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ORIGINAL ARTICLE

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Sick building syndrome in relation to building dampness in multi-family residential buildings in Stockholm

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Abstract ***Objectives***: The aim was to study relationships between symptoms compatible with sick building syndrome (SBS) on one hand, and different indicators of building dampness in Swedish multi-family buildings on the other. ***Methods***: In Stockholm, 609 multi-family buildings with 14,235 dwellings were identified, and selected by stratified random sampling. The response rate was 77%. Information on weekly symptoms, age, gender, population density in the apartment, water leakage during the past 5 years, mouldy odour, condensation on windows, and high air humidity in the bathroom was assessed by a postal questionnaire. In addition, independent information on building characteristics was gathered from the building owners, and the central building register in Stockholm. Multiple logistic regression analysis was applied, and adjusted odds ratios (OR) were calculated, adjusted for age and gender, population density, and selected building characteristics. ***Results***: Condensation on windows, high air humidity in the bathroom, mouldy odour, and water leakage was reported from 9.0%, 12.4%, 7.7% and 12.7% of the dwellings, respectively. In total 28.5% reported at least one sign of dampness. All indicators of dampness were related to an increase of all types of symptoms, significant even when adjusted for age, gender, population density, type of ventilation system, and ownership of the building. A combination of mouldy odour and signs of high air humidity was related to an increased occurrence of all types of symptoms (OR = 3.7–6.0). Similar findings were observed for a combination of mouldy odour and structural building dampness (water leakage) (OR = 2.9–5.2). In addition, a dose-response relationship between symptoms and number of signs of dampness was observed. In dwellings with all four dampness indicators, OR was 6.5, 7.1, 19.9, 5.8, 6.1, 9.4, 15.0 for ocular, nasal, throat, dermal symptoms, cough, headache and tiredness, respectively. ***Conclusion***: Signs of high air humidity, as well as of structural building dampness, are common in multi-family buildings in Stockholm. Reports of building dampness in dwellings is related to a pronounced increase of symptoms compatible with the SBS, even when adjusted for possible confounding by age, gender, population density, and building-related risk factors.

Key words Air pollution · Building dampness · Dwelling · Mould growth · Indoor environment · Sick building syndrome (SBS) · Questionnaire

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Introduction

Since the population spends a large proportion (65%) of the time in the dwelling (Moschandreas 1981), the home environment is an important area for indoor environmental research. Disorders that have been associated with indoor air pollution includes non-specific symptoms from eyes, upper airways, and facial skin, such disorders sometimes being referred to as the sick building syndrome (SBS) (Kreiss 1989; Hodgson 1995; Apter et al. 1994). Most SBS studies have dealt with office workers (Skov et al. 1987; Stenberg et al. 1994; Zweers 1992), and there are few studies on SBS in relation to domestic exposures (Norlen and Andersson 1993; Norbäck and Edling 1991; Bornehag 1994, Valbjørn and Kousgård 1984). Various factors, such as wall-to-wall carpeting, type of ventilation system, high room temperature, low outdoor air supply flow rate, and low air humidity have been shown to influence the prevalence of SBS symptoms (Kreiss 1989; Hodgson 1995; Apter et al. 1994). Some authors have reported an increase of SBS in newer buildings (Skov et al. 1987; Nordström et al. 1995; Engvall et al. 2000). In addition, SBS may be related to personal factors, such as female gender (Stenberg et al. 1994; Norbäck et al. 1996; Engvall et al. 2000), age (Engvall et al. 2000), allergic disorders (Björnsson et al. 1998; Norbäck and Edling 1991; Skov et al. 1987), and bronchial hyperresponsiveness (Björnsson et al. 1998).

