Relating Sick Building Symptoms to Environmental Conditions and Worker Characteristics

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Abstract

Recent concern has centered on "sick buildings" in which there has been an unusually high percentage of health complaints by the building's occupants. Typically, these symptoms are thought to be tied to indoor air quality characteristics, such as high levels of respirable particles or volatiles, thermal conditions, *etc.* In addition, recent studies have drawn connections between SBS symptoms and *non*-environmental variables, i.e., personal and occupational factors.

We review Hedge, *et al.* (1995) and perform additional analyses of their data. In a study of 27 air-conditioned office buildings, they measured nine indoor environmental conditions at various locations within each building and concurrently questioned workers on sixteen SBS symptoms and a number of other personal factors. The analyses we perform are among the first to attempt to draw formal statistical connections between SBS symptoms and both personal worker characteristics and indoor air pollutants simultaneously. The analyses are based on severity scales for each symptom which include information not only on the frequency with which an individual experienced a symptom, but also on how much the symptom disrupted the individual's work. Results from sixteen linear mixed effects models indicate that significant predictors are primarily personal and occupational (rather than environmental) in nature.

Keywords: Work-related illness, occupational health, indoor air quality, mixed linear models

1 Introduction

Over the past decade, concerns about the relationship between indoor air quality in the workplace and a wide variety of health complaints have been increasing. The term "Sick Building Syndrome" (SBS) was first defined by the World Health Organization (WHO) in the early 1980's. It is used to describe a range of physical symptoms reported by workers within a building to which no specific etiologic factor can be attached (WHO, 1983). Various groups within WHO, the American Thoracic Society (ATS), and the Commission of European Communities (CEC) have all attempted to characterize SBS by compiling slightly different collections of symptoms. The ATS identifies the following as SBS symptoms:

- Eye irritation;
- Headache;
- Throat irritation;
- Recurrent fatigue, drowsiness, or dizziness;
- Chest burning, cough, or sputum production;
- Wheezing or chest tightness with paroxysmal cough;
- Malaise associated with an inability to concentrate or short-term memory problems;
- Nasal congestion or rhinitis.

Most of these are also included by WHO and CEC in their lists of SBS symptoms. In addition to those above, CEC and WHO add skin irritation, such as red or dry skin (Godish, 1995).

In order to qualify as an SBS symptom, the symptom must be primarily experienced while in the workplace, although it may linger shortly after leaving. When an unusually high proportion of office workers complain of these types of symptoms, the building is considered to be "sick." As yet, there seems to be little consensus on how high that proportion must be. It is important to keep in mind that it is the *building* which is considered "sick," based on prevalence data for the individuals within the building. In this paper we will be concerned with "permanent" SBS. The term "permanent" SBS refers to situations in which the indoor air quality appears to be fine, according to government regulations, but SBS symptoms are widespread and persistent among the workers. The symptoms may remain even after extensive remedial action (WHO, 1983). This rules out instances in which, due to some particular event (such as office renovation or maintenance), a temporary outbreak of symptoms is followed by a return to previous conditions; this is called "temporary" SBS.

Since the symptoms are connected with time spent in the sick building, it has been speculated that they are caused by exposure to something inside the building. As compiled by Godish (1995), suggested causes include: insufficient ventilation or thermal control; inadequate maintenance of building systems; changes in thermal or contaminant loads; changes in building operation; inadequate building design; and other physical, chemical, biological, or psychosocial factors. WHO (1983) suggests that SBS symptoms are not likely to be attributable to any one contaminant, but rather to some combination. In particular, while each compound may be at a sub-threshold level individually, the mixing of pollutants either may have a synergistic effect on a the sensory system or may cause a chemical reaction which produces a more irritating compound. In addition, according to WHO, "sick" buildings often share the following characteristics:

- Forced ventilation system relying on partial recirculation of air;
- Light construction;
- Large interior surface-to-volume ratio;
- Energy efficiency and a fairly warm and homogeneous thermal environment;
- Airtight building envelope.

CEC agrees that the phenomenon occurs primarily in climate controlled buildings and is due to some combination of factors (Godish, 1995). In order to help identify causes of SBS symptoms, Mølhave (1987) has compiled a categorization of symptoms based on WHO's definition:

- Sensoric irritation in eye, nose, or throat;
- Skin irritation;
- Neurotoxic symptoms;
- Unspecific hyperreactions;
- Odor and taste complaints.

Hodgson (1989) credits Mølhave's categorization and argues that each of the various categories of symptoms could represent individually recognizable pathophysiologic entities. For example, neurologic symptoms, such as headaches, could be due to solvent neurotoxicity, while eye and nose irritation could be caused by allergenic contaminants. SBS may or may not represent a single entity and consequently may or may not result in a common physiologic abnormality among workers in a problem building.

