Research Report



# Ventilation system hygiene

## A review of published information on the occurrence and effects of contamination

CIBSE

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# VENTILATION SYSTEM HYGIENE - A REVIEW OF PUBLISHED INFORMATION ON THE OCCURRENCE AND EFFECTS OF CONTAMINATION

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# 1. INTRODUCTION

## 1.1 Purpose of this report

Information about the operation and maintenance of HVAC equipment, the personnel involved in their day-day upkeep and the procedures and tools they use is of interest to all working in the field of building services. One particular feature which is currently being questioned is the standard of cleanliness of ducted systems and the relationship, if any, between the presence of dirt on the internal surfaces of such installations and the quality of air supplied to occupied spaces.

The HVCA has introduced a guide to the standards of internal cleanliness to be met for new ductwork installations (DW/TM2, HVCA, 1991). However, concern has been expressed about the effects of any subsequent build-up of contamination during normal operation.

This report reviews the published information on the subject of ductwork contamination and its influence on indoor air quality. It also seeks to determine whether there is evidence to demonstrate the effectiveness of current good practice in ductwork cleaning procedures.

## 1.2 The duct cleaning issue

It is widely accepted that ventilation system progressively become contaminated with dirt. Contamination potentially begins when the various components of a system arrive on site. Storage areas are often exposed and consequently dust and debris are likely to infiltrate the ends of ductwork that are left open. These sources of contamination can largely be avoided by following the guidance contained in the HVCA guide DW/TM2. During operation however, the process of dirt and dust entering the ductwork continues through the use of low efficiency and/or poorly fitting filters; poor maintenance can also result in fungi growing on filters and shedding spores and hyphal fragments into the duct. As recently as 10 years ago, the process of dust accumulation was allowed to continue indefinitely.

Employers now face a number of statutory obligations to provide good hygiene especially in respect of air quality. These requirements are embodied in the Health and Safety Executive documents 'Control of Substances Hazardous to Health Regulations (COSHH)' 1988, the 'Workplace (Health, Safety and Welfare) Regulations' (which come into effect in 1996 for existing workplaces) and the 'Management of Health and Safety at Work Regulations' (applicable from 1993).

Of particular importance in these documents is the requirement that "in the case of mechanical ventilation systems (including air conditioning systems) they should be regularly and properly cleaned, tested and maintained to ensure that they are kept clean and free from anything which may contaminate the air". The regulations provide no guidance on the standards that need to be achieved in practice to meet requirements regarding such terms as "regularly", "properly", "clean" and "contamination". However these terms represent important considerations for all those involved in ventilation system hygiene as there are no established methods to estimate the risks of component or system designs, or to compare alternative designs. Nor are there criteria for deciding at which stage of pollution a ventilation system should be cleaned, or how to rate the result of cleaning. The situation is further compounded by a lack of information about the influence of surface roughness on dust absorption, the suitability of the cleaning method and the result of cleaning (Leskinen 1991).

Another area that remains unclear relates to the suitability of biocides used to disinfect ventilation ductwork. For example, claims are made that only "food grade material" is used, but this does not necessarily imply that they do not, or can not, contribute to indoor air pollution. In the USA certain biocides have been specifically approved by the Environmental Protection Agency as safe for disinfecting ventilation ductwork.

### 1.3 Terms of reference

The project objectives were:

(1) To identify and assess the existing literature on the subject of ductwork contamination and its effect on the quality of air supplied to occupied spaces in buildings;

(2) To determine whether there is evidence to demonstrate the effectiveness of current good practice in ductwork cleaning procedures;

(3) To recommend a programme of research to provide objective information not available from past or current investigations on this topic.

## 2. IMPLICATIONS OF CONTAMINATED VENTILATION SYSTEMS

Mechanical ventilation is a well established method of controlling indoor air quality (IAQ). Ventilation removes pollutants in the air by dilution and/or by using filters. However, ventilation can introduce new problems which would not exist without forced air movement. For example pollutants may concentrate in some places, and may be propagated and thus redistributed through the system.

It is generally accepted that the pollution load in a room originates from a variety of sources. The main indoor sources of concern at present are emissions from building materials, filters, dirty ducts and the building occupants themselves. These all have a bearing on IAQ. Little has been done to analyse the problems, to identify potential sources or to eliminate them. In a recent review of issues and initiatives relevant to the building industry, "pollution and hazardous substances" was ranked as a priority item.

