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Indoor Air Humidity and Sensation of Dryness as Risk Indicators of SBS

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Abstract

Questionnaire reports on symptoms and sensations from 4943 office workers, measurements of indoor climate from 540 office rooms in 160 buildings, and measurements of TVOC in 85 rooms were used in an analysis of the role of indoor air humidity and the sensation of dryness as risk indicators of SBS (Sick Building Syndrome) symptoms. The sensation of dryness was strongly associated with the prevalence of SBS symptom reports. There were no associations between measured indoor air humidity and the prevalence of SBS symptoms or the sensation of dryness. A number of significant associations were demonstrated between the sensation of dryness and technical, air quality, psychosocial and personal variables. The frequency of reports of perceived "dry air" is an important indicator of the "sickness" of a building; indoor air humidity is not an indicator.

KEY WORDS:
Sick building syndrome, Epidemiology, Humidity, Dryness, Office

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Introduction

The role of low indoor air humidity as a risk factor of sick building syndrome (SBS) and other indoor related disorders is not clear. It is assumed that dry indoor air could cause a drying out of the mucosa of the upper airways and thus impair the ciliary function, resulting in an increased occurrence of respiratory infections (Green, 1979; Arundel et al., 1986). In contrast, Andersen et al. (1974) found no drying out of the mucosa after exposure to 8% relative humidity (RH) for 76 hours in a chamber experiment. No increased clearance rate of the ciliary transport system could be detected after 8 hours at 70% RH among healthy adults (Proctor, 1982). It has been shown in laboratory studies that some bacteria and viruses have decreased survival at humidities in the range of 30–60% RH (studies reviewed in Sterling et al., 1985), but this effect has not been shown in field conditions (Nevalainen, 1989).

Inconclusive results have been presented from studies on the effect of air humidification on the prevalence of respiratory infections and abseenteism (nine studies reviewed in Green, 1979 and Reinikainen et al., 1991). Both positive and negative as well as no effects of air humidification are shown. Typically the relative humidity was raised by humidification with up to 10% in the range of 20 to 50%.

In a number of epidemiological studies no significant association has been found between indoor air humidity and prevalence of SBS-symptoms (Bakke and Levy, 1990; Burge et al., 1990; Skov et al., 1990; Nelson et al., 1991). In the Danish Town Hall study (Skov et al., 1990) as well as in studies by Burge et al. (1987), Kateman et al. (1990), and Sundell et al. (1993b) buildings with humidification and rooms with humidifier had elevated symptom prevalence as compared to buildings without. In contrast, in an experimental study, Reinikainen et al. (1991) found that humidification to 30–40% RH

in an office building reduced the complaints of dryness of skin and eyes as well as the sensation of dryness as compared to periods without humidification (with RH between 20 and 30%). In another experimental study of SBS the prevalence of symptoms decreased during periods of air humidifying (Wyon, 1992). From England, Rycroft and Smith (1980) reported outbreaks of skin symptoms among workers, symptoms allegedly caused by low relative humidity (35%), i.e., "low humidity occupational dermatoses".

The sensation of "dry air" is a common finding in investigations of suspected sick buildings. Chamber studies by Andersen et al. (reviewed in Andersen and Proctor, 1982) have shown that this perception is more often due to the air being polluted or too warm than to the air being physically dry. In a study of photographically assessed eye redness and sensory eye irritation in patients suffering from hayfever, Kjaergaard et al. (1990) showed that sensory irritation, provoked by exposure to birch pollen in the eye, in general occurred before any increased eye redness. This sensory irritation was often expressed as "dryness".

The purpose of this study was to analyse associations between SBS symptoms and the sensation of dryness, and to analyse associations between the sensation of dryness and air humidity, room characteristics, and chemical factors.

Material and Methods

A total of 4943 office workers, comprising about 1/3 of all workers in office buildings in three provinces in northern Sweden, the office buildings being selected on a probability basis, responded to a questionnaire on demographic factors, work characteristics, perceptions of physical climate, symptoms and building characteristics at work and at home. Of this number, 4819 persons responded to all relevant work-related questions, and 4809 to all home-related questions (Tables 1 and 3). The questionnaire study was performed during October-December 1988 (Stenberg et al., 1993; Sundell et al., 1993a; 1993b).

