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SICK BUILDING SYNDROME: THE ACOUSTIC ENVIRONMENT

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ABSTRACT

The acoustic environment was investigated in an office building with a history of occupant complaints. A scoring system was developed for rating occupants' sick building symptoms. High scores were associated with the occurrence of high levels of infrasound (< 20 Hz) in the rooms, and low levels with low scores. The infrasound came from the ventilation system as air-borne noise, rather than structural-borne vibration. Levels of infrasound were often amplified in the tightly sealed rooms, and could be higher at work stations than at supply grilles. Repeated or long-term exposure to infrasound may be triggering an allergic-type response.

INTRODUCTION

The office building studied was a 10-storey mechanically ventilated block in a Stockholm suburb, with a history of occupant symptoms (1). Factors investigated included chemical, microbiological, psychological and physical factors. Of these, the physical factors gave the most promising clues to the occupants' symptoms. The strongest associations with symptoms were found with complaints of dry, stuffy and dusty air, static electricity, unwanted temperatures, draughts and noise. The thermal conditions were investigated in some detail. Several faults were found. Corrective measures included lowering the supply air temperature and installing an extra heating battery to give better thermal control. A follow-up study (2) showed that the thermal conditions were improved and that the perceived air quality was better. However, there was only a slight reduction in occupants' symptoms. The findings indicated that the thermal conditions could be a contributing factor in sick building syndrome (SBS), but not the only factor.

An investigation was therefore carried out on the complaints of noise. Occupants had complained of both general noise (e.g. passing trains) and ventilation noise. The investigation covered measurements in the audible range (20–20 000 Hz) and the infrasound range (<20 Hz). It has been known for some time that infrasound can have a variety of effects on the human body. Infrasound acts on the labyrinth in the inner ear and may cause lethargy, disorientation, seasickness, digestive disorders, cough, troubled sight and general dizziness (3, 4, 5, 6, 7). Vibration at 7 Hz has been shown to prevent concentration and cause tiredness, headache and nausea, i.e. some typical SBS symptoms. The most dangerous frequency appears to be 8 Hz, which seems to be a natural resonance frequency of the circulation, and can cause cardiac or vascular overload resulting in a heart attack or stroke.

METHOD

Sick building symptoms. A scoring system was developed for rating the occupants' symptoms (1, 8). The symptoms chosen were taken from a questionnaire that has been proposed as a standard in Sweden (9). The three-point frequency scale was changed to a five-point scale for frequency and intensity, see Figure 1.

19) Have you had any of the following problems in the last week? (1 = little/seldom, 5 = a lot/often)

	1	2	3	4	5
Fatigue/tiredness	☐	☐	☐	☐	☐
Headache	☐	☐	☐	☐	☐
Nausea/dizziness	☐	☐	☐	☐	☐
Difficulty concentrating	☐	☐	☐	☐	☐
Itching, burning or irritated eyes	☐	☐	☐	☐	☐
Irritated, runny nose	☐	☐	☐	☐	☐
Blocked nose	☐	☐	☐	☐	☐
Dry skin/tight feeling in skin on face or neck	☐	☐	☐	☐	☐
Flushed skin/rash on face or neck	☐	☐	☐	☐	☐
Itching/prickling/burning feeling in the face	☐	☐	☐	☐	☐
Itching hands or arms	☐	☐	☐	☐	☐
Rash on hands or arms	☐	☐	☐	☐	☐
Dry throat, hoarseness	☐	☐	☐	☐	☐
Sore throat	☐	☐	☐	☐	☐
Cough	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐

20) Do you believe any of these problems are associated with the indoor climate at work?
1 ☐ Yes—which?.. 2 ☐ No

Figure 1. Extract from questionnaire, used to rate occupants' symptoms.