Numerous studies have been conducted worldwide in attempts to attribute specific causes to these permanent SBS symptoms. Starting in the early 1970's, the National Institute of Occupational Safety and Health (NIOSH) conducted extensive investigations of problem buildings in the United States (Seitz, 1989). From a total of 529 buildings inspected during 1971-1984, NIOSH teams identified inadequate ventilation as the primary cause of health complaints in just over 50% (280 buildings). Each of the following was identified as the primary cause in 10-15% of the buildings: contamination from indoor sources (80 buildings); contamination from outdoor sources (53 buildings); and unknown contamination source (68 buildings). Indoor sources include such things as office equipment, environmental tobacco smoke, cleansers, *etc.* Outdoor sources include road construction dust and asphalt, gasoline fumes, boiler gases, *etc.* Contamination from the building fabric itself (particleboard, fiberglass, glues, *etc.*) was cited as the primary cause of health complaints in only 4% (21 buildings). It must be noted, though, that these buildings do not represent a random sample; no standard investigative protocol was used by NIOSH for most of these building inspections; and many investigations were reviewed retrospectively, possibly leading to misclassification (Seitz, 1989). In addition, there is no indication of what (if any) sort of statistical analysis was carried out in the process of identifying a building's primary cause of health complaints.

During the same time period, Finnegan, *et al.* (1984) interviewed workers in nine office buildings (two of which had a history of occupant complaints) in the United Kingdom (U.K.) and compared the self-reports of SBS symptoms among them. Evidence was found showing a higher prevalence of symptoms in air-conditioned buildings over naturally ventilated buildings. Hedge (1984) found similar results concerning ventilation in a study of 1,332 U.K. workers who were located in five types of differently ventilated offices, and also found a higher prevalence of various health symptoms among women than men. Soon thereafter, 4,369 office workers in fourteen Danish Town Halls and an additional fourteen affiliated buildings were surveyed by Skov, *et al.* (1987); none of the buildings had a record of dissatisfaction with the air quality. Extensive analyses of the physical conditions of the buildings and of the air quality were carried out concurrently. Considerable variation in SBS symptom prevalence between genders (especially within individual job categories) and between buildings was found; however, there was little difference between mechanically ventilated buildings and naturally ventilated buildings. According to Hedge, *et al.* (1992), prevalence of SBS symptoms has consistently been shown to be higher in air-conditioned buildings than in naturally ventilated buildings, thus empirically confirming WHO's 1983 opinion. A meta-analysis conducted by Mendell and Smith (1990) concur with Hedge, *et al.*'s opinion. The logical explanation is that air is circulated through many potential sources of contamination in an air-conditioning system. Other studies have looked for a relationship between ventilation rate and reports of SBS symptoms. Hedge, *et al.* (1992) lists four recent intervention studies which have given conflicting results. Two studies (Menzies, 1990, and Nagda, *et al.*, 1990) found that increasing ventilation rates increased reports of SBS symptoms. On the contrary, one other study (Jaakola, *et al.*, 1990) found no effect and one study (Jaakola, *et al.*, 1991) found that increasing the ventilation rate marginally decreased symptom reports.

In an attempt to relate SBS to particular pollutants, Gravesen, *et al.* (1991), citing the same Town Hall study as Skov, *et al.* (1987), speculated that the reporting of SBS symptoms might be somehow related to the quantity of dust particles in the air. Their results indicated that while none of the reported symptoms correlated with the measured indoor air pollutants, symptoms were correlated with the quantity of macromolecular organic dust (MOD) molecules of biological origin. A fleece factor (the area of material surface divided by the room volume) and a shelf factor (the area of open shelving divided by the room volume) were also shown to be correlated with symptom reporting. Hedge, *et al.* (1995) in a study of 939 workers from 5 office buildings attempted to draw connections between SBS symptoms and levels of carbon monoxide, carbon dioxide, formaldehyde, repirable particulates, temperature, humidity, and illuminance. They failed to find any correlations between a weighted average of reported number of symptoms and any of the environmental pollutants.

Studies have clearly not pointed consistently to one or more environmental causes of SBS. There does seem to be greater agreement among studies showing relationships between SBS symptoms and many personal factors, such as gender, allergies, *etc.* or occupational factors, such as use of video display terminals (VDT's), job stress, *etc.*. For example, it has been suggested that a VDT's electromagnetic field attracts fibers and particles into the immediate vicinity of the worker (Hedge, *et al.*, 1993). The fibers are then inhaled or transferred to the eyes by the worker's fingers; this result has not been confirmed, however. Godish (1995) discusses the importance of personal worker characteristics, such as gender or smoking status, and psychosocial risk factors, such as job category, satisfaction with work environment, or job dissatisfaction. These more personal factors, in addition to factors such as type of ventilation system and office design, were studied by Burge, *et al.* (1987), Wilson and Hedge (1987), and Hedge, *et al.* (1989). The nationwide study surveyed 4,373 office workers in 47 office sites in the U.K; most of the buildings did not have a prior history of occupant complaints. They found that a variety of individual factors (gender, age, perceived environmental control, and perceived environmental conditions), occupational factors (VDT use and job stress), and organizational factors (organization type and office type), among others, played a large role in the reporting of SBS symptoms. Their results again confirmed the difference in SBS symptom prevalence between air-conditioned and un-conditioned buildings; however, symptoms were less prevalent in mechanically ventilated (but with no conditioning) than in naturally ventilated buildings. These surveys did not include any measures of the physical environmental conditions; thus, the prevalence of SBS symptoms cannot be imputed to possible exposure to polluted air in these offices. More recently, Zweers, *et al.* (1991) surveyed 7,043 Dutch workers in 61 offices and found that a worker's gender, job satisfaction, history of allergies, and satisfaction with complaint handling had the highest correlations with symptom reports. However, only up to 20% of the variation in the data was explained by the predictors in a multiple regression. In addition, when building number was added to the model, the increase in explained variation was very small. This implies that the remaining variation in the response is due to unmeasured factors which are *not* related to specific buildings; this might indicate that the buildings are in fact not "sick".

