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Particulate Matter Intervention Study: A Causal Factor of Building-Related Symptoms in an Older Building

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Abstract Five floors of a 20-year old 6-story office building were investigated using an integrated step-by-step investigation strategy. This involved a walkthrough inspection, an occupant questionnaire, and targeted environmental monitoring of indoor air quality and comfort parameters. The initial questionnaire survey revealed a high occurrence of building-related symptoms. The walkthrough inspection and environmental monitoring identified deposits of surface dust (indoor surface pollution – ISP) on carpets and hard surfaces, and elevated levels of carbon dioxide and respirable suspended particulate matter (RSP) throughout the building. An intervention study (blinded to the occupants) was targeted at reducing ISP levels by replacing normal carpet cleaning practices with higher performance vacuum cleaners and improved cleaning practices. The intervention reduced ISP levels and significantly lowered RSP concentrations by approx. 80% from initial values and against control floors. A follow-up SBS questionnaire revealed significant reductions in all but two of the symptoms. The most significant reductions occurred with symptoms of eye irritation, throat irritation, dry unproductive cough, and nose irritation. The study showed that in older buildings with poor ventilation, a build-up of ISP, and elevated RSP levels, using higher performance carpet cleaning practices can reduce RSP to acceptable levels and can reduce SBS symptoms.

Key words Sick building syndrome (SBS); Older buildings; Respirable suspended particulate matter (RSP); Intervention study; Indoor surface pollution (ISP); Vacuum cleaning.

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Introduction

Few studies have investigated the effects of surface or suspended particulate matter as a causal factor of sick building syndrome (SBS). Several factors strongly suggest that particulate matter may, in some buildings, be an important causal factor of SBS. These include the observations that our total exposure to respirable suspended particulates (RSP) is dominated by indoor concentrations, and that indoor concentrations of RSP tend to be higher than outdoor concentrations (Yocom and McCarthy, 1991).

The potential sources of suspended particulate matter identified in buildings include: *Building Materials*, made from fibres such as glass, cellulose, and asbestos; *Combustion Devices*, such as gas appliances, gas hot water heaters, and boilers; *Occupant Activities*, such as tobacco smoking, photocopy dusts, and re-suspended dusts; and *Infiltration from Outdoor Sources*, such as atmospheric dust, and combustion emissions from mobile and stationary sources (Baechler et al., 1991). The same authors suggest also a typical indoor RSP concentration range between 100 to 500 $\mu g/m^3$, with the highest concentrations occurring in areas where tobacco smoking is permitted.

However, some of the research in this area has found no clear relationship between RSP concentrations and factors that were expected to influence concentrations such as levels of indoor surface pollution (ISP) and ventilation rates (Raw et al. 1993; Yocom and McCarthy, 1991).

Indoor surface pollution has been suggested as a major risk factor for SBS symptoms because of its toxic and irritant effects, or through immunological mechanisms (Raw et al., 1993). While little research has been conducted in this area, studies on SBS by Raw and Hamilton (1994), Raw et al. (1993) and Gyntelberg et al. (1994) have focused on the issue of ISP and results show some clear relationships to SBS symptoms.

Surface Dust, Suspended Particulate Matter and SBS

Indoor surface pollution (ISP) as described by Raw et al. (1993) is more than just settled dust or the amount

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of airborne particulates settled since surfaces were last cleaned. ISP may be more of a continual deposition process where building occupants can contribute substantially by shedding or introducing microorganisms, skin scales, debris from clothing, debris tracked in on shoes from outdoors, as well as by-products from smoking, eating and drinking (Raw et al., 1993).

Some of the earlier research on SBS showed a clear relationship between the incidence of eye irritation and suspended respirable particulate matter concentrations (Norbäck et al., 1990). A fraction of surface dust, described as macromolecular organic dust (MOD) by Gravesen et al. (1990), has been extracted from floor carpets and other horizontal surfaces and shown to be associated with mucous membrane irritations and general SBS symptoms. The same study also reported significant concentrations of bacteria, mould and total proteins in areas with floor carpets compared to areas with hard floor coverings. The Danish Town Hall Study also revealed an association between the area of fabric-covered surfaces (the fleece factor) and the prevalence of both mucous membrane irritation and general symptoms, with carpet noted as the predominant fleecy material (Skov et al., 1990).

Even without extensive research, floor carpets are widely known as a sink for indoor air pollutants such as settled dust, tracked-in soil, spills, and chemicals, and because of this have been banned from use in school rooms in several Scandinavian countries. Carpet removal has also been shown to reduce a number of SBS symptoms in other studies (Norbäck and Torgen, 1989; Norbäck et al., 1990). A study by Ragsdale et al. (1995) on the impact of carpet cleaning on IAQ also showed that good carpet maintenance may improve indoor air quality.

Tan et al. (1995), in a study of 3 commercial office buildings, revealed that the primary source of suspended particulate matter in the buildings investigated was exacerbated by poor housekeeping practices and improper maintenance procedures and schedules. There has long been a suggestion that poor cleaning practices can contribute to ISP levels where particulate matter deposits are allowed to accumulate in fabric surface coverings and along edges of furniture and walls and in crevices. In buildings where ISP has been allowed to build up, using low-efficiency vacuum cleaning equipment can exacerbate this situation as the normally used bag-type filters can allow smaller particulates such as the respirable fraction to "blow through" the filters. This can cause particulate matter to be re-aerosolised from surface deposits which can elevate concentrations of suspended particulate matter to levels that have the potential to affect the health of building occupants (Schneider et al., 1993; Raw e 1993).

The biological contamination by dust mites in fa covered office chairs has been reported by Leinst al. (1990) and was suggested to be a consequenc the occupants providing a suitable climate in the fa covering for mite survival. Greenfield (1987) Schmidt (1992) further suggested that dust mites microbial contamination are often abundant in holstered furniture and fabric-covered office partiti particularly when they are not cleaned regularly. importance of bio-contaminants such as fungi and mite excreta existing in these habitats is that they known to cause a large range of allergic response sensitized individuals (Dales et al., 1990) which explain a partial role in the SBS.

While there are many potential sources in buildi research has clearly shown that poor cleaning pract in respect of carpets and fabric-covered furniture a potential major factor in the high concentrations o door suspended particulate matter (Raw et al., 19 Gravesen et al. (1986) also reported that rooms carpeting are known to have higher average level accumulated dust, organic macromolecular com nents of dust, and airborne moulds. Carpet typic has a high surface area and is known to act as a s to reduce airborne levels of many pollutants; it can remain a significant contaminant source when serv as a sink for organic dust (Godish, 1995). This demonstrated in a study by Hanssen (1993) wh showed that RSP levels in schools were related to b the presence of carpet and occupancy of the buildi It was also clearly shown in this study that replac the "normally used" low-efficiency cleaning equ ment with high-efficiency vacuum cleaners, can sign cantly reduce the indoor concentrations of suspend particulate matter.

This paper concerns the use of a blinded in vention study with no-action control areas with a low-up study in an older office building with "norm (low-efficiency) housekeeping procedures. The aim the study was to establish potential causal relati ships between deposits of surface pollution, respira particulate matter concentrations, sick building sy drome symptoms, and building-related complaints.

Experiment Design and Methods

The Building

The building, which was from around 1965, consist of 6 occupied floors, a mezzanine level carpark a a ground floor carpark and was located in the cent business district of Perth (Australia). It was design and used as open-plan office space. The current tenancy had arranged the spaces with approximately 25% of the floor area as separate offices with floor to ceiling partitions and the remaining 75% demarcated with fabric-covered partitions (1.6–1.8 m high) and file storage units (1.6–2.4 m high). Practically all office chairs were fabric-covered. All floors throughout the building were carpeted with a hard-wearing short-pile synthetic carpet. The fleece factor and shelf factor were not calculated. Smoking was not permitted in the building for at least the last five years of occupancy. However, prior to this period, anecdotal evidence suggests that previous tenants permitted smoking throughout the building. The offices had been redecorated by painting and new carpets approximately three years before the study period. The fabric-covered office partitions were a mixture of partitions that had always been in the building (for approx. the last 15 years) and partitions that had been in long-term storage for at least the last five years. The only water damage visible was storm rain infiltration along the window sills on both the eastern and western ends of the building. The carpets and ceilings showed no signs of water damage and no major incidents were reported by the occupants.