Tightening the building envelope and other efforts to decrease the quantity of outdoor air introduced into a building, coupled with an increase in the duration of time people spend indoors have seen an increase in the numbers of IAQ complaints.

The Construction Products Directive of the European Union (48) and the Health and Safety Commission "Workplace health, safety and welfare Approved Code of Practice" (49) require that products and surface finishes do not contribute to indoor air pollution. However, there is little guidance on the hygiene conditions that should be achieved. There are at present no standards that set out acceptable levels of cleanliness for duct surfaces, levels for the presence of microorganisms or indeed criteria for IAQ.

Since 1976, when an air conditioning system was implicated in causing the famous outbreak of Legionnaires Disease in Philadelphia USA, there have been many studies to examine the impact of air conditioning on indoor air quality. However, few studies have reviewed the levels of air contamination caused by microorganisms. There is concern that HVAC equipment (humidifying, cooling and heating coils, filters and ductwork) may become a source of microorganisms. That being the case, the HVAC system is potentially able to disperse microorganisms into the occupied space. People suffering from various symptoms while in air conditioned rooms may show sensitisation to fungi that can be isolated from air conditioning equipment. For example, in June 1987 a woman in Florida USA won a workers' compensation benefit case claiming that she was exposed to pathogenic moulds that caused her to become hypersensitive. Her doctor stated that he had established the fact that her illnesses were directly attributable to a contaminated workplace (Robertson 1990).

*Economic impact*
Large buildings may include several miles of ductwork in the ceiling voids and service cores and several hundred diffusers. The cost of cleaning the ductwork and associated components could run into many thousands of pounds.

A common view among cleaning organisations is that access arrangements in existing systems are totally inadequate. They estimate that perhaps as much as 50% of the cost of cleaning a system for the first time is attributable to arranging permanent access. They also point out that compared with the installation costs of an air conditioning system, cleaning costs are a relatively small sum of money and there are arguments that it should be planed for. Subsequent cleaning operations would then be considerably cheaper, although there is at present no answer to the question of "how often should it be cleaned" ?

The greatest possible improvement in the performance of the system is thought to be gained from cleaning of heating and cooling coils. This assumes that airflow and heat transfer efficiencies will be increased. More difficult to evaluate, however, is the effect of duct cleaning on human performance at work. Economically, this is where the greatest potential for payback exists.

## 3. SYSTEM CONSIDERATIONS

The primary function of air conditioning is to control the purity, movement, temperature and relative humidity of the air in a space within specified limits.

Normally the purity requirement is addressed by specifying an amount of outdoor (fresh) air to be supplied to the conditioned space. The amounts specified are predominantly those identified in professional guides and codes as being sufficient for respiration and the dilution of contaminants, particularly body odours, to acceptable levels.

The process of removing dust and aerosols from the supply airstream by means of fibrous media filters appears to be directly related to an air purity requirement but, in practice, filter choice tends to be concerned more with preventing fouling of the ventilation system than improving air purity in the space. The filters used range from the most inefficient prefilter, capable of capturing only very large particles, to the super efficient absolute or HEPA filters. Normally filters are classified according to tests set out in BS 6540: Part 1:1985/Eurovent 4/5. Those most frequently used have efficiencies of the order of 75% (EU5). Some authors, for example Pasanen et al (1992) and Prokopiw (1988), recommend that filtration efficiencies should not be less than about 85% (EU7). This is the minimum necessary to prevent the small atmospheric particles of soot and oil fumes (typically <10 micron in diameter) entering, and perhaps accumulating in, the ventilation system.

The most commonly used material for ducts in ventilation systems is galvanised sheet metal. However, even in such systems the supply air is likely to come into contact with many other materials. For example, in existing systems, the airflow is likely to impinge on small areas of asbestos, copper, aluminium, rubber, neoprene, canvas, mastics, brickwork, foam insulants and silencer materials such as rockwool and fibreglass. Where flexible ducting is involved, materials such as paper, plastic and man made fibres (NILFLAM) may come into contact with the air. With the current interest in passive cooling technologies such as hollow floor slabs (for example "TERMODECK"), ductwork in the future could contain a substantial quantity of a composite material like concrete.