The body of literature on SBS is vast; our summary here is by no means comprehensive. Most studies have related some SBS symptoms to problems with the indoor air climate, but none have clearly linked SBS symptoms to specific air pollutants alone (Hedge, *et al.*, 1992, and Mølhave, 1990). A few studies have found relations between SBS symptoms and environmental factors. For example, research has continually shown that SBS symptoms are more prevalent among workers in air-conditioned offices than in naturally ventilated offices. However, studies have more commonly found stronger associations between SBS symptoms and a variety of organizational, occupational, and personal variables. The study reported in Hedge, *et al.* (1995)

was conducted in an effort to clarify some of these issues. The data considered in this paper are taken from that study. Section 2 describes the data collection methods used by Hedge, *et al.* and summarizes some analyses already carried out by them. Our analyses and results are presented in Section 3, while conclusions are found in Section 4. The Appendix contains questions of interest from the survey distributed by Hedge, *et al.* in their study.

2 Data Collection and Previous Analyses

Hedge, *et al.* (1995) surveyed 4,479 workers from 27 air-conditioned office buildings in the eastern and mid-western United States within 1990-1991. The offices were mostly occupied by private sector financial, insurance, sales, and marketing companies, and were selected according to the type of organization, type of ventilation, and office layout. All buildings were air-conditioned and mechanically ventilated. Within each building, between four and eight office areas were chosen in which to take environmental samples. These sites were typically located in distinct office areas which were densely occupied and did not have full height obstructions, often located on different floors of the building. Following is a list of the variables measured with their variable names (directly following) in italics:

- Carbon monoxide (*CO*, parts per million (*ppm*));
- Carbon dioxide (*CO2*, *ppm*);

- Formaldehyde (*form*, *ppm*);
- Nicotine (*nic*, μg per m^3);
- Respirable suspended particles (*rsp*, of less than 2.5 μm in diameter, *mg* per m^3);
- Ultraviolet particulate matter (*uvpm*, of less than 3.5 μm in diameter, μg per m^3);
- Temperature (*temp*, °C);
- Humidity (*hum*, %);
- Illumination (*illum*, *lux*).

See Hedge, *et al.* (1994, 1996) for details on the sampling methods used to gather these data. As these variables were being measured at each area, approximately thirty questionnaires were handed out to workers in the immediate vicinity. Workers answered questions on occurrence of SBS symptoms, job characteristics, perceived ambient conditions, and other occupational and personal variables. (Most of the survey questions are shown in the Appendix.) It should be noted that the indoor air quality of each building did meet the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) regulations (ASHRAE, 1989). However, one building had a history of occupant health complaints.

Hedge, *et al.* (1996) describes two sets of analyses: relating SBS symptoms first to the environmental factors measured, and second to occupational and personal characteristics. The first set of analyses considered the frequencies of symptom occurrences as found in Question # 14 (Q14; see the Appendix). Hedge, *et al.* dichotomized Q14 to create a new response variable for each symptom by combining answers of "never" or "1 to 3 times a month" into one category (coded 0 = "absent"), and by combining answers of "1 to 3 times a week" or "almost every day" into another category (coded 1 = "present"). However, if the symptom was reported as getting worse or staying the same when the individual left work (see Q18), then the response was coded as absent, strictly ensuring the inclusion of building related symptomsonly. This is a conservative method of determining which symptom occurrences should be counted as building related; it is conceivable that some symptoms (especially ones that have been occurring over a long period of time) would not noticeably decrease after the individual had left work.

A separate logistic regression was run for each dichotomous symptom response with all environmental factors as possible predictors. Individuals were assigned environmental measurements corresponding to the area from which their survey was distributed. The analyses gave the following statistically significant positive relationships:

- Each of *irritated, sore eyes* (Q14b), *tired, strained eyes* (Q14c), and *unusual tiredness, lethargy* (Q14q) with *illum*;
- Each of *stuffy, congested nose* (Q14g) and *runny nose* (Q14h) with *hum*;

- Each of *dry eyes* (Q14a), *dry skin* (Q14e), and *excessive mental fatigue* (Q14i) with *form*.