The normal work of the current occupants dealt with large amounts of A0 and A1 size property and building plans and related paperwork. Their working situation produced continuous desktop clutter with plans and drawings also temporarily placed on the floor for several days at a time. The windows of the building were unopenable and located on the western and eastern ends of each floor. Comfort cooling was provided through a mixture of approximately 10–12% outside air and re-circulated air. The HVAC system supplied air to the whole building from a single air-handling unit (with chilled water only) to all floors via a central riser duct and through ceiling-mounted strip diffusers. A single return air riser duct extracted room air from all floors through one return air vent located adjacent to the service core of the building. The air filters were a synthetic dry bag type with an efficiency rating of 35% cut-off to No.1 test dust. Filters were normally changed once per year and washed two or three times during their year's service. No services or maintenance routines were changed and no other important exposures occurred during the study period. The only major changes in the building during the study period were the intervention activities.

Initial Investigation Design

Five floors of the building were investigated using a combination of monitoring for indicator parameters, walkthrough inspection surveys and a building occupant questionnaire survey. Monitoring strategies included spatial and temporal monitoring of carbon dioxide, carbon monoxide, temperature, and relative humidity, and spatial monitoring of formaldehyde, respirable particulate matter (RSP), and indoor surface pollution (ISP). Walkthrough inspection checklists were the type used by the USEPA as part of their Large Buildings Studies Integrated Protocol (USEPA, 1993). Monitoring locations (tiles) were chosen using the randomization method described in this same protocol.

Questionnaire Survey

The occupants were asked to report symptoms that they had experienced while working in the building in the last 6 months from a list of 12 typical symptoms and "other" for reporting any other symptoms that had been experienced.

- Tiredness
- Heavy headedness
- Headaches
- Dizziness/Nausea
- Poor concentration
- Irritation of the eyes
- Irritation of the nose
- Irritation of the throat
- Dry unproductive cough
- Dry or flushed face
- Itching or scaling scalp or ears
- Dry hands or itching red skin

Occupants were also asked to report how often they noticed environmental factors while working in the building in the last 6 months from a list of 16 factors:

- Dust
- Draughts
- Temperature too warm
- Too much variation in temperature
- Temperature too cold
- Stuffy or stale air
- Dry air
- Unpleasant odour
- Static electricity
- Tobacco smoke present
- Noise (from inside or outside)
- Poor lighting
- Ventilation system noise
- Skin bites but no insect visible
- Cramped space
- Excessive humidity.

A range of other questions asked occupants for their responses on factors such as general demographics, health background, comfort, and work- and job-related factors. The questionnaire design used in these investigations was a table format type and was distributed to every occupant in each study area. A brief explanation of the questionnaire and the importance of completing every question was given to groups of approximately 15 people at a time near their work area. Questionnaires were collected via sealed collection boxes located on each floor.

Environmental Monitoring

Random Allocation of Monitoring Locations (Tiles)

Each study area was divided into monitoring "tiles" as per the method suggested by the USEPA (1993). Representative sampling areas that approximated occupant exposure were selected. This randomizing of monitoring locations is intended to minimize potential investigator bias in the choice of monitoring locations.

Each floor was divided into tiles that were 5 m^2 in area. Tiles not representing typical office environments, such as service corridors, were excluded. Remaining tiles were allocated an identifying number starting from the most north-west corner, and every twelfth tile was temporarily assigned as a monitoring site. Where allocated sites were immediately adjacent, and no advantage was gained from their closeness, the second tile was randomly reassigned to provide a better spatial spread of sites.

Monitoring equipment was located and measurements were taken at individual work stations, with the person's consent, and at a height between 1.1 and 1.5 metres above floor level. This procedure was to approximate, as near as possible, actual exposure experienced by the building occupants without using personal monitoring equipment.

Monitoring Schedule

Temporal monitoring was conducted at each monitoring site in order to detect variations throughout a typical day. This included the simultaneous measuring of carbon dioxide, carbon monoxide, air temperature and relative humidity. Typically, monitoring occurred four times throughout the day at 2-hour intervals.

Spatial monitoring was conducted at each monitoring site at one point in time during the monitoring day in order to detect variations throughout the building. This involved the simultaneous monitoring of carbon dioxide, carbon monoxide, air temperature and relative humidity.

Respirable particulate matter samplers were placed at the beginning of each monitoring day, between 9:00 and 10:00 a.m., and retrieved at the end of a typical working day, approximately 5:00 p.m. (giving 7 to 8 hours sampling time or 800 to 900 litres of sam air).

Monitoring and Sampling Techniques

Respirable particulate matter was determined g metrically. Filter medium preparation, weighing, a racy specifications, and operating parameters are ir cordance with Australian Standards (AS-3640) USEPA monitoring standards (Winberry et al., 199

A known volume of air was drawn by a preci pump at 1.9 litres per minute through a 25 mm di eter 0.8 μm pore size mixed cellulose membrane f paper. The pumps used for sampling were of two t manufactured by "Gilian". Pump types were (1) " ian High Flow Sampler" model HFS 513A, and "Gilian – Gil Air" model No. Ex IA I/IIC TC (Au 1234 X). Filter membranes were housed in a respir cyclone air sampler for RSP fraction manufactured Cassella. Pump flow rates were calibrated with a litre volume bubble airflow calibration instrument using sampling head with filter membrane in train

Filter membranes were stored in a desiccator room temperature (circa 24°C) several days before p weighing and then returned to the desiccator in sampling head cassette after sampling for 24 hours fore post weighing. The difference in weight betw the unused filter membrane and the exposed fi membrane was determined using an electronic "6 ure microbalance" Satorius Microbalance Model M4 with readability to 1 μg. The mass of respira particulate matter per cubic metre was calcula against the volume of air pumped through the cycl sampler. Respirable particulate matter results are ported as micrograms per cubic metre ($\mu g/m^3$).

Quality control for respirable particulate sampli included one duplicate parallel sample and two bla samples per floor (per three samples). Despite the l volume of air sampled (<900 litres) and the low m of sample, the sampling method was accurate agai the duplicate and blank samples for each of the floo Only one sample on one floor was repeated due to u acceptable differences between the blank controls a the samples.

Air temperature and relative humidity were measur with whirling hygrometer. Readings were taken c rectly from a dry bulb and a wet bulb thermomet and relative humidity was calculated using a standa conversion slide rule as supplied with the instrume The hygrometer was maintained and calibrated a cording to manufacturer's standards, compliant wi Australian Standards, and the wick boiled clean an thermometers calibrated against a standard. The hy gromeer was manufactured by "Dobbie Bros. Austr lia", fitted with thermometers manufactured by "Brannan, England". Air temperature is reported in degrees Celsius (°C) and relative humidity is reported as a percentage (%RH). Measurement accuracy for temperature and relative humidity are at ±0.1°C and ±0.2% RH respectively.

Carbon dioxide (CO_2) concentrations were measured by drawing air samples with a "Komyo Kitigawa" sampler pump (Pump AP-1) through "Kitigawa" precision gas detector tube (tube No. 126C @ range 300–7,000 ppm) according to manufacturer's specifications.

Carbon monoxide (CO) concentrations were measured using a "GEM/AMAHSCO Gas Exposure Monitor Toxic Gas Dosimeter" type No.3EF22. Measurements were 5-minute averages at each location, the monitor being left running for the entire monitoring day. Concentrations are reported in parts per million (ppm).

Formaldehyde was sampled using passive, diffusion, monitoring badges containing a 2-4-DNPH treated membrane. Badges were exposed to the indoor air for approximately 8 hours at each monitoring tile. The quantity of formaldehyde captured on each of the membranes was determined by using High Performance Liquid Chromatography. Details of this method are presented in Dingle (1995). The concentrations of formaldehyde were calculated against the time period the monitoring badges were exposed.

Indoor surface pollution was measured on hard surfaces including desktops (within the working area), computer boxes (on top and closest to an occupant's working area) and computer screens (on top and closest to an occupant's working area) at each monitoring tile. Samples were taken using a wipe sampler constructed to be similar to the one evaluated by Lioy et al. (1993). Filter papers were prepared and weighed using the same procedures as for gravimetric determination of respirable particulate matter. Three locations in the monitoring tile and surrounding the RSP monitoring locations were chosen and marked for follow-up sampling. Duplicate samples were taken at one of these three locations in each monitoring tile as quality control with blank controls. ISP samples were taken after RSP sampling to avoid confounding the RSP measurements. Levels of surface pollution are reported in micrograms per square metre ($\mu g/m^2$).

