Indoor Air 2000; 10: 101–110
http://journals.munksgaard.dk/indoorair

INDOOR AIR
ISSN 0905-6947

Development of a Multiple Regression Model to Identify Multi-Family Residential Buildings with a High Prevalence of Sick Building Syndrome (SBS)

KARIN ENGVALL[1,3]*, CHRISTINA NORRBY[1], JEANETTE BANDEL[1], MARIE HULT[2] AND DAN NORBÄCK[3]

Abstract The aim was to develop a multiple logistic regression model to identify multi-family houses with an increase of sick building syndrome (SBS). In Stockholm, 609 multi-family buildings with 14,235 dwellings were selected by stratified random sampling. The response rate was 77%. Multiple logistic regression analysis was applied, adjusting for ownership of the building, building age and size, age, gender, and atopy. Females, subjects with allergy, those above 65 yr, and those in new buildings reported significantly more SBS. Subjects owning their own building reported less SBS, but the relationship between ownership and building age was strong. A regression model, including factors with a high explanatory value was developed. According to the model, 5% of all buildings built before 1961, 13% of those built 1976–1984, and 15% of those built 1985–1990 would have significantly more SBS than expected. In conclusion, SBS is related to personal factors, building age, and ownership of the building. To identify multi-family buildings with more SBS than expected, it is necessary to adjust for ownership and population characteristics.

Key words Atopy; Building age; Multi-family building; Indoor air quality; Self-administered questionnaire; Sick building syndrome (SBS).

Practical Implications
This paper describes characteristics of multi-family buildings in Stockholm that have higher than expected occurrence of sick building syndrome symptoms. After applying a model for adjusting results to accommodate known individual differences in symptom rates, the authors show that ownership of the building and when it was built are both associated with excess symptom rates in occupants.

Received for review 4 June 1999. Accepted for publication 29 January 2000.

Introduction

Up to the mid-1970s, the quality of indoor air was considered to depend mainly on outdoor air. But conditions have changed as a result of the changes in construction techniques and new building materials in the wake of the oil crisis. These various strategies have affected the indoor climate in our dwellings in a number of ways. People complain about the thermal climate and shortcomings in ventilation. At the same time, the proportion of people with some form or oversensitivity or allergy has increased substantially. Concepts such as "healthy" and "sick" buildings have emerged. Therefore today there is an increased concern about health effects and discomfort related to the indoor environment and a demand for knowledge on how to construct buildings leading to a healthy indoor environment. Such knowledge cannot be based exclusively on technical standards or hygienic guidelines, but must include evaluations on health and comfort of inhabitants of new buildings of different type. As the population in the industrialised world spends about 65% of their lives in their homes (Moschandreas, 1981), the home environment is an important area for indoor environmental research. Most epidemiological indoor studies on adults have dealt with office workers (Kreiss, 1989; Hodgson, 1995; Apter et al., 1994; Skov et al., 1987; Stenberg et al., 1994; Sundell et al., 1994), and there are few studies on medical symptoms among adults in relation to domestic exposures (Norlen and Andersson, 1993; Norbäck and Edling, 1991; Bornehag, 1994, Valbjørn and Korsgaard, 1984).

Disorders that have been associated with indoor air pollution include asthma, allergies, and non-specific symptoms from eyes, upper airways and facial skin.

[1]*Stockholm Office of Research and Statistics, Stockholm, Sweden,* [2]*White Architects LTD and Chalmers University of Technology, Department of Building Services Engineering, Sweden,* [3]*Department of Medical Science/Occupational and Environmental Medicine, University Hospital, Uppsala University, S-751 85 Uppsala, Sweden, Tel: +46 1866 3649, Fax: +46 1851 9978, e-mail: karin.engvall@bepe.a.se, *Author to whom correspondence should be addressed*

These non-specific symptoms are sometimes referred to as the sick building syndrome (SBS) (Kreiss, 1989; Hodgson, 1995; Apter et al., 1994). The SBS concept was established due to observations that certain combinations of symptoms were increased in problem buildings (Kreiss, 1989). Recently, the concept of SBS has been criticized as unspecific, mixing different types of symptoms, and a subclassification of SBS depending on the type of symptom has been suggested (Hodgson 1995; Järvholm 1993). As appears from the literature, some investigators have restricted their studies to symptoms perceived to be related to the indoor environment (Bornehag, 1994). Others have restricted their studies to symptoms improving, or disappearing, when being away from the indoor environment (Skov et al., 1987). Finally, many Scandinavian authors have studied general prevalence of SBS symptoms, without such restrictions (Stenberg et al., 1994; Sundell et al., 1994; Norbäck and Edling 1991).

As reported in three review articles, various factors, such as wall-to-wall carpeting, type of ventilation system, high room temperature, and low ventilation flow rate have been shown to influence the prevalence of SBS-symptoms (Kreiss, 1989; Hodgson, 1995; Apter et al., 1994). In addition, SBS is also influenced by personal factors, such as female gender (Kreiss, 1989; Hodgson, 1995; Apter et al., 1994), psycho-social work conditions (Boxer, 1990; Crawford and Bolas 1996), and allergic disorders (Björnsson et al. 1998; Norbäck and Edling 1991; Stenberg et al., 1994;). There are few studies on SBS in relation to different aspects of the home environment (Norlen and Andersson 1993; Norbäck and Edling 1991; Bornehag 1994). Information on symptoms compatible with SBS, e.g., on nasal and ocular symptoms, are available in some studies on asthmatic symptoms in adults, in relation to building dampness in dwellings (Dales et al., 1991; Brunekreef, 1992; Pirhonen et al., 1996). To make priorities, decision makers need scientifically based decision models, making it able to discriminate between "healthy" and "sick" buildings, based on occurrence of symptoms. By means of statistical modelling, large SBS studies can be used to create decision models, controlling for the distribution of other important predictors of SBS.