With odds ratios of 1.01 to 1.55, the relationships do not appear to be terribly strong in a practical sense, even though they are significant statistically.

A variety of factors not accounted for in these analyses may have pulled the results both towards and away from the null hypotheses of no relationships between symptoms and environmental measurements. On the one hand, observe that the sample size is in a sense artificially inflated: for every one set of environmental measurements taken, approximately thirty observations are included (one for every worker surveyed). This may induce statistical significance when, in fact, there is no relation, thus pulling the results *away* from the null. On the other hand, statistical significance without practical significance may be a consequence of not including the workers' characteristics in the model. When the distributions of one or more characteristics are associated with the response, unassociated with the distribution of environmental factors, and excluded from the analyses, the statistical results can be pulled toward the hypotheses of no relationships. For example, age may explain a large amount of variation in the reporting of symptoms. By not including a variable such as age, actual differences due to environmental factors may be obscured, thus pulling results *towards* the null. Finally, using only "presence" or "absence" of an individual symptom as a response variable does not take advantage of all of the available information about that symptom (see Q15 through Q18) and may also obscure significant relationships.

The second analysis conducted by Hedge, *et al.* was aimed at relating the personal and occupational factors from the questionnaire to SBS symptoms. The total number of symptoms occurring (the sum across symptoms of the previous response variable for each person, giving possible values of 0 through 16) was regressed linearly on the various non-environmental conditions, separately for men and women. The predictors found to be significant were: VDT use, job stress, job satisfaction, perceived indoor air quality, history of allergies, history of migraines, eyewear use, and age. See Hedge, *et al.* (1996) for more details. Take note from the listing in the Appendix that the symptoms are very diverse in nature, and could conceivably have *very* different causes. It is also likely that some of them are highly correlated with each other (*e.g.*, *dry eyes* and *irritated, sore eyes*). By combining all the symptom occurrences into one (the total number), some information may be lost; two very different patterns of symptom occurrence can result in the same total number. In particular, significant relationships between individual symptoms and one or more variables may be lost in the summation across symptoms. However, this analysis does give an idea of which personal and occupational factors are associated with higher levels of general symptom reporting.

The analyses conducted so far by Hedge, *et al.* have drawn connections between the symptoms and both the environmental and personal factors. Their results do confirm the importance of gender, VDT use, job stress, job satisfaction, and age in the reporting of SBS symptoms. However, more investigation is needed, particularly in drawing simultaneous connections between a symptom and both the environmental and non-environmental factors. This will enable us to identify potential confounders among the predictors as well. We are particularly interested in determining if there are additional differences in symptom reporting due to buildings after accounting for all the variables measured in this study. Such a result could indicate either that some buildings are indeed "sick" or that important predictors related to buildings were not measured.

3 Current Analyses and Results

The analyses in Hedge, *et al.* (1996) focused first on the presence or absence of a symptom and second on the total number of symptoms experienced. We would like to focus on the "strength" or "seriousness" of a particular symptom. The amount of disruption that a person experiences due to a particular symptom in a workday (see Q15) is one indicator of how "serious" that symptom is; frequency of a symptom's occurrence is another. It seems reasonable to use both of these pieces of information to judge symptom severity. We propose four "severity" scales to be considered for each symptom (see Table 1). As in Hedge, *et al.* (1996), an individual may only be assigned a symptom severity score greater than zero if the symptom is experienced at least once a month (as determined by Q14) and if the symptom gets better when away from work (by Q18). Severity scales 1 and 2 in Table 1 merely merge the responses to Q14 and Q15 in two logical ways. With Severity 3, we attempt to create a scale in which the distance between assigned scores relates to some real measurement, *e.g.*, days. We determine the average number of days per month that a symptom was experienced and multiply this number by 1, 2, or 3 depending on whether the symptom was "not at all", "somewhat" or "very" disruptive. We assume 5 working days per week and 4.5 weeks per month. As an example, an answer of "2" to Q14 corresponds to "occurred 1 to 3 times a month", which we take as occurring on average 2 days per month. If the respondent also answered that the symptom was "very" disruptive, then his or her Severity 3 score for that symptom would be $2 \cdot 3 = 6$. Finally, Severity 4 is based on the idea that severity might also be globally measured by the amount of disruption alone. It is plausible that when answering Q15, individuals either consciously or unconsciously included information about frequency of symptom occurrence. As further justification, it is generally accepted in the medical research community that for survey data, answers to global questions which directly address a variable provide more accurate measurements of that variable than combinations of information from questions meant to address that same variable from different angles. We will carry out analyses using each of the four severity scales in turn and then compare the results.