Intervention Experiment Design

The initial investigation identified concentrations of respirable suspended particulate matter above international guidelines. These concentrations were considered a potential causal factor for symptoms and complaints in the building. The normal cleaning practices were also observed as being "poor" as cleaners were working to a time budget and not to cleanliness standards. This resulted in poor floor coverage by vacuum cleaning and minimal cleaning of hard surfaces; however, the offices looked superficially cleaner when litter was removed from the floors, any spills were cleaned, most of the desktops were wiped, and rubbish bins were emptied.

The lack of more thorough cleaning was suspected as being a major contributing factor to the elevated deposits of surface pollution on carpets, chairs, fabric-covered partitions and between office furniture. These built-up deposits of dust were targeted for an intervention strategy to determine any association between the surface dust and the elevated levels of respirable particulate matter recorded in the initial investigation and to record any changes in symptom prevalence.

The building was divided into five separate areas on a floor by floor basis. An intervention strategy involving a high performance cleaning regime was conducted on two floors. A third floor received a sanitation control intervention and the two remaining floors were maintained as control areas. The sanitation intervention did not involve cleaning practices, was not considered successful, and is not discussed in the post-intervention results section.

Experimental Controls

The *second* and *fifth* floors were used as *the controls* for the experiment where normal cleaning practices continued and no intervention action was taken.

Blinding Strategy

After the building was divided into floors, the people involved in organizing the cleaning interventions were asked to pick a floor at random by drawing straws on the day the initial cleaning was performed. The initial cleaning was also performed on a Saturday which was normally a non working day. No other people were in the building on this day except the security guards.

The continuous carpet cleaning over four weeks on the third floor (described in detail below) was performed after hours (6:00 p.m.) when by law all occupants were required to leave the building. This was also the normal time the building's current cleaners performed their duties and ensured that the extra cleaning actions would not be seen. During this period on the third floor, the normal cleaning staff emptied rubbish bins and cleaned hard surfaces as normal, but no normal vacuum cleaning was performed.

A question in the follow-up survey asked the occupants if they had "noticed any changes to their work environment during the last four weeks" as a cross check to determine whether they had become aware of the intervention actions. This was also an open question to give the occupants free range to answer.

Follow-Up Study

Four weeks after the initial intervention period, a follow-up study was performed. This involved a questionnaire survey, and environmental monitoring of RSP, ISP, CO_2, air temperature and relative humidity on all floors. Formaldehyde and carbon dioxide were not monitored post-interventions. The questionnaire was distributed to all occupants on all the floors. The questionnaire was identical to the initial questionnaire; however, it asked for observations only during the previous 4 weeks as this coincided with the intervention period. This may present a methodological problem, but a six-month recall period, as used in the initial questionnaire, would have confounded results as it overlapped with the period already covered by the first questionnaire. Furthermore, the intervention period had to be concluded within four weeks as several minor renovations and movements of furniture were scheduled directly after this period. Table 1 shows the timetable of intervention actions over the four weeks.

Carpet Cleaning Strategy

Intensive cleaning of the intervention floors involved the removal of visible dust deposits from all carpets (including crevices along walls and between furniture). Chairs and fabric-covered partitions were also cleaned. Both the vaccuum cleaners used had a rotating brush head as standard attachments supplied by the manufacturers. A crevice tool and a fabric-cleaning head were also used to clean appropriate surfaces. The lowing specific intervention actions were taken on e of the floors.

On the first floor in the building, a single intens cleaning of all carpets, chairs, and cloth-covered titions was conducted. The higher performance uum cleaning equipment used was a commerci available "Kirby" vacuum cleaner with a higher formance bag type filtering system. This cleaning performed on one day only during the initial in vention period. Normal cleaning and vacuum clean practices were not interrupted by this intervention were maintained as normal throughout the in vention period.

On the third floor in the building, an ongoing h performance cleaning was conducted throughout intervention period. An initial single intensive hig performance cleaning of all carpets, chairs, and clo covered partitions was also conducted. After the ini cleaning, the carpets were cleaned twice per week the evenings as per the normal vacuum cleaning gime. This continued for the duration of the 4-w intervention period. Normal vacuum cleaning pr tices by the existing cleaning contractors were stopp and all other normal daily cleaning practices, such trash removal and hard surface cleaning, were ma tained. The higher performance vacuum clean equipment used was a commercially available "Ther ax" vacuum cleaner with a primary water filtrat system and secondary electrostatic filter.

Other Intervention Conducted on the Fourth Floo

On the fourth floor in the building, a single sanitat treatment was conducted. This treatment was appl

Table 1 Interventions timetable

Intervention period	Intervention action
Week 0	• End of the initial building investigation, environmental monitoring and questionnaire survey
Week 1 (weekend) Initial intervention period. Performed during the normal working week.	• Intensive cleaning of all carpets, chairs and fabric-covered partitions on the first floor and thir floor (Saturday). • Once only sanitation treatment applied on the fourth floor. • Higher performance vacuum cleaning of carpets on the third floor on the Tuesday and Thursday evenings. • Monitoring for RSP conducted on the first and third floors.
Week 2 Performed during the normal working week.	• Higher performance vacuum cleaning of carpets on the third floor on the Tuesday and Thursday evenings. • Monitoring for RSP conducted on the first and third floors.
Week 3 Performed during the normal working week.	• Higher performance vacuum cleaning of carpets on the third floor on the Tuesday and Thursday evenings. • Monitoring for RSP conducted on the first and third floors.
Week 4 Performed during the normal working week.	• Higher performance vacuum cleaning of carpets on the third floor on the Tuesday and Thursday evenings.
Week 5 Performed during the normal working week.	• Follow-up occupant questionnaire survey conducted. • Post-intervention monitoring of RSP, carbon dioxide, air temperature, relative humidity an indoor surface pollution conducted on all floors.

as an atomized vapour spray to all carpets, chairs, and cloth-covered partitions. The ingredients were a mixture of alcohol and a camphor oil substitute. This treatment is normally used in houses with allergy sufferers as a means of controlling fungus, mould, bacteria and dust mites. This treatment is applied specifically to dry out substrates and desiccate microorganisms. No alterations were made to the normal cleaning practices on this floor.

Data Treatment

Respondents were asked to report symptoms experienced when working in the building. A positive response to a symptom was taken as being "building-related" and included in the analysis only if the second part of the question "did this symptom get better when away from the building?" was also answered positively. Failure to respond to a question also received no score by interpolating that the symptom or factor was not experienced while in the building.

Differences in questionnaire scores between intervention and initial values and against control values were calculated using t-tests (paired where possible). Actual significance (P) values are given for differences in symptom scores and environmental monitoring. Otherwise $P \leq 0.050$ was used to determine significance. The symptom results also include values up to $P \leq 0.100$ to show changes just outside the normal test for significance. All statistics were calculated using SPSS for Windows 3.x Release 6.1.3 (SPSS Inc.) and Microsoft Excel for Windows 3.x Version 5.0a (Microsoft Corp.) In accordance with accepted practice, figures derived after the interventions were subtracted from the initial values; hence a positive result shows a reduction in a target parameter and a negative result shows an increase.

Results of Part 1 – Initial Building Investigation

Walkthrough Investigation

The following were the main observations made during the walkthrough inspection.

1. The current carpet cleaning practices appeared to be relatively poor with many areas being "missed" by the cleaners. The shelves, tops of filing cabinets and bookshelves, office machinery and computers, chairs and office partitions were never scheduled to be cleaned by the normal cleaners, nor by any yearly special cleaning. A once-a-year "spring cleaning" was scheduled and involved shampooing and removing stains from all carpets.
2. The vacuuming equipment was a "normal" bag type with the typical low-efficiency filtration used in these units.
3. Surface dust was observed throughout the building on carpets, chairs, fabric-covered partitions, bookshelves, computer boxes and screens, and on top of filing cabinets (this also gave evidence of poor cleaning practices).
4. Many desktops and large areas of the floor throughout the building were cluttered with paperwork. Very often it was observed that piles of large site and building plans remained in the same place for up to two weeks and more. This situation restriced the areas underneath from being cleaned as the normal cleaners were never observed shifting papers during cleaning.
5. The original design capacity of the building's ventilation had most likely been exceeded by an increased density of occupants. The HVAC system may not be able to supply comfortable conditions adequately or supply adequate amounts of outside air to the occupants. This was confirmed during an interview with the Mechanical Ventilation Engineer responsible for the building.
6. Similarly, the building's ventilation design capacity had most likely been exceeded by increasing items of office equipment that generate heat in the building. The HVAC system may not be able to cope adequately with the increases in heat load. This was also confirmed by the Mechanical Ventilation Engineer responsible for the building.
7. A build-up of surface pollution was observed in the HVAC air-handling plant room and in most places the HVAC system duct work was inspected.
8. There was a slight but definable odour on entering the building, reminiscent of old buildings, but it was not a mouldy odour. Several other odours were detected at specific locations while walking through the building, including those characteristic of ozone and low-level VOCs, particularly near office machinery such as photocopiers and plan printers.
9. Tobacco smoking was banned in the building and was not permitted within the building envelope. However, odours of environmental tobacco smoke were detected in both of the emergency stairwells in the building, in the lift well, and in the rear entrance passageway. The source appeared to be infiltration from occupants smoking cigarettes outside the entrance from the mezzanine level carpark and at the rear entrance of the building. Several times, occupants or visitors to the building were also observed smoking in the stairwells while walking down to the exits.