Building dampness is a common indoor exposure, related to an increase of respiratory symptoms (Husman 1996; Peat et al. 1998; Pieckova and Zdenka 1999). Most of these studies have been on asthma symptoms in children in relation to dampness in dwellings, and there is little information on SBS symptoms among adults in damp dwellings (Platt et al. 1989; Waegemakers et al. 1989; Brunekreef 1992; Dales et al. 1991; Norbäck et al. 1999). Besides the study by Dales et al. (1991), on 14,799 adults, there are few larger population studies on SBS in relation to building dampness in dwellings. Such dampness comprises different aspects of the indoor environment facilitating growth of micro-organisms (Björnsson et al. 1995), and house dust mites (Sporik et al. 1990), including high air humidity, condensation on cold surfaces, permanent dampness in the building, and episodes of water leakage (Norbäck et al. 1999). Building dampness may also increase the emission of volatile organic compounds (VOCs) due to degradation of building materials. One example is degradation of phthalate esters, used as plasticisers in poly-vinyl chloride (PVC) floor coatings or glues (Wieslander et al. 1999).

The aim of our investigation was to study relationships between symptoms compatible with SBS on one hand, and different indicators of building dampness in multi-family buildings on the other. The following buildings-related hypothesis was tested: symptoms compatible with SBS are related to previous episodes of water leakage, condensation on windows, high air humidity in the bathroom, and mouldy odour in the dwelling. This was done by applying a standardised self-administered questionnaire in a large random sample of dwellings within an urban area (Stockholm).

Material and methods

Study population

In 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 1960 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 ten respondents were excluded.

In each included apartment ($n = 14{,}235$), one randomly selected adult person (>= 18 years) was drawn by combining the building register with the civil registration register, irrespective 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 approximately 1 year old, 1,568 were found not live at the actual address, according to information from the mail office or the current occupier of the apartment. The proportions of subjects not living at 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 (77%) answered the questionnaire. 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 for less than 1 year ($n = 736$). The proportion of participants were similar in all age classes of the 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 sick building syndrome symptoms and personal factors

A validated self-administered postal questionnaire was used, previously developed by selecting relevant questions from a more extensive interview questionnaire (Engvall and Sandstedt 2000). Information on age and gender was obtained from the postal questionnaire. 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). These questions on symptoms were similar to those of 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). A recall period of 3 months was used for the symptoms. For each symptom, there were three alternative answers: "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, facial skin, headache, tiredness) was calculated for each symptom. In the multiple logistic regression analysis, weekly symptoms were assigned "1" and both "yes, sometimes," and "no, never" were assigned a zero value.

Assessment of building dampness

The self-administered questionnaire contained questions on episodes of water leakage during the past 5 years, condensation on windows, slow drying of wet towels in the bathroom, and perception of mouldy odour in the dwelling.

Assessment of other building characteristics and factors in the dwelling

Information on building age, ownership, and number of apartments in the building was obtained from the central building register in Stockholm. In parallel with the questionnaire study, a telephone interview was made with the owner of each building. Information gathered from the owners included type of ventilation system. Information on the number of subjects living in the dwelling and the number of rooms was obtained from the postal questionnaire, and population density (number of subjects/room) was calculated.

Table 1 Personal characteristics of participants (n = 9,808)

Characteristic	n	(%)
Age		
18–44	4,904	51
45–64	2,397	25
> 64	2,365	24
Female gender	5,783	60
Current smoker[a]	766	26

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

Statistical methods

Statistical analysis was performed by multiple logistic regression, and adjusted odds ratios with 95% confidence intervals (OR; 95% CI) were calculated. In all statistical analyses, two-tailed tests and a 5% level of significance were applied. In the initial model (A) control was made for potential confounding by age and gender, and each of the four questions on building dampness was introduced separately in the models. To avoid possible confounding by other important building-related factors, we controlled for age, gender, type of ventilation system, ownership, and population density in the apartment (inhabitants/room), as well as each of the four questions on building dampness separately (model B). As the next step, two combination dampness variables were created. The first was a combination of mouldy odour and high air humidity (either condensation on windows or high air humidity in the bathroom), using dwellings without reports of mouldy odour, condensation in windows, or high air humidity in the bathroom as reference category. The second was a combination of mouldy odour and a history of water leakage, using dwellings without mouldy odour or water leakage as reference category. Finally, to address the dose-response relationships between symptoms and dampness exposure, a building dampness index was constructed, in accordance with a previous study on dampness in office buildings (Wan and Li 1999). In these analyses, control was made for age, gender and the building dampness index. The index considered all four dampness conditions (i. e. condensation on windows, high humidity in bathrooms, mouldy odour, and water leakage), and we defined variable values as follows: (1) if the answer included any one of the four dampness conditions; (2) if the answer included any two dampness conditions; (3) if the answer included any three dampness conditions; (4) if the answer included all dampness conditions; otherwise 0 if the answer was "none".