The aim of this study was to develop a model to identify houses with an increased occurrence of symptoms compatible with the sick building syndrome (SBS), controlling for important predictors of SBS. This was done by applying a standardised self-administered questionnaire and the construction of a multiple logistic regression model in a large random sample of dwellings within an urban area (Stockholm).

Approach

Study Population

During November-February 1991 and November-February 1993, 609 out of 11,805 (5%) multi-family buildings in Stockholm were selected from a central building register, by stratified random sampling. The stratification was based on building age, to achieve a sufficient number of buildings in each age class. The division of the buildings into age classes was based on major changes in building technology. The main sampling, of 378 buildings, was done in 1991. An additional sampling of 231 buildings built before 1961 was done in 1993, to obtain a sufficient number of older buildings in the total sample. All dwellings (n= 14,235) in these 609 buildings were selected for the study. Out of these, 12 buildings were used for care of old people only and were not included in the study. In larger buildings with more than 29 apartments (n= 250), 30 apartments were randomly selected for the study. In buildings with less then 30 apartments (n= 347), all apartments were included. Finally, all buildings (n=84) with less than 10 respondents were excluded.

In each included apartment (n=14,235), one randomly selected adult person (>=18 yr) was drawn by combining the building register with the civil registration register, irrespectively of the number of inhabitants living in the apartment. A self-administered postal questionnaire was sent to these subjects. Since the combined building and civil registration register was about one year old, 1,568 did not live at the actual address, according to information from the mail office or the current inhabitant of the apartment. The proportion of subjects not living on the actual addresses were similar (9.8–11.5%) in all age classes of buildings. In total, 9,808 out of 12,667 with correct addresses answered the questionnaire (77%). Similar response rates were obtained in 1991 and 1993 (78% and 77%, respectively). In the statistical analysis, further restrictions were made, excluding those who reported in the questionnaire that they had lived in the current dwelling less than one year (n=736). The proportion of participants were similar in all age classes of buildings (74–80%), with the lowest response rate for buildings built before 1930, and the highest for buildings built in 1976–84. Moreover, the response rate was similar for publicly owned buildings (69%), buildings owned by the inhabitant (72%), and privately owned buildings (69%)

Assessment of SBS-Symptoms and Personal Factors

A validated self-administered questionnaire was used, previously developed by selecting relevant questions from a more extensive interview questionnaire (Engvall, 1991). Information on age, gender, asthmatic symptoms, hay fever, and eczema was obtained from the questionnaire. Atopy was defined as either reporting asthmatic symptoms, hay fever or eczema.

Besides questions on the perception of the indoor environment in the dwelling, the questionnaire contained seven questions on SBS; one on eye symptoms, one on nasal symptoms, one on throat symptoms, one on cough, one on facial skin symptoms, and two on general symptoms (headache and fatigue). Headache and fatigue were not analysed in the present study. These questions on symptoms were similar as in the self-administered questionnaire developed by the Department of Occupational Health in Örebro (Andersson, 1998). The current version (MM040NA), has been used in subsequent hospital studies (Nordström et al., 1995) and in the large Office Illness Study in northern Sweden (Stenberg et al., 1994; Sundell et al., 1994).

A recall period of 3 months was used for the symptoms. For each symptom, there were three alternatives to answer "no, never," "yes, sometimes," and "yes, often." Often means every week. There was one additional question for each symptom, asking if the respondents attributed the symptoms to the indoor environment in the dwelling. The prevalence of weekly symptoms (eye, nose, throat, cough, or facial skin) was calculated for each symptom. In addition, the prevalence of home-related symptoms was calculated. In addition, the prevalence of subjects with at least one weekly symptom was calculated. There were two questions on headache and fatigue in the questionnaire, but since these questions are less specific, they were not addressed in this study. In the multiple logistic regression analysis, weekly symptoms were assigned "1" and both "yes, sometimes," and "no, never" was assigned a zero value.

Assessment of Building Characteristics

Information on number of apartments in the house, building age, and ownership was obtained from the central building register in Stockholm. In parallel with the questionnaire study, a telephone interview was made with the building owner of each building. Information gathered from the owners included type of ventilation system.

Statistical Methods

Statistical analysis was performed by multiple logistic regression. The regression was performed step by step, initially including all factors, then keeping the factors with the highest explanatory values in the model, and excluding non significant factors (two-tailed $P<0.05$). Initially, two overview models were tested, using "at least one weekly symptom" and "at least one home-related weekly symptom" as independent variables. Later, each type of symptom was analysed in ten separate models, using the same type of step by step regression, and excluding some variables with low explanatory values. Five of the models dealt with ocular, nasal, throat, cough, and facial skin symptoms, irrespectively of the subjects opinion about relations between symptoms and the dwelling. The other five models dealt with the same five types of symptoms, but making a restriction to symptoms perceived to be related to the home environment.