10. The levels of conversational noise were observed to be relatively high in many locations throughout the building and could be a considerable annoyance to occupants unable to work in these conditions.
11. Some of the occupants also reported discomfort and annoyance from odours during several minor renovations that occurred several months before the study.

Initial Questionnaire Response

Table 2 shows the results of demographic data and personal characteristics reported by the occupants. A total of 78% of the building's 184 occupants completed and returned the initial questionnaire survey (a total of 143 respondents). The demographic personal characteristics and health history data are shown in Tables 2 and 3.

Subjective Symptom Reporting

The symptom scores for the individual floors showed variations; however, none of the floors were significantly different from each other within $P \leq 0.05$. Results for the whole building showed that 73% of the occupants experienced tiredness; 59% experienced poor concentration, 54% experienced heavy-headed 54% experienced headaches; 51% had irritation c eyes; 45% had irritation of the nose; 44% had irrit of the throat; 37% experienced a dry or flushed 34% a dry unproductive cough; 27% experienced ness/nausea; 21% had itching or scaling scalp or and 18% had itching back of hands or irritated sk

Environmental Factors

Results for individual floors show variations wit casionally one or two factors being significantly d ent from one or all the other floors. Most of th vironmental factors showed a relatively uniform d bution of perceptions throughout the building.

Results for the whole building showed that env mental factors with most dissatisfaction were relat comfort conditions. Specifically, perceptions incl temperature too warm by 70%; stuffy or stale ai 69%; too much variation in temperature by 67%; by 60%; temperature too cold by 52%; noise (fror side or outside) by 48%; cramped space by 48%; lighting by 43%; dry air by 37%; ventilation sy noise by 34%; excessive humidity by 33%; unplea odour by 30%; draughts by 27%; static electricit 19%; and tobacco smoke present by 12%.

Table 2 Demographic data and personal characteristics

Category	1st Fl	2nd Fl	3rd Fl	4th Fl	5th Fl	Average	Std. dev.
No. occupants per floor (n)	27	22	40	30	24	29	7.1
Gender ratio female/male (%)	22/78	45/55	20/80	23/77	39/61	30/70	11.4/11.4
Average age (years)	37	34	37	35	35	36	1.3
Hours at work/week/person (hrs)	37.2	38.3	37.1	38.2	37.8	38	0.6
Job category							
Managerial (%)	7	9	8	13	13	10	2.8
Professional (%)	63	18	68	67	35	50	22.5
Technical (%)	–	9	–	–	–	na	na
Clerical (%)	30	64	25	20	43	36	17.6
Secretarial (%)	–	–	–	–	9	na	na
Full-time/Part-time work							
Full-time	96	100	85	100	92	95	6.3
Part-time	4	0	8	0	4	3	3.3
Casual or temporary	0	0	8	0	4	2	3.6

Table 3 Current and past health status

Category	1st Fl	2nd Fl	3rd Fl	4th Fl	5th Fl	Average	Std. dev.
Smoking status							
Current smoker (%)	11	23	15	7	4	12	7.4
Current "social smoker" (%)	19	–	8	17	17	12	8.0
Former smoker (%)	22	23	23	27	13	22	5.2
Have never smoked (%)	48	55	55	50	65	55	6.6
Suffer from eczema (%)	4	10	13	7	13	9	3.9
Suffer from asthma (%)	4	14	10	10	17	11	4.9
Suffer from dust allergy (%)	12	33	21	33	25	25	8.8
Suffer from mould allergy (%)	0	5	5	3	8	4	2.9
Suffer from migraines (%)	19	45	13	13	25	23	13.3

Table 4 Average carbon dioxide concentrations by floor

Floor	Average (ppm)	Standard deviation (ppm)	Minimum (ppm)	Maximum (ppm)
1st Fl	883	224	600	1200
2nd Fl	828	142	700	1100
3rd Fl	822	206	600	1200
4th Fl	750	130	500	1000
5th Fl	683	130	500	850

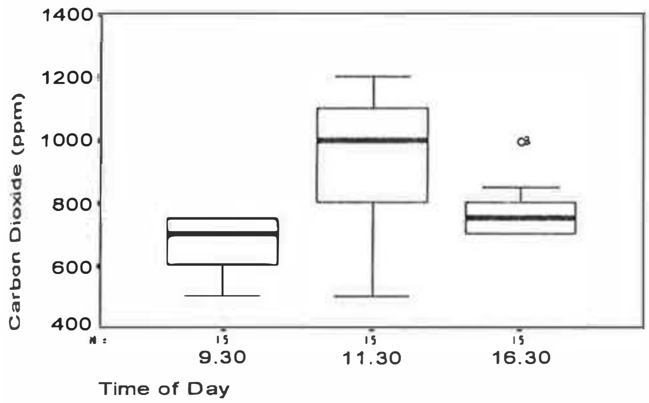

Fig. 1 Average carbon dioxide concentrations by time of day

Further Analysis of Questionnaire Data

Further analysis of environmental perceptions and psychosocial factors from the questionnaire data revealed the following salient features:

- 60% of the occupants rated their indoor environment as "clean".
- 58% of the occupants rated their work space as "reasonably comfortable".
- 53% of the occupants worked in "open space with partitions".
- 24% of the occupants had no window in their work space and no window visible from their work space.
- 60% of occupants used a photocopier either "often" or "sometimes".
- 51% of the occupants were "not very satisfied" with the conversational privacy of their work space.
- 55% of the occupants were "not very satisfied" with the freedom from distracting noise at their work space.

Initial Environmental Monitoring

Carbon Dioxide Concentrations

All monitoring tiles (except one on the 4th and 5th floors) recorded CO_2 concentrations greater than 800 ppm (Table 4). Three monitoring tiles on the 1st and 3rd floors also recorded the highest CO_2 concentrations of 1200 ppm.

One tile on the 5th floor had the lowest recorded concentration of 500 ppm and the whole floor had the lowest average concentration of 750 ppm. The location on the 5th floor with the lowest recorded concentration was a private office with a lower local occupant density than other parts of the building.

The average carbon dioxide concentrations throughout the monitoring day showed a peak during the middle of the day (Figure 1).

Respirable Suspended Particulate Matter

The average concentrations of respirable particulate matter (RSP) on each floor are given in Table 5. The average respirable suspended particulate matter (RSP) concentrations on all floors were ≥180 μg/m³. The highest concentration of 520 μg/m³ was recorded the 2nd floor and the lowest of 60 μg/m³ was recorded on the 5th floor.