Results

Among the participants, the proportion that were female was 60%, and 25% were above 64 years (Table 1). The questionnaire contained questions on allergy and asthma, and in total 38% had either a history of eczema, or any type of allergy or asthma. Since the questions did not separate asthma and allergies, and asthma may be caused by building dampness, information from these questions was not used in further statistical analysis. In total, 40% of subjects were living in publicly owned buildings, 29% in buildings owned by the inhabitant, and private landlords (Table 2) owned 31%. The age distribution of the apartments of the participants is given, compared with the age distribution of the total stock of apartments in the Stockholm community (Table 3). Natural ventilation was most common in buildings built before 1961, and non-existent in buildings built after 1975. Supply and exhaust ventilation was most common in building from 1976–84, while exhaust ventilation only was most prevalent in the newest buildings, as well as in buildings from 1961–75.

There were four different indicators of building dampness; two should detect high air humidity (condensation on windows or slow drying of towels in the bathroom), one should detect microbial growth (mouldy odour), and one should detect a history of increased dampness in the building materials (structural building dampness). Of the total material of 9,808 dwellings, 9.0%, had reports on condensation on windows, 12.4% had signs of high air humidity in the bathroom, 7.6% had mouldy odour, and 12.7% had a known history of water leakage during the past 5 years (Table 4). In total, 408 out of 9,808 dwellings showed incomplete answers on the questions on dampness or mouldy odour. In total, respondents in 2,273 dwellings did not know if there had been a history of water leakage during the past 5 years, which was classified as

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	3,710	38
30–69	197	33	4,091	42
≥70	53	9	1,105	12
Type of ownership				
Publicly owned	228	38	3,897	40
Owned by inhabitant	171	29	2,795	29
Private landlord	198	33	3,010	31
Type of ventilation[b]				
No mechanical ventilation	197	34	2,663	28
Exhaust air only	261	45	4,679	49
Supply/exhaust air	125	21	2,145	23

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

missing values. In total, 28.5% of the dwellings had reports on at least one sign of dampness, and 0.34% of the subjects reported all four signs of building dampness in their dwelling.

A history of water leakage was most common in the oldest buildings, built before 1931 (15%), and least common (4.9%) in the newest buildings, built in 1985–90. All other types of building dampness (condensation, high air humidity, mouldy odour), were most common in buildings from 1961–75, and less common in both newer and older buildings (Table 4). Both signs of condensation, high air humidity and mouldy odour were 2–3 times less common in dwellings owned by the inhabitant than other types of ownership. The proportion of dwellings with at least one sign of dampness was 32.5% in publicly owned buildings, 29.4% in buildings owned by private landlords, and 19.0% in apartments owned by the occupier. For water leakage, the highest figure (16.1%) was seen in dwellings owned by private landlords (Table 5). There were less-pronounced differences in reports on building dampness in relation to type of ventilation system, with least dampness in buildings with both supply/exhaust ventilation, and the highest figures in buildings with exhaust air only (Table 5). The population density was 10–20% higher in buildings with signs of dampness, a numerically small but statistically significant difference. The proportion of building with an extreme population density (≥2 persons per room) was low (2.8%). In dwellings with condensation on windows ($n = 768$), the mean population density was 0.96 (standard deviation (SD) = 0.44), compared with 0.78 (SD = 0.37) in those without this dampness sign ($P < 0.001$). In dwellings with high air humidity in the bathroom ($n = 1125$), the mean population density was 0.93 (SD = 0.40), compared with 0.78 (SD = 0.37) in those without this sign ($P < 0.001$). In those with a mouldy odour ($n = 642$), the mean population density was 0.92 (SD = 0.42), compared with 0.79 (SD = 0.37) in those without such odour ($P < 0.001$). Finally, in dwellings with water leakage ($n = 849$), the mean population density was 0.83 (SD = 0.41), compared with a mean value of 0.77 (SD = 0.36) in dwellings without water leakage ($P < 0.001$).