Based on these ten separate logistic regression models, a final classification model was constructed, aiming to identify "risk" buildings with significantly high occurrence of at least one SBS symptom. In this model, probabilities for each type of symptom were calculated, for each type of combination of significant predictors (ownership, age, gender, atopy). In each building and for each type of symptom (10 models), the expected number of subjects with the particular symptom was calculated. This was done by multiplying the number of subjects with each combination of predictors, with the probability for the particular combinations. The expected numbers of subjects with the particular symptom was summed up to a total expected number. Then the expected number of subjects for each building was compared, statistically, with the observed number of symptoms. In this project, a "risk" building was defined as a building with an occurrence of symptoms above the 99% upper confidence interval limit, in at least one of the ten models.

Results

Among the participants, the proportion of females were 60%, 25% were above 64 yr, and the proportion with atopy was 38%, and 26% were current smokers

Table 1 Personal characteristics among participants (n=9808)

	Proportion among participants	
	n	(%)
Age class		
18–44	4904	51
45–64	2397	25
>64	2365	24
Female gender	5783	60
Atopy	3630	38
Current smoker[a]	766	26

[a] Available only for subjects in the last sample of 3,241 subjects in dwellings built before 1960

Table 2 Number of building and number of participants, with respect to building size, ownership and type of ventilation

	Number of buildings		Number of participants	
	N	(%)	N	(%)
Number of apartments[a]				
1–9	29	5	160	2
10–14	75	12	636	6
15–29	243	41	3710	38
30–69	197	33	4091	42
>=70	53	9	1105	12
Type of ownership				
Public owned	228	38	3897	40
Owned by the inhabitant	171	29	2795	29
Private landlord	198	33	3010	31
Type of ventilation[b]				
No mechanical ventilation	197	34	2663	28
Exhaust air only	261	45	4679	49
Supply/exhaust air	125	21	2145	23

[a] 12 buildings were used for care of old people only and not included in the study. [b] 14 buildings had other types of ventilation systems, not classifiable

Table 3 Number and proportion of participating apartments in the study[a], as compared to the total number of apartments in multi-family houses in Stockholm

Building year	Participants in the study		Total number of apartments in Stockholm	
	N	(%)	N	(%)
–1930	1,718	17	51,089	19
1931–1960	2,458	25	139,259	52
1961–1975	1,869	19	52,739	20
1976–1984	2,310	24	15,101	6
1985–1990	1,453	15	8,038	3
Total material	9,808	100	266,226	100

[a] One randomly selected subject from each apartment

(Table 1). In total, 40% were living in public owned buildings, 29% in buildings owned by the inhabitant, and 31% were owned by private landlords (Table 2). The age distribution of the apartments of the participants is given, as compared to the age distribution of the total stock of apartments in the Stockholm community (Table 3). Natural ventilation only was most common in buildings built before 1961, and non-existing in buildings built after 1975. Supply and exhaust ventilation was most common in building from 1976–1984, while exhaust ventilation only was most prevalent in the newest buildings, as well as in buildings from 1961–1975 (Table 4).

The three-month prevalence of weekly symptoms, compatible with the sick building syndrome, was quite high in the population (Table 5). Respiratory symptoms, including cough, nasal symptoms, and throat symptoms were most common. In addition, most symptoms were more prevalent among females than men. In total, 36% reported at least one weekly symptom, and 13% reported at least one weekly building-related symptom.

To see if the time difference between the two samples had any influence, occurrence of personal factors, symptoms and attitudes to the home environment were compared for the older age classes (<1961) available in both samples. In 1991 year sample, the proportion of subjects in older buildings with ocular, nasal, throat, and dermal symptoms were 6%, 8%, 5%, and 6%, respectively. The corresponding figures in 1993 year sample were 7%, 12%, 7%, and 7%, respectively. In addition, the proportion of building related symptoms were similar, as well as the proportion of subjects dissatisfied with the apartment.

First, two overview models were created, in order to identify explanatory variables of importance for SBS-symptoms in the material. In the first initial overview model, using "at least one weekly symptom" as the independent variable, atopy had the strongest prediction value, followed by building age, gender, ownership, age of participant, type of ventilation system, and number of apartments in the building. In the second initial overview model, using "at least one weekly building-related symptom" as the independent vari-

Table 4 Distribution of type of ventilation system in different age classes of buildings in multi-family houses in Stockholm

Building year	Natural ventilation only (%)	Exhaust ventilation (%)	Supply and exhaust ventilation (%)	Mixed systems[a] (%)
–1930	74	20	3	3
1931–1960	61	38	1	0
1961–1975	7	71	20	2
1976–1984	0	36	64	0
1985–1990	0	76	21	3
Total material	46	46	7	2

[a] Combinations of different systems in the buildings

Table 5 3-month prevalence of weekly SBS symptoms in females and males

Type of symptom	Symptoms in females		Symptoms in males		All participants	
	Total (%)	Building related (%)	Total (%)	Building related (%)	Total (%)	Building related (%)
Eye irritation	10	4	6	3	8	4
Nasal	14	6	11	6	13	6
Throat	11	6	6	4	9	5
Cough	8	3	6	2	7	3
Facial skin irritation	10	5	4	2	8	4

able, atopy had the strongest prediction value, followed by building age, age of participant, ownership, gender, type of ventilation system, and number of apartments in the building.

In the next step, final regression models for each type of symptom, in total ten models, were developed. The aim of these models was to reduce the number of explanatory variables, without decreasing the explanatory value of the model too much. In these multiple regression models, females, subjects with allergic disposition, and those above 64 yr reported significantly more SBS. In addition, subjects living in a building owned by inhabitants or by private landlords reported less SBS than those living in a public owned building. Moreover, subjects in newer buildings had more SBS, but there was a strong relationship between ownership and building age. No significant relationship between SBS and type of ventilation system was observed (Table 6).

