or without humidification than in buildings with natural ventilation or in sets of buildings with either natural or exhaust ventilation. Insufficient information was available for conclusions about the potential increased risk of SBS symptoms with humidification or with recirculation of return air. The statistically significant associations of mechanical ventilation and air conditioning with SBS symptoms are much more frequent than expected from chance. The consistent associations reported in this synthesis are not likely to be a consequence of confounding by personal or job factors, textiles, building age, indoor temperature, indoor humidity, depth of building bays, and dusty surfaces. All studies were performed in moderate or cold climates; thus, the findings reported in this paper may not apply for buildings in hot humid climates.

The reasons for the consistent increases in symptom prevalences with mechanical ventilation and particularly with air conditioning remain unclear. Multiple deficiencies in HVAC system design, construction, operation, or maintenance may contribute to the increases in symptom prevalences, including deficiencies that lead to pollutant emissions from HVAC systems.

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REFERENCES

Hedge, A.(1984) "Evidence of a relationship between office design and self-reports of ill health among office workers in the United Kingdom", *Journal of Architectural Planning and Research*, **1**:163-174

Mendell, MJ (1993) "Non specific symptoms in office workers: a review and summary of the epidemiologic literature", *Indoor Air* 3: 227-236

Mendell, M.J. and Smith, A.H. (1990) "Consistent pattern of elevated symptoms in air-conditioned office buildings: A reanalysis of epidemiologic studies", *American Journal of Public Health*,. 80(10): 1193-1199. Seppänen, O and William Fisk, W.J.: Association of ventilation system type with SBS symptoms in office workers, Accepted for publication in 2001 in International Journal of Indoor Air Quality and Climate.

Skov, P., Valbjorn, O., Pedersen, B., and DISG (1990) " Influence of indoor climate on the sick building syndrome in an office environment " *Scandinavian Journal Work, Environment and Health,* **16***,* pp. 363-371.Sundell J, Andersson B, Andersson K, Lindvall T (1993) Volatile organic compounds in ventilating air in buildings at different sampling points in the buildings and their relationship with the prevalence of occupant symptoms. *Indoor Air* 3: 82-93.

Sundell, J. (1994) "On the association between building ventilation characteristics, some indoor environmental exposures, some allergic manifestations and subjective symptom reports", *Indoor Air*, Supplement No. 2/94.

Zweers, T., Preller, L., Brunekreef, B., and Boleij, J.S.M. (1992) "Health and comfort complaints of 7043 office workers in 61 buildings in the Netherlands", *Indoor Air* 2(3): 127-136.