Indoor climate investigations and measurements were carried out, during January-April 1989, in office rooms of 567 persons in 160 out of a total of approximately 210 buildings (Figure 1) that were included in the questionnaire study (Sundell et al., 1991; 1993a; 1993b). Working in the investigated buildings were 3926 of the 4943 persons included in the questionnaire study.

In 540 office rooms the outdoor airflow rate was measured as specified by the Nordic Ventilation Group (1982) using a calibrated hot-wire and IR-instrument (Miran 1A), and nitrous oxide as tracer gas (decay method). Temperature and humidity were measured once in each room at three heights at the working place (0.1 m and 1.1 m above the floor, and 0.1 m below the ceiling) as well as in the supply air to the room. Calibrated hot wire instruments were used with an accuracy of ± 0.3°C for temperature and ± 2% for relative humidity (Rotronic Hygroscopic DV-2 with probe SA-100C). The mean outdoor temperature was $+1.9$°C (SD 3.0°C, range -10 and $+12$°C). For further information on the indoor climate study see Sundell et al. (1991). In parallel with the physical measurements, observations were made as to e.g. room size, surface materials, fleece and shelf factors, age of furniture, smoking habits, cleaning routines and occurrence of humidifiers, copying machines and laser printers.

Concentrations of total volatile organic compounds (TVOC) were measured in intake air, supply air and room air of 85 rooms in 29 buildings, while the concentration of formaldehyde was measured in room air only (Sundell et al., 1993a).

Symptoms to be considered by the respondents were 1) "general" symptoms including "fatigue", "feeling heavy-headed", "headache", "nausea/dizziness" and "difficulties concentrating"; 2) mucous membrane symptoms including "itching, burning or irritation of the eyes", "irritated, stuffy or runny nose", "hoarse or dry throat" and "cough"; 3) skin symptoms including "dry facial skin", "flushed facial skin" and "itching, stinging, tight or burning sensations in facial skin". In the questionnaire, responses to symptom questions as well as environmental perception of "dry air" were to be given in one of three categories: "Yes, often (every week)", "Yes, sometimes" or "No, never" related to the three months prior to the questionnaire. For each symptom the respondents were asked whether they attributed it to the indoor climate at the workplace.

Four different sets of data were used in the analysis (Figure 1):

1) Questionnaire responses of 4943 office workers.
2) Questionnaire responses plus data from observations and measurements of the office rooms of 567 persons in 160 buildings.
3) Data from 2) plus measurements of formaldehyde and TVOC in 85 rooms in 29 buildings.
4) Data as in 3) but with questionnaire responses

