SYMPTOM PATTERNS AND AIR QUALITY IN A SICK LIBRARY

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ABSTRACT

The results from many cluster analyses of symptoms and technical risk factors in a longitudinal, comprehensive field study of a sick library are that one symptom pattern consisting of "fatigue/heavy head" was affected by indoor air concentrations of volatile organic compounds (VOC) and the proportion of return-air. There was no single technical variable linked to the cluster of irritation reactions in the eyes, nose and throat. Eye irritation is connected with VOC-surplus and the reaction in the upper airways with humidity factors. In this building, the air flow affects the surplus of VOC and humidity, the temperature and the humidity affect each other, and the return-air amount affects the indoor air concentrations of VOCs and carbon dioxide.

INTRODUCTION

The construct Sick Building Syndrome (SBS) has been used since the midseventies to describe a collection of symptoms with unknown origin, reported primarily from occupants of public buildings. Patterns of five symptom complexes are regularly encountered: Manifestations in the eyes, nose, throat, and skin, and general manifestations, such as headache and lethargy. They increase in severity over the day and resolve rapidly on leaving the building (1). The aims here were to identify symptom patterns reported from occupants of a sick building, and to connect these patterns of symptoms with potential hazards (technical variables, henceforth referred to as risk factors).

One assumption for the study was that the most sensitive occupants react first when the air quality is bad. With increasing deterioration, even less sensitive subjects become affected, and, as a consequence, a gradually larger group will report symptoms. This means that the environmental related symptoms should increase in prevalence over the day and as a consequence, it is in order to analyze changes over the day for occupants reactions to the environment (2, 3). This report focuses on symptom patterns possibly connected to the environment. The hypothesis is that if two or more symptoms are generated by the environment, then the occupants should report these symptoms together, and the symptoms related to the environment should also be reported from a larger group of occupants compared to other symptoms.

METHODS

The present research is part of "The Library Study" in which a dose-effect relationship was found between the VOC-concentration and increase in mean prevalence of eight specific symptoms (2, 4). The suggestions are that VOC is the cause of symptoms reported from this building and that recirculation increases the concentrations. The study is a quantitative, longitudinal field study of a sick library in which the proportion of recirculated air was manipulated (2, 3, 4). Every Thuesday over a whole fall-winter-spring-period the subjects reported perceived air quality and symptoms when they arrived at the building and after at least three hours stay. The symptoms are (A) fatigue, (B) heavy head, (C) headache, (D) feeling sick and dizzy, (E) difficulties in concentrating, (F) itching, smarting, and irritation of eyes, (G) congested and runny nose, (H) cold, (I) sinusitis, (J) dryness, hoarseness, and sore throat, (K) cough, (L) dry skin in face, (M) dry skin on hands, (N) face erythema, (O) scaling and itching scalp or ears, and (P) itching, stinging, tightness, and feeling of warmth in face without visible skin rash. It has been shown elsewhere (e.g. 4) that eight of the symptoms (A, B, C, E, F, J, N, P) increased significantly from morning to afternoon. Simultaneously with the symptom reports, triads of

air samples (intake air, supply air, and exhaust air) were collected in the ventilation system for monitoring possible chemical/technical hazards. Nine weeks, spread over a time period of 26, are included in the analyses of symptom patterns and risk factors (i.e., temperature, relative humidity (RH), VOC, amount return air, air flow and carbon dioxide) since data from all technical variables were available during these weeks (for details, see 2).

"Amount return air" is a construct related to ventilation. It might also reflect "accumulation" in interaction with other technical variables. It was specified as proportion (%) of return air, and calculated with the help of both the concentration of carbon dioxide (CO_2), and air flow measurements. The ventilation-related constructs "air movements/draft/airing of the building" was operationally defined as total air flow (m^3/hour). In this building the supply air is spread by diffusers in the ceiling, and the exhaust is sucked out via main ventilation ducts, also in the ceiling. Therefore, the difference between exhaust and supply air temperature might indicate low or no local air movement or ventilation short cut.

