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Indoor Air 1993, 3: 237–245
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Indoor Air
ISSN 0905-6947

Sick Building Syndrome: Cleanliness is Next to Healthiness

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Abstract

There is evidence that sick building syndrome (SBS) is caused, in part, by indoor surface pollution (ISP): contaminants such as dust, fibres and micro-organisms, deposited on or in surfaces in buildings. A study is described which clarifies the relative importance of a number of possible causes of SBS in a single building. The building, which had a high initial prevalence of SBS symptoms, was used in a double-blind controlled intervention study with weekly symptom questionnaires. The four interventions were: ventilation system cleaning, air filtration, hot-water extraction cleaning of chairs and carpets, plus high grade filter vacuuming and dusting, and dust mite treatment (application of liquid nitrogen). Only the last two interventions brought about a reduction in symptoms. It is concluded that cleaning which effectively reduces ISP can reduce SBS symptoms. This may be related to the presence of dust mites in furnishings. Improved cleaning may entail better cleaning specifications and/or consideration of requirements for cleaning when selecting and positioning office furniture. If ISP and the temporary local pollution levels created by it are a problem, then monitoring of ambient conditions (by instruments or by human assessors) will not adequately represent the conditions to which occupants are exposed.

KEY WORDS:
Sick building syndrome (SBS), Indoor surface pollution, Intervention study, Air cleaning, Office cleaning, Dust mites

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Introduction

Sick Building Syndrome and its Causes

Sick building syndrome (SBS) is a phenomenon whereby people experience a range of symptoms when in specific buildings. The typical symptoms are irritation of the eyes, nose, throat and skin, headache, lethargy and lack of concentration. Although present generally in the population, these symptoms are more prevalent in some buildings than in others. The symptoms are 'building-related', reducing in intensity when the person is away from the suspected building. Most explanations of SBS have focused on ventilation and indoor air quality, but there is also growing evidence of an important role of contamination deposited on surfaces in office buildings: indoor surface pollution (ISP).

ISP is not just settled dust, and should not be seen merely as a proxy for the average level of airborne particulates since the surface was last cleaned. There are many sources of ISP, airborne and otherwise. Building users contribute micro-organisms, skin scales, debris from clothing (particularly shoes), plus the products of activities such as smoking, eating and drinking. The users can also provide the climate required by micro-organisms for survival in office chairs, for example Leinster et al. (1990) report the presence of dust mites in office chairs.

New materials are often suspected of causing SBS because they can release pollutants. Older materials can cause different problems if the materials themselves decay (releasing particles or fibres) or if they become a reservoir of dust and dirt, particularly organic material which causes pollution itself or which provides a breeding site for organisms such as fungi and house dust mites which can cause allergic responses and asthma. Photocopiers, paper and green plants can also contribute to ISP. Ventilation systems can contribute to ISP by providing insufficient filtration of outside air or transmitting pollutants within a building (if air filters are not appropriate and in good order) and by emitting pollutants from within the system (e.g. fibres from filters or duct lining, accumulated dust and micro-organisms which have colonised the system).

Mechanisms by which Indoor Surface Pollution could cause SBS

If ISP is responsible for the symptoms of SBS, this could in theory be attributed to toxic effects, irritation, infection or immunological mechanisms. The health effects of particles can be modified by the adsorption of gases and vapours, both inorganic and organic. Conversely, the effect of gases and vapours can be increased if they are adsorbed by particles which remain in the respiratory tract long enough to deliver a concentrated local dose of the pollutant. This could, in theory, be a higher dose than the ambient airborne concentration of the gas would indicate.

Although micro-organisms may be significant, SBS is very unlikely to be an infectious illness because of its pattern of occurrence (Raw, 1992). Also there is no evidence of SBS being passed on outside the workplace. The nature and time pattern of SBS means that it could result from allergic reaction to chemical or microbiological agents. Allergic reactions would however not normally occur in such a large number of people or with such a variety of symptom patterns, and only some people who report SBS have been shown to be allergic or hypersensitive. A mixture of allergens, plus irritant or toxic effects might account for the symptoms. The effect of air conditioning can be explained if agents originate in the air conditioning system itself or if the system is associated with a suitable environment for production of allergens within the building.