Table 3 Number and proportion of participating apartments in the study (one randomly selected subject from each apartment) compared with the total number of apartments in multi-family houses in Stockholm

Building year	Participants in 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

Table 4 Distribution of different characteristics of building dampness in different age classes of buildings in multi-family houses in Stockholm

Time of construction	Condensation on windows (%)	High air humidity in bathroom (%)	Mouldy odour in dwelling (%)	History of water leakage[a] (%)	At least one sign of dampness[b] (%)
–1930	7.1	11.9	6.0	15.0	28.0
1931–1960	8.7	10.7	6.9	12.2	26.9
1961–1975	12.5	17.6	11.8	14.6	35.5
1976–1984	8.2	11.0	7.3	8.1	24.8
1985–1990	6.4	12.1	3.0	4.9	20.9
Total material	9.0	12.4	7.6	12.7	28.5

[a] Any episode of a major water leakage during the past 5 years
[b] Condensation on windows, high humidity in the bathroom, mouldy odour in the dwelling, or a history of water leakage

Table 5 Different characteristics of building dampness in relation to type of ownership and type of ventilation in multi-family houses in Stockholm

	Condensation on windows (%)	High air humidity in bathroom (%)	Mouldy odour in dwelling (%)	History of water leakage[a] (%)
Type of ownership				
Publicly owned	12.5	14.1	10.0	11.6
Owned by inhabitant	4.7	7.1	2.8	9.6
Private landlord	7.4	13.5	7.5	16.1
Type of ventilation				
No mechanical ventilation	8.7	12.3	6.6	13.8
Exhaust air only	9.7	12.6	9.1	11.8
Supply/exhaust air	6.8	10.7	5.7	10.6

[a] Any episode of a major water leakage during the past 5 years

The 3-months prevalence of weekly symptoms, compatible with the SBS, was quite high in the population, particularly tiredness and nasal symptoms, and all symptoms were more prevalent among women than men (Table 6). For all symptoms, there were significant relationships between all four indicators of dampness, with the most pronounced association for mouldy odour (Table 7). A similar result was obtained, even when controlling for age, gender, population density, type of ventilation system, and ownership of the building (see model B in Table 7).

Mouldy odour was used as an indicator of exposure to microbial pollutants, while the other questions were measures of high air humidity (condensation/slow drying towels), or dampness in the building construction (water damage). Two combined indicators of building dampness in combination with mouldy odour were constructed. The first was a combination of mouldy odour and high air humidity (either condensation on windows or high air humidity in the bathroom). The second was a combination of mouldy odour and a history of water leakage. A pronounced increased association between dampness and symptoms was observed, for both combined dampness indicators (Table 8).

Finally, to address the dose-response relationships between symptoms and dampness exposure, we constructed a building dampness index, in accordance with a previous study on dampness in office buildings (Wan and Li 1999). The index considered all four dampness conditions (i. e. condensation on windows, high humidity in bathrooms, mouldy odour, and water leakage), and was defined as the number of "yes" answers to these four questions. Dwellings without any signs of dampness were used as reference category. A clear trend, with an increase of OR in relation to the number of dampness signs was observed for all types of symptoms, with very high OR (5.82 to 19.91) in dwellings with all four signs of building dampness (Table 9).