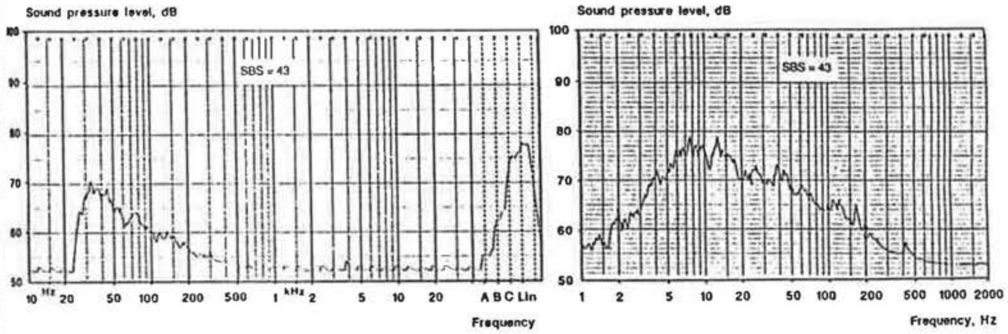
The ratings for all symptoms were added up to give each respondent an SBS score. Ratings of 1 were changed to 0, so that a respondent with no symptoms would have a zero score. Those who said that they found ventilation noise to be a problem had an average SBS score of 29, whereas those who were not troubled by ventilation noise had an average SBS score of 19. The difference indicates that ventilation noise is associated with SBS.

Acoustic measurements. Both occupied and unoccupied rooms were investigated. Where the rooms were occupied, the relationship (if any) between the occupant's SBS score and the levels of infrasound was examined. Noise was measured with a condenser microphone attached to a Brüel & Kjaer Precision Sound Level Meter, the signals being recorded on a portable Digital Audio Tape (DAT Walkman) tape recorder. Recordings were made at work stations and supply ventilation grilles. The recordings were analysed with the aid of two acoustic filters: a B&K Audio Frequency Spectrometer, which gives sound levels in the audible range (20–20 000 Hz), the A-, B- and C-weighted values, and the unweighted (linear) values; and a B&K Tunable Band Pass Filter, which gives levels in the range 1–2000 Hz. The signals were then passed to a B&K Level Recorder to produce the spectrograms.

RESULTS

Figure 2(a) shows a conventional spectrogram from 20 to 20 000 Hz, made from a recording at a work station. The peak value is 70 dB at 35 Hz, and the A-weighted value is 55 dB(A). Typical noise levels in offices (10) are 50-70 dB(A), so a result like this could easily be rated as acceptable by an investigator. However, the unweighted (Lin) value of 78 dB provides the clue that there is some more energy outside the audible range. Figure 2(b) shows the spectrogram from the same recording run through the Tunable Band Pass Filter to show the range from 1 to 2000 Hz. There are peaks of 79 dB at 8 and 13 Hz. The occupant's SBS score was 43.

Figures 3–8 show spectrograms from the work stations in several other rooms, together with the occupants' SBS scores. There is a general (rough) trend towards lower SBS scores as the level of infrasound decreases.



(a) (b)

Figure 2. Spectrogram from a work station: (a) conventional recording in audible range; (b) same recording run through low bandpass filter to show infrasound component.

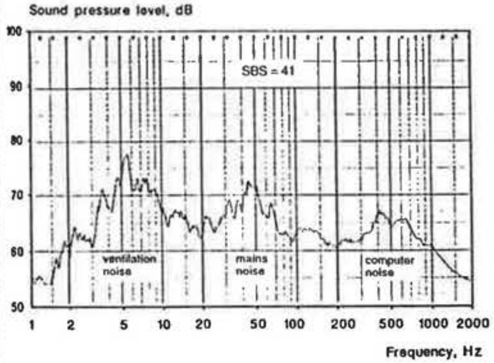


Figure 3. Work station spectrogram.

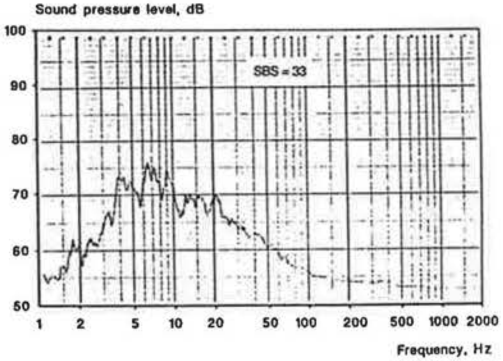


Figure 4. Work station spectrogram.