Indoor Surface Pollution (ISP) on Hard Surfaces

Figure 2 shows the average indoor surface pollution levels recorded on computer boxes, desktops and

Table 5 Respirable particulate matter concentrations

Floor	Average RSP concentration (μg/m³)	Standard deviation (μg/m³)	Minimum (μg/m³)	Maximum (μg/m³)
1st Fl	310	135.3	170	440
2nd Fl	259	231.4	78	520
3rd Fl	187	65.1	120	250
4th Fl	178	108.2	74	290
5th Fl	233	151.4	60	340
Whole building	233	135.5	60	520

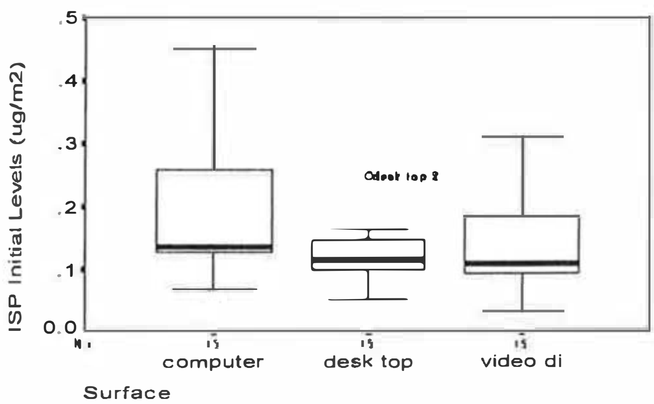

Fig. 2 Average indoor surface pollution concentrations on hard surfaces

Table 6 Average air temperature

Floor	Average (°C)	Standard deviation (°C)	Min (°C)	Max (°C)
1st Fl	23.6	0.9	22.4	25.2
2nd Fl	24.2	0.7	23.2	25.0
3rd Fl	24.1	0.3	23.5	24.8
4th Fl	24.1	0.4	23.4	25.0
5th Fl	23.6	0.8	22.6	25.2

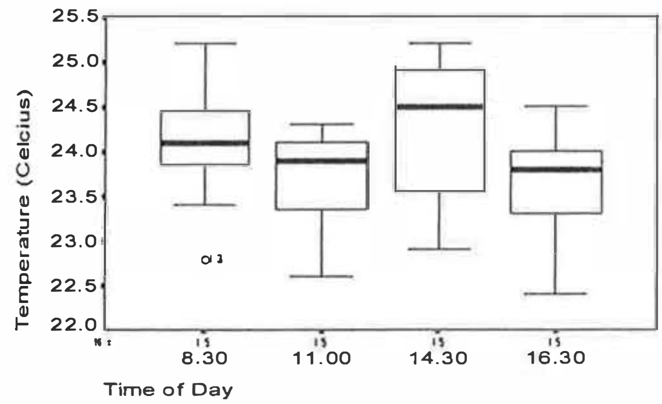

Fig. 3 Average air temperatures by time of day

video display units. The lowest concentrations of 0.032 µg/m^2 indoor surface pollution (ISP) were measured on a video display unit, and the highest ISP concentrations of 0.452 µg/m^2 were recorded on computer boxes. The ISP on the computer boxes was also highly variable with the greatest range in levels being recorded from these units.

Air Temperature

The maximum temperature of 25.2°C was recorded on the 1st floor at 8:30 in the morning and on the 5th floor at 2:30 in the afternoon (Table 6 and Figure 3). The minimum air temperature of 22.4°C was recorded on the 1st floor at 16:40 hours. The greatest range in temperature was 2.5°C and was also recorded on the 1st floor.

Relative Humidity

The highest relative humidity (RH) of 55% was recorded on the 4th floor (Table 7). The minimum RH of 40% was recorded on the 3rd floor at 14:30 hours. The greatest range of 19% was recorded on the 4th floor but otherwise all locations were within 10% difference in RH, with a peak in the middle of the day (Figure 4).

Carbon Monoxide

All locations recorded a time-weighted average of 1 ppm or less for a typical 8-hour period.

Formaldehyde

All locations showed the presence of formaldehyde b recorded concentrations of less than 50 ppb (parts p billion) which is typical for office buildings of this a

Results of Part 2 – Post-Intervention Environmental Monitoring

Most environmental parameters measured in the f low-up study, specifically carbon dioxide, air tempe ture and relative humidity, recorded variations wi some changes statistically significant compared to t initial recordings. However, none of these variatio were associated with the cleaning interventions their effects.

Post-Intervention Respirable Suspended Particulat Matter Concentrations

Significant changes were observed in RSP conce trations following the interventions. Table 8 shows t results of RSP monitoring and includes data from t initial monitoring and from four weeks after the inte vention actions. The average concentrations of RS were significantly reduced by approximately 80 ($P \leq 0.05$) on both of the intervention floors against the initial values and against the control floors.

Figure 5 shows the decline in respirable particula matter following the carpet cleaning interventions co

Table 7 Average relative humidities

Floor	Average (%)	Standard deviation (%)	Min (%)	Max (%)
1st Fl	47	2	43	53
2nd Fl	45	3	42	51
3rd Fl	43	13	40	54
4th Fl	46	5	36	55
5th Fl	47	4	42	52

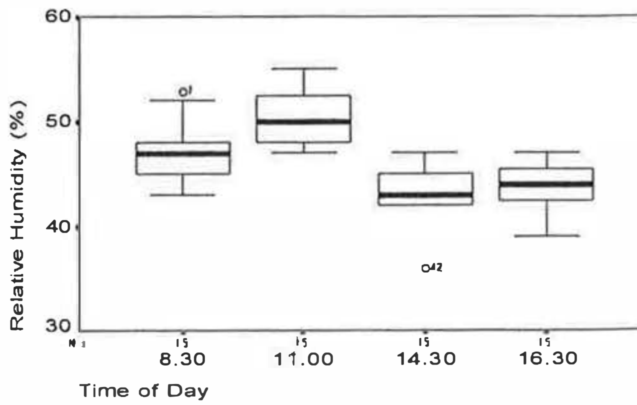

Fig. 4 Average relative humidities by time of day

Table 8 Reductions in respirable suspended particulate concentrations

Floor	Intervention action	Average levels before interventions (μg/m³)	Average levels after interventions (μg/m³)	Reduction (before – after) (μg/m³)	P-value against initial values	P-value against control floors	Percentage reduction from the initial levels
1st Fl	Intervention	310	38	270	0.038	0.038	87%
2nd Fl	Control	260	240	20	–	na	8%
3rd Fl	Intervention	190	33	160	0.034	0.031	84%
5th Fl	Control	230	210	20	–	na	9%
Combined controls	Combined intervention floors	245	35.5	209.5	0.031	na	85.5%

ducted on the first and third floors. The figure also shows a trend in the data collected on the intervention floors at 5 days, 2 weeks and $3\frac{1}{2}$ weeks after the intervention.

Post-Intervention Indoor Surface Pollution Concentrations

The levels of ISP varied greatly from initial recordings. However, the variations in ISP mostly showed no association with either the cleaning interventions or with reductions in RSP. The only change that showed any association was a significant reduction (P≤0.05) of ISP recorded from the computer boxes on the third floor against initial values but not against controls. Otherwise the measurement of ISP from hard surfaces may be a methodological problem.

Results of Part 3 – Post-Intervention Follow-Up Questionnaire Results

A total of 61.5% of the building occupants completed and returned the follow-up questionnaire (113 respondents), a response that was 16% less than in the initial questionnaire. The missing respondents on the third floor (Table 9) may be due to the 16% of the people on that floor who had part-time, casual, or temporary employment and were not present during the follow-up stage.

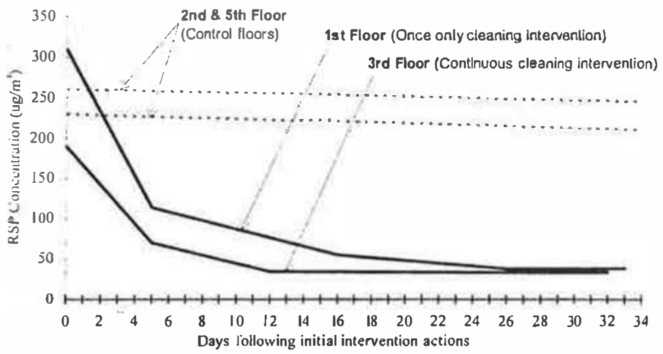

Fig. 5 RSP Concentrations following intervention actions

Total Symptom Scores

When the scores for all symptoms on each floor were averaged as a total symptom index, the total symptom scores on the cleaning intervention floors were reduced significantly (P≤0.060 to 0.000) against their initial scores and against the control floors using paired t-tests (Table 10).

Neither the two intervention floors nor the control floors showed a statistical difference between each other, hence the grouping of these floors into "control floors" and "intervention floors". When these groups are compared to each other and to initial scores, the reduction of symptoms by 17% on the cleaning intervention floors is highly significant at P=0.000.

The only exception to this was no significant difference between the 1st floor (intervention) and the initial score for the 5th floor. The 5th floor (control) also showed a significant increase in total symptom scores after the intervention period against its previous scores. However, this increase was not significant against the 1st floor at the first questionnaire. A similar trend occurred when comparing the combined control floors (2nd & 5th) against the initial scores for the 5th floor and the 1st floor. Other changes not normally considered significant (P≤0.100) are also shown in Table 10 to give a better representation of the trends in changes between questionnaires.