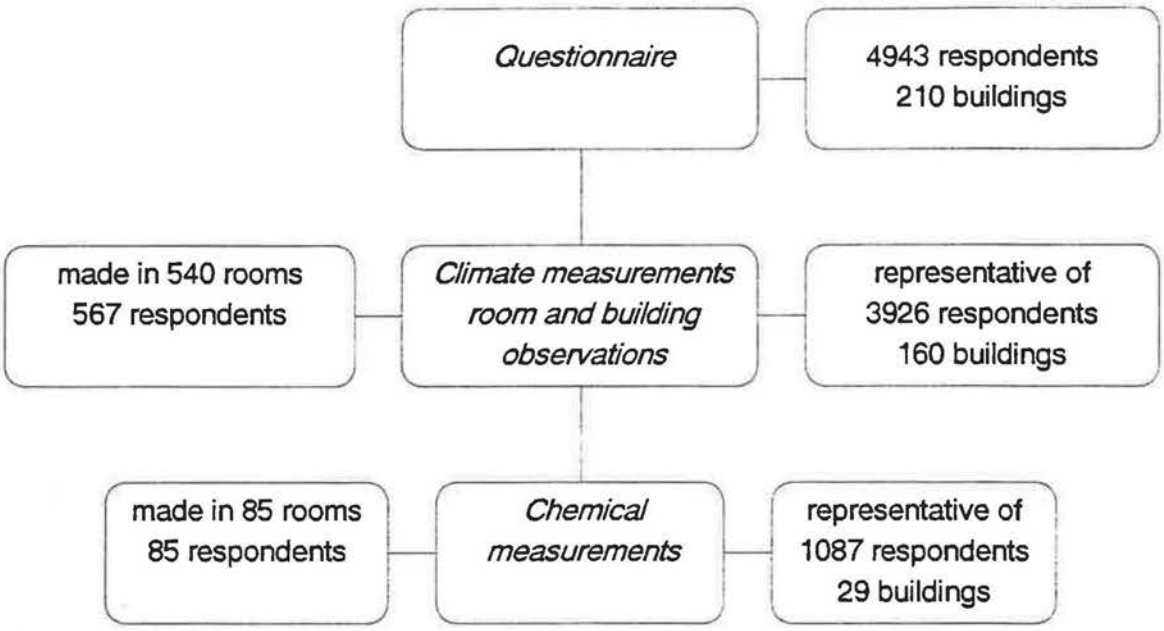

Fig. 1 The structure of the study.

from all respondents in the 29 buildings (1087 persons).

Statistical Methods

Univariate and multivariate regressions were used in the analysis of associations between sensations, symptoms, personal, technical and indoor climate factors. Also, multivariate logistic regression analysis was used to control potential confounding factors, such as gender, personal sensitivity, job-related and psychosocial factors as well as building and room factors.

The Odds Ratio (OR) is used as a measure of the strength of the association between sensation of "dry air", health outcome and exposure factors. The OR is an estimate of the odds, approaching the relative risk, of being affected when exposed, and ORs are given as point estimates with a 95% confidence interval within brackets (95% CI). In some (aggregated) analyses, buildings are weighted by the number of persons working in them. In the logistic analysis, measured values are dichotomized and, when appropriate, the median value is used as the cut point.

The data were analysed using Epi Info version 3 (Center for Disease Control, Atlanta) and SPSS/PC+ (SPSS Inc., Chicago) statistical packages.

Results

Air Temperature and Humidity in Office Rooms

The indoor air humidity in room air is a function of the absolute humidity of outdoor air, the outdoor airflow rate and the presence of sources and sinks of humidity in the room and its service systems. The "additional" humidity – the difference between the absolute humidity in indoor and outdoor air – is a function of the production of humidity in the room, adsorption and desorption of humidity to and from surfaces and the amount and humidity of supplied ventilating air. The lower the outdoor air humidity the greater the "additional" humidity, due to a larger desorption of humidity from indoor surfaces. The linear relationship between the outdoor air humidity and the "additional" humidity, during January–April, has been calculated (Figure 2) and used for adjusting measured humidity levels to the same outdoor absolute humidity of 4.5 g/m^3. The association has been tested for different data sets (e.g. data from each month) with results that were close to the one shown in Figure 2. Non-linear models have also been tested but were not found to be more accurate than the linear model used, within the actual outdoor air humidity interval. As the indoor climate measurements were made during vary-