## 4. POSSIBLE HAZARDOUS EFFECT

### 4.1 Introduction

All human endeavour involves risk. The success or failure of any venture depends on how well the risks are assessed and dealt with. Risk is usually taken to mean the combination of hazard and vulnerability and its assessment can be used to reduce the costs and/or consequences of work or operations with uncertain outcomes. In assessing risk at work management would be expected to include the effects on property, production, the quality of output and the possible injuries to people. There is a case that it should also include environmental damage outside and away from the building since the public are becoming more aware of the global consequences of building construction and use.

#### 4.1.1 *Concept of risk*

Ventilation and air conditioning systems are thought by some to have the potential to become a hazard. For example, a poorly maintained ventilation system might become a generator of pathogens and then, through normal operation, transmit them, perhaps to cause human respiratory ailments. In this report hazards or hazardous effects associated with ventilation systems (taken to include all the component parts of the supply, the people served, the exhaust system and the external surroundings), have been identified on the basis of "what happens if?" questions. Hazards can be expressed in various ways, thus in the case of a contaminated ventilation supply system it might be in terms of the numbers and types of viable particles dispersed per volume of air (ie a health hazard). Alternatively, hazard may be expressed in terms of the period during which viable particulates remain viable, or of their potential effects. Hazard is usually determined separately for each particular situation. It may be the result of a specific event or action at a particular location (for example plant start-up), or may be that expected to arise due to a combination of events in a particular area (for example condensation).

Vulnerability is essentially a means of describing the amount of damage or loss of performance that would be caused by a known level of a hazard. For ventilation systems vulnerability relates to the chances that a particular hazard might occur and the range of consequences associated with it. A highly vulnerable part of a system (for example people) could be associated with significant damage when exposed to relatively low levels of contamination. Alternatively, a part with low vulnerability (for example filters) may be associated with little or no damage even when subject to relatively high levels of contamination.

As part of this review we have examined the condition of ventilation systems in four office buildings (see Appendix 3) to permit comparisons to be made with published figures for values and vulnerabilities. These figures may be peculiar to or representative of specific climates or other conditions. Ultimately, risk assessment leads to allocation of a cost or cost ratio (for example decontamination cost versus replacement cost). Scientific publications are completely devoid of such information.

**4.1.2** ***Problems of research***
Reports into the effects of contaminated ventilation systems fall into three broad groups; those derived from hypothesis testing, from experience, and from field studies.

The vast majority of reported work falls into the second and third groups. Such work tends to incorporate fewer scientific controls and as a result, objective verification suffers. The following difficulties are apparent:

- In field studies, where cross-sectional research designs are favoured, it is often difficult to find differences in indoor contaminant levels between normal and problem buildings and to compare the data collected from various areas with each other. This is due to the fact that the contaminants are derived from both the indoor and outdoor sources and many factors influence the development and concentrations of airborne contaminants.

- Differences in quantity and quality of, say, spore sources and meteorological conditions cause a strong temporal and spatial variation in outdoor air spore levels and flora. The most distinct difference in airborne spore levels is observed between the Subarctic and Temperate zones in the winter when snow and frost interrupt microbial activities in nature covering up spore sources and thus preventing the release of spores into the air. However, the Subarctic winter offers an excellent opportunity to study indoor fungal spore sources and other factors affecting indoor air spore levels without disturbance caused by outdoor spore sources (Pasanen 1992).

- Side by side comparisons of air samples have demonstrated that the variation of spore concentration with time in buildings is a problem. In one study, there were minute-by-minute variations. Weekly variations of airborne propagules of between one and two orders of magnitude have been observed in houses (Miller 1990).

- Besides outdoor air each building has indoor sources of fungal spores including foodstuffs, house dust, house plants, pets, bedding, carpets and furniture from which spores, and sometimes yeasts, are released into the air.

#### 4.1.3 *Presentation of evidence*

The following sections of this report assess the published research evidence and information on the possible effects of contaminated ventilation systems. For the purposes of the study the effects have been broadly grouped under five headings:

- Reduced airflow
- Altered response of plant sensors
- Odours
- Disease
- Sick building syndrome.

### 4.2 Reduced airflow

#### 4.2.1 *Possible mechanisms*

Experience suggests that particulates are deposited in ventilation ductwork. If the process is continuous, particulates could build-up within the ventilation system to such an extent that system performance becomes impaired and could, as a result, adversely affect indoor air quality. Performance can become impaired in at least two ways. Firstly a part, or parts, of the system may become blocked. Secondly, the overall frictional resistance to airflow in the system may increase and thereby reduce air flowrate. Neither process would be readily detected.