Similar factors were found to be significant predictors for building-related symptoms, except age, but the odds ratios were numerically higher for atopy and ownership, and lower for gender. For building-age, the relationships were inversed, namely a lower occurrence of building-related symptoms in elderly subjects (Table 7).

By means of the final classification model, based on the 10 separate logistic models, the individual probabilities for different types of symptoms was calculated for different combinations of the four predictors (ownership, age with cut-off at 65 yr, gender, and atopy). Calculated probabilities for symptoms, and building related symptoms, for different combinations of the four predictors are given in Tables 8 and 9.

In the next step, the expected number of subjects with each type of symptom was calculated for each single building, by multiplying the individual probability with the number of subjects for each specific combination of the four predictors. This procedure is demonstrated by the following example:

In a non-publicly owned building with 43 apartments, 30 randomly included apartments, and 22 out of 30 participants, there were eight combinations (cells) of predictors (Table 8). The probability for eye symp-

Table 6 Significant predictors of total symptoms in the final models (OR=odds ratio)

Factor	Eye OR (95% CI)	Nose OR (95% CI)	Throat OR (95% CI)	Cough OR (95% CI)	Facial skin OR (95% CI)
Ownership:					
private	1	1	1	1	1
public	1.4 (1.38–1.47)	1.4 (1.41–1.48)	1.7 (1.68–1.79)	1.3 (1.27–1.36)	1.2 (1.19–1.27)
Age:					
18–64 yr	1	1	1	1	1
>64 yr	1.6 (1.57–1.69)	1.2 (1.21–1.29)	1.4 (1.33–1.43)	1.5 (1.43–1.54)	0.4 (0.37–0.40)
Gender:					
male	1	1	1	1	1
female	1.5 (1.47–1.58)	1.1 (1.05–1.11)	1.6 (1.58–1.68)	1.2 (1.17–1.26)	2.3 (2.18–2.35)
Atopy:					
no	1	1	1	1	1
yes	6.8 (6.56–7.04)	6.5 (6.28–6.64)	4.9 (4.71–5.02)	5.6 (5.43–5.83)	4.6 (4.45–4.77)

Table 7 Significant predictors of building-related symptoms in the final models

Factor	Eye OR (95% CI)	Nose OR (95% CI)	Throat OR (95% CI)	Cough OR (95% CI)	Facial skin OR (95% CI)
Ownership					
private	1	1	1	1	1
public	1.8 (1.79–1.96)	1.8 (1.74–1.87)	2.6 (2.51–2.72)	1.6 (1.52–1.68)	1.3 (1.23–1.35)
Age:					
18–64 yr	1	1	1	1	1
>64 yr	1.0 (–)	0.8 (0.73–0.80)	0.9 (0.83–0.92)	0.7 (0.63–0.72)	0.2 (0.17–0.21)
Gender:					
male	1	1	1	1	1
female	1.3 (1.27–1.40)	0.9 (0.86–0.93)	1.3 (1.24–1.35)	1.1 (1.02–1.14)	1.9 (1.77–1.95)
Atopy:					
no	1	1	1	1	1
yes	11.1 (10.95–12.42)	6.3 (6.06–6.58)	6.0 (5.90–6.47)	10.1 (9.44–10.82)	5.6 (5.29–5.86)

Table 8 Probability for total symptoms, with respect to significant predictors

Factor		Eye	Nose	Throat	Cough	Facial skin
public owned building						
no atopy						
<65 yr	male	0.03	0.06	0.04	0.03	0.03
	female	0.04	0.06	0.06	0.03	0.06
>64 yr	male	0.04	0.07	0.05	0.04	0.01
	female	0.06	0.07	0.08	0.05	0.02
atopy						
<65 yr	male	0.14	0.28	0.15	0.14	0.11
	female	0.21	0.29	0.23	0.16	0.23
>64 yr	male	0.21	0.32	0.20	0.19	0.05
	female	0.30	0.34	0.29	0.22	0.10
private owned building						
no atopy						
<65 yr	male	0.02	0.04	0.02	0.02	0.02
	female	0.03	0.04	0.03	0.03	0.05
>64 yr	male	0.03	0.05	0.03	0.03	0.01
	female	0.04	0.05	0.05	0.04	0.02
atopy						
<65 yr	male	0.11	0.21	0.10	0.11	0.10
	female	0.16	0.22	0.15	0.13	0.20
>64 yr	male	0.16	0.25	0.13	0.15	0.04
	female	0.23	0.26	0.19	0.18	0.09

tom in each cell is multiplied by the number of individuals in the cell, and summed for all cells, to obtain the expected number of subjects with eye symptoms in the building. In the building, the expected proportion with eye symptoms among the participants was 1.56/22 (7%). The actual number with eye symptoms was 27%. The observed number was compared statistically, with the expected number, using the formula below, adapted from Cochran (1977):

$$X=\frac{\frac{Y}{n}-p}{\sqrt{\frac{1}{n}\cdot\frac{Y}{n}\left(1-\frac{Y}{n}\right)\left(1-\frac{n}{N}\right)}} \qquad [1]$$

Y=number of participants with the particular symptom

n=number of participants

Y/n=observed proportion of subjects with the particular symptom

p=expected proportion with the particular symptom in the building

N=number of apartments in the building

In the example above (Table 10), Y=6; n=22; Y/n=0.27; p=1.56/22; N=43

This gives X=3.02

Using a 99% 2-tailed confidence interval, X should be above 2.55 or below −2.55. Using a 95% confidence interval, X should be above 1.96 or below −1.96. In this example, X>2.55, and the conclusion is that the observed proportion of eye symptoms are significantly higher than expected ($p<0.01$).