The reductions in total symptom scores relate to reductions in the personal symptom index (PSI) of 1.59

Table 9 Reductions in sample size between the questionnaires

Floor	Initial quest' (n)	Follow-up (n)	Difference (n)	Percentage of building total (%)
1st	27	16	11	6.0
2nd	22	21	1	0.5
3rd	40	28	12	6.5
4th	30	26	4	2.2
5th	24	22	2	1.1
Totals	143	113	30	16.3

Table 10 Decreases in total symptom scores after interventions: percentage difference and level of significance

Floor			Before intervention				After intervention				Combined intervention floors
			1st fl	2nd Fl	3rd Fl	5th Fl	1st Fl intervention	2nd Fl control	3rd Fl intervention	5th Fl control	
After intervention	1st Fl (Intervention)	%	11.5	6.8	10.3	–	na	na	na	na	na
		p value	(0.010)	(0.102)	(0.011)	–					
	2nd Fl (Control)	%	–	–	–	–	8.5	na	na	na	na
		p value	–	–	–	–	(0.060)				
	3rd Fl (Intervention)	%	17.5	12.7	16.2	9.5	–	14.4	na	na	na
		p value	(0.006)	(0.005)	(0.000)	(0.051)	–	(0.023)			
	5th Fl (Control)	%	–	–	–	−5.9	9.4	–	15.4	na	na
		P value	–	–	–	(0.062)	(0.011)	–	(0.002)		
Combined intervention floors		%	15.4	12.2	13.4	6.6	–	15.8	–	12.6	na
		P value	(0.000)	(0.000)	(0.043)	(0.024)	–	(0.000)	–	(0.000)	
Combined control floors		%	–	–	–	−9.9	12	–	18.1	–	16.6
		p value	–	–	–	(0.003)	(0.001)	–	(0.000)	–	(0.000)

Notes: Negative values show an increase and positive values show a decrease; –=No change in values within a significance of P≤0.100

less symptoms per person (controls versus interventi floors) and almost 2 symptoms less per person on third floor against initial values (Table 11).

Reductions in Specific Symptoms Associated with Cleaning Interventions

Significant reductions occurred in all but two of symptoms. The most significant reductions occurr with symptoms of eye irritation, throat irritation, unproductive cough, and nose irritation (Table which were reduced by 20% to 30% on both the int vention floors compared to both the initial values a the controls. The only exception to the above was t nose irritations were not significantly reduced on first floor with the once only cleaning interventio Among the other symptoms with significant diff ences, headaches, poor concentration, itching har and itching scalp were only reduced either on the 3 floor or on the 1st floor. Another salient feature of th results is that several symptoms showed an actual crease on the control floors after the interventions. T was reflected in the increase in total symptom sco on one of the control floors mentioned previously. other variations in symptoms tested were significa within P≤0.100.

The reductions in specific symptoms on the 3rd flo with the continuous cleaning intervention were grea with a higher significance. These reductions are sho more clearly in Figure 6 when represented in a Rad diagram similar to the format used in the MM Qu tionnaire by Andersson et al. (1993).

Perceptions of Environmental Factors

Many of the perceptions of environmental facto showed significant variations on all floors to the init questionnaire response. However, there was no cle pattern of association with intervention actions. Th is, significant "changes in perceptions" occurred both intervention floors against their initial values b these changes were either not simultaneously sign cant against the control floors, or were significa against one or the other of the control floors.

When the intervention floors were combined as

Table 11 Reductions in personal symptom index (PSI)

Floor	Initial quest'	Follow-up	Difference
1st Fl	5.70	4.31	1.39
3rd Fl	5.55	3.61	1.94
Comb. controls	4.94	5.45	−0.51*
Comb. controls – Comb. interventions	5.45	3.86	1.59

*Negative values show an increase

Table 12 Reduction in specific symptoms following interventions: percentage difference (%) and the level of significance (P value)

	Eye irritation		Throat irritation		Dry cough		Nose irritation		Headache		Concen-tration		Itching hands		Tiredness		Itching scalp		Dizziness	
	(%)	P-value	(%)	P-value	(%)	P-value	(%)	P-value	(%)	P-value	(%)	P-value	(%)	P-value	(%)	P-value	(%)	P-value	(%)	P-value
Control group before – Control group after	–	–	–	–	–	–	–	–	–	–	−16	(0.071)	−16	(0.042)	−13	(0.080)	–	–	–	–
Control group after – Intervention group after	41	(0.000)	24	(0.015)	16	(0.082)	18	(0.066)	17	(0.053)	19	(0.051)	20	(0.028)	19	(0.026)	–	–	–	–
Intervention group before – Intervention group after	29	(0.001)	30	(0.001)	24	(0.006)	21	(0.014)	17	(0.044)	13	(0.080)	–	–	–	–	11	(0.090)	12	(0.085)
1st Floor (intervention) Before – After	32	(0.023)	23	(0.070)	21	(0.099)	–	–	28	(0.039)	–	–	16	(0.089)	–	–	–	–	–	–
3rd Floor (intervention) Before – After	26	(0.011)	33	(0.002)	25	(0.016)	28	(0.012)	–	–	17	(0.084)	–	–	–	–	15	(0.092)	–	–

(Note: negative values show an increase and positive values show a decrease)

single group, there appeared to be a group of factors that were reduced against the combined control floors. Specifically, the perceptions showing reductions are shown in Table 13. However, none of these reductions were significant against the control floors, and hence cannot be considered as true changes in perceptions.

The combined control floors also showed significant reductions against their initial values of too cold 18.6% (0.075), stuffy stale air 11.8% (0.046), and variations in temperature 9.5% (0.080).

The rating of cleanliness (Table 14) showed no association with the cleaning interventions, other than improvements on the first floor, and were significant only against initial values and not against control floors. This pattern was continued on rating specific surfaces of computer and desktops and bookshelves. The occupants on the combined intervention floors were 5% less satisfied with the general cleanliness and 6% less satisfied with carpet cleanliness than on the control floors. The control floors also showed no significant changes to cleanliness rating or cleanliness of any particular surface. Surfaces including chair legs, chair seats, and office partitions showed no changes in cleanliness rating.

Post-Intervention Results from the Fourth Floor: Sanitation Intervention

The results of the fourth floor intervention were not reported in detail in the follow-up results as this paper concerns cleaning interventions and not sanitation processes. Even so, the fourth floor also recorded a significant reduction in RSP concentrations. However, neither the total symptoms nor any individual symptom showed any significant difference. The only result from the questionnaire data was a significant reduction in perception of relative humidity. However, this was not associated with any other environmental measurements; particularly the reduction in average RH by 3% on the fourth floor was similar to variations in RH measured as a building-wide phenomenon.

Discussion

The results of the intervention experiment confirmed that the "normal" low-efficiency vacuum cleaning practices and equipment was a major factor contributing to the deposits of ISP in the building. The building occupants also contributed significantly to poor cleaning practices by restricting access of the cleaners to surfaces covered by their paperwork normally left on desktops and on floors. The environmental monitoring showed that RSP can be reduced by removing