We propose a linear mixed effects model: all main effects due to the environmental and non-environmental variables are considered fixed, and effects due to building and area within a building are considered random. Considering buildings to be random indicates that we are not interested in making inferences about these 27 buildings in particular; the same holds true for the nested variable corresponding to areas within a building. We are interested, however, in making inferences about all levels of the remaining predictors; hence the need for fixed effects. (For more details on linear mixed models, see SAS Institute, Inc. (1992, Chapter 16), Searle (1971), or Searle, *et al.* (1992).) The use of mixed models, with area as a random effect, eliminates the problem of inflated sample sizes discussed earlier. Using a mixed model also assumes that the response variable is continuous. The ordinal response scales, although not strictly continuous, can be considered approximately continuous. In addition, due to its relation to days, Severity 3 is even closer to a true continuous variable.

The following personal variables were included in the initial models (one model for each symptom): length of time worked in building (Q1); age (Q4); sex (Q5); health history (Q6); smoking status (Q7); use of correction lenses (Q8); job characteristics (Q19); use of office equipment (Q20); job type (Q21); and VDT use (Q22). Also included were building number (*bldg*), area number within building (*area*), year of study completion (*year*), and smoking policy (*policy*), the last two being building-wide variables. (Complete descriptions of the answer scales and a listing of the variable names can be found in the Appendix.) All environmental factors, which are area-wide variables, were included as well. For the variables *CO*, *CO2*, and *form*, the natural logs of the amounts measured were used. Finally, to account for a change in laboratory personnel between the 1990 and 1991 samples, interactions between the environmental factors and year were also added.

Sixteen linear mixed models (one per symptom) were run for each of the four severity scales, with all main effect and interaction terms listed above. The next step involved finding the most parsimonious model for each symptom. Since the theory behind SBS has traditionally assumed a physical cause behind the symptoms, all environmental variables, the variable *year*, and the two random effects were kept in each model while considering which personal and occupational effects to eliminate. Personal and occupational main effects which were not significant at the 0.10 level were dropped from each symptom's model based on the appropriate F-test (SAS Institute, Inc., 1992). Next, environmental by year interactions which were not significant were dropped using the same tests. *policy* was considered a potential confounder, because it would logically be related to *nic*, *rsp*, and *uvpm*, all of which are related to the amount of tar in the air. After temporarily removing *policy* from each model, the remaining non-significant predictors were dropped based on likelihood ratio tests, again using the 0.10 level cutoff. It was necessary to use the likelihood ratio test for the remaining building- and area-based variables because of the multicollinearity between them. Finally, after determining which environmental variables were significant, *policy* was added to and kept in each model if it was significant, as determined by the likelihood ratio test. The variable *policy* was added in this way so as not to obscure the effects of the environmental measurements related to smoking.

If significant environmental measurements remained, then interactions between these environmental conditions and building were tested for significance. These building interaction terms are important for policy-making reasons. For example, a significant interaction between building and CO would tell the researcher that CO levels have different effects on the response in different buildings. Thus, changing a national policy, for example, regarding CO levels would not be effective in controlling symptom reporting for all buildings. This would be true even if the addition of the interaction causes the main effect of CO to be no longer significant.

Also note that the interaction *form*year* was included in the model as long as either it or *form* alone was significant for the following reason: the method of measuring formaldehyde changed between the years 1990 and 1991. In 1991, only levels 0.018 *ppm* or above were detectable; in 1990, the detection limit was 0.002 *ppm*. If no formaldehyde was detected in the 1991 sampled buildings (as was true in almost half the samples), then the value was set to $\ln(0.018) = -4.0$; no values were below the detection limit in the 1990 samples. In the models, then, *form* represents formaldehyde measurements in 1990, while *form* and *form*year* together represent measurements in 1991. Because of the upwardly biased 1991 measurements, the 1990 measurements seem to give a more reliable measure of the formaldehyde effect.

In comparing the four severity scales, we considered them to be "consistent" for a particular model and a particular variable if three or four of the four scales concurred on whether or not the variable was a significant predictor based on the F test. The results were about 95% consistent across the four scales, and reassuringly there was no pattern to the remaining inconsistencies. We thus accepted the scales as approximately equivalent and chose to focus our attention on the third because of its basis in days. Table 2 shows the predictors remaining in the final models for each of the sixteen symptoms using Severity 3. Most noticeable, perhaps, is that only a couple of the environmental variables are significant predictors of any response. The three significant associations are that of *hum* with *irritated, sore eyes* (with an F-test p-value=0.019) and with *tired, strained eyes* (p=0.041), and that of *form*year* with *dry skin* (p=0.004). In addition, *policy* is a significant predictor of *hoarseness* (p=0.074). It should be noted that none of the other severity scales determine humidity to be a significant predictor of any of the symptoms. Thus, either the significance is due to chance or the relationships between humidity and the two symptoms above are very weak. Also, the association between *policy* and *hoarseness* is also unique to Severity 3. Furthermore, assuming that there is some real connection between *policy* and *hoarseness*, it is unclear what this means. On the one hand, *policy* may represent some interaction of the measured smoking related variables (*nic*, *rsp*, and *uvpm*) or it may represent some smoking related pollutants that were not measured. Alternatively, it could be a proxy for some psychosocial factor, such as satisfaction with smoking policy.