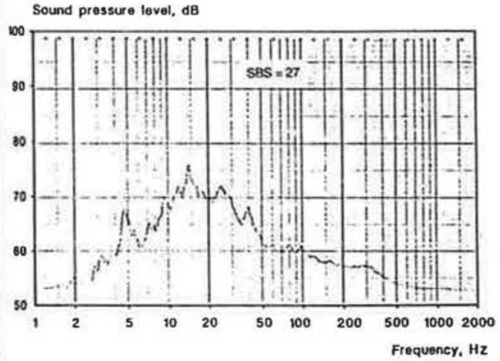


Figure 5. Work station spectrogram.

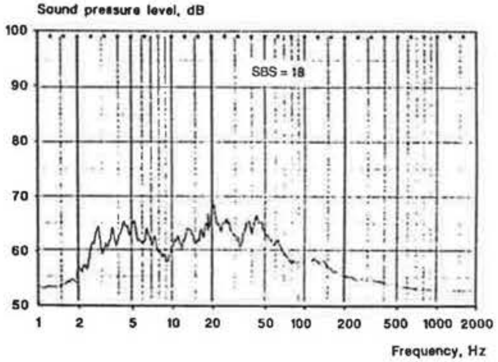
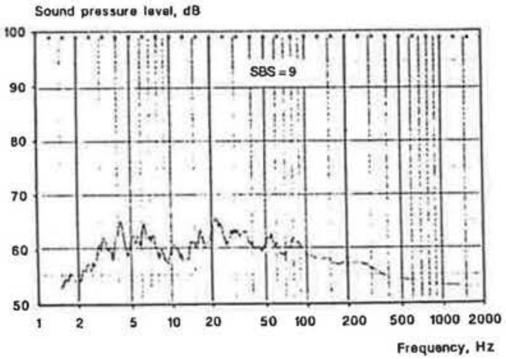


Figure 6. Work station spectrogram.



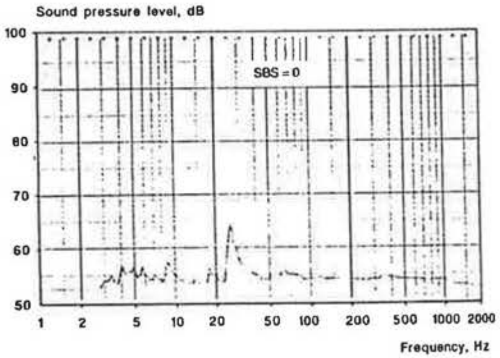


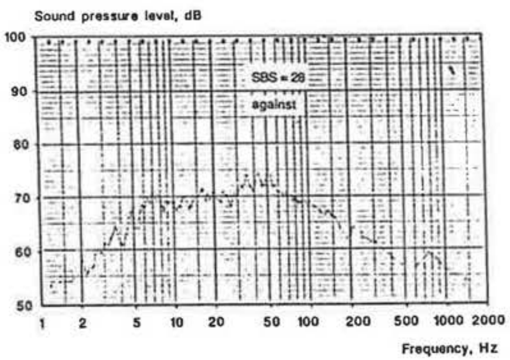
Figure 7. Work station spectrogram.

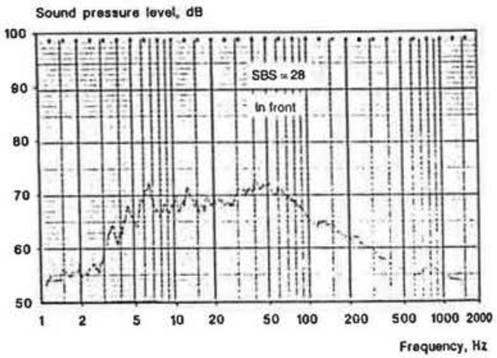
Figure 8. Work station spectrogram.

Figures 9(a, b) show spectrograms from recordings made at the supply grilles. Recordings were made with the microphone pressed against the grille and with the microphone just in front of the grille but not touching it. The recordings are similar, which indicates that there is little or no structural-borne vibration affecting the recordings.