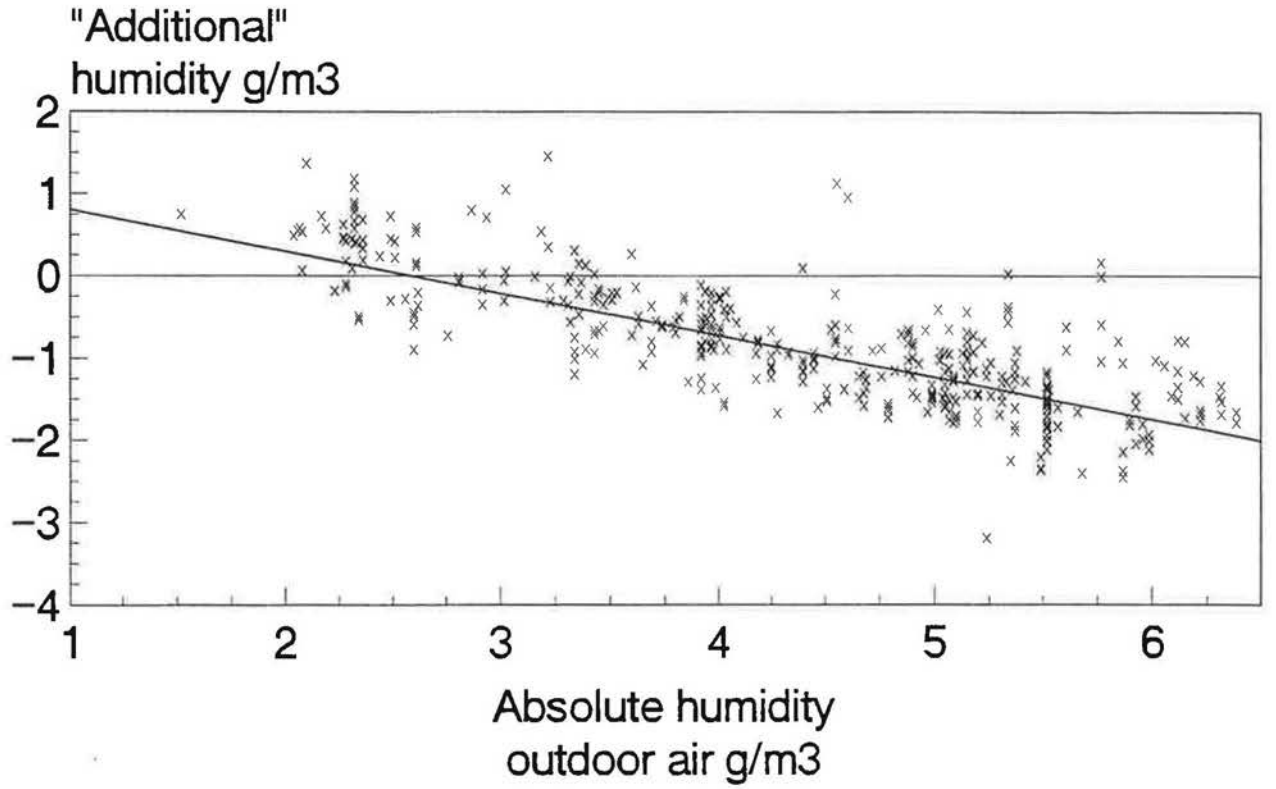

Fig. 2 The association (linear regression) between the absolute humidity of outdoor air and the "additional" humidity of indoor air in offices in northern Sweden during January–April. The "additional" humidity is the difference between the absolute humidity in indoor and outdoor air. n = 567. Regression line: y = 1.37 − 0.52X. Correlation 0.80, $p > 0.0001$