While adverse health effects are more commonly reported in air-conditioned buildings, levels of airborne particulates should be lower than in naturally ventilated buildings because of the filtration provided (see, for example, Schneider, 1990). However, the level of dust to which office workers are exposed can be 4–5 times higher than indoor ambient airborne levels (Raw et al., 1991). This is because people create their own 'dust cloud' in the course of their work by stirring up settled dust. But ISP is more than potential air pollution, effective only when inhaled, since it can be transferred direct to the hands and thence to the face, or ingested with food or drink; these aspects have hardly been explored at all.

We therefore undertook a further study which sought to replicate our previous results and compare the effectiveness of office cleaning with treatment of the ambient air. The study also sought to improve methods for longitudinal studies of SBS, so that in the longer term it is possible to develop a consistent and coherent approach to the reduction of SBS. A single office building was selected, and a longitudinal study performed with a set of experimental interventions. First, some of the evidence from past studies is summarised.

Direct Evidence for the Importance of Indoor Surface Pollution

Skov and Valbjørn (1987) found two primary correlates of SBS: the "fleece factor" (area of carpet, curtains and other fabric divided by the volume of the space), and "shelf factor" (length of open shelving or filing space divided by the volume of the space). These factors reflect possible sources of pollution such as organics and ISP. The researchers proposed that when the temperature is high and/or the relative humidity is low, or there is high work activity, the potentially allergenic material is released. Temperature and humidity could, in addition, play a direct causal role. Macromolecular organic dust in samples taken from the floor was found to be correlated with mucosal and general symptoms (Gravesen et al., 1990). Four buildings were selected for a follow-up study, one year after the original study. Indoor climate parameters were similar to those originally measured and generally within accepted limits. Symptoms were more prevalent where the workers reported that the standard of office cleaning was not good.

Hedge et al. (1993) found a significant correlation between the levels of deposited man-made mineral fibres (MMMF) and SBS. The level of airborne MMMF did not have a significant effect. The deposited MMMF may be significant in its own right or, more likely, it reflects the general level of cleaning and ISP. Levels of deposited MMMF have been found to be higher where cleaning is rated as poor (Schneider et al., 1990) and the same paper provides some support for the view that the level of deposited MMMF is correlated with the total level of deposited material. Laxen (1990) found that the only environmental factor correlated with '% staff unhappy about the office environment' was deposited dust. There was no such correlation with temperature, humidity, CO_2 or airborne dust, bacteria or fungi.

Experimental studies (Raw et al., 1991) have sought to identify the causal effects responsible for the correlation between 'fleece' and 'shelf', cleaning and SBS. In the first experiment, cool shampooing was used with vacuum cleaning on carpets, chairs and other fabric surfaces. Hard surfaces (on furniture, window sills, and window blinds) were then cleaned using wet techniques to remove dust. Paper files were vacuum cleaned in order to remove dust as thoroughly as possible. The vacuum cleaners used were fitted with high efficiency final filters. The cleaning regime in the second experiment was similar, but with steam cleaning replacing the cool shampooing and no vacuuming of the paper files. Both experiments were carried out double-blind. Staff reported a large positive improvement in symptoms and environmental conditions following either cleaning treatment, relative to a control group. The overall reduction in weekly symptoms was greater in the second experiment: the cleaning in this experiment reduced the prevalence of dust mites, particularly in chair covers. This does not prove that mites were responsible for the symptoms, but does raise the possibility.

Indirect Evidence for the Importance of Indoor Surface Pollution

The apparent success of treating SBS by the removal of carpets (Norbäck and Torgen, 1989) could be attributed to the reduction of potential for surface pollution. Abildgaard (1988) found a high correlation between airborne levels of bacteria and dust in schools. The lowest levels were in schools without carpets, the highest levels in schools with old carpets and high levels of settled dust.