Finally, the proportion of buildings with at least one symptom significantly increased ($p<0.01$), defined as "risk" buildings in this study, was calculated for the total stock of multi-family houses in Stockholm of different ages. Weighting was done with respect to the proportion of apartments sampled in the building, and the age of the sampled buildings (Table 3). According to these calculations, 5% of all buildings built before 1961, 13% of all buildings built 1976–1984, and 15% of those built 1985–1990 would be "risk buildings," e.g.

Table 9 Probability for building-related symptoms, with respect to significant predictors

Factor		Eye	Nose	Throat	Cough	Facial skin
public owned building						
no atopy						
<65 yr	male	0.01	0.03	0.02	0.01	0.01
	female	0.01	0.03	0.03	0.01	0.03
>64 yr	male	0.01	0.03	0.02	0.01	0.00
	female	0.01	0.02	0.03	0.01	0.00
atopy						
<65 yr	male	0.10	0.18	0.13	0.08	0.07
	female	0.12	0.17	0.16	0.09	0.13
>64 yr	male	0.10	0.14	0.12	0.06	0.01
	female	0.12	0.13	0.15	0.06	0.03
private owned building						
no atopy						
<65 yr	male	0.01	0.02	0.01	0.01	0.01
	female	0.01	0.02	0.01	0.01	0.02
>64 yr	male	0.01	0.01	0.01	0.00	0.00
	female	0.01	0.01	0.01	0.00	0.00
atopy						
<65 yr	male	0.06	0.11	0.06	0.06	0.06
	female	0.07	0.10	0.07	0.06	0.10
>64 yr	male	0.06	0.09	0.05	0.04	0.01
	female	0.07	0.08	0.06	0.04	0.02

Table 10 Example of calculation of expected number of eye symptoms in a non-public building

		Probability for eye symptoms (p)	Number of participants who answered the questionnaire (n)	Expected number of eye symptoms (n×p)
no atopy				
<65 yr	male	0.02	5	0.10
	female	0.03	8	0.24
>64 yr	male	0.03	0	0.0
	female	0.04	2	0.08
atopy				
<65 yr	male	0.11	1	0.11
	female	0.16	4	0.64
>64 yr	male	0.16	1	0.16
	female	0.23	1	0.23
Total			22	1.56

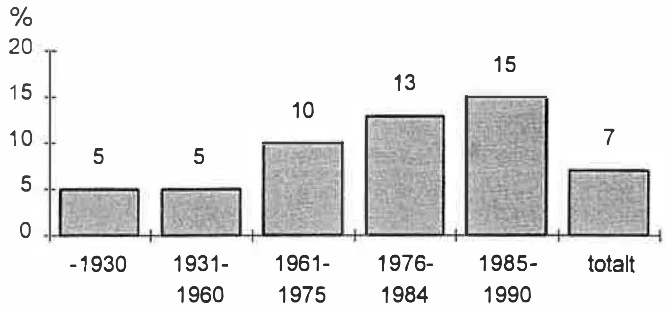

Fig. 1 Proportion of "risk" building in Stockholm, among buildings of different building periods, with "at least one weekly symptoms higher than expected"

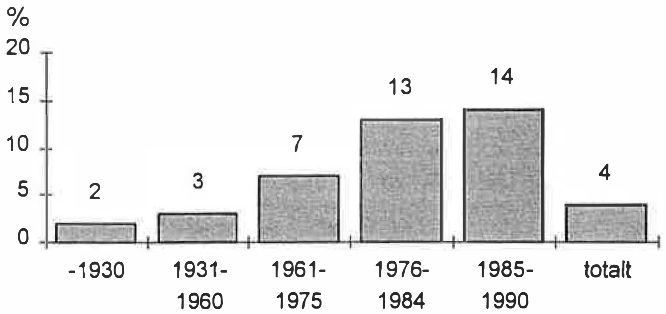

Fig. 2 Proportion of "risk" building in Stockholm, among buildings of different building periods, with "at least one weekly building-related symptoms higher than expected"

would have more of at least one type of symptom than expected (Figure 1). Lower absolute figures for older buildings, but similar figures for newer buildings were found for building-related symptoms (Figure 2). It was estimated that 7% of the total building stock in Stockholm would have more symptoms than expected, and 4% would have more building-related symptoms than expected.

Discussion

Our results suggest that symptoms compatible with sick building syndrome is common in the general population in Stockholm, and related to atopy, age, female gender, building age, and ownership of the building. Similar predictors were identified, irrespective of studying total symptoms or building-related symptoms. Moreover, we have developed a method to create a decision model to identify "risk" buildings, controlling for the distribution of personal risk factors and building characteristics.

Selection bias due to low response rate is not likely since the participation rate was high (77%). The proportion of participants were similar in the two samples from 1991 and 1993, in all age classes of buildings (74–80%), and similar with respect to ownership. Moreover, there were similar occurrences of SBS symptoms in the same age classes of older buildings from the two samples (1991 and 1993). The study group was a stratified random population sample, with a higher proportion of subjects in newer buildings, due to the enrichment of buildings of certain age classes. The enriched study population enabled us to get a higher power for certain types of buildings, as compared to a pure random population sample of the same size. When calculating expected occurrence of "risk" building, the results were adjusted with respect to the different sampling proportions.