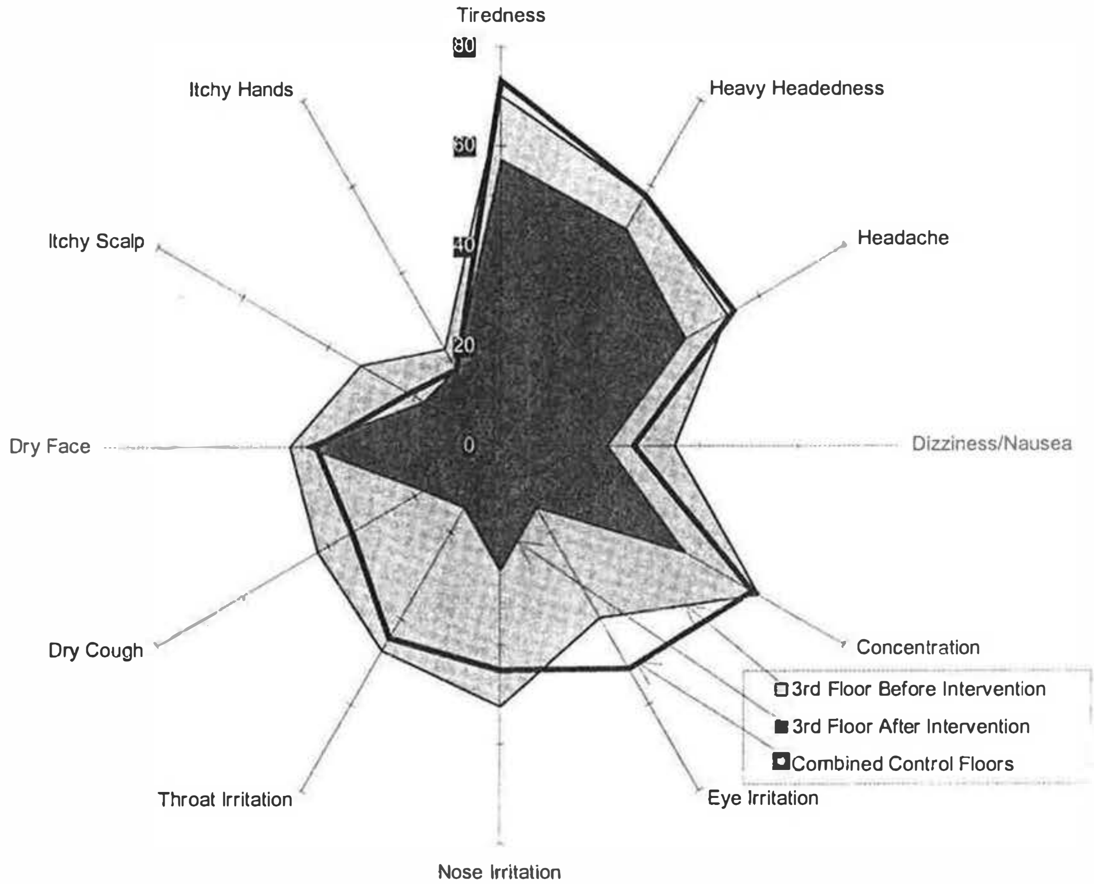

Fig. 6 Reduction in symptoms on the third floor after continuous cleaning intervention

ISP deposits which can in turn reduce general SBS symptoms.

Initial Building Investigation

The walkthrough investigation in the initial building study was effective in identifying a major problem with the current housekeeping practices by revealing that many desktops and large floor areas throughout the building were cluttered with paperwork, in some places for up to two weeks and more. This situation prevented the areas underneath from being cleaned as the normal cleaners were instructed not to disturb paperwork left on desktops and floors and consequently were never seen shifting papers during cleaning. This situation of paperwork cluttering surfaces is similar to that described by Raw et al. (1993) in their cleaning intervention study.

The poor cleaning performance was also partly due to the gradual cutting back in cleaning budgets that meant surfaces such as tops of filing cabinets and bookshelves, office machinery and computers, chairs and office partitions were never scheduled to be cleaned.

The tight time budget also meant that cleaners had to perform their duties and move on to the next building as quickly as possible. The routine monoton cleaning the same place every day without adeq time effectively meant that if a cleaner never clea between furniture, that area would probably neve cleaned but more because of habit rather than lazir This situation was also noticed with the workers forming the continuous intervention cleaning on third floor two nights per week. The greatest causes of this "best practice" fatigue identified was serious obstruction to cleaning by the design and out of furniture, and the perception that the inten

Table 13 Changes in perception of enviromental factors: vention floors against controls

Enviromental factor	Percentage difference	P-value
Too cold*	30.1	(0.000)
Odour	22.7	(0.009)
Poor lighting	17.4	(0.077)
Variations in temperature*	15.9	(0.004)
Excessive humidity	15.0	(0.096)
Too warm	12.9	(0.008)
Indoor noise	11.4	(0.083)
Cramped space	6.82	(0.066)

*Control floors also showed significant reductions

Table 14 Changes in the rating of cleanliness of surfaces

Floor		General cleanliness rating	Computer tops	Desktops	Bookshelf	Carpets
1st Fl –	% Diff.	10%	11%	14%	19%	–
Initial values	P value	(0.021)	(0.064)	(0.034)	(0.008)	–
Controls –	% Diff.	−5%	–	–	–	−6%
interventions	P value	(0.061)	–	–	–	(0.102)

Note: 10% would mean the surfaces were rated as 10% cleaner by all occupants

cleaning did not appear to be very much more effective at removing ISP compared to the initial cleaning. That is, it was hard work and very time-consuming.

Evaluation of the demographic and personal characteristics from the questionnaire data produced the following salient features: the gender ratio in the building was 30% female to 70% male; virtually all the occupants worked a normal full week and half with professional jobs; one quarter of the occupants were current or recreational smokers; just under half the occupants suffered from hay fever and a quarter suffered from dust allergy, and migraine headaches.

Building-related symptoms experienced by the occupants were elevated with more than half the building experiencing tiredness, poor concentration, heavy-headedness, and headaches. A second group of symptoms reported by just less than half the occupants were the mucous membrane irritations of eye, nose, and throat.

The environmental factors reported with most dissatisfaction were related to comfort conditions and suggested that the HVAC system was not able to provide a comfortable work environment. One other environmental factor reported by the occupants was dust, noticed by 60% of the occupants.

The initial environmental monitoring revealed carbon dioxide concentrations elevated above 800 ppm which was the current Occupational Safety and Health Association's recommended maximum level. The peak CO_2 levels also related to the maximum building occupancy at around 11:30 a.m. (anecdotal information from the employee managers). These two factors indicated that the building appeared to have poor ventilation and was unable to deliver adequate amounts of outdoor air to the occupants.

The average RSP concentrations on all floors exceeded 120 $\mu g/m^3$ which is greater than most international guidelines, and suggested that a significant source of suspended particulate matter may be present in the building.

The air temperatures in the building did not appear to be related to occupancy of the building or time of day and also demonstrated the inability of the HVAC system to provide enough comfort cooling to compensate for heat sources in the building such as the occupants and office machinery.

The RH levels in the building were similar to the CO_2 levels in that they appeared to be related to occupancy. The other parameters of carbon monoxide and formaldehyde levels were well within current acceptable limits at all locations.

Reductions in Suspended Particulate Matter

The results shown in Figure 5 highlight that the once only intensive cleaning intervention was able to reduce RSP concentrations significantly when compared to initial levels and the control floors. These results also show little difference between the once only (first floor) and the continuous cleaning intervention (third floor). Both interventions also appear to show that these levels are maintained at lower concentrations to a range of between 30 and 40 $\mu g/m^3$ for up to 4 weeks after removing the deposits of surface dust.

The extra data collected on the intervention floors at 5 days, 2 weeks and $3\frac{1}{2}$ weeks after the intervention were measured to search for any trends in RSP levels and revealed an interesting gradual decline beyond 5 days and a levelling out of reductions at around 4 weeks following the interventions.

This maintenance of reduced RSP concentrations recorded on the intervention floors may be due to the fabric-covered surfaces acting as a sink for any residual or new contamination by RSP on that floor. These results suggest that little advantage is gained from continual higher performance cleaning of the carpets in regard to RSP levels. However, more research is needed in this area before this can be clearly stated.

The inability of the fabric-covered surfaces to act as a sink may explain the initially high RSP levels recorded in the building. That is, the carpets and furnishings may have been "saturated" in their capacity to trap particles and any disturbance of these surfaces may have resulted in re-suspension of particulate matter, particularly since fabric-covered surfaces other than the carpets had never been cleaned in the life of the building.

Slight but insignificant reductions of RSP also occurred on the control floors. While these changes may have been due to small variations in seasonal influences, weather conditions, activities indoors, or a slight redistribution of RSP from control floors throughout the building, it is not clear from the results, as little information has been collected on these factors and how they impact on RSP levels.

Reductions in Symptoms due to the Interventions

The reductions in RSP concentrations on the intervention floors was also associated with a statistically significant reduction in all but two of the symptoms. Significant reductions in general symptom prevalence has also been reported in other intervention studies by Raw et al. (1993) after high efficiency vacuuming of surfaces, intensive office cleaning practices, and dust mite reduction measures.

The symptoms with most significant reductions were the mucous membrane irritations including eye irritation, throat irritation, dry unproductive cough, and nose irritation. This provides some evidence for the suspicion that elevated suspended particulate matter is responsible for these symptoms, as changes in mucosal clearance have been known to be associated with exposure to particulate matter (Berglund et al., 1992). The reduction in tiredness/fatigue (and malaise) recorded on the intervention floors has also been reported in association with poorly cleaned carpets, evidenced by a reduction in these symptoms after carpet removal (Nexo et al., 1983).