Several of the UK building 'risk factors' for SBS (1970s construction, open plan offices and occupation by Government organisations (Wilson and Hedge, 1987) could be related to levels of ISP: the age of the building for obvious reasons, and the Government buildings in the sample were less well maintained. Open plan spaces can make it more difficult to determine who is responsible for dirty surfaces, or for providing easy access for cleaning staff. Low job status is also a risk factor for SBS (Skov and Valbjørn, 1987; Wilson and Hedge, 1987) and this too could be related to the quality of furnishings and their maintenance and cleaning.

Increasing ventilation will have little effect on ISP and could increase environmental problems, for example through draughts, increased transfer of contaminants from the ventilation system and increased disturbance of settled dust in the building. This would explain the limited success there has been in linking SBS to ventilation rates and indoor pollutant levels.

Temperature, humidity and air movement are determinants of indoor air quality, not just of comfort, since they can alter the rate of emission and deposition of pollutants from materials in the building and from people. Symptoms are generally correlated with perception of hot, stuffy or dry air (Wallace et al., 1991; Wilson and Hedge, 1987) but sensation of dry air is not always correlated with relative humidity: it can also be caused by dust and gaseous air pollutants.

VDU operation has been found to be correlated with SBS (Skov and Valbjørn, 1987; Wilson and Hedge, 1987) but the reason for this has not been established. VDU work may be correlated with a more direct causal factor such as being restricted for long periods to a poor working environment. However, if the effect were due primarily to this it would be expected that all the symptoms of SBS should be associated with VDU work, whereas only certain symptoms appear to be so associated. Alternatively, the electric field around VDUs can cause higher levels of small airborne charged particles in the vicinity of the user's face (Schneider et al., 1993).

The supposed health benefits of using air ionisers have been the subject of a number of studies and much debate. It is difficult to prove beyond all doubt that ion generators have no benefit, but the balance of published evidence is against them (Raw, 1992). Ionisers are able to deposit dust out of the air, and this may explain why the findings on ionisers are variable. Their effect may depend on how much dust is in the air, what pollutants are adsorbed by the dust and what cleaning is carried out to remove deposited dust.

Method

The Building

The building had four occupied floors and a basement car park. It was built in 1975 and had approximately 1300 occupants with a design capacity of 1525. Most of the office areas were open plan, demarcated with partitions and cupboards up to 2.5 m in height. There was generally inadequate storage space, with the result that many areas of the building had papers and other items stored on desks, on top of cupboards and on the floor. The windows were locked shut except on Floor 3. The size and layout of the windows restricted solar gain and direct daylighting. The lighting of the building was therefore largely artificial, using fluorescent strip lighting.

Comfort cooling was provided via a mixture of fresh and recirculated air, supplied by three plant rooms, one located above each of three vertical service cores. Distribution of air was through ceiling mounted fan coil units and perimeter induction units. Room air was extracted through the light fittings into a plenum and from there via the service core ducts to the atmosphere.

Research Design

A preliminary investigation of the building identified likely causes of problems which could be studied experimentally using interventions intended to improve the indoor environment. The building was divided into six areas (Ground Floor, Floor 1 North, Floor 1 South, Floor 2 North, Floor 2 South, and Floor 3). Each area had a different test regime which ran in parallel with the others. Floor 2(S) acted as a control: in this area no treatment was performed.

The interventions were carried out double blind as far as possible; since this was not possible for one experiment, a placebo control was used. The building users' symptoms and environmental comfort were monitored throughout the building using self-completion questionnaires (administered weekly for 2 months before the planned interventions and 2 months after). Monitoring of the building environment, as appropriate to the intervention carried out, was conducted so as to represent conditions in the office for a period equivalent to that evaluated using questionnaires. Four interventions were carried out, as follows.

Cleaning the ventilation system. On Floor 2(N) the perimeter induction units were cleaned to remove dust on the air supply nozzles, the intake grilles and the floor under the units. The air handling unit serving this floor (and Floor 1(N) immediately below) was also cleaned to remove stagnant water, loose rust and any other surface contamination, and the fresh air filters were renewed. The treatment was in effect from Week 13.