Parallel samples of VOCs were collected at 7 a.m. and 3 p.m. every week (intake, exhaust and supply air), and then were subjected to gas chromatography and mass spectrometry. VOC-concentration indoors is operationally defined as the mean concentration of 34 VOCs in exhaust and supply air. VOC-change is the difference between the afternoon concentrations and the morning concentrations. Because the VOC-concentrations have a large variation even over hours, there are strong validity threats for use of the VOC-concenrations as an absolute measure of "indoor air quality", but as an index for comparisons between weeks in a longitudinal study (the same VOCs, and the same time every week), the construct is assumed reliable.

Interactions among the air, activities, and materials in the building was supposed to be reflected by the surplus variables, i.e., the difference between exhaust air and supply air samples for RH, CO_2 and VOC). The difference in the concentrations of VOCs (and CO_2) reflect chemical processes indoors, and processes connected with moisture are reflected by the humidity difference. Positive values indicate emission (from materials and activities into the air), and negative values indicate absorption/adsorption (from the air and activities to the materials). Zero indicates stability/equilibrium. Since the relative humidity, temperature, and VOC may interact, the concepts of "emission", "absorption" and "adsorption" pose validity threats as absolute measurements, but since at least the materials are the same in this longitudinal case study, the surplus variables are useful as relative measures for comparisons among weeks.

By clustering symptoms and trisk factors, reactions due to the physical environment might be identified. The grouping of symptoms was accomplished by application of hierarchical clustering (HCA), specifically, the complete linkage method, that is Johnson's "max" method or "farthest neighbor" (e.g. 5, 6). The cutoff level (number of clusters to be used in the solution) was determined by plotting the amalgamation coefficient (the numerical value at which various cases merge to form a cluster) against the number of clusters implied by the hierarchical tree.

RESULTS

Symptom patterns obtained in the mornings and afternoons

Since the analysis is performed on the individual level, the similarity measure was positive matching dichotomy coefficients (6). The 16 symptoms group in 15 clusters in the morning and 11 clusters in the afternoon (Figure 1). When the visitors arrive at the building "dry skin in face" and "dry skin on hands" agglemerate in one sub-cluster, but after more than three hours stay in the building there are three clusters with more than one symptom. The first one is the same as for the morning, the second cluster groups "itching, smarting, and irritation of eyes", "congested and runny nose" and "dryness, hoarseness, and sore throat", and the third cluster agglomerates "heavy head", "fatigue" and "difficulties in concentration." The other symptoms appear alone. To decide whether the cluster solution should be rejected, the symptom pattern for the day was analyzed (both morning and afternoon reports). Since the afternoon sample contained the same clusters as the morning sample, the composite should correspond to the afternoon sample. Except for "difficulties in concentration", the two analyses

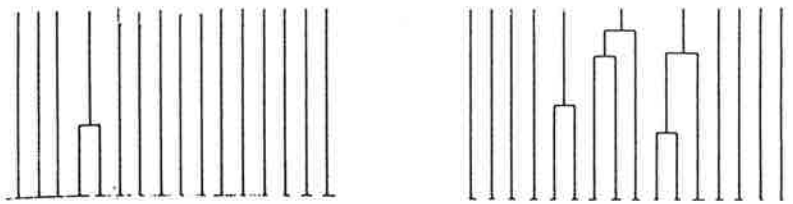

Figure 1. Symptom patterns obtained in the mornings (left), and the afternoons (right). See Methods for the codes.

agree. "Difficulties in concentration" was therefore not assumed to be valid for the second step of the analysis (connection with technical risk factors).

For validation, multidimensional scaling (MDS) was performed on the similarity matrices obtained from the morning and the afternoon reports. The hierarchical clustering schemes were then superimposed over the multidimensional scaling solutions. The common characteristics extracted from the data by MDS and HCA for both sampling occasions (a.m. and p.m.) are that left in a central area of the MDS plots is a main group of symptoms: "fatigue", "heavy head", "difficulties in concentration", "itching, smarting, and irritation of eyes", "congested and runny nose", "dryness, hoarseness, and sore throat", "dry skin in face", and "dry skin on hands". All these symptoms are present in the symptom patterns identified above. A new combination was tried to identify why these symptoms behave in a specific way. The symptom patterns obtained by HCA and MDS are graphed together with the prevalence of each symptom (Figure 2). Since the correlation between prevalences and cophenetic value is negative (morning: r=-0.89, afternoon. -0.92; p<0.001) the symptoms that agglomerate earliest (are reported together) are also highest in prevalence.