#### 4.2.2 *Evidence of vulnerability*

An overall assessment of the evidence available is that information is available to improve understanding of the theory and practice of particulate deposition, where it occurs and typical accumulation rates. Knowledge of the accumulation rate of particulates is an essential prerequisite to deciding the frequency of cleaning.

In theory the deposition velocities of aerosols can be predicted, but the equations available are cumbersome. The deposition velocity of particles determines how long they remain airborne before being deposited in the ductwork. For example, calculations suggest that spherical particles with a diameter of 100 microns (large in comparison with the sizes normally found in filtered ventilation system) would drop out of an airstream if its velocity falls below 0.25 m/s. Such airspeeds are much lower than the average velocities (typically 2.5 m/s) used in conventional ventilation systems.

El-Shobokshy (1982) experimentally validated two highly regarded deposition equations and concluded that they gave results that were broadly in agreement with experimental results for both rough and smooth surfaces. Computer simulation work (Wallin 1993) suggests that deposition rates increase rapidly in straight ducts as surface roughness accumulates, reaching a peak in a brief period. In a series of laboratory experiments (Riffat et al 1991) examining deposition rates, it was concluded that particle deposition occurred at a steady rate along the length of a duct.

Work still in progress elsewhere is specifically aimed at examining the relationship between dust deposition rates in ductwork fittings and aspects of system design, is being undertaken as a EUROVENT project, Liskinen (1991) and more recently a TNO publication (1993). A similar project has been submitted for SERC funding (1994) by Reading University.

*Typical deposition rates*

Table 1 details the surface densities of dust collected in some 32 ventilation systems covering a wide range of ages and locations. Surface densities vary from 1.10 - 140.8 g/m$^2$ with average surface density figures for the four studies varying from 6.8 - 18.2 g/m$^2$. These figures translate into yearly accumulation rates of 0.51 - 12.8 g/m$^2$/yr. The results given by Laatikainen et al (1991) are relatively high, probably because one system had dirtier ducts than the other systems due to a high concentration of pollen.

**Table 1** **Dust accumulation in ventilation systems**

| Reference no. | 7 | 8 | 13 | BRE (Appendix 3) |
|---|---|---|---|---|
| No. & type of system studied | 7 ventilation systems (1RA) | 6 systems, 2 with humidification but 8 supply ducts sampled (2FA, 4RA) | 13 ventilation systems (no cooling or humidification) (7FA, 6RA) | 4 systems with cooling. 2 with humidification (2FA, 2RA) |
| Surface density g/m$^2$ (avrg) | 3.6-140.8 (18.2) | 1.2-58.3 (10.6) | 1.1-50.9 (6.8 excluding extreme value of 50.9) | 1.3-10 (7.6) |
| Yearly accumulation rate g/m$^2$ | 0.51-12.8 (2.3) | 1.2-8.3 (3.5) | (0.7) | 0.26-3.3 (1.3) |
| Age of systems (years) | 5-11 | 4-31 | 5-29 | 3-20 |

FA = Fresh air only
RA = Recirculated air

The large ranges can be attributed to many factors:

- Different dust collection methods: Sticky labels (BRE); Dust loosened by razor blade and collected by a pump onto a millepore filter (Valbjørn et al 1990): Dust loosened with a nozzle and collected onto a filter (Laatikainen 1991)
- Building age
- Filter efficiency
- Maintenance (frequency of filter change).

Measurements of the accumulation rate in "TermoDeck" concrete ducting (BRE 1992), where airspeed was less than about 1m/s and filtration at EU3 grade, indicated an accumulation rate of about 2 g/m$^2$ per year.

Dust layers in the 5 to 10 g/m$^2$ range are clearly visible and most accurately described as a thick surface coating. However, some researchers (Pasanen et al 1992, BRE 1993, Valbjørn 1990) judge such layers to be too thin to have any practical effect on flow rates in ventilation ducts.

Observational evidence reported by duct cleaning companies, Prokopiw (1998), HAC (1992), Barnes (1985), suggests that, in practice, dust accumulation rates do occur that are capable, over periods of between 12 and 20 years, of restricting or blocking airflow, altering the balance of a system and perhaps preventing the movement of dampers.

Measurements by Wallin (1985), on kitchen exhaust systems in apartment housing suggests that the build-up of contamination was responsible for reducing system flowrate by 20 to 30% after periods of about 4 years. Wallin concluded that low air velocities in the duct system decreased the dust deposition rate.

