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# A LONGITUDINAL STUDY OF PERCEIVED AIR QUALITY AND COMFORT IN A SICK LIBRARY BUILDING

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A study of perceived air quality, reported symptoms, and general comfort was conducted during 8 months in a 5-year old library building which had been classified as sick by health authorities. In total, 7000 questionnaires were filled in two times a day by staff (n≈60) and visitors (n≈100). The results show that 3 environmental variables ranked worst in degree for both staff and visitors: too dry, stuffy and dusty. The staff and visitors agreed in their symptom reports and the momentary reports were found to be more reliable than retrospective ones (last 3 weeks). The library staff gave consistantly higher and the visitors higher or equal symptom frequencies as the occupants of 4 reference healthy buildings. Eight symptoms showed a significant increase in frequency from morning to afternoon. These are believed to be critical symptoms in the sick building syndrome because they include all 5 symptoms defined by WHO. The symptom prevalence showed a high correlation with the percentage of persons being satisfied with the indoor climate but the library does not meet the ASHRAE criteria of 80% satisfied; the change over the day being 71 to 62% for the visitors and 54 to 41% for the staff. A promising finding is that the prevalence change over the day of the 8 SBS symptoms shows a strong linear relationship with the mean concentration of 34 VOCs as measured in exhaust air (r=0.96).

## INTRODUCTION

Recent research indicates that physical, chemical, psychological and physiological variables are involved in sick building problems and that these variables interplay in a complex way (7, 10, 12, 13, 14, 15, 16, 17, 19). Furthermore, the air quality of a building is not static – it changes all the time due to changes in outdoor climate, ventilation setting, use of the building, etc. Effects on humans caused by the physical environment are also affected by many other factors like host sensitivity, environmental experience, work place conditions, capacity for coping, etc (3, 8,11). So far, most published studies of sick buildings can be

characterized as cross-sectional, that is the buildings and their occupants have been studied at one occasion. Very little is known about the variability in occupant reports and in the behavior of a specific building over time as reflected in chemical/physical measures. Thus, results of case studies as well as cross-sectional studies may present interpretation problems both with regard to sensitivity and specificity of the methods of measurement and with regard to representativeness of results. It seems imperative that longitudinal studies of occupants and buildings over pro-longed periods of time are a necessary supplement to the cross-sectional ones. The aim of the present study was to describe variability and relationships be-tween occupant symptoms, perceived air quality and chemical/physical environ-mental variables in one sick library building during a fall-winter-spring period.

## METHOD

The study was conducted in a 5-year old, six stories, energy-efficient concrete university library building (4, 6). The building volume is 100,500 $m^3$ and the floor-area 23,500 $m^2$. The length of book shelfs is 52,000 m, 1,200,000 books are stored, and there are about 930 seats for reading. Every day of the week, between 9 a.m. and 5 p.m., there are ca. 3,500 visitors, mostly university students. In a week day, ca. 60 out of 120 staff members are present in the library. The supply air is particle filtered, and optionally preheated and/or humidified. The ventilation system is run 24 hours a day, all days of the week. For 8 months (fall, winter, spring) the building was studied with regard to indoor air quality and self-reported symptoms. Two main ventilation settings were studied: 75% return air or no return air (100% outdoor air). For a description of the chemical and physical measurements of i.a. volatile organic compounds (VOC), see (5).

Every Tuesday during the 8-month study period, questionnaires were distributed to both staff and visitors. Immediately after arriving in the morning, the staff answered the questionnaire and before leaving in the afternoon they filled in another version of the questionnaire.

Almost all visitors were university students, from whom 100 volunters were selected in the morning (9-11 a.m.) and in the afternoon (12 a.m. - 5 p.m.) according to the principle first come first serve. The visitors answered individually while seated in different parts of the library building. In the afternoon group, the visitors had to stay indoors in the library building for at least 3 hours before they were allowed to respond on the questionnaire. The morning visitors were requested to respond within half an hour after arriving. The evaluations made by staff and visitors refer to the presence of specific symptoms at the moment of filling in the questionnaire (right now) as well as how frequent each symptom has occurred during the last 3 weeks (often, sometimes, seldom). The symptoms asked for were [1] mental fatigue, [2] sensation of pressure in head, [3] headache, [4] feeling sick and dizzy, [5] problems to concentrate, [6] itching, smarting and irritation of eyes, [7] congested and running nose, [8] frequent colds, [9] sinusitis, [10] dryness, hoarseness and sore throat, [11] hacking cough, [12] dry skin in face, [13] dry skin on hands, [14] face erythema, [15] scaling and itching scalp or ears, [16] itching, stinging, tightness, and feeling of warmth in face without visible skin rash. Furthermore the questionnaire comprised questions on whether the respondents were satisfied with the indoor climate (yes or no) and (on a 7-point category scale from good to bad), the percieved working situation, the general impression of the environment, and the momentary perception of the environmental variables: stuffiness, odor strength, dustiness, draft, temperature (good to too warm/cold), humidity (good to too humid/dry), light (good to too light/dark), and loudness (good to too silent/noisy).