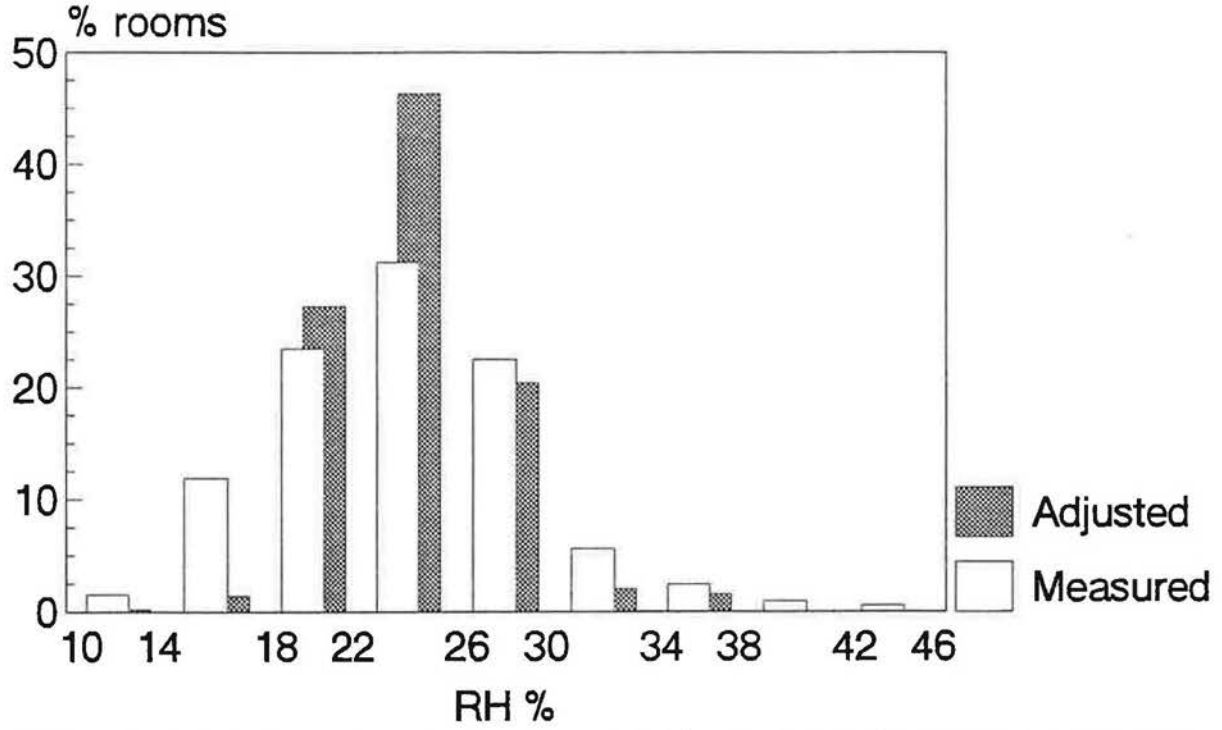

Fig. 3 Measured and adjusted (for an outdoor absolute humidity of 4.5 g/m^3) relative humidity of indoor air in 567 office rooms in northern Sweden. Measured: Mean 24.0%, SD 5.2%, Median 23.8%, Range 11.8–42.7%. Adjusted: Mean 24.0%, SD 3.3%, Median 23.7%, Range 9.8–37.6%

ing outdoor conditions, such adjustments were deemed necessary in order to make a reasonable assessment of a person's relative exposure to indoor air humidity in different locations.

Figure 3 shows the distributions of measured and adjusted relative humidities in the office rooms, both with a mean value of 24.0% RH. The air temperature in the investigated office rooms had a mean value of 22.9°C (median 22.9, range 19.6–25.6).

Table 1 Selected characteristics of study populations in relation to the sensation of "dry air" at work.

	"Dry air" at work		
	"Yes often"	"Sometimes"	"No, never"
Questionnaire study n = 4819			
Men % (n)	16.6 (381)	34.5 (790)	48.9 (1119)
Women % (n)	43.1 (1090)	34.6 (874)	22.3 (565)
Born 19—, mean year			
Men	46.5	44.4	45.8
Women	47.5	46.5	46.4
Asthma %			
Men	11.0	8.5	7.9
Women	12.7	9.0	6.8
Hayfever %			
Men	18.0	18.4	14.9
Women	14.7	11.9	9.6
Eczema %			
Men	25.0	20.4	16.6
Women	32.8	25.3	19.6
Current smoker %			
Men	19.6	18.9	20.2
Women	31.3	28.7	27.1
Open plan office %			
Men	24.1	14.3	9.8
Women	19.4	14.2	10.3
Copier in room %			
Men	16.9	8.9	6.7
Women	12.9	9.1	5.1
Measurement and inspection study n = 567			
Men % (n)	31.3 (36)	27.8 (32)	40.9 (47)
Women % (n)	58.4 (264)	27.0 (122)	14.6 (66)
Air temperature °C (mean)			
Men	22.6	22.8	22.9
Women	22.9	22.8	22.9
Relative humidity % (mean)			
Men	25.4	23.3	23.6
Women	23.8	23.9	24.4
Built or rebuilt after 1976 %			
Men	67	63	63
Women	73	57	58
Much handling paper %			
Men	29	20	8
Women	30	22	15
Chemical measurement study n = 85			
Men % (n)	33.3 (6)	44.4 (8)	22.2 (4)
Women % (n)	62.7 (42)	22.4 (15)	14.9 (10)
TVOC in room air above median %			
Men & women	42	63	
Formaldehyde above median %			
Men & women	60	37	
"Lost" TVOC %			
Men & women	75	31	

There were no consistent associations between measured indoor air temperature or humidity (adjusted "additional" humidity, adjusted RH or adjusted absolute humidity) and single perceived symptoms or group of symptoms for women or men.

Through multivariate linear regression analysis, associations have been determined between measured relative humidity of room air and characteristics of the room. The resulting model "explaining" 71% (correlation 0.84) of the variation in measured RH in rooms (without air humidification) was:

Equation 1.

$$RH = 32.0 + 3.0*AHo + 2.4*F - 0.8*T - 0.07*Q - 0.15*h - 0.03*V$$

Where

RH = relative humidity of room air in %
AHo = absolute humidity of outdoor air g/m^3
F = "fleecefactor", m^2/m^3 of textile surfaces per room volume
T = room air temperature
Q = outdoor airflow rate *l*/s.p
h = ventilation running hours/day during weekdays
V = room volume per occupant m^3/p

All variables in the equation are significant ($p < 0.05$). In rooms with air humidification the RH was raised 2.4% RH on average.