*Filtration*
It is well understood that filtration is important to duct cleanliness. During system operation, particulates enter the ductwork through filters of low filtration efficiency and as a result of air bypassing poorly fitting filters. It is also possible that substantial quantities of particulates are released into the ductwork unless care is taken when changing filters.

Laatikainen (1991) has demonstrated a significant correlation between filter classification and the dust accumulation rate in a ventilation system. Dust accumulation rates in supply ducts are about three times slower with filters rated EU7 than with EU3 rated filters (Pasanan 1992). The greatest difference is found between the coarse filters EU2 - EU4, presumably because of the wide disparity in filtering efficiency.

The average dust density in exhaust ducts was 2.7 times higher than in the supply ducts (Valbjorn 1990). This presumably reflects the fact that exhaust air is not normally filtered. Most surprisingly the Valbjorn reports that little difference was found in the average amounts of dust in certain supply ducts of systems with and without recirculation. Such a result must be treated cautiously, however, because no account was taken of filter efficiency.

From the point of view of vulnerability to deposition, Pasanan et al (1992) detected no significant difference between dust accumulation levels on different floors of the same building. This suggests that all parts of the supply ductwork are equally vulnerable. However BRE's experience suggests that dust is mostly deposited where constrictions such as heating coils or dampers occur, and that finer dust is more evenly spread throughout the system.

## 4.3 Altered system response

### 4.3.1 *The possible mechanism*
Ventilation systems are sometimes operated by adjusting the flowrate of supply (and exhaust) air in relation to the level of pollution existing in an occupied space - the so-called demand controlled ventilation (DCV). The sensors used in such a control arrangement are mainly for temperature, carbon dioxide, moisture and volatile organic compounds. Sometimes these sensors are located in the ventilation ductwork. During

normal operation of the DCV ventilation system, dust and other contaminants could build up on the surface of the sensing elements sufficient to alter their response and impact on air quality.

#### 4.3.2 *Evidence of vulnerability*

We are aware of only one publication regarding the performance of sensors for DCV. In 1992 the International Energy Agency (Annex 18) published information on sensor tests. The report suggests that there is a complete lack of information from sensor manufacturers to advise on maintenance and calibration intervals for 10 of the 15 sensors examined. Where manufacturers were able to give information it was not very specific, (for example, more than two years between calibrations).

### 4.4 Odour

#### 4.4.1 *Possible mechanisms*

Odours in ventilation systems are thought to develop through the combination and interaction of the component parts of the contaminants deposited on surfaces.

#### 4.4.2 *Evidence of vulnerability*

This is a poorly researched area. The evidence available is largely laboratory based and superficial about both odour generation and the source components.

Filters have been implicated as a source of pollution in ventilation systems and the most frequently measured variable is air quality (in decipol) (Bluyssen 1993, Valbjorn et al 1990). The source strength (in olf) of new filters appears to be unrelated to airflow but very strongly related with used filters (Bluyssen 1993). There appears to be large variation in odour emission between used filters from buildings situated in different locations (Seppanen 1991).

Used filters represent a hostile environment for microbes because they are usually low in nutrients and water content. However, microbes are extremely adaptive and they utilise even the scarcest opportunities to grow, some doing so at low temperatures because growth is mainly controlled by moisture; relative humidities of 75% appear to be sufficient to support growth (Valbjorn et al 1990).

Bluyssen (1993) has suggested that odours are associated with microbial growth in the trapped dust layer. Fungi for example, are know to be capable of producing odorous metabolic products and irritants. Microbial activity is also associated with $CO_2$ production. Contaminated filters are therefore regarded as a potential odour source in a ventilation system.

Not always is there a direct relationship between perceived air quality (in olf) and chemically determined source strength (in $\mu g/m^3$). This is explained by the fact that particulate matter in filters from different locations will have different characteristics. The human nose perceives some of these as annoying while the concentration of the pollutant may not be detectable by an instrument. Alternatively the perceived pollutants may not be included in the group of compounds measured by the instrument.

## 4.6 Disease (Caused by non-viable particulates)

### 4.6.1 *Possible mechanisms*

The mechanism of interest is that the ductwork can be instrumental in causing an increase in the concentration of particulates in the supply air. Under certain conditions, the deposited dust in the ventilation system is re-entrained into the supply air stream and then dispersed into the occupied spaces (black streaking around supply diffusers is taken to be visible proof of the action). The particulates are assumed to be of respirable size, mainly inorganic materials and non-viable fragments of micro-organisms, and have the potential to impair the health and welfare of people. It is further assumed that deposited particulates could under certain circumstances be modified by gaseous pollutants before being re-entrained.