This lack of significant environmental relationships with the response counters the original thinking behind SBS, but confirms the results of Hedge, *et al.* (1989) and the opinion of Godish (1995) discussed earlier. Either SBS is in fact not caused by exposure to physical irritants, or the appropriate irritants have not been measured. (See Section 4 for more discussion on this issue.) Also very noticeable is that there is no uniformity or similarity across the symptoms as to which predictors remained in the models. Among the personal and occupational variables, *environ*, *migraine*, and *backpain* appear in the greatest numbers of models (16, 11, and 12, respectively, out of 16). Besides these three, just about every possible worker-related predictor is significant for at least one symptom. Some of the results seem counterintuitive; it seems odd, for example, that back pain appears in so many models. Perhaps back pain is serving as a proxy for an unmeasured variable, such as satisfaction with some working condition. The random effect of *bldg* is significant in six of the sixteen final models, which means that there is variation in those six symptoms that is explained either by the buildings themselves or by some unmeasured variable associated with the buildings. The lack of significance in the other ten models indicates that no variation in the responses is caused by some unmeasured building related factor. This seems to indicate that, with regard to those ten symptoms, the buildings are not "sick." Discussion of the variable *offlimit* will be taken up in the next section.

It is possible that individuals respond to the same environmental conditions with slightly different symptoms. For example, in response to a toxin, one person may experience lethargy while another may experience headaches. The categories suggested by Mølhave (1987) help divide the studied symptoms into four groups of similar types. Sensoric irritation (I) will include symptoms a, b, c, d, and f; skin irritation (II) will include e and o; neurotoxic symptoms (III) will include i, j, k, m, n, and q; and unspecific hyperreactions (IV) will include g, h, and l. (This study did not examine the occurrence of odor and taste sensations.) In order to get a better overall picture of which predictors are significant for which groups of symptoms, we averaged symptom scores within a group together and carried out the same model-fitting procedure as before for each group using each scale. There is even greater agreement across the four scales as to which predictors are significant for each symptom group. Again focusing on Severity 3, *sex*, *allergy*, and *environ* are significant predictors for each group. Group I also includes *eye*, *migraine*, *hayfever*, *backpain*, *copier*, *correct*, *vdt*, *enthus*, and *stress*; II includes *eczema*, and *mono*; III includes *migraine*, *backpain*, *enthus* and *stress*; and IV includes *smoke*, *age*, *asthma*, *hayfever*, *backpain*, *copier*, *correct*, and *nostress*. The only building- or area-wide variable which was significant for any group was *policy*, which is significant at the

0.10 level for symptom groups I and II. Once more, we see a lack of significance in the relationship between environmental variables and symptom reports, and again it is unclear what the significance of policy represents.

4 Discussion and Conclusions

This multi-building study by Hedge, *et al.* (1996) has allowed a comprehensive study of some of the suggested causes of SBS symptoms. We have demonstrated that the reporting of symptoms can be explained largely by worker and job characteristics rather than by environmental factors. However, there are some problems with the collection of the Hedge, *et al.* data that have not been mentioned yet. Some of these are sampling problems which cannot be rectified, yet must be taken into account when interpreting the final models. For example, in three buildings, the researchers were not allowed to distribute the questionnaires themselves. It is thus impossible to know if the questionnaires were indeed distributed as requested in the immediate vicinities of the selected environmental sampling sites. In order to account for this discrepancy, we added an indicator variable (*offlimit*) for these three buildings to each model; *offlimit* was a significant predictor in the model for *tired, strained eyes* only. Since *offlimit* was almost uniformly non-significant, we will not consider it problematic for model interpretation. As an additional difficulty, the nicotine level was sampled in only one of the six buildings which prohibited smoking in all areas.

As it was found that the nicotine level in that one building was below a detectable limit, it was assumed that the levels for the other non-smoking buildings would likewise be effectively zero. In our analyses, the variable *nic* for these six buildings was set to zero. This is a conservative method of dealing with the problem, and will bias the results towards the null hypotheses of no associations.

Furthermore, in an attempt to obtain a homogenous sample of buildings, only those with one kind of ventilation system were sampled. It has already been shown in multiple studies that type of ventilation system does have an effect on reporting of symptoms, and that buildings with mechanical ventilation (such as those with air conditioning) tend to have higher rates of symptom occurrences. Inferences from this study can only be drawn to buildings with air conditioning. Also, buildings already designated as "sick" (*i.e.*, with a strong history of worker health complaints) were intentionally not included in the sample. On the one hand, this eliminates the possibility that differences between "sick" and "healthy" buildings are due to some kind of mass hysteria or social phenomenon within sick buildings. For example, general knowledge among the workers that their building is considered sick may create an inflated perception of the prevalence of symptoms. Godish (1995) concurs that the psychosocial dynamics of problem buildings may in fact be a risk factor in the reporting of SBS symptoms. On the other hand, by not including sick buildings, we may not be able to find the real causes of differences in SBS symptom reporting. To illustrate this point, suppose a particularly high level of some pollutant always causes SBS symptoms. Then by not including problem buildings in the sample, we have a sample of buildings which all have low levels of that particular pollutant and thus would be unable to draw the necessary connection. Finally, some plausible predictors were not recorded. These include architectural features of the buildings studied, such as office design or office facing (see Hedge, *et al.*, 1989), as well as other kinds of air pollutants. It is impossible to know how these unmeasured variables (already shown to be important in other studies) could have changed the analyses.