Sensation of "Dry Air" at Work

In total, 16.6% of the men and 43.1% of the women reported experiencing "dry air" "Yes, often (every week)" at work. Some characteristics of persons and rooms associated with the sensation of "dry air" at work are given in Table 1.

The variables that in both bivariate and multivariate regression analyses, using data for 540 persons, significantly covaried with elevated dryness

Table 2 Odds ratios for reporting "At least one symptom every week" as a function of perceived sensation of "dry air" and working in rooms with "lost" or "gained" TVOC.

"Dry air" at work	"Lost TVOC" OR (95%CI)	"Gained TVOC" OR (95%CI)
"Yes often"	42.7 (7.0–324) (n = 36)	21.3 (2.3–286) (n = 10)
"Sometimes or never"	1.78 (0.3–13) (n = 16)	1 (n = 19)

sensations were: a low "virtual" age of the building (i.e. a late year of erection or remodelling), rooms of the type "open-plan offices", the presence of a copying machine in the room, a large amount of work with papers (i.e. handling papers), the occupant not being satisfied with the social conditions at work, having asthma or eczema, and having the sensation of "dry air" at home. In bivariate analyses there were also significant elevated prevalences of dryness sensations for young persons (age <40 years old) and in rooms for 1–2 persons with a low ventilation rate, associations that disappeared in multivariate analysis. No consistent associations were found between the sensation of "dry air" and the physical indoor air humidity (measured or adjusted, relative or absolute) or with room air temperature.

Analysis with data from the 85 office rooms where chemical measurements were made shows a large covariation between "lost" TVOC (the difference between the concentrations of TVOC in supply air and room air) and the sensation of dryness. The OR for having the sensation of "dry air" "Yes, often" was 4.3 (1.47–12.7) and 3.7 (95%CI 1.28–10.7) for having "At least one symptom every week" when working in a room (and building) with "lost" TVOC. The odds ratios for having "At least one symptom every week" for different combinations of having the sensation of "dry air" and working in rooms with "lost" or "gained" TVOC are given in Table 2.

Also, aggregate analysis with data from the 29 buildings, with 1087 respondents, where chemical measurements were made, showed weak but significant associations between the sensation of "dry air" and "lost" TVOC ($r=-0.23$ for women and -0.29 for men with $p<0.0001$). The concentration of TVOC in room air had an inverse association with the sensation of "dry air": the more TVOC in room air the lower the prevalence of the sensation ($r=-0.52$ for women, and -0.19 for men with $p<0.0001$) (see also Table 1).

Table 3 Selected characteristics of study populations in relation to the sensation of "dry air" at home.

	"Dry air" at home		
	"Yes often"	"Sometimes"	"No, never"
Questionnaire study n = 4809			
Men % (n)	5.1 (118)	29.2 (674)	65.7 (1514)
Women % (n)	7.9 (198)	32.5 (814)	59.6 (1491)
Born 19— mean year			
Men	47.7	44.2	45.8
Women	48.7	46.4	47.0
Asthma %			
Men	14.5	9.6	7.6
Women	13.1	11.3	8.8
Hayfever %			
Men	20.2	18.4	14.8
Women	16.2	14.0	11.0
Eczema %			
Men	21.1	24.1	17.0
Women	40.4	30.3	24.1
Current smoker %			
Men	25.4	20.7	18.9
Women	38.1	28.6	28.9
Pet animals at home %			
Men	25.4	32.0	33.2
Women	29.8	32.4	35.9
Apartment house %			
Men	43.6	28.7	26.4
Women	62.8	39.1	32.4
Home in a rural area %			
Men	8.5	15.4	17.9
Women	8.6	16.4	21.8
Home built 1978–1983 %			
Men	28.0	16.3	19.8
Women	25.3	17.4	16.7
Heating by electric radiators %			
Men	35.9	35.8	27.6
Women	36.2	37.0	26.6
Mechanical exhaust ventilation %			
Men	32.2	25.0	23.0
Women	29.9	23.6	18.9
Signs of humidity damages at home %			
Men	13.6	8.1	9.5
Women	17.1	10.1	9.3
Signs of water damage in floor %			
Men	15.4	5.5	5.2
Women	13.1	7.3	4.8
Visual mould growth at home %			
Men	5.1	3.8	2.6
Women	5.0	3.8	2.0
Condensation on windows during winter %			
Men	9.4	6.3	5.0
Women	11.1	4.2	3.4