Figures 10–12 show spectrograms at the supply grilles (vent) and work stations (desk) in three rooms. Within the audible range, sound levels are higher at the supply grilles than at the work stations. However, the level of the infrasound component is amplified at the work stations, and can even be higher than at the supply grille.

Figure 13 shows a tracing made at an exhaust ventilation grille. The shape of the spectrogram is different to that at supply grilles, with a lower level of the infrasound component.





(a) (b)

Figure 9. Supply grille spectrogram: microphone (a) against grille; (b) in front of grille.

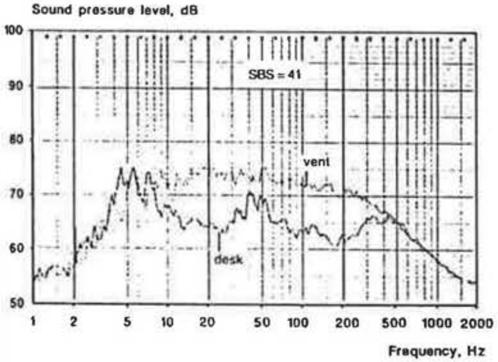


Figure 10. Work station and supply grille.

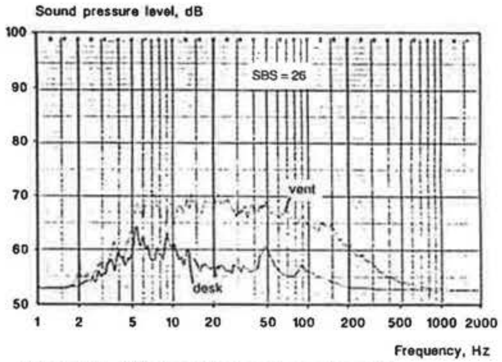


Figure 11. Work station and supply grille.

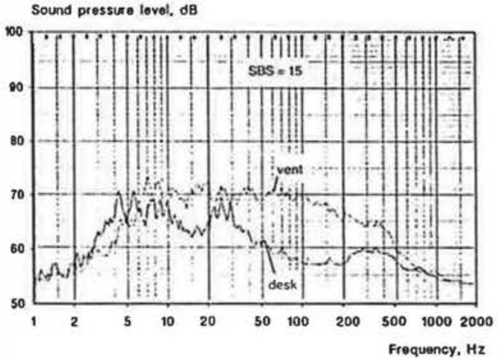


Figure 12. Work station and supply grille.

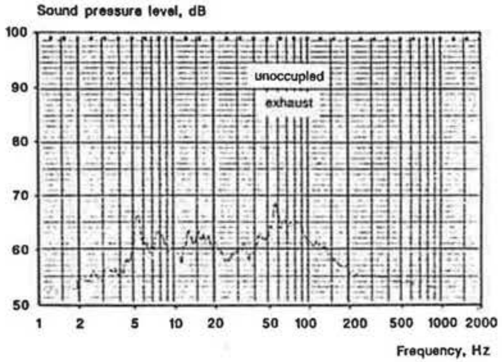


Figure 13. Exhaust grille.

DISCUSSION

The occurrence of high levels of infrasound (>70 dB) was associated with high SBS scores. The results appear to support the hypothesis that infrasound, produced by ventilation systems, may be causing some of the sick building symptoms in many modern office buildings.

If ventilation systems produce infrasound, why has this only begun to cause a problem in recent years? An explanation may lie in the tight sealing of modern buildings, which could be amplifying the lower frequencies of the ventilation noise. Loudspeaker manufacturers use this technique of sealing enclosures to reinforce the base response of their products.

Thus one cause of the sick building syndrome could be ventilation systems producing infrasound *in conjunction with* buildings being tightly sealed. Either factor alone may not be sufficient to produce symptoms. However, once a building is tightly sealed, it becomes a prerequisite to fit it with mechanical ventilation, rather than natural ventilation. The reason buildings are sealed is to save energy. The result is that many occupants are spending several hours a day in tightly sealed enclosures being subjected to infrasound. Many have said that they experience a "pulsing" feel when they are in the building.