Air filtration. On Floors 1(N) and 3, ceiling mounted air filtration units were installed. On Floor 1(N) desktop filtration units were also placed around the office space. The filter units combined particulate removal (down to 0.03 μm) with an activated carbon filter to remove gaseous pollutants. Office air was drawn in, filtered and re-emitted with minimal creation of air movement in the vicinity of the occupants. The number and location of the filters was that specified by the suppliers. For part of the time the filter units contained filter medium to extract airborne pollution (both gaseous and particulate), and for part of the time they had dummy (ineffective) filters, acting as a placebo. On Floor 3 the majority of the units were in place from Week 10, the rest from Week 12. From Week 14 they were acting as a placebo. On Floor 1(N) the filters were acting as a placebo from Week 10 and as treatment from Week 14.

Office cleaning. Floor 1(S) received hot water extraction cleaning ('steam cleaning') of the chairs and carpet. Also the surfaces of furniture were cleaned with wet cloths, and paper files were vacuum cleaned, to remove dust as thoroughly as possible. Hot water extraction cleaning was completed throughout the area on the Saturday prior to Week 9. The rest of the treatment was split between Weeks 9 and 12, approximately half the area being treated at each stage. The reason for this split was that the vacuum cleaners were found in Week 9 to be fitted with standard filters. High efficiency final filters had been specified, and this was achieved at Week 12.

Liquid nitrogen. On the Ground Floor, the office chairs were treated with liquid nitrogen to kill dust mites, then cleaned using a vacuum cleaner with a high efficiency final filter. Most of the chairs were treated on the Saturday prior to Week 9, the remaining area on the Saturday prior to Week 12.

Questionnaire Survey and Environmental Monitoring

Subjects initially reported how many SBS symptoms they had experienced in the last 12 months, from a list of 17 symptoms: itching/irritated/dry eyes, watering eyes, eye strain, blocked or stuffy nose, runny nose, other itching/irritation, sore throat/cough, dry/irritated throat, chest tightness or breathing difficulty, flu like symptoms, itching face without rash, rash or irritated skin, other dry skin symptoms, headaches, lethargy and/or tiredness, forgetfulness and/or lack of concentration and an open category 'other' for reporting any other symptoms that had been experienced. The frequency of each symptom was also recorded as daily or most days, weekly, monthly, less often or never. A range of other questions about the respondents' background and their evaluation of the office environment were also asked but they are not the subject of the analysis reported here. Similarly, the paper is concerned with changes over time, and the background data are not discussed here.

Over the following 16 weeks the subjects then reported each Friday how many building-related symptoms had occurred in the last week. Questionnaires were completed in weeks 1, 2, 3, 5, 6, 7, 9, 10, 11, 13, 14, 15 and 16. Weeks 8 and 12 were intended to be used for implementation of the interventions. Week 16 was used only for the air filtration study.

Eye strain and 'other' symptoms were not used in the analysis, since they were not regarded as SBS symptoms (there were many different 'other' symptoms, including a variety of musculoskeletal problems, insect bites and gastric symptoms). Symptom scores are therefore the number of symptoms reported as experienced in a particular week, out of a total of 15. A symptom was recorded as building-related if it was better when away from the building, and only building-related symptoms were analysed. The weekly number of symptoms reported per person was averaged over the three weeks in each test period to provide a mean symptom index of each test area for each period.

Environmental conditions were monitored for two months before and two months after the planned interventions. The monitoring varied with the intervention to be carried out. Monitoring in the control area and outdoors provided controls for all the interventions. The monitoring covered the following:

- temperature and relative humidity (in all areas);
- carbon dioxide (in all areas);
- total volatile organic compounds (in all areas);
- airborne bacteria and fungi (not on the Ground Floor);
- mite and dust levels in chairs (Ground Floor and Floor 2(S) only);
- airborne particulate matter in the room air (in all areas);
- airborne particulate matter – personal monitoring (not outdoors or on the Ground Floor).