## RESULTS AND DISCUSSION

The two groups of respondents, the staff and visitors were somewhat different: The mean age among the staff was higher compared to the visitors (44 and 24

years, respectively) and there were more women among the staff (85 and 40%, respectively). Concerning time spent in the library, the groups were comparable (study mean: 6 h a day, 5 days a week for both staff and visitors).

Comparison of reports from staff and visitors. The staff and visitors differ only marginally in their perceptions of different climate variables. They all judged the air to be too dry, stuffy and dusty. Both groups agreed that stuffiness, dustiness, and warmness became worse during the afternoon compared to the morning (paired t-test, $p<0.001$). The staff also reported dryness and the visitors reported odor and draft as becoming significantly worse from morning to afternoon.

The prevalence of the 16 symptoms varied during the 8 months, but a common feature was that the symptoms became more frequent in the afternoon, for both staff and visitors. In Table 1, the mean of the 16 symptom reports are given for the staff and visitors. In the table the symptom frequency for 4 typically healthy buildings is given for comparison (1). Probably due to the repeated building exposure of the staff, they reported a higher mean frequency of symptoms during the last three weeks as compared to the visitors. This interpretation is supported by the result that the symptom frequency is about the same for staff and visitors when the momentary symptom perception is reported (right now). Furthermore, the staff and visitors agreed more in reported symptom profiles for the question right now ($r=0.84$; $p<0.001$) than for the question referring to the last three weeks (($r=0.54$; $p<0.05$). Although these coefficients of correlations, at most reflect 70% common variance, the results indicate that momentary perceptions are more reliable than retrospective judgements (last 3 weeks) for characterizing the indoor climate.

The symptom frequency from the retrospective judgements of the staff is consistantly higher than for the occupants of the reference healthy buildings. The visitors give consistantly higher or equal symptom frequency compared to the referents.

The change over the day of the visitors symptom reports (morning frequency subtracted from the afternoon frequency) may be assumed to be a measure of building-related reactions. Eight symptoms showed a significant change from the morning to the afternoon. Five of these symptoms were classified by WHO (17) already in 1983 as typical for sick buildings (marked with an asterisk in the following list): *mental fatigue ($p=0.0001$), sensation of pressure in head ($p=0.0001$), *headache ($p=0.0001$), problems to concentrate ($p=0.0001$), *eye irritation ($p=.0001$), *dryness, hoarseness, sore throat ($p=0.001$), *face erythema ($p=0.002$), and itching, stinging, tightness, and feeling of warmth in face without visible skin rash ($p=0.0001$). Thus, the symptom pattern of this building coincides with the WHO definition. In addition, the prevalences of the 8 critical symptoms are higher compared to the referents, the healthy buildings. Taken together, these two results support the diagnosis of the library building being sick.

We are inclined to believe that a sick building is characterized more by the profile of symptoms than the high prevalence of specific symptoms (7). In this

Table 1. Symptom reports for different groups and conditions. 'Often' and 'right now' stands for the percentage of the group reporting that they have perceived the symptom 'often during the last 3 weeks' and 'right now at the moment in the afternoon when filling in the questionnaire', respectively.