Clustering of symptom increase and technical risk factors

For the composite analyses of symptoms and chemical/physical factors several clusterings were performed on the basis of Pearson correlation coefficients. Four separate analyses included specific classes of technical variables and change over the day for all symptoms. The technical variables were classified as (1) ventilation factors (return air, air flow, and surplus temperature), (2) daily mean of the risk factors, (3) emissions/surplus, and (4) change over the

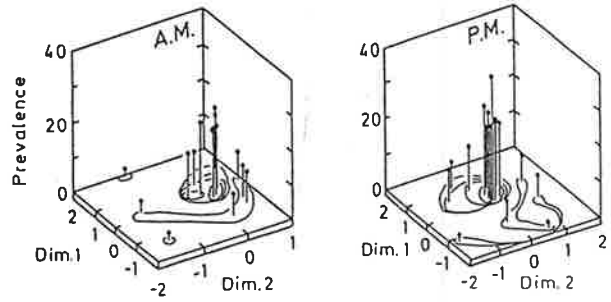

Figure 2. Symptom patterns obtained by MDS and HCA on data from the mornings (left), afternoons (right) plotted together with symptom prevalence. The lines enclose symptoms clustered.

Table 2. Summary results from 4 cluster analyses on classes of technical variables and all symptoms (for codes, see method section).

Symptom Code	%	Ventilation Flow	%	T-diff	Daily mean CO_2	RH	VOC	T	Change over the day CO_2	RH	VOC	T	Surplus CO_2	RH	VOC	T
A	15	-	X	-	X	-	X	-	-	-	-	X	-	-	-	-
B	13	-	X	-	X	-	X	-	-	-	-	X	-	-	-	-
C	04	-	X	-	X	-	X	-	-	-	-	X	-	-	-	-
G	02	X	-	X	-	X	-	-	-	-	-	-	X	X	-	-
M	00	X	-	X	-	X	-	-	-	-	-	-	X	X	-	-
I	00	X	-	X	-	X	-	-	-	-	-	-	X	X	-	-
O	01	X	-	X	-	X	-	-	-	-	-	-	X	X	-	-
E	15	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-
L	01	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-
N	03	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-
H	00	-	-	-	-	-	-	-	X	-	X	-	-	-	-	-
P	05	-	-	-	-	-	-	-	X	-	X	-	-	-	-	-
F	08	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
K	01	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
D	01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
J	04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

day of the risk factors. The summary results are shown in Table 2. "Heavy head" and "fatigue" (and "headache") group the ventilation factor return air, while "congested and runny nose" and "dry skin on hands" agglomerate with air flow and surplus of temperature. Daily mean of VOC and CO_2 and temperature change are also associated with the "return-air symptoms", while the symptoms associated with the air flow are connected to surplus/emissions of RH and CO_2. Concerning the other symptoms included in the symptom patterns the results are that "dry skin in face" agglomerates with RH-change, "itching, smarting, and irritation of eyes" group with VOC-surplus, and "dryness, hoarseness, and sore throat" has no clear connection with any of the chemical/technical variables. In short, only one symptom pattern (heavy head/ fatigue) is clearly associated with specific classes of technical risk factors. A replication was conducted to be able to decide if the foregoing resulting clusters should be rejected. The symptoms that had a significant increase from morning to afternoon were clustered together with all technical variables. The results are shown in Figure 3.

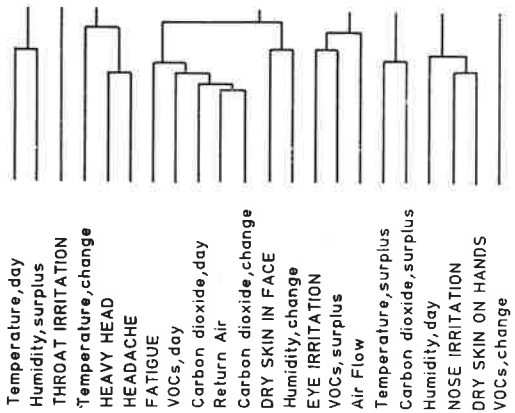

Figure 3. Resulting clusters from composite analysis on technical variables and the eight symptoms included in the typical symptom patterns.