Data Treatment

Weekly symptom scores were converted to monthly means, each month having data from the first three weeks. The first month (Weeks 1–4) was intended to allow responses to reach a constant level before the main baseline period (Weeks 5–8). Interventions were planned for the end of Week 8, leaving two 'after' periods (Weeks 9–12 and 13–16). The four periods are referred to as Before_1, Before_2, After_1 and After_2. Several of the treatments were delayed by a month, therefore only in period After_2 had all the treatments had been completed. In the case of the air filter studies, interventions were one week late and hence After_1 is Weeks 10–13 and After_2 is Weeks 14–16. The final schedule of interventions and monitoring (including questionnaire administration) is shown in Table 1.

Paired t-tests were performed between consecutive periods for each of the interventions. Where there was a significant reduction in symptoms due to an intervention, a further test was carried out to determine whether the reduction was greater than that which occurred in the control group over the same period. The latter test treated the difference in the mean number of symptoms between periods as the dependent variable in between-group t-tests.

Table 1 Schedule of monitoring and interventions

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Monitoring	▭	▭	▭		▭	▭	▭		▭	▭	▭		▭	▭	▭	af
Ventilation system												T				
Air filters (1)										T				P		
Air filters (2)										P				T		
Office cleaning (1)								T								
Office cleaning (2)								T_1				T_2				
Liquid nitrogen (1)								T								
Liquid nitrogen (2)												T				

af = air filter invention only; T = treatment (subscripts 1,2 indicate two stage treatment); P = placebo

Similarly, data from the environmental monitoring were subjected to testing of differences between periods.

Results and Discussion

Symptoms

There was a strong downward trend in symptoms during the study (Table 2). Even between $Before_1$ and $Before_2$ there was a significant reduction overall (Mean index 3.48 vs 2.55 symptoms, $t=11.03$, $p<0.001$, $df=461$) and the control group continued to show a decrease in symptoms until the $After_2$ period. It is not clear whether this was an effect of repeated questionnaire completion, the changing season (moving from August to November) or some other change unrelated to the experimental interventions. Unfortunately the overall trend defeated our attempt to obtain a flat baseline in the before period, which in turn complicates the interpretation of the data. Only in comparisons between $After_1$ and $After_2$ is the interpretation relatively free from the effects of unknown confounders.

The following paragraphs summarise the results for each experimental group, referring to the data in Table 2 (all tests of significance are one-tailed). Mean values for the $After_1$ period differ depending on whether the comparison is with $Before_2$ or $After_2$ because paired t-tests were used, i.e. all difference shown represent a change in the respondents who returned questionnaires in both periods.

Cleaning the ventilation system did not bring about a reduction in symptoms, in fact the symptom index in this condition was very similar throughout to that in the control condition. Although cleaning was probably needed in order to avoid health problems in the future, it seems that the cleaning was not sufficient to have any discernable benefit for the health of the staff at this point. Complete cleaning, including the ductwork and plenum, might have been more effective, but this was not possible within the timescale of the project. Since the change was introduced at Week 12 this result is not in doubt as a result of the general downward trend which confused results at Week 9. Any effect of this treatment on the air filtration experiment on the floor below can therefore be discounted.

Air filtration brought about no reduction in symptoms, either when the units were first installed on Floor 3 or when the dummy filters were exchanged for working filters on Floor 1(N). There may have been an initial placebo effect (regardless of whether real or dummy filters were fitted) but this was not significantly greater than the change in the control condition.

The effect of implementing the full cleaning programme at Week 9 was to bring about a significant reduction in symptoms. This reduction was not sig-

Table 2 Changes in mean symptom index between the $Before_2$ and $After_1$ periods, and between the $After_1$ and $After_2$ periods