Another methodological problem is possible recall bias in relation to awareness of the exposure among participants. In this study, however, building age and ownership was obtained from the building register, and information on type of ventilation was obtained from the building owner. Thus, information on these building related factors was gathered independently of the participant. In contrast, age and gender was obtained from the responders, but it is less likely that these variables are affected by any serious recall bias.

In addition, attitudes, e.g., to factors in the building, may affect the reporting of symptoms. Such recall bias is difficult to differentiate from a true relationship between building-related factors and symptoms. The observation, however, that similar predictors were identified, irrespectively of studying total symptoms or building-related symptoms, makes it less likely that our results are seriously affected by attitudes to the building.

The total number of symptoms was relatively large, and consequently the number of models was large as well. To avoid problems with mass significance when identifying "risk buildings," a 99% confidence interval was applied in the final decision model to identify such buildings. Thus, we do not believe that our conclusions are seriously biased by selection or information bias, or due to chance findings. The true adverse health effect of building factors could, however, been underestimated if there were a health-based selection.

In total, 60% of the responders were females. This figure is slightly higher than the proportion of femals in the adult population in the Stockholm area (53%) at the time of the investigation, according to local population statistics. In accordance with previous studies we found a higher prevalence of SBS symptoms among females than men, with most pronounced differences for facial dermal symptoms (OR=2.3), and least pronounced for nasal symptoms (OR=1.1). The gender differences were less pronounced for building-related symptoms (OR=0.9–1.9). Our results agree with previous studies. In one early Danish study in the adult population (>15 yr), females reported more mucosal irritation than men during springtime (OR=1.9) (Valbjørn & Korsgaard, 1984). In a random sample from mid-Sweden, women had a higher proportion of airway symptoms (OR=1.7) and dermal symptoms (OR=1.7), but these differences were not statistically significant when adjusting for allergy to nickel, hyperreactivity, and proneness to infection (Norbäck and Edling, 1991). In the large ELIB study women had higher proportion of ocular, throat and dermal symptoms (Norlen and Andersson, 1993). Similar gender differences have been reported in specific occupations, e.g., office workers. The Danish Town Hall study reported that the odds ratio (OR) was 1.6 for mucosal irritation in females (Skov et al., 1989). The Swedish Office Illness Project reported an OR of 2.8 for female gender in relation to facial skin symptoms (Stenberg et al., 1994).

The relationship between age and SBS seems to be more complex. We found a higher prevalence of facial dermal symptoms in younger subjects, but more of all other types of symptoms among those above 65 yr. The age relation was inverse, with more symptoms in younger subjects, if only building-related symptoms were considered. In the Danish study population study, younger subjects (<40 yr) reported more mucosal irritation during springtime (OR=1.5) than older subjects (Valbjørn & Korsgaard, 1986). In two mid-Swedish population samples, no relation between age and SBS, of any type, was observed (Björnsson et al., 1998; Norbäck et al., 1995; Norbäck and Edling, 1991). The large ELIB-study also report varying relations between age and SBS (Norlen and Andersson, 1993).

A history of atopy was found to be one of the strongest predictors for all SBS symptoms (OR=4.6–11.1), irrespectively if studying symptoms in general, or building-related symptoms. This is in agreement with other studies in the general population (Björnsson et al., 1998, Norbäck and Edling, 1991), as well as in office workers, as reviewed by Mendell (1993). Unfortunately, we did not have information on smoking habits in this study. We have included data on smoking habits in subsequent studies in the Stockholm area, and it did not turn out to be a major predictor of SBS symptoms (unpublished data). Similar results was found in another population study on SBS in adults (age 20–65 yr) performed in 1989 in mid-Sweden, where current smoking or ex-smoking was not a signficant predictor of any type of SBS-symptoms (Norbäck and Edling, 1991). In the large office study from the Netherlands, there were no clear relationship between the prevalence of SBS and active smoking (Zweers et al., 1992). The Danish Town Hall study found a slight increase of general symptoms such as headache and fatigue among current smokers (OR=1.3), but no relationship between current smoking and mucosal symptoms (Skov et al., 1989).

We found that "risk" buildings, defined as a building with a significant increase of at least one symptom, was more common in newer building. The relationship between building age and SBS was significant, even when controlling for personal factors and ownership of the building. The relationship was more pronounced when considering building-related symptoms, only. Building technology has changed over time and new types of constructions, more sophisticated ventilation systems and new building materials have been introduced during the last decades. Our age classes for buildings were selected to reflect major changes of building technology. Some other studies have shown an increase of SBS symptoms in younger buildings, both in offices (Skov et al., 1987), hospitals (Nordström et al., 1995), and dwellings (Norlen and Andersson 1993). It has also been shown that moving from old to new buildings resulted in an increase in SBS-symptoms (Norbäck et al. 1990).

Ownership was found to be one of the major predictors of SBS in our multi-family buildings. The relationship was consistent for all types of symptoms, irrespectively if studying symptoms in general, or building-related symptoms. The ELIB study found a difference in perception of indoor climate between single-family houses and multi-family houses, with more satisfied inhabitants in single-family houses (Norlen and Andersson, 1993). To our knowledge, no other SBS studies are available, comparing SBS in multi-family houses with different ownership. In Sweden, a large proportion of multi-family apartments of all ages are rental, owned by the community, with similar living standards and rental costs as private apartments. In offices in the United Kingdom, a higher prevalence of SBS in the public sector as compared to the private sector (Hedge et al., 1989) been reported. The reason for influence of ownership of dwellings is unclear, but one possible contributing factor could be difference in social status or economic value of the dwelling, but it could also depend on difference in building maintenance.