| Symptom | Referents (n=196) | | Staff (n≈167) | | Visitors (n≈2500) | |
|---|---|---|---|---|---|---|
| | Often | Right now | Often | Right now | Often | Right now |
| 1. Mental fatigue | 13 | - | 32 | 31 | 29 | 35 |
| 2. Sensation of pressure in head | 10 | - | 20 | 19 | 17 | 24 |
| 3. Headache | 06 | - | 15 | 08 | 08 | 07 |
| 4. Feeling sick and dizzy | 02 | - | 09 | 01 | 02 | 03 |
| 5. Problems to concentrate | 02 | - | 10 | 04 | 21 | 22 |
| 6. Eye irritation | 07 | - | 35 | 25 | 16 | 25 |
| 7. Congested and running nose | 04 | - | 38 | 22 | 10 | 21 |
| 8. Frequent colds | 03 | - | 15 | 05 | 05 | 08 |
| 9. Sinusitis | 01 | - | 10 | 04 | 02 | 02 |
| 10. Dryness, hoarseness, sore throat | 06 | - | 25 | 19 | 09 | 22 |
| 11. Hacking cough | 03 | - | 11 | 07 | 05 | 06 |
| 12. Dry skin in face | 12 | - | 39 | 21 | 19 | 26 |
| 13. Dry skin on hands | 16 | - | 34 | 23 | 16 | 18 |
| 14. Face erythema | 04 | - | 13 | 07 | 07 | 08 |
| 15. Scaling and itching scalp or ears | 07 | - | 16 | 11 | 09 | 10 |
| 16. Itching, stinging, tightness, and feeling of warmth in face without visible skin rash | 05 | - | 28 | 19 | 08 | 13 |
| Mean of the 16 symptoms | 06 | - | 22 | 14 | 11 | 16 |

Note. The referents refer to the study by Andersson et al. (1).

case, the typical symptom profile of the so called sick building syndrome (SBS) would include the 5 WHO symptoms supplemented by another 3. Since the 8 symptoms referred to have not been investigated over the time of the day in other buildings, further studies are required before the results can be judged conclusive. It is still an open question whether the significant increase in symptom frequency over the day is typical for the sick building or is a common characteristic of individuals staying in any building.

Dissatisfaction and prevalence of symptoms. The correlations between symptom prevalence and the percent of the visitors or the staff being satisfied with the indoor climate were high for the afternoon data (visitors: $r=-0.80$, $p<0.001$; staff: $r=-0.79$; $p<0.1$). Thus, the symptom prevalence among occupants accounts for 64% of the variance of the (dis)satisfaction reports. For the morning, data is only available for visitors, and the correlation was then weak ($r= -0.51$). The change in symptom prevalence over the day correlated strongly with the absolute prevalence of satisfaction with the indoor climate in the afternoon. For the visitors the coefficient of correlation was $-0.71 (p<0.001)$.

Both ASHRAE and WHO have suggested as criteria for acceptable indoor air quality, a minimum percentage of persons reporting that they are satisfied.

ASHRAE (2) suggests that 80% should not be dissatisfied and WHO (18) suggests that 95% should not be annoyed. Later, WHO (19) have argued that 90% should be free of mucosal irritation and 50% should be free of involuntary odor of the indoor air. The indoor air quality in the present library building does not meet the two suggested criteria values for persons not being dissatified. Already in the morning, only 71% of the visitors and 54% of the staff were satisfied. As expected the satisfaction went down during the day to the figures 62% and 41% for visitors and staff, respectively.

If extrapolations are made from the data in this study, the mean prevalence of the 8 symptoms considered critical for the sick building syndrome is about 10% when 80% of the visitors were satisfied with the indoor climate in the afternoons.

Covariation between symptoms, satisfaction reports and VOCs. In searching for psychophysical dose-response relationships, the highest positive correlation is found between prevalence change over the day of the 8 SBS-related symptoms (visitors) and the mean concentration of 34 volatile organic compounds as measured in exhaust air ($r=0.96$; $p<0.001$). The plot behind this relationship shows no systematic curvature and will therefore be considered linear. Since symptom prevalence correlates highly with percent dissatisfied, a linear but less strong relationship is also found between percent dissatisfied and mean concentration of the 34 VOCs ($r=-0.67$). This latter relationship is comparable to Fanger's (9) plots relating percent dissatisfied to his dilution factor expressed in l/s,olf. However, the two relationships carry no resemblance at all. In Fanger's data, the percent dissatisfied decreases with increased dilution of the air. His relationship is characterized by a strong deceleration while our data show a clear linearity for the same range of percent satisfied/dissatisfied.

Since our data were collected longitudinally, the form of the relationships has to be interpreted with caution because there is a possibility that the time of the year will causatively influence both the feeling of well being of persons and the concentration of VOCs in air, in such a strong way that the two latter mainly reflect this reality. Furthermore, the VOCs admittedly only represents a fraction of the contaminants present in indoor air. Although the neat, linear relationship found between symptom prevalence and VOC concentration is intriguing, it is not yet proven that any VOCs cause the SBS.