Intervention	$Before_2$	$After_1$	Change	T	DF	p<
Ventilation system	2.80	2.39	−0.41	1.37	40	ns
Filtration placebo	2.98	2.43	−0.55	2.39	67	0.010
Filtration treatment*	2.90	2.40	−0.50	1.91	26	0.034
Cleaning Week 9*	1.86	1.37	−0.49	2.84	85	0.003
Cleaning Week 12	2.71	2.19	−0.52	1.26	19	ns
Liquid nitrogen Week 9*	2.96	2.42	−0.53	2.24	63	0.015
Liquid nitrogen Week 12	3.34	3.01	−0.33	0.83	27	ns
Control	2.54	2.16	−0.39	2.46	72	0.008
Intervention	**$After_1$**	**$After_2$**	**Change**	**T**	**DF**	**p<**
Ventilation system*	1.99	1.97	−0.02	0.09	35	ns
Filtration treatment*	2.61	2.42	−0.19	0.78	62	ns
Filtration placebo	3.26	2.78	−0.49	1.46	37	ns
Cleaning Week 9**	1.44	1.29	−0.15	1.40	83	ns
Cleaning Week 12*	2.40	1.67	−0.73	1.99	19	0.030
Liquid nitrogen Week 9**	2.69	2.31	−0.38	2.03	62	0.024
Liquid nitrogen Week 12*	3.20	2.82	−0.38	1.79	35	0.042
Control	2.07	2.22	0.15	−1.03	76	ns

*Treatment introduced; **Treatment still in effect nificantly greater than that in the control group, comparing $Before_2$ with $After_1$, although it was significant comparing $Before_2$ with $After_2$ ($t = 1.67$, $p < 0.05$, $df = 153$). In the area in which the treatment was completed at Week 12, the reduction in symptoms was significant in its own right and in relation to the control group ($t = 2.55$, $p < 0.01$, $df = 95$ comparing $After_1$ with $After_2$; $t = 2.67$, $p < 0.01$, $df = 99$ comparing $Before_2$ with $After_2$).

The more clear cut result for Week 12 cleaning may have occurred because the vacuum cleaners used at Week 9 did not meet the specification or for some reason unrelated to the treatment. Whatever the reason for this difference, office cleaning brought about a significant reduction in symptoms only when the complete programme was instigated: hot water extraction cleaning of the carpets and chairs was not sufficient on its own. The negative result with hot water extraction (without high performance vacuum cleaning of paper files) contrasts with our previous study (Raw et al., 1991). Enquiries with the cleaning contractor revealed that the temperature of the water used was only 45 C, rather than the 70 C estimated for the earlier study. It is possible that the higher temperature is required to denature allergens in the dust.

The liquid nitrogen treatment brought about a significant reduction in symptoms on both occasions on which it was used, although only at Week 12 was the reduction significantly greater than that in the control group ($t = 2.03$, $p < 0.025$, $df = 111$). The complication here is that the group treated at Week 9 also showed an improvement relative to control at Week 12 ($t = 2.26$, $p < 0.02$, $df = 138$). This may represent a continuing benefit due to either desensitisation of the staff or a general reduction in pollution in the space (there was no physical boundary between the two treatment areas). Comparing $Before_2$ with $After_2$, there was not a significant difference between treatment weeks, the reduction being 0.86 symptoms for the later treatment and 0.85 for the earlier. In both groups, the reduction was significantly greater than in the control condition (Week 9 treatment: $t = 2.08$, $p < 0.02$, $df = 129$; Week 12 treatment: $t = 2.17$, $p < 0.02$, $df = 102$).

Environmental Monitoring

The results of environmental monitoring were not so clear, and there were no significant changes between periods. There were three reasons why this might have occurred, quite apart from the possibility that there were really no changes. First, there was a greater than anticipated spatial variation in environmental parameters within each area of the building, so that each measurement could be taken to represent only a local area. Second, there was some resistance to wearing the personal dust monitoring devices, which meant that different occupants were used each week. Third, and probably most critical, the unplanned changes to the intervention dates meant that (a) a complete cycle of monitoring the different locations within each area was not possible in all the 'After' conditions and (b) there were fewer 'After' measurements in total for each intervention. As a consequence, there was too much variance in measurements to have a reliable estimate of changes over time. It would therefore be unwise to conclude too much on the basis of the environmental monitoring results.

It is, therefore, not possible to draw certain conclusions. Where an intervention was successful, we cannot say what environmental change was responsible, although there were certainly dust mites in the chairs (up to 600 g^{-1} of dust). We are examining the effect of liquid nitrogen treatment of dust mites in a separate study. Where an intervention was not successful, we cannot say if this was because the environment was not changed, or because a change in the environment did not bring about a change in symptoms.