Another potential complication is that we are comparing environmental variables which were measured on one day with symptoms experienced over the previous month. In matching individual symptom reports with the environmental data, we are assuming that the one day on which sampling took place gave a representative value for each of the environmental variables over the previous month. This type of problem is common in studies of this kind. We are also assuming that the workers who were found in the immediate vicinity of a particular sampling area actually spend the majority of their time in that area. For example, a secretarial worker might indeed spend the majority of the workday at his or her desk; however, a manager or technician might be needed in several areas throughout the building during any one workday. To model a very mobile worker's symptoms on the environmental variables found in one location could be misleading. There are techniques to measure an individual's exposure to various pollutants; however, these methods tend to be much more costly and thus infeasible to implement on this scale.

In our analyses, we did not include the percieved indoor air quality (PIAQ) index of Hedge, *et al.* (1995, 1996). This variable has been shown to be an important predictor in previous analyses. We felt that significance of this variable may be an indicator of some real, perhaps unmeasured, environmental factor. Thus inclusion of PIAQ may have reduced the observed effect of some environmental factor or artificially eliminated the effect of building. For thorough examination of this variable as a possible predictor of symptoms see Hedge, *et al.* (1995, 1996).

Due to the number of variables that were measured and to computational requirements, we did not include most interactions in our models, including those between environmental variables. However, with 37 variables in total under consideration, it is computationally too difficult to consider even all the 666 two-way interactions. Just limiting attention to the two-way interactions between the environmental variables would result in 36 additional variables to study. As suggested by Mølhave (1987) and WHO (1983), some of the differences in symptom experiences may be due to interactions between low levels of environmental factors rather than to high levels of a single factor. Perhaps one way to approach this hypothesis would be by carrying out controlled experiments on the effects of combinations of suspected pollutants. If it is established that an interaction of effects is needed in this more controlled setting, one could then explicitly test for the given association in more complicated real world setting. In general, this approach to testing for connections between environmental factors and symptom reporting could be useful. For example, it could also provide a more reliable way to see whether the main-effect association between *humidity* and both *irritated, sore eyes* and *tired, strained eyes* is real, or just a chance association.

In conclusion, this data analysis has been largely exploratory in nature. Many of the factors already discussed may lead to inaccurate measurements and misrepresentations of the actual association between symptom reporting and building-wide variables. Thus, these models are not intended for prediction purposes. However, they have helped to emphasize some connections or lack of connections between symptom reports and both worker and building-wide variables. In particular, our results point to the need to account for personal and occupational factors when considering the effect of indoor air pollutants on symptom reports. Although we found an overall lack of significant environmental predictors, we recommend further study of the relationship between specific symptoms and potentially causative environmental conditions, perhaps in more controlled settings. In any case, the techniques employed here should be useful in other studies of the causes the sick building syndrome.

Appendix

The sixteen symptoms listed below were included in the questionnaire distributed by Hedge, *et al.* (1995).

a.	Dry eyes	i.	Excessive mental fatigue
b.	Irritated, sore eyes	j.	Nervousness, irritability
c.	Tired, strained eyes	k.	Headache across forehead
d.	Sore, irritated throat	l.	Wheezing, chest tightness
e.	Dry skin	m.	Nausea
f.	Hoarseness	n.	Dizziness
g.	Stuffy, congested nose	o.	Skin irritation, rashes
h.	Runny nose	q.	Unusual tiredness, lethargy

(At the recommendation of Hedge, *et al.*, symptom p (diarrhea) was excluded from the analyses since diarrhea was only included in the questionnaire for validation purposes. It is not an SBS symptom.) Five questions about each of these sixteen symptoms were posed, shown below; the scale of the answer is given in parentheses:

Q14: "During the past month, how often have you experienced each of the following symptoms while working in this building?" (never, 1 to 3 times a month, 1 to 3 times a week, almost every day)

Q15: "Overall, during the past month, how much has your work been disrupted by this symptom?" (not at all, somewhat, very)

Q16: "What time of day is this symptom usually experienced?" (AM, PM, all day, no pattern)

Q17: "Are you currently experiencing this symptom?" (yes, no)

Q18: "During the past month, what happened to this symptom at times you were away from work?" (got worse, stayed the same, got better)

A missing response to Q14 was recoded to "never"; thus it was assumed that lack of reponse indicated a lack of occurrence. This is a conservative method of dealing with missing data and will bias any statistical results *towards* a null hypothesis of "no association".