"Fatigue/heavy head" groups with return air and change over the day in temperature and CO_2, and daily mean of VOC and CO_2. "Dry skin in face" is also connected to this (return air) cluster and to humidity change as well. "Itching, smarting, and irritation of eyes" agglomerate with VOC-surplus and air flow. "Congested and runny nose" and "dry skin on hands" group with humidity factors (mean and change). "Dryness, hoarseness, and sore throat" appears in a single group. In short, the foregoing cluster solution could not be rejected by these results.

Patterns among technical variables.

The last analysis tried to identify covariations among technical variables. The similarity measure was correlation coefficients. Two main clusters are present of which one is related to total air flow and the other to the proportion of return air (Figure 4). The "air flow cluster" contains all of the surplus variables and daily mean temperature. One sub-cluster contains mean temperature and surplus of RH and the other sub-cluster groups air flow and surplus of VOC, CO_2 and temperature. Within the "return air cluster" there are also sub-clusters. One contains humidity variables and temperature change, and the other return-air amount and the variables related to VOCs and CO_2.

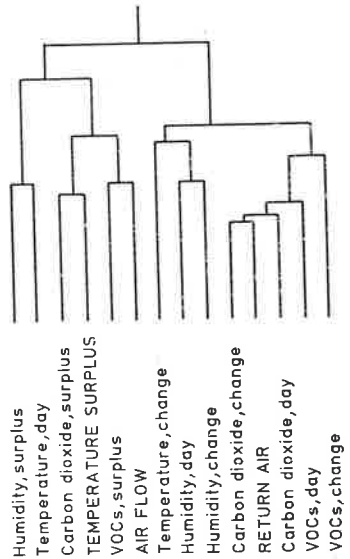

Figure 4. Results of pattern analysis on technical variables.

DISCUSSION

Most symptoms do not appear togeather, but one symptom pattern ("dry skin on hands/dry skin in face") is present among the visitors in the library both in the mornings and the afternoons. As a consequence, this pattern is probably not related to the environment. In contrast, two additional patterns (fatigue/ heavy head and irritation in the eyes/nose/throat) are present only in the afternoons. Since there is a negative correlation between cophenetic value and prevalences, the symptoms that agglomerate earliest (are present in patterns) are also highest in prevalence. These symptom patterns may be effected by the environment, but since there are two patterns of symptoms the conclusion is that there may be different risk factors in the library effecting different parts of the human body.

The results from clustering of symptom increase and technical risk factors indicate that "dry skin on hands/dry skin in face" (probably not related to the environment) is not affected by any single class of risk factors, but that relative humidity is the critical variable. One of the symptom patterns with high increase over the day (fatigue/heavy head) is connected to recirculation, i.e. return air and indoor air concentrations of VOC and CO_2. The return-air proportion affects the concentrations of VOCs and CO_2 (accumulation in the air). The classes of the technical variables (in connection with symptom increase) suggest that these symptoms accumulate over the day.

Referring to the cluster of irritation symptoms there is no single technical variable that is clearly linked to all three irritation reactions or modalities. Since "itching, smarting, and irritation of eyes" groups with VOC-surplus, eye irritation may be connected to emissions from materials and activities into the air. Iritation in the nose and throat group with humidity factors. These factors (mean and surplus of RH) and VOC-surplus are associated with the total air flow. Because the similarity measures were correlation coefficients, the indications are that high air flow may detoriate the air quality in this sick building (high surplus of VOC and RH). Therefore, ventilation in terms of total air flow might (indirectly) affect all three irritation symptoms or modalities.

In summary, by clustering symptoms and technical variables (risk factors) it was possible to identify symptom patterns reported from occupants of a sick building, and to connect these patterns of symptoms with potential hazards.

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