Sensation of "Dry Air" at Home

The prevalence of the sensation of "dry air" "Yes, often (every week)" during the last three months at home was 5.1% for men and 7.9% for women. Characteristics of persons and homes associated with the sensation of "dry air" at home are given in Table 3. The prevalences were elevated in apartment houses, OR 2.1 (95%CI 1.40–3.1) for men and OR 3.2 (95%CI 2.3–4.3) for women, as compared to single-family houses. Buildings 6–10 years of age had more complaints concerning "dry air" than younger or older buildings, OR 1.68 (95%CI 1.09–2.6) for men and OR 1.65 (95%CI 1.16–2.4) for women. Measurement of indoor air humidity was not made in the homes. Respondents were, however, asked to report whether there used to be condensation of water vapour on the inside of windows during the winter season, as an indicator of

Table 4 Odds ratios and 95% confidence interval for reporting general, mucous membrane and skin symptoms as a function of reported sensation of "dry air" at work. 4943 persons in 210 office buildings.

Symptoms	Sensation of "dry air" at the workplace		
	"No, never" OR	"Yes, sometimes" OR (95% CI)	"Yes often (every week)" OR (95% CI)
Men			
General	1	1.37 (1.07–1.8)	3.2 (2.5–4.2)
Mucous membrane	1	2.5 (1.9–3.4)	8.3 (6.1–11.2)
Skin	1	2.0 (1.5–2.7)	5.1 (3.7–6.8)
Women			
General	1	1.30 (1.01–1.68)	3.2 (2.6–4.1)
Mucous membrane	1	1.8 (1.26–2.5)	6.0 (4.5–8.2)
Skin	1	1.8 (1.32–2.3)	5.5 (4.2–7.1)

Table 5 Odds ratios and 95% confidence interval for reporting general, mucous membrane and skin symptoms as a function of reported sensation of "dry air" at home. 4943 persons.

Symptoms	Sensation of "dry air" at home		
	"No, never" OR	"Yes, sometimes" OR (95% CI)	"Yes often (every week)" OR (95% CI)
Men			
General	1	1.28 (1.02–1.6)	3.1 (2.0–4.6)
Mucous membrane	1	1.9 (1.5–2.4)	4.3 (2.8–6.5)
Skin	1	1.5 (1.15–1.9)	4.4 (2.9–6.7)
Women			
General	1	1.17 (0.97–1.4)	2.5 (1.9–3.5)
Mucous membrane	1	1.37 (1.12–1.7)	3.1 (1.8–2.5)
Skin	1	1.8 (1.5–2.2)	3.8 (2.8–5.3)

the indoor air humidity. Reports of window condensation were associated with an elevated risk of "dry air", OR 1.82 (95%CI 0.90–3.6) for men and OR 3.3 (95%CI 1.94–5.5) for women. Also reports on "signs of water damage", and "visual mould growth" were positively associated with elevated frequencies of the sensation "dry air". The risks associated with type and age of building and condensation were close to multiplicative. Other factors, in a bivariate analysis, that for both men and women were associated significantly with elevated levels of reported "dry air" were: electric heating, the home being situated in an urban area, mechanical ventilation, and reported water/mould damages. Of personal factors reported, asthma, hayfever and especially eczema covaried with elevated prevalences of reports of "dry air". Persons reporting the sensation of "dry air" at work significantly more often reported the same sensation at home also.

Table 6 Odds ratios for having at least one symptom "Yes often (every week)" as function of sensation "dry air" at work and at home. 4943 persons.