Surprisingly, we found no consistent relation between the type of ventilation system and SBS. Type of ventilation, however, may only be a crude measure of the air exchange rate in dwellings which depend on loading and design.

The group of symptoms investigated by us included ocular, nasal, throat symptoms, cough and facial dermal symptoms. It is obvious that this type of symptom is non-specific and may occur in the population for many reasons. For simplicity, the commonly accepted term SBS have been used in this paper for this group of symptoms. These are in agreement with SBS symptoms, as initially defined by the working group of the World Health Organization (Akimenko et al., 1986), but as other researchers (Stenberg et al., 1994) we have included facial dermal symptoms. Recently, the concept of SBS has been criticised as unspecific (Hodgson, 1995; Järvholm, 1993), and a subclassification of SBS depending on the type of symptom has been suggested (Hodgson, 1995; Järvholm, 1993; Mølhave, 1989). Moreover, some researchers have restricted their investigations to work-related (Skov et al., 1987) or building-related SBS symptoms (Björnsson et al., 1998), usually by using the criteria of improvement when leaving the particular indoor environment. Other researchers have studied the general prevalence of SBS symptoms without such restrictions (Stenberg et al., 1994; Nordström et al., 1995; Norbäck & Edling, 1991). In our studies, we have followed the recommendation to study a specific type of symptom separately. Since there is no general agreement on whether symptoms in general, or building-related symptoms, are preferable from a methodological point of view, we have studied both. Building-related symptoms may be a better measure of sensory effects due to the indoor environment, but may also be more affected by attitudes and recall bias. On the other hand could it be difficult for the respondent to really know if the symptoms are caused by the indoor environment.

In Scandinavia, self-administered questionnaire studies are commonly used as a first step in routine investigations in problem buildings (Andersson, 1998). The distribution of important risk factors for SBS, e.g. demographic factors or occurrence of atopy, may differ between buildings. To identify building-related problems, it is important to take such aspects into consideration. This investigation has demonstrated a new method to create such decision models and identify "risk" buildings, controlling for other important risk factors.

By applying this model in the Stockholm area, we could study the proportion of risk building in relation to changes of building technology. In buildings built before 1961, only 5% were considered to be "risk" buildings. These buildings were mostly stone buildings, majority without mechanical ventilation. A generation of buildings followed (1961–1975) built during a building boom, with possible consequences for the indoor environment. Among these, 10% were classified as "risk" buildings. The next generation of buildings (1976–1984) was influenced by energy saving demands with many changes in construction techniques and new building materials. Due to the combination of new, fairly unproven building materials and ventilation in air-tight building has given rise to building problems of moisture which is not removed by ventilation air has been observed. This promotes the growth of mould. Moreover, dampness related problems in the floor construction became more common, partly due to increased use of concrete slabs and casein containing self-levelling mortar (Bornehag, 1994; Cynkier and Göthe, 1992). In these buildings, the occurrence of "risk" buildings were found to be 13%. Because of indoor air problems from this period, the awareness of possible health consequences increased in the society. Despite this awareness, the highest occurrence of "risk" building (15%) was found in the newest buildings (1985–1990). This frustrating observation suggests that the awareness about the indoor environment still has not resulted in construction of more healthy buildings. However, in this building period we also found the widest dispersion between buildings with the high and low occurrence of "risk" buildings. It is therefore important with further epidemiological research on buildings from the nineties, to identify new building with a low prevalence of SBS, to guide the direction for future building design.

In conclusion, decision makers need scientifically based decision models, to make priorities and identify "risk" buildings where measures should be taken, based on occurrence of symptoms. In many types of buildings, like offices and schools, there are lots of tenants who can answer a questionnaire an give there opinion on indoor environment. But in multi-family houses there are sometimes only 10–20 households in one building. This means that the frequencies of SBS will be more influenced by individual factors. Our approach is to calculate individual probabilities for different symptoms, followed by statistical testing in individual buildings to see if the observed occurrence of symptoms is higher than expected. In such decision models, it is necessary to control for the distribution of personal risk factors and building characteristics (e.g. ownership and age), to optimise the identification "risk" buildings where inspections and improvements of the indoor environment should be made.

Acknowledgements

This study was supported by grants from the Swedish Council of Building Research (BFR), the City of Stockholm, the Social Board of Welfare and Health and the Swedish National Institute of Public Health.

References

Akimenko, V.V., Andersson, I., Lebowitz, M.D. and Lindvall, T. (1986) "The "sick" building syndrome". In: Berglund, B., Berglund, U., Lindvall, T. and Sundell, J. (eds) *Indoor Air, volume 6, (Evaluation and conclusions for health sciences and technology)*, Stockholm, Swedish Council for Building Research, pp. 87–97.

Andersson, K. and Strid, G. (1992) "The use of standardised questionnaires in building-related illness (BRI) and sick building syndrome (SBS) surveys". In: *NATO/CCMS pilot study on indoor air quality*, Oslo, National Institute of Occupational Health, pp. 47–64.

Andersson, K. (1998) "Epidemiological approach to indoor air problems", *Indoor Air*, Suppl. 4, 27–34.

Apter, A., Bracker, A., Hodgson, M., Sidman, J. and Leung, W. Y. (1994) "Epidemiology of the sick building syndrome", *J Allergy Clinical Immunology*, **94**, 277–288.