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## REFERENCES

1. Andersson, K., Fagerlund, I., Bodin, L., & Ydreborg, B. (1988). Questionnaire as an instrument when evaluating indoor climate. In B. Berglund & T. Lindvall (eds.), Healthy Buildings '88. Vol. 3 (pp. 139-145). Stockholm: Swedish Council for Building Research, D21.

2. ASHRAE. (1989). ASHRAE Standard 62-1989: Ventilation for Acceptable Indoor Air Quality. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

3. Baird, J.C., Berglund, B., Berglund, U., & Lindvall, T. (1990). Symptom pattems as an early warning signal of community health problems. Environ Int 16, 3-9.

4. Berglund, B., Johansson, I., Lindvall, T., & Lundin, L. (1989). Air quality and symtoms in a sick library building with a return-air ventilation system. In E. Kulic, B. Todorovic, & P. Novak (eds.), CLIMA 2000, Vol. III (pp.13-18). Amersfoort, The Netherlands: REHVA.

5. Berglund, B., Johansson, I., Lindvall, T., Lundin, L. (1990) A longitudinal study of airborne chemical compounds in a sick library building. In Proceedings Indoor Air '90. Toronto, Canada, July 29 - August 3, 1990.

6. Berglund, B., Johansson, I., Lindvall, T., Lundin, L., & Morath, C. (1988). Air quality and symptoms in a sick library. In R. Perry & P.W. Kirk (Eds.), Indoor and Ambient Air Quality. London: Selper, pp. 355-364.

7. Berglund, B., & Lindvall, T. (1986). Sensory reactions to "sick buildings". Environ Int 12, 147-159.

8. Evans, G.W., Colome, S.D., & Shearer, D.F. (1988). Psychological reactions to air pollution. Environ Res 45, 1-15.

9. Fanger, P.O. A comfort equation for indoor air quality and ventilation. In B. Berglund & T. Lindvall (eds.), Healthy buildings '88. Vol. 1 (pp.39-51). Stockholm: Swedish Council for Building Research, D19.

10. Finnegan, M.J., Pickering, C.A.C., & Burge, P.S.(1984). The sick building syndrome: Prevalence studies. Brit Med J 289, 1573-1575.

11. Helson, H. (1974). Adaptation level theory. In E.C. Carterette & M.P. Friedman (eds.), Hanbook of Perception. Vol. 1. (pp. 565-621). New York: Mc Graw-Hill.

12. Jaakkola, J.J.K., Reinikainen, L.M., Heinonen, O.P., Lindholm, M., Majanen, A., Sivukari, M., & Seppänen, O. Indoor air quality requirements for healthy office building based on epidemiologic study. In B. Berglund & T. Lindvall (eds.), Healthy Buildings '88. Vol. 3 (pp. 565-574). Stockholm: Swedish Council for Building Reserarch, D21.

13. Molina, C., Pickering, C.A.C., Valbjørn, O., & de Bortoli, M. (1989). Sick Building Syndrome. A Practical Guide. Luxembourg: Commission of the European Communities, EUR 12294 EN, Cost Project 613: Indoor Air Quality & Its Impact on Man, Report No. 4.

14. Skov, P., Valbjørn, O., & DISG (The Danish Indoorclimate Study Group). (1987).The "sick" building syndrome in the office environment: The Danish Town Hall Study. Environ Int 13, 339-349.

15. Skov, P., Valbjørn, O., Pedersen, B., & DISG (The Danish Indoorclimate Study Group). (1989). Influence of personal characteristics, job-related factors and psychosocial factors on the sick building syndrome. Scand J Work Environ Health 15, 286-295.

16. WHO. (1983). Indoor Air Pollutants: Exposure and Health Effects. Copenhagen: World Health Organization, EURO Reports and Studies No. 78.

17. WHO. (1986). Indoor Air Quality Research. Copenhagen: World Health Organization, EURO Reports and Studies No. 103.

18. WHO. (1987). Air Quality Guidelines for Europe. Copenhagen: World Health Organization, European Series No. 23.

19. WHO. (1989). Indoor Air Quality: Organic Pollutants. Copenhagen: World Health Organization, EURO Reports and Studies No. 111.