### 4.6.2 *Evidence of vulnerability*

Very little data exist about the capacity of ventilation ductwork, poorly maintained or otherwise, to re-entrain and disperse dust and other particulates.

However, Turner et al (1990) have shown that under normal circumstances the overall levels of respirable suspended particles (RSP), usually considered to be particles with diameters < 2 µm, can be higher in naturally ventilated buildings not equipped with a filtration system than in mechanically ventilated buildings. This statement relates to situations where the filters in the mechanically ventilated systems were less than 10% efficient in the RSP range, subject to poor maintenance, excessively loaded and poorly fitting.

An increase in dust emission from a supply system is reckoned to be due to either a filter shedding fibres or a secondary source of pollution. Some work by Lester et al (1992) suggests that small particles (0.5 - 2 µm size) that are not captured by filters are later entrained into the airstream from the air handling unit and the duct work and deposited in the rooms. This process is velocity dependent and presumably can only be limited by fitting additional filters towards the supply diffuser end of the HVAC system (Charkowska, 1992).

The effects on health of increased dust concentrations depends on two factors, the size of the particles and their chemical composition. In a building in which a considerable number of employees were complaining of symptoms of the respiratory tract, air samples showed that the concentration of airborne particulates varied from 14.2 - 131.5 µg/m$^3$ in the air supply ducts and 15.6 -31.2 µg/m$^3$ in the offices. Analysis of the samples in the supply ducts identified fibres from the pre-filters, fibreglass, mineral dust, mould etc. The same particulate materials were found in the rooms as in the ducts although the proportion of each differed in the two locations (Samimi 1990). This work demonstrates that the ventilation system itself can become an additional polluter of the space it serves.

In the UK the guideline normally used in relation to dust contamination is the Health and Safety Executive document EH40/91 Occupation Exposure Limits 1991. The document recommends that personal exposure should be kept below 10mg/m$^3$ 8 hour time weighted average (TWA) total inhalable dust and 5mg/m$^3$ 8-hour TWA respirable dust.

Currently there is growing concern about the methods and materials used in the manufacture of filters and their possible health effects. Shumate et al (1990) have developed a quantitative test method to measure the extent of fibre shedding from air filtration media. This methodology was used to evaluate fibre glass and organic fibre filtration media. Both filter products shed small amounts of fibres in the respirable range (less than 0.3μm in diameter). The difference between filter media was negligible. The number of fibres released in to the environment was 0.0015% for particles greater than 0.19μm in size. The rate of particle shedding for both products was reduced with time.

## 4.7 Disease (Caused by biological contaminates)

### 4.7.1 *Possible mechanism*

The underlying mechanism of interest is that the ductwork may become both a reservoir and a multiplier of biological agents and biologically derived materials which are then automatically dispersed through the normal operation of the ventilation system. These biological items, chiefly including bacteria, fungal spores and endotoxins are thought to have the potential to impair the health and welfare of people either by causing an infection or by causing an allergic reaction. To aid understanding of the health implications, an explanation of terms and mechanisms is given in Appendix 2.

### 4.7.2 *Evidence of vulnerability*

Microbial contamination of indoor air encompasses the effects of viruses, bacteria and fungi. In our view the literature dealing with microbial contamination is probably the most difficult to interpret. Many different species of fungi and numerous bacterial types have been found inhabiting ventilation systems. However, published work tends to concentrate on fungi. Miller (1992) considers that this emphasis occurs because viruses are thought to be transmitted almost entirely by personal contact and, although bacteria are reported to be present in air samples, there is no direct evidence that they contribute to disease apart from the specific case of legionellosis.

The literature contains three extremely informative documents dealing with various aspects of viable particulates in the workplace; these are Burge (1990) on the ecology of fungi, Environmental Health Professional Practice on mould fungal spores (1985) (64) and World Health Organisation Series No 3 (1988) setting out the effects of biological contaminants in indoor air. We have drawn heavily on these documents for the background information which is given in Appendices 1 and 2. The thrust of the review has been to assimilate the knowledge contained in a small collection of papers reporting experiments, surveys and observational studies on different aspects of biological contamination associated with ventilation ductwork. Overall the collection provides detailed, but highly specialised, views about specific aspects of contamination, in particular:

- surface contaminants and the potential for microorganism growth within ventilation systems
- the potential for ventilation systems to act as a multiplier of microorganisms
- the links between ductwork conditions and disease.