Following are the questions which are used in the initial linear mixed effects models and which are not described in the text; italicized words are variable names.

Q1: "How long have you worked in this building (in years)?" (*time*; less than 1, 1, 2, ..., 7, 8 or more);

Q4: "How old are you?" (*age*; 19 or less, 20-29, 30-39, 40-49, 50-59, 60 or more);

Q5: "What is your sex?" (*sex*; male, female);

Q6: "Please indicate any of the following that you suffer from:" (*migraine*, *asthma*, *eczema*, *hayfever*, other *allergies*, chronic *back*pain);

Q7: "What is your smoking status?" (*smoke*; non, former, current);

Q8: "What types of correction lenses do you usually wear?" (*eye*; none, reading glasses, regular glasses, other glasses, contact lenses);

Q20: "How often do you use the following at work?" (for each of photo*copier*, self-copying/*carbon*less copy paper, and *correct*ion fluid; several times a day, about once a day, 3-4 times a week, less often, never);

Q21: "What is your work category?" (*job*; managerial, professional, technical, clerical, secreterial, other);

Q22: "About how many hours a day do you work with a computer or word processor?" (*vdt*; never use, less than 1, 1, 2, ..., 6, 7 or more).

In order to ease interpretability of the model, Q8 was recoded to: 1 = none, 2 = glasses, and 3 = contact lenses. The twelve job characteristic statements shown below constitute Q19; workers answered on a scale of 1 ("strongly agree") to 5 ("strongly disagree").

a. "My job is usually interesting."
b. "I'm happy in my job."
c. "I dislike my job."
d. "I am satisfied with my job."
e. "I'm enthusiastic about my job."
f. "My job is rather monotonous."
g. "My job is not very stressful."
h. "I usually have to work fast."
i. "I often feel stressed at work."
j. "My job demands a lot of concentration."
k. "I often feel overworked."
l. "The office environment is satisfactory for my job."

Due to concerns about multicollinearity, five statements from Q19 were excluded from the analyses: a, b, c, d, and k. The remaining variables' names, in order, are as follows: *enthus*, *mono*, *nostress*, *fast*, *stress*, *conc*, and *environ*. The variable *year* (coded as 0 = 1990, 1 = 1991) was included primarily because some of the environmental samples were handled by different technicians; there was a changeover in lab personnel between the years 1990 and 1991. The building-wide variable *policy* had the following structure: 1 = smoking prohibited; 2 = smoking restricted to separately ventilated areas; 3 = smoking restricted to rooms with local air filtration; 4 = smoking restricted to rooms with no additional air treatment; and 5 = smoking restricted to work stations.

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Table 1: Variable Scales for Severity of Symptoms

Frequency (Q14)	Disruption (Q15)	Severity 1	Severity 2	Severity 3	Severity 4
1	1	0	0	0	0
	2	0	0	0	0
	3	0	0	0	0
2	1	1	1	2	1
	2	4	2	4	2
	3	7	3	6	3
3	1	2	4	9	1
	2	5	5	18	2
	3	8	6	27	3
4	1	3	7	20.25	1
	2	6	8	40.5	2
	3	9	9	60.75	3

Table 2: Final Models for Severity 3 Scale

Symptom		Significant Predictors
a.	Dry eyes	*bldg, smoke, sex, eye, migraine, hayfever, allergy, back, copier, enthus, stress, environ*
b.	Irritated, sore eyes	*age, sex, eye, migraine, allergy, back, copier, correct, enthus, stress, environ, hum*
c.	Tired, strained eyes	*sex, eye, migraine, allergy, back, copier, correct, vdt, enthus, stress, environ, offlimit, hum*
d.	Sore, irritated throat	*bldg, age, sex, allergy, back, stress, environ*
e.	Dry skin	*sex, allergy, mono, environ, year, form*year*
f.	Hoarseness	*age, sex, migraine, asthma, hayfever, allergy, back, correct, environ, policy*
g.	Stuffy, congested nose	*bldg, smoke, age, sex, asthma, eczema, hayfever, allergy, back, copier, correct, nostress, environ*
h.	Runny nose	*age, sex, asthma, eczema, hayfever, allergy, back, correct, vdt, nostress, environ*
i.	Excessive mental fatigue	*smoke, migraine, allergy, back, enthus, nostress, stress, environ*
j.	Nervousness, irritability	*area, sex, migraine, allergy, back, carbon, enthus, nostress, stress, environ*
k.	Headache across forehead	*bldg, age, sex, eye, migraine, allergy, enthus, fast, environ*
l.	Wheezing, chest tightness	*migraine, eczema, allergy, enthus, mono, conc, environ*
m.	Nausea	*time, migraine, allergy, back, conc, environ*
n.	Dizziness	*bldg, migraine, allergy, back, carbon, mono, nostress, stress, environ*
o.	Skin irritation, rashes	*eczema, allergy, vdt, enthus, mono, environ*
q.	Unusual tiredness, lethargy	*bldg, age, sex, migraine, allergy, back, enthus, stress, environ*