Table 6 Three-months prevalence of weekly sick building syndrome (*SBS*) symptoms in female and male participants

Type of symptom	Symptoms in female participants (n = 5,783) (%)	Symptoms in male participants (n = 4,105) (%)	All participants (n = 9,808) (%)
Eye irritation	10	6	8
Nasal	14	11	13
Throat	11	6	9
Cough	8	6	7
Facial skin irritation	10	4	8
Headache	12	6	10
Tiredness	28	19	24

Discussion

Our results suggest that signs of building dampness is common in multi-family dwellings in Stockholm, and related to an increase in ocular, respiratory, and facial dermal symptoms, as well as headache and tiredness. Moreover, a pronounced dose-response relationship was observed between symptoms and the number of signs of

Table 7 Different symptoms in relation to four building dampness characteristics. Model A includes age, gender, and each of the four dampness indicators, separately in the model. Model B includes age, gender, population density (subjects/room), type of ventilation, type of ownership, and each of the four dampness indicators separately in the model *OR(95%CI)* odds ratios with 95% confidence intervals

Type of symptom	Model	Condensation on windows Adjusted OR (95%CI)	High air humidity in bathroom Adjusted OR (95%CI)	Mouldy odour in dwelling Adjusted OR (95%CI)	History of water leakage[a] Adjusted OR (95%CI)
Eye irritation	A	3.25 (3.12–3.38)***	2.98 (2.88–3.09)***	3.95 (3.79–4.12)***	1.56 (1.49–1.63)***
	B	3.14 (3.01–3.27)***	2.94 (2.83–3.05)***	3.75 (3.60–3.92)***	1.57 (1.50–1.65)***
Nasal	A	2.83 (2.73–2.93)***	2.00 (1.94–2.06)***	2.98 (2.88–3.09)***	1.36 (1.31–1.42)***
	B	2.72 (2.62–2.81)***	1.94 (1.88–2.01)***	2.83 (2.73–2.93)***	1.36 (1.31–1.41)***
Throat	A	3.59 (3.46–3.74)***	3.31 (3.19–3.43)***	3.68 (3.53–3.83)***	2.05 (1.97–2.14)***
	B	3.22 (3.09–3.35)***	3.23 (3.12–3.35)***	3.48 (3.33–3.62)***	2.18 (2.09–2.28)***
Cough	A	2.75 (2.63–2.87)***	2.41 (2.32–2.51)***	3.40 (3.25–3.56)***	1.54 (1.47–1.62)***
	B	2.58 (2.47–2.70)***	2.30 (2.21–2.40)***	3.30 (3.16–3.46)***	1.52 (1.44–1.59)***
Facial skin irritation	A	2.34 (2.24–2.43)***	2.54 (2.45–2.63)***	3.10 (2.97–3.23)***	1.54 (1.48–1.62)***
	B	2.11 (2.02–2.20)***	2.42 (2.33–2.51)***	2.93 (2.80–3.06)***	1.56 (1.48–1.63)***
Headache	A	3.57 (3.44–3.70)***	3.11 (3.03–3.19)***	3.52 (3.39–3.66)***	1.27 (1.22–1.33)***
	B	3.30 (3.19–3.43)***	3.07 (2.96–3.17)***	3.37 (3.24–3.51)***	1.27 (1.21–1.33)***
Tiredness	A	2.21 (2.14–2.28)***	2.17 (2.11–2.30)***	2.52 (2.44–2.60)***	1.34 (1.30–1.38)***
	B	2.19 (2.12–2.25)***	2.16 (2.11–2.22)***	2.38 (2.31–2.46)***	1.35 (1.30–1.39)***

***$P < 0.001$

[a] Any episode of a major water leakage during the past 5 years

Table 8 Different symptoms in relation to combinations of mouldy odour and other building dampness characteristics [*OR* (*95%CI*)] odds ratios with 95% confidence intervals

Type of symptom	Mouldy odour and signs of high air humidity[a] Adjusted OR (95%CI)[c]	Mouldy odour and structural building dampness[b] Adjusted OR (95%CI)[c]
Eye irritation	5.50 (5.20–5.81)***	5.20 (4.82–5.62)***
Nasal	4.28 (4.08–4.49)***	4.31 (4.03–4.61)***
Throat	5.29 (5.01–5.58)***	5.08 (4.72–5.48)***
Cough	3.97 (3.74–4.22)***	3.78 (3.46–4.12)***
Facial skin irritation	4.05 (3.83–4.28)***	2.94 (2.70–3.20)***
Headache	5.97 (5.68–6.28)***	3.32 (3.08–3.58)***
Tiredness	3.67 (3.51–3.84)***	4.12 (3.87–4.39)***