*Surface contaminants*
The amount of dust accumulated in a duct may determine whether or not it should be cleaned. However, it is not so much the amount as the composition of the dust that gives an indication of whether or not it poses a threat to health.

Although much concern has developed about the effect of contaminated ventilation ductwork, the results of a study by Turner et al (1990) in 26 Swiss buildings suggests that conditions obtaining in air-conditioned buildings are little different than those in non-air conditioned buildings. Table 2 below relates the principle measurements. The airborne microbiological samples yielded a wide range of fungal species, these were generally similar to outdoor air sample results.

**Table 2 Airborne microbes (cfu/m³) found in ventilated buildings**

| | Airborne microbes (cfu/m³) | |
|---|---|---|
| | Range | Mean |
| Mechanically ventilated | 111-1000 | 405 |
| Naturally ventilated | 116-775 | 345 |
| Mixed ventilation | 13-554 | 420 |

In a series of microscopic examinations to determine the composition of dust layers in supply ducts in four buildings (3 air conditioned, 1 mechanically ventilated) (BRE 1990) it was concluded that the layers were mainly crystalline and carbonaceous dust deposits with occasional traces of textile, aluminium and rust particles. Visual inspection indicated that the contamination was generally consistent throughout the duct system with heavier deposits on the bottom of the ductwork and other internal horizontal surfaces.

More detailed analyses of dust layer compositions in supply air ducts and filters in 13 buildings by Valbjørn et al (1990) showed that the layers contained macromelecular organic components of biological origin, microfungi and bacteria. The content of the macromelecular organic components was from 0.9 to 8.9 mg per g of dust from the ducts and 0.2 to 5.1 mg/g of dust from the filters. The numbers of viable particulates are given in Table 3

**Table 3 The number of viable particles found in supply air ducts and filters**

| | | No. of viable particles /g of dust |
|---|---|---|
| Microfungi | Supply air ducts | 79-6200 |
| | Filters | 70-3400 |
| Bacteria | Supply air ducts | 50-5000 |
| | Filters | 100-6700 |

Further refinement of samples showed that the dominant micro-fungi were Penicillium, Chaetomium, Aspergillus, Alternaria, Mucor & Rhizopus.

Valbjørn et al concluded that:

- There were fewer bacteria in the supply air ducts of systems operating on 100% outdoor air than in systems with recirculation.

- The dust found in supply ducts did not differ microbiologically (macromelecular organic components and microfungi) from floor dust in the buildings.

- Dust in supply ducts is "cleaner" than that in exhaust ducts.

Other researchers are broadly in agreement about the make-up of dust layers. Laatikainen et al (1991) and Pasanan et al (1992) report inorganic residues (which typically include phosphates, ash, chalk, metal oxides, soot, mineral wool) ranging from 58 - 91% of the total dust. Laatikainen et al (1991) put the average protein content of the dust layers at slightly less than 1%. However the average amount of total pollen in the dust was 9%, and they concluded that most of the protein in the dust was pollen.

Samples taken from ventilation systems in Sweden showed that low numbers of microorganisms were found on the surface of the air supply duct. In comparison with the supply air duct the numbers of microorganisms in exhaust ducts were in some cases different, although in other cases there was no apparent difference (Sverdrup et al 1990).

These results are consistent with the view that the contamination accumulated in ventilation systems originated from outdoor air and possibly reflects on the quality of filtration normally used and on the air tightness of the filter cassette and assembly frame.

*Bacteria*
The extent and overall importance of bacteria in ventilation systems can best be gauged through work carried out by Hugenholtz et al (1992).

Samples (taken over 1 year) from an air handling unit in a "healthy" building (ie, one with no record of building-related illness) were as follows. The down-stream surfaces of the cooling coil had highly variable microbial populations, both spatially and temporally ranging from no detectable bacteria to $10^5$ bacterial cfu/cm$^2$. Conversely, the up-stream surface of the cooling coil had consistently high bacterial numbers, $10^5$-$10^6$ cfu/m$^2$. The highest numbers of heterotrophic bacteria were found in the water samples from an evaporative condenser and on the upstream surfaces of the cooling coil. Fungi however tended to dominate on dry surfaces such as the fan chamber housing, duct surface and some parts of the return side cooling coils. Other studies by Miller (1992) and BRE (1993) tend to confirm that bacteria are less prevalent in the ductwork than fungi.