Success of Blinding Strategy

The success of blinding the building occupants to the intervention was confirmed from the follow-up questionnaire where no occupants noticed that the cleaning practices had been altered, except for one person on the third floor who noticed that the "cleaning was better".

Perceptions of Environmental Factors

The perceptions of dust might have been expected to be reduced on the intervention floors considering the successes of the intervention actions and the reductions in suspended particulate matter recorded. Even so, several environmental factors did improve on the intervention floors.

Perceptions of dust only showed increases on the first floor against one of the control floors, and on the third floor against both of the control floors. However, this was not evident when combined intervent floors were compared to combined control floors.

The decrease in unpleasant odour on the in vention floors may be due the reductions in respira particulate matter; however, the decrease was only s nificant against control floors on the first floor. I reasonable to assume that the cleaning interventi removed odorous deposits of surface pollution. T may also provide further evidence that the carpet v able to act as a sink and adsorb odorous substan from the indoor air after it had been cleaned.

When the occupants were specifically asked to r the general cleanliness and the cleanliness of spec surfaces in their work area there was also no asso ation with the cleaning interventions. The rating cleanliness on specific surfaces was the last question the questionnaire, in order not to confound sympto reporting and environmental perceptions.

Even though several environmental factors did i prove on the intervention floors, the results from t perceptions of environmental factors are confusing a do not lead to a simple interpretation with the oth results of RSP and symptom reductions. This may due to a phenomenon where the occupants' perce tions of their environment were more related to t high levels of building-related symptoms experience and that any reduction in symptoms can bring abo changes in the perception of the environment whi may not necessarily be measured as an improvemen

The Sanitation Intervention on the Fourth Floor

It is suspected that the reduction in RSP on the four floor may be due to a similar mechanism as occurr on the cleaning intervention floors. That is, the alcoh and camphor spray applied to fabric-covered surfac may have affected the nature of particulates in such way that they became conglomerated and the norm cleaning practices may have been able to gradual clean away particulate matter. Similarly, the reducti may be due to the removal of dead and decaying m crobes and their debris and excrement by the norm cleaning practices, as the alcohol base of the substan used is designed to desiccate microorganisms and d out substrates.

However, it is generally accepted that anti-microb agents, such as the type used on the fourth floor, a less effective in preventing biological contaminati than other methods such as source control by remov or altering the basic conditions that lead to infestati (Baechler et al., 1991). The reduction in the percepti of excessive humidity on the fourth floor may indica a potential "drying out" effect of the sanitizing ca phor oil vapour. However, any drying out effect m have been on the mucous membranes of the occupants rather than in the environment. This may have been reflected in the reduction of perception of excessive relative humidity which did not correlate with environmental measurements.

Methodological Problems with the Cleaning Intervention Study

While the experiments were successful in reducing visual ISP, RSP, and symptom levels, there are several problems that need to be addressed for future investigations. A problem with the questionnaire was that occupants were unwilling to give their names and subsequently the follow-up analysis was unable to utilize paired t-tests to evaluate more accurately within-occupant changes. This would have affected the sensitivity of detecting changes between the questionnaire responses, and in particular may have disqualified a number of other changes that in the current analysis had P-values between 0.100 and 0.150. Similarly the reduction in sample size of 16% less of the occupants responding in the follow-up questionnaire may have affected sensitivity.

The slight reductions in RSP on the control floors may also be due to the normal cleaning staff improving the efficiency of their cleaning practices as it was necessary to make the normal cleaning staff aware of the intervention actions in order to coordinate their cleaning services. The implication is that the cleaners may have improved their practices in order to "save face" with the building management. This situation may have been more clear if outdoor air measurements had been performed in parallel to the indoor measurements.

The results from ISP monitoring showed no association with reductions in visual levels of ISP or with RSP concentrations. This may be an indication that RSP was not a significant component of ISP. While it is generally accepted that the ISP levels are more stable over time than RSP concentrations, other studies have also found no correlations between surface and airborne particulate concentrations (Sansone, 1987).

The lack of association between RSP and ISP is more likely due to methodological problems with the ISP sampling technique. Some of the more important problems with ISP sampling include the relatively small sample area used. This can give a misrepresentation of the actual surface pollution because of the normal large variations in ISP around a person's working area, often observed in office buildings. The number of samples taken was the same as for RSP sampling; however, a much higher sample number may have reduced the noise from the large variations revealed.

Another problem with the ISP may have been the transfer of static electricity charge to the filter paper observed at the point of sampling which could lead to a possible loss of sample from static repulsion. It may also be important to note that ISP sampling methods sample a large range of particulates right up to visible particles. The researchers involved with designing and evaluating the ISP sample method used here also showed that smaller particles can be lost to surface scratches and wood grain (Lioy et al., 1993). Similarly, the filter paper used in this method is not able to collect all of the surface dust, especially where it is built up to thick deposits.

A major criticism of the study design was that the ISP concentrations from carpets and chairs were not monitored. However, specialist equipment used for dust sampling, such as that used by Gyntelberg et al. (1994), was not available for the study. Therefore vacuum cleaners were used to remove the deposits from a known surface area and the dust captured was post-weighed. This was attempted during the initial cleaning phase but several major problems became apparent. One was that no matter how often the chairs and carpets were cleaned, the next passing with a vacuum cleaner would always remove more particulates. This prevents any accurate measurement of re-deposition on these surfaces. Even if it were possible to completely remove the particulates, the sampling of these surfaces on the control floors would have generated too much noise in the results due to the small surface area being monitored and the wide variations between the few chairs and the pieces of carpet that were tested. There is also the problem that any monitoring location would have been directly adjacent to a major source of particulates (the carpets) and would measure re-dispersal from the source and not re-deposition of dust.

While ISP measurements showed no associations to the intervention, it seems reasonable to suggest that if there is less surface dust there should be less possibility for dust to be re-suspended into the air by occupant activities or by cleaning staff and their equipment.

While the blinding strategy appeared to be successful, the slight suspicion that the building's normal cleaners may have to "save face" with management was only a potential problem on the third floor as the normal cleaners were stopped from vacuuming the carpets during the intervention period. The same cleaning staff were also responsible for cleaning hard surfaces, emptying rubbish bins etc., and could see how their normal duties had been changed. This situation may have had a small effect on the RSP results on the control floors; however the changes recorded there could also be due to the variations in particulate matter that appear common both indoors and outdoors. The study design also reinforces the need to keep all third parties involved in building studies blinded to intervention strategies, although in some cases this may be difficult to achieve, especially where normal operations need to be suspended or changed, as occurred in this investigation.

Conclusions

The results of the intervention experiment confirmed that the "normal" low-efficiency vacuum cleaning practices and equipment used on carpets, and their complete lack of use on other fabric-covered surfaces, was a major contributing factor to the build-up of ISP deposits in the building. The activities of the building occupants also contributed significantly to poor cleaning practices by restricting the cleaners from gaining access to surfaces covered by paperwork and building plans normally left on desktops and on floors.

The post-intervention environmental monitoring confirmed that the cleaning interventions were able to reduce elevated concentrations of RSP and may be effective in maintaining lowered concentrations for the month after the initial cleaning. The removal of surface deposits may allow surfaces such as carpets to act as a sink again by trapping particulate matter.

It was demonstrated that the elevated levels of respirable particulate matter were responsible for general SBS symptoms and in particular irritation of the mucosal membranes. Specific symptoms included irritation of the eyes, nose and throat, and a dry unproductive cough. However, the improvements made to the indoor air quality were not reflected in any clear association in the perceptions of environmental factors by the occupants, other than a general improvement in perception of a range of factors that were not expected to be associated with elevated levels of particulates.

Effective cleaning methods for carpets and furnishings in buildings is an important issue as it is difficult if not impossible to isolate occupants from these potential sources of indoor air pollution. In particular, there is a strong need to consider the type of equipment used in cleaning buildings and to assess the effectiveness of the cleaning methods and practices. There is also a clear responsibility of the occupants not to obstruct cleaners in performing their work by allowing paperwork that "should not be touched" left covering large surface areas after hours and on weekends.

This and other studies on office cleaning clearly show that more attention should be paid to the design and selection of furniture, and the layout of offices to facilitate office cleaning by making it a much ea task to perform.

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