Björnsson, E., Janson, C., Norbäck, D. and Boman, G. (1998) "Symtoms related to the Sick Building Syndrome in general population sample: associations with atopy, bronchial hyper-responsiveness and anxiety", *The International Journal of Tuberculosis and Lung Diease*, **2**, 1023–1028.

Bornehag, C.-G. (1994). "Analysis of patterns in indoor air. Investigation of air quality in sick buildings with problems from self-leveling mortar", Stockholm, Building Research Council, R:23:1994 (Thesis).

Boxer, P.A. (1990) "Indoor Air Quality: A psychosocial perspective", *Journal of Occupational Medicine*, **32**, 425–428.

Brunekreef, B. (1992) "Damp housing and adult respiratory symptoms", *Allergy*, **47**, 498–502.

Cochran W.G. (1977) *Sampling techniques*, New York, John Wiley & Sons.

Crawford, J.O. and Bolas, S.M. (1996) "Sick building syndrome, work factors and occupational stress", *Scandinavian Journal of Work and Environmental Health*, **22**, 243–250.

Cynkier, I. and Göthe, C.-J. (1992) "Sick Buildings" – The indoor residential environment in flats in Stockholm suburb". In: Lester J.N., Perry R. and Reynolds G.L. (eds), *Proceeding of Indoor Air International Conference on "Quality of Indoor Environment"*, Athens, pp. 665–667.

Dales, R..E., Burnett, R. and Zwanenburg, H. (1991) "Adverse health effects among adults exposed to home dampness and moulds", *American Review of Respiratory Diseases*, **43**, 505–509.

Engvall, K. (1991) "Health and Housing – The Stockholm Questionnaire", City of Stockholm Environment and Public Health Administration and City of Stockholm Office of Research and Statistics.

Hedge, A., Burge, P.S., Robertson, A.S., Wilson, S. and Harris-Bass J. (1989) "Work-related illness in offices: A proposed model of the "sick building syndrome"", *Environment International*, **15**, 143–158.

Hodgson, M. (1995) "The sick-building syndrome", *Occupational Medicine: State of the art Reviews*, **10**, 167–175.

Hult, M., Engvall, K., Norrby, C. and Bandel, J. (1999) "Applying a multiple logistic regression model to identify multi-unit residential buildings with high risk of SBS in the city of Stockholm". In: Raw, G., Aizlewood, C. and Warren, P. (eds.) *Proceedings of Indoor Air '99*, Edinburgh, Scotland, Vol. 1, pp. 829–834.

Järvholm, B. (1993) "Is it time to change the terminology of sick building syndrome", *Indoor Environment*, **2**, 186–188.

Kreiss, K. (1989) "The epidemiology of building-related complaints and illness", *Occupational Medicine: State of the Art Reviews*, **4**, 575–592.

Mendell, M.J. (1993) "Non-specific symptoms in office workers: a review and summery of the epideminologic literature", *Indoor Air*, **3**, 227–236.

Moschandreas D.J. (1981) "Exposure to pollutants and daily time budgets of people", *Bulletin of the New York Academy of Medicine*, **57**, 845–859.

Mølhave, L. (1989) "The sick buildings and other buildings with indoor climate problems", *Environment International*, **15**, 65–74.

Norbäck, D. and Edling, C. (1991) "Environmental, occupational and personal factors related to the prevalence of sick building syndrome in the general population", *British Journal of Industrial Medicine*, **48**, 451–462.

Nordström, K., Norbäck, D. and Akselsson, R. (1995) "The influence of indoor air quality and personal factors on the Sick Building Syndrome (SBS) in Swedish Geriatric Hospitals", *Occupational and Environmental Medicine*, **52**, 170–176.

Norlen, U. and Andersson, K. (1993) "An indoor climate survey of the Swedish housing stock (the ELIB study)". In: *Proceedings of Indoor Air '93*, Helsinki, 6th International Conference on Indoor Air Quality and Climate, Vol. 1, pp. 743–748.

Pirhonen, I., Nevalainen, A., Husman, T. and Pakkanen, J. (1996) "Home dampness, moulds and their influence on respiratory infections and symtoms in adults in Finland", *European Respiratory Journal*, **9**, 2618–2622.

Skov, P., Valbjørn, O. and the Danish Indoor Study Group (1987) "The "sick" building syndrome in the office environment: The Danish town hall study", *Environment International*, **13**, 339–349.

Skov, P., Valbjørn, O. and the Danish Indoor Study Group (1989) "Influence of personal characteristics, job-related factors and psychosocial factors on the sick building syndrome", *Scandinavian Journal of Work and Environmental Health*, **15**, 286–295.

Stenberg, B., Eriksson, N., Höög, J., Sundell, J. and Wall, S. (1994). "The sick building syndrome (SBS) in office workers. A case-referent study of personal, psychosocial and building-related risk indicators", *International Journal of Epidemiology*, **23**, 1190–1197.

Sundell, J., Lindvall, T., Stenberg, B. and Wall, S. (1994) "Sick building syndrome (SBS) in office workers and facial skin symptoms among VDT-workers in relation to building and room characteristics: Two case-referent studies", *Indoor Air*, **4**, 83–94.

Valbjørn, O. and Kousgard, N. (1994) "Headache and mucous membrane irritation at home and at work. Danish Building Research Institute", Research Institute (SBI-report 175) Copenhagen, Danish Building.

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