$^{***}P < 0.001$

[a] A combination of mouldy odour and either condensation on windows or high air humidity in the bathroom

[b] A combination of mouldy odour and episodes of major water leakage during the past 5 years

[c] Adjusted for age, gender, and each of the two combined dampness indicators, separately in the model

Table 9 Adjusted odd ratios and 95% confidence intervals [*OR*(*95%CI*)] for relationships between different symptoms and building dampness index. Adjustment was made for age, gender and dampness index. Coding of dampness index: 0 = none of the four signs present; 1 = any of the four signs of dampness present (condensation on windows, high air humidity in bathroom, mouldy odour, or water leakage); 2 = any two of the four dampness indicators present; 3 = any three of the four dampness indicators present; 4 = all four indicators present

Type of symptom	Number of dampness characteristics			
	1 Adjusted OR (95%CI)	2 Adjusted OR (95%CI)	3 Adjusted OR (95%CI)	4 Adjusted OR (95%CI)
Eye irritation	1.45 (1.40–1.52)***	3.07 (2.93–3.22)***	5.42 (5.07–5.80)***	6.53 (5.61–7.61)***
Nasal	1.17 (1.14–1.21)***	1.99 (1.90–2.08)***	4.22 (3.96–4.50)***	7.12 (6.20–8.17)***
Throat	1.47 (1.42–1.52)***	3.25 (3.10–3.40)***	4.11 (3.83–4.40)***	19.91 (17.05–23.24)***
Cough	1.70 (1.64–1.77)***	2.22 (2.10–2.35)***	2.79 (2.56–3.03)***	5.82 (4.95–6.85)***
Facial skin irritation	1.51 (1.46–1.56)***	2.61 (2.49–2.74)***	2.82 (2.61–3.04)***	6.10 (5.22–7.12)***
Headache	1.37 (1.33–1.42)***	2.60 (2.48–2.72)***	5.31 (4.98–5.66)***	9.36 (8.13–10.78)***
Tiredness	1.40 (1.37–1.43)***	1.84 (1.78–1.91)***	3.56 (3.35–3.78)***	14.95 (12.44–17.98)***

$^{***}P < 0.001$

dampness. To our knowledge, this is the second-largest epidemiological study on adults relating signs of dampness in the home to symptoms, and associations were stronger than in many comparable studies.

Selection bias due to low response rate is less likely since the participation rate was high (77%). The proportion of participants was similar in the two samples from 1991 and 1993, in all age classes of buildings (74–80%), and similar with respect to ownership. The age distribution among the participants was similar to that in the general population, with 24% of elderly subjects (> 64 years) in our study compared with 20% in the total population in Stockholm (Anonymous 2000). 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 sufficient number of buildings of different age classes. There was a lower proportion of buildings from 1931–60, and a higher proportion of newer buildings (1976–1990) in our study, but we found no major influence of building age on reports on dampness. Buildings from 1931–1960 had a similar prevalence of all four types of dampness characteristics, compared with the total material, but newer buildings had somewhat less mouldy odour and water leakage. It is, however, less likely that the stratified random sampling should have biased the observed relationships between dampness and symptoms.

Another methodological problem is possible recall bias in relation to awareness of the exposure among participants. In this study, information on 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 accordance with most previous epidemiological studies in this field (Husman 1996; Peat et al. 1998) information on both building dampness and medical symptoms was assessed by the same questionnaire. This could result in recall bias, leading to an increased reporting of environmental exposures among symptomatic subjects. When compared with expert observation in dwellings, however, a good reproducibility of self-administered questions on building humidity, visible moulds, and flooding has been reported. From

Canada, the Netherlands, and Sweden, with similar reporting of signs of dampness by subjects with and without respiratory symptoms (Dales et al. 1994; Brunekreef et al. 1994; Norbäck et al. 1999).

Another problem, as pointed out in the review by Peat et al. (1998) is covariation between building dampness and other environmental factors in the building, e.g. population density and ventilation flow. In this study, we made adjustments for other building factors, such as population density, type of ventilation system, and ownership of the building, without any major change of the associations between signs of dampness and symptoms.