If investigators examine the acoustic environment, they often only report a single A-weighted value to describe it. A-weighting, however, gives the greatest attenuation in the infrasound region (–50 dB at 20 Hz, more at lower frequencies). Thus A-weighting gives almost no indication of the presence of infrasound. Many authorities specify A-weighted thresholds, and there is a tendency to assume that the acoustic environment is acceptable if these thresholds are not exceeded. But A-weighted thresholds may be the reason that the effects of infrasound in modern buildings have been ignored. Perhaps the time has come to re-evaluate the usefulness of A-weighting for building investigations.

Infrasound may act by causing an allergic-type response. An allergic or hyperreactive response usually results from a person's threshold for a stimulus being lowered by repeated or long-term exposure to that stimulus. It is possible that infrasound is such a stimulus, and can eventually produce the clinical symptoms of an allergic or hyperreactive response. This would explain why a person can spend several weeks or months in a building before developing symptoms, which is a common feature of SBS. Once a person has become sensitised to infrasound, that person would be more sensitive to its effects. This could explain why people with SBS fail recover completely when they move to apparently healthier buildings.

Complaints in buildings have often been dealt with by increasing ventilation fan speeds. This can increase the level of infrasound, which may be why increasing ventilation rates often fails as a solution to SBS. Avoidance measures can include reducing fan speeds, and replacing fans with ones that give a different audio spectrogram. New buildings can be designed with exhaust-only ventilation systems, which would give a lower level of the infrasound component.

The results reported here indicate that low-frequency components of ventilation noise are amplified in a tightly-sealed building. Low frequencies (5–10 Hz) at sufficient levels (> 70 dB) appear to be contributing to some symptoms of SBS. Noise generally, and low-frequency noise in particular, is a frequently overlooked aspect when "sick" buildings are investigated.

ACKNOWLEDGEMENTS

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DISTRIBUTIONS OF SENSORY EVALUATIONS ON THERMAL AND CROSS-VENTILATION CONDITIONS IN NATURAL-VENTILATED TEMPERATE-CLIMATE CLASSROOMS

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ABSTRACT

Using data from a large number of teacher questionnaires distributed to public elementary schools in Kawasaki, Japan, we determined factors having the strongest influence on their sensory evaluations of thermal and cross-ventilation conditions in natural-ventilated temperate-climate classrooms. These influential factors were derived from various factors regarding to thermal-related environmental controls used by teachers and classroom architectural planning factors. Then, using data from student questionnaires, we determined seating-dependent distributions of similar sensory evaluations for groups of classes with respective category of influential factors. As the results, windows and doors were fully opened except being closed for the safety and noise control reasons. The class directional orientation and the window types related to architectural openings had the strongest influence on sensory evaluations. The classrooms facing southward and having window types tend to be fully opened provided the most comfortable thermal environment.

INTRODUCTION

Most public school classrooms in central Japan, a temperate-climate region, are not provided with air-conditioning systems and rely solely on natural cross-ventilation as the means of obtaining thermal comfort during typically hot, humid summers. However, teachers and students occupying these classrooms are generally known to be uncomfortable under this physical environment; to such a degree in fact, that the resultant thermal conditions lead to an adverse learning environment.

As one means of improving the thermal environment of naturally cross-ventilated classrooms, their physical environment could be analyzed by measuring [(1), (2)], though limitation arise with regard to the types of classrooms studied. Therefore, to clarify how to best improve classroom thermal environment, we investigated many classroom types, by analyzing the results of a large number of teacher questionnaires, specifically considering sensory-based evaluations of thermal and cross-ventilation conditions.

As the teacher responses include valuable data indicating how thermal-related environmental controls were used and survey data showing what classroom architectural planning factors were present, on analysis, after we determine which have strongest influence on teacher sensory evaluations, being refereed to as "influential factors". Then, using data from corresponding student questionnaires, we investigated seating-dependent distributions of student sensory evaluations for groups of classrooms having the most influential factors.