Conclusions

Implications of this Study

The results support earlier findings on the benefit of intensive office cleaning of soft furnishing and other surfaces. The reasons for the benefits are also clarified: there is strengthened evidence for the role of dust mites from the fact that liquid nitrogen treatment of the chairs significantly reduced the prevalence of symptoms. The office cleaning treatment also provided indirect evidence of the role of dust mites and confirmed that dust on papers and hard surfaces must be considered in addition to the soft furnishings. No benefit was obtained from installing air filters in the rooms or from cleaning the air conditioning plant and induction units.

What can be Done?

It is well understood that cleanliness of building services is important for health. The findings of this study suggest that another major requirement for hygiene is in fabric furnishings and storage areas where dust can gather. Wherever possible an excess of such materials and storage areas should be avoided. Reduction of ISP can be seen as an example of source management being a better approach to pollution control than removal of pollutants which have already become airborne or otherwise reached a position from which occupant exposure is inevitable. It also follows the familiar rule that options should be selected to minimise deposition of pollutants in 'sinks' and, where possible, to replace materials (e.g. textiles, paper) which can act as sinks: sinks mean a pollutant has to be managed twice.

Occasional treatment to remove mites (e.g. steam cleaning, acaricides, liquid nitrogen) may be beneficial. Normal vacuum cleaning is ineffective for this purpose. Another approach would be to use high performance vacuum cleaners with high efficiency filters, or to incorporate central vacuum cleaning in building designs, to remove dirt from offices. It also needs to be questioned whether the relatively constant environment in air-conditioned offices promotes the indoor viability of mites and micro-organisms generally. The case for implicating dust mites in SBS is not yet fully proven and it would be advisable to identify mites in the furnishings (particularly chair covers) before proceeding with costly eradication measures.

Further research will clarify the primary causes of SBS and their interactions and provide a basis for cost-effective prevention and cure. However, a certain amount can be achieved by the application of current knowledge in the process of specification, design, construction, installation, commissioning and maintenance of buildings and their services. This will need to be directed in an integrated and multi-disciplinary manner to all stages in the life of the building, and to cover the building itself (and its location), the indoor environment, the organisations which occupy buildings and the needs of individual workers. There are many possible causes of SBS and they are interrelated and interactive. SBS is a multifactorial problem which demands a multidisciplinary approach: a comprehensive view and systematic checking of possible problems, not a standard approach applied to all buildings.

At the very least, when measures for reducing SBS are evaluated in a particular building, office cleaning and/or specific mite reduction measures must be considered, particularly in older buildings. This should of course be evaluated along with the more established approaches related to improving building services design, operation and maintenance, and reducing pollution from materials and processes in the building. In addition, more attention could be paid to design, furniture selection and layout in offices to make effective cleaning an easier task.

Implications for Research

An important causal factor in SBS may simply not have been measured in many studies of SBS. This factor, ISP, has been shown experimentally to be a determinant of SBS in some buildings. ISP can also explain why there has been difficulty in demonstrating an association between SBS and other factors related to pollution (ventilation and airborne pollution levels).

Measurement of ambient air pollution, whether by human panels or by mechanical instruments, may not adequately reflect people's exposure to airborne pollution. This applies to pollution derived from ISP, but also to any pollutants which have localised sources related to occupant activities, for example correction fluids, glossy paper or photocopiers.

We have tended to think of indoor air pollution as a problem caused partly by ISP. This has lead to errors in study design and associated measurements, and it may be time to think of ISP as a problem in its own right, taking appropriate measures to combat it.

Acknowledgements

This research forms part of the programme of the UK Department of the Environment and is published by permission of the Department. Environmental monitoring was carried out by Thomson MTS. The authors are very grateful for the kind support of the staff of the study building, particularly the occupational health and building services staff, in addition to Cadogan Medical Co Ltd, ServiceMaster plc, Rentokil Ltd and Anatomia Filtaire.

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