A number of statistical tests were done, but all were highly significant. Thus, we do not believe that our conclusions are seriously biased by selection or information bias, or due to chance findings, or selection of a particular statistical model.

At least one sign of building dampness was found in 28.5% of the dwellings, with a history of water damage in the past 5 years in 12.7%, high air humidity in bathrooms in 12.4%, condensation on windows in 9.0%, and mouldy odour in 7.6%. A similar total prevalence of dampness in dwellings (17–24%), using different definitions, has been reported from other Swedish studies on adults (Norbäck and Edling 1991; Norbäck et al. 1994; Norbäck et. al. 1999). In those Swedish studies, water leakage during the past year was reported in 13–16% of the dwelling, and mouldy odour was reported in 2.3–6.0%. Brunekreef reported dampness in 25% of homes in Helmont, the Netherlands (Brunekreef 1992). Dales et al. (1991) reported building dampness in 38% of Canadian homes, with reports of flooding during the past year in 19% of the homes. In the UK, dampness was found in 31%, and actual mould growth was found in 46% of public housing in Glasgow (Platt et al. 1989).

Few other studies have compared building dampness in different types of buildings. Building technology has changed over time, and new types of construction, more-sophisticated ventilation systems, and new building materials have been introduced during the past decades. Our age classification for buildings considered major changes in building technology. Buildings built before 1961, were mostly stone buildings, many without mechanical ventilation. Then followed a generation of buildings (1961–1975) that were constructed during a building boom, and were mostly publicly owned. These buildings had the highest prevalence of dampness, suggesting that the building boom had negative consequences on the indoor environment. The newest buildings, fabricated in 1985–1990 had the lowest occurrence of dampness, particularly water leakage and mouldy odour, suggesting improved building technology in this aspect. We found no major difference between publicly owned buildings and those with private landlords, but 2–3 times fewer reports of dampness in buildings owned by the inhabitants. Water leakage was most common in buildings owned by private landlords, maybe reflecting differences in maintenance organisation. The association between type of ventilation system and population density, and building dampness, was less pronounced. As expected, buildings with mechanical supply/exhaust ventilation, and consequently the highest airflow rate, had least dampness. Dwellings with a high population density, and consequently higher emission of dampness from subjects and their activities, had a higher proportion of various types of dampness, illustrating that dampness is related to household factors, installations, and building construction.

Even when adjusting for possible confounding by age, gender, population density, type of ventilation system, and ownership of the dwelling, we found a pronounced association between SBS symptoms and different indicators of building dampness. Reports of mouldy odour were used as a proxy-variable for exposure to microbial pollutants. Two new indicators of building dampness, combined with the proxy for microbial exposure, were constructed. The first was a combination of mouldy odour and high air humidity (either condensation on windows or high air humidity in the bathroom). The second was a combination of mouldy odour and a history of water leakage. As expected, by using the combined exposure indicators, the associations between dampness and symptoms was strengthened, with ORs ranging from 3.67 to 5.97, and an OR > 5 was found for eye irritation, throat symptoms, and headache. A similar approach has been applied in earlier Finnish dampness studies. By combining mouldy odour with structural building dampness in day-care centres, the authors observed a stronger association between building dampness and symptoms in day-care personnel, particularly for ocular and respiratory symptoms (Ruotsalainen et al. 1995). The health significance of mouldy odour has also been pointed out by Jaakkola et al. (1993). Mouldy odour during the past year (ORs from 2.38 to 6.87) and water damage over a year ago (ORs from 2.54 to 8.67) reported by parents, had the strongest association with respiratory symptoms in children. A dose-response relationship of the occurrence of symptoms with the frequency of days with mould odour was observed. Moreover, there was a relationship between water damage that took place more than a year ago, and the occurrence of symptoms (Jaakkola et al. 1993).