	"Dry air" at work		
	Yes, often	Yes sometimes	No, never
"Dry air" at home			
Yes, often	14.8	6.2	4.3
Yes, sometimes	7.7	2.0	1.4
No, never	6.2	1.8	1

Symptom Reports vs the Sensation of "Dry Air"

There were strong and significant associations between the prevalence of reported sensation of "dry air" at home and at the workplace, and of all reported symptoms, especially "tiredness", "itching, burning or irritation of the eyes" and "dry facial skin". Tables 4, 5 and 6 show the odds ratios for reporting general, mucous membrane and skin symptoms when reporting the sensation of "dry air" at work and/or at home. For symptoms that were attributed to the indoor climate at the workplace the association to dryness sensations at the workplace were stronger than for symptoms that were not attributed to the indoor climate (not shown).

Discussion

Reliability and Validity of Data

Measurements of indoor air temperature and humidity took place 3–6 months after the time of the questionnaire study. As we wanted to analyse health-data against building-data, it was important that the data on indoor climate and room characteristics should be representative for the questionnaire period. Buildings or rooms that had been subject to changes, potentially influencing the indoor thermal climate or air quality, were excluded from the study in order to increase comparability (Sundell et al., 1993a; 1993b).

As discussed in Sundell et al. (1993a) the validity of the data on room temperature and indoor air humidity is more doubtful. Reasons are that measurements were made only once in each room and under varying outdoor conditions. The regression model (Equation 1), explaining the variation in room air RH with differences in room characteristics and changes in outdoor air humidity, has a good correlation and is reasonable with regard to the climatic conditions and season of the year when measurements were made. Therefore, measured humidity values should be reliable. The validity of the humidity estimates in the analysis of associations to symptom reports was probably increased by the adjustment of the measured values to the outdoor absolute humidity at the time of measurement (Figure 1). Still, point estimates of the indoor climate introduce a certain unsystematic misclassification in the climate estimates. Thus, possible associations between indoor climate factors, reported sensations or symptoms could be underestimated in the analysis.

A large number of persons, buildings and rooms, representative of typical office poulations in Sweden, have been studied in the investigation (Sundell et al., 1993a, b; Stenberg et al., 1993). The questionnaire used has been shown to have a fair to good test-retest reliability for single symptoms or symptom groups (kappa values between 0.30–0.60) (Sundell et al., 1993a). It is shown that the mean response of a large group of occupants is fairly stable even though the individuals of the group may have changed partly (ibid). Thus, on group level, the questionnaire works well in studies of associations between building factors and symptom reports.

"Dry Air" vs Dry Air vs SBS

In agreement with many other studies (Bakke and Levy, 1990; Burge et al., 1990; Skov et al., 1990; Nelson et al., 1991) the present study indicates that physical indoor air humidity in the range of 10–40% RH is not an important factor related to the prevalence of SBS.

The sensation of "dry air", at home as well as at work, is strongly associated with the prevalence of SBS symptom reports at work. The perception of dryness at work is not associated with the physical air humidity indoors at work. For homes the sensation of dryness is significantly positively associated with occupant-reported condensation of water vapour inside windows as well as with other humidity-related observations such as visual water damages or mould growth. Reports of condensation inside windows have been shown to be closely linked to measured indoor air humidity in homes and to a low ventilation rate (Sundell et al., 1993c). A number of associations exist between the sensation of dryness and engineering and air quality variables, notably with "lost" TVOC. As discussed in Sundell et al. (1993a) "lost" TVOC may indicate the production of irritating substances such as aldehydes and free radicals. Thus, associations found in the present study are well in accord with results from chamber studies (Andersen and Proctor, 1982; Kjaergaard et al., 1990) where the sensation of dryness was reported to be primarily an effect of irritating substances in the air.

Besides psychosocial factors, a number of personal factors such as female gender, and allergic diseases such as asthma and eczema are significantly associated with raised prevalences of the sensation of "dry air". Obviously, individuals have a varying degree of sensitivity to factors in the environment which are associated with the perception of "dry air" and SBS (Hedge et al., 1989). For instance persons that report the sensation of dryness at home are more prone to report the same sensation at work as well as SBS symptoms at work. This proneness is most likely the result of an increased sensitivity to specific chemical or physical irritants, but can also to some extent be the result of a response behaviour of being more inclined to report sensations or symptoms.

Conclusion

The "sensation of dryness" is an important indicator of an indoor environment that provokes SBS symptom reports. "Sensation of dryness" seemingly has little to do with physical air humidity. There are some indications that persons who experience

hyperreactivity disorders also report "sensations of dryness" at work and at home.

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