The SBS includes ocular, nasal and throat symptoms that could be due to mucous membrane irritation, secretion or inflammation (Koren and Devlin 1992). In addition, there are specific mechanisms for ocular symptoms due to indoor environmental factors, including increased blinking frequency, decreased tear film stability, and corneal damage (Kjaergaard 1992). Sensory irritation of the olfactory system (odour) or the trigeminal free nerve endings (chemical sensory irritation) have been proposed as important mechanisms behind the SBS (Cain and Cometto-Muniz 1995). Recent studies have shown decreased tear film stability (Wieslander et al. 1999), increase of nasal mucosal swelling or biomarkers of inflammation in people living in damp buildings (Hirvonen et al. 1999; Wieslander et al. 1999; Wålinder et al. 2000a; Wålinder et al. 2000b). In addition, other studies have shown an increase in general symptoms such as headache or fatigue in damp buildings (Hirvonen et al. 1999; Norbäck et al. 1994; Li et al. 1997; Wan and Li 1999). Concerning symptom specificity, we found relationships for most types of SBS and all types of dampness indicators. This suggests that there are individual differences in response to dampness-related exposures, but no specific pattern of SBS symptoms in damp dwellings.

Despite the large number of studies suggesting respiratory effects of building dampness (Husman 1996; Peat et al. 1998), it remains unclear as to which dampness-related exposures are causative factors. Two of our dampness indicators were aimed to detect high air humidity. It is less likely that increased air humidity per se causes symptoms, but at higher air humidity, condensation may occur, causing microbial growth on indoor surfaces. High indoor air humidity also facilitates growth in numbers of house-dust mite, a known indoor allergen (Munir 1998). Water leakage may lead to microbial growth inside the building construction, sometimes without visible signs of mould growth (structural dampness) (Wålinder et al. 2000b). In addition, structural dampness may also cause chemical degradation of building material, e.g. formation and emission of 2-ethyl-1-hexanol at alkaline degradation of di-ethyl-hexyl phthalate (DEHP) in poly-vinyl chloride (PVC) materials (Wieslander et al. 1999). In damp buildings, the inhabitant may be exposed to volatile organic compounds of microbial origin (MVOC) (Wessen and Schoeps 1995). Some of these compounds have a characteristic mouldy odour (e.g. 1-octen-3-ol or geosmin), as indicated by our last dampness indicator. Perception of odour is, however, a complex issue and may be modified by personal factors, as well as the composition of odorous mixtures (Cain and Cometto-Muniz 1995). Finally, microbial growth in damp buildings may lead to exposure to particulate pollutants with inflammatory or immune-modulating properties, e.g. endotoxin (Thorn and Rylander 1998) and (1–3)-beta-D-glucan (Rylander 1999).

In accordance with an earlier study in office worker in Taipei, Taiwan, we tested the dose-response relationship between dampness and symptoms, by constructing a dampness index (Wan and Li 1999). By using a dampness index consisting of the number of dampness signs, we saw that a pronounced trend was demonstrated, with 95% confidence intervals without any overlapping in most cases. The most pronounced associations were found in buildings with four signs of dampness (ORs from 5.82 to 19.91). It seemed that there were somewhat different trends for different types of symptoms. A three-fold increase in ocular and throat symptoms (OR $>$ 3) was already observed at two signs of dampness, while nasal symptoms, tiredness, and headache were increased (OR $>$ 3) at three signs of dampness, and cough and facial dermal symptoms only at four signs of dampness.

In conclusion, signs of high air humidity, as well as structural building dampness, are common in multi-family buildings in Stockholm, and are related to household factors, installations, and the building construction. A pronounced increase in ocular, nasal, and lower respiratory symptoms, facial dermal, and general symptoms was observed in subjects in damp buildings, even when we had adjusted for possible confounding by age, gender, population density, and building-related risk factors. By combining signs of dampness with perception of mouldy odour, a proxy variable for microbial exposure, we found that the associations were strengthened. Moreover, a dose-response relationship between symptoms and dampness was confirmed. Measures should be taken to reduce dampness and microbial growth in dwellings. This could be achieved in different ways, e.g. by keeping a sufficient air-exchange rate in relation to the production of humidity by the occupants, by preventive and adequate maintenance, quick repair of water leakage, and by avoiding constructions with increased risk of building dampness.

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