The possibility that bacteria become airborne was examined in a study involving measurements at various locations in a system. Air samples contained low levels of bacteria ($10^3$ cfu/m$^3$) with the exception of the post-coil air sample at the start of the study. This was probably due to the presence of condensate on the coils (Hugenholtz et al, 1992).

Sverdrup et al (1990) reported observing increased numbers of bacteria appearing in the airflow in a ventilation system after start-up. For the system examined the increase was small compared to the numbers occurring within the occupied zone. This is consistent with human activity being the main source of microorganisms in the occupied spaces. The number of bacteria in the room decreased once the ventilation system was operated.

*Fungi*

To assist in the understanding of the following sections, a resume of the ecology and principal effects of fungi, based on a report by Burge (1990), has been included as Appendix 2.

Miller (1992) develops the case for believing that exposure to toxigenic moulds such as penicillia and aspergilli, as opposed to phylloplane moulds (non parasitic), represents a significant health hazard. His case is built on three kinds of data: Results of lung tissue autopsies in Japan; animal models of the resistance to fungal pathogens; and large epidemiological studies of the respiratory health of children in Canada and the USA.

Ventilation systems can have a distinct effect on indoor air fungal spore levels, particularly during the frost-free seasons. Under normal conditions airborne spore levels are usually higher in buildings with natural ventilation than in buildings with mechanical ventilation. In naturally ventilated buildings, fungal spores enter the indoor air through open windows and doors. In buildings with mechanical exhaust systems, infiltration and the entrance and impaction of spores in construction are potentially increased because of high negative pressures inside the building. However, mechanical exhaust ventilation also removes spores from indoor air more efficiently than natural ventilation. The lowest airborne spore levels have been observed in buildings with mechanical supply and exhaust systems. The low spore levels are attributed to filtering of the supply air, high ventilation rates and low air infiltration (Pasanen et al 1992).

Rytkonen et al (1988) studied the conditions of growth of *Aspergillus fumigatus* and *Penicillium* sp, two fungi that are associated with ventilation systems. This work suggests that the conditions obtaining in most supply systems are potentially ideal for their survival and multiplication. The minimum growth temperature for both fungi was found to be 9-10°C. The colonial growth rate was approximately half of that observed at higher temperatures. A. fumigatus grew fastest at 30°C and Penicillium sp. at 19-22°C. The relative humidity of the air appears to have a direct effect on fungal germination. As the RH decreases there is a lag in the time to generation which differs between species as does the RH level at which germination fails to occur.

From a ductwork contamination point of view, at the optimum growth temperature, the number of spores increases as the ambient air humidity increases. At temperatures above or below the optimum growth temperature, sporulation decreases significantly as the relative humidity of the air approaches saturation, at RH levels of between 92 and 96%. The quickest way of controlling or eliminating growth occurs when substrate temperature increases and the relative humidity of the air decreases; a situation developing from drying of the medium below a critical level.

The one important outcome of this work is that fungal germination should be expected whenever water is available in a medium, even when the atmospheric relative humidity is low. For contamination of the air to occur with fungi or fungal products, a reservoir containing living fungi is necessary to provide inoculum, an amplifier is necessary to allow growth and reproduction of the organism, and a means of dissemination is required. A reservoir can be a dirty filter, damaged and wet sound lining in a ventilation system, standing water in drip pans or humidifiers, or condensation or intrusive water on surfaces. The presence of slime, obvious fungal growth or obvious mouldy odours can be assumed to represent contamination. Accumulated dry pigeon droppings are most likely to harbour *Cryptococcus*.

It seems entirely reasonable to assume that the insides of ventilation systems are unlikely to become wet (other than within humidifier sections) when operating normally. However Pasanen (1990) warns that it is important to consider all possibilities. He points to the example of an intermittently operated central air system where part of the ductwork is located in unheated spaces. Such an arrangement he suggests could result in condensation, which in turn would support fungal growth in the ducts, resulting perhaps in increased fungal spore levels in the supply air. If air is recirculated, both supply and exhaust air ducts may act as fungal spore sources for indoor air.

Other work reviewing the extent of contamination in ventilation systems revealed that, in nearly half the systems sampled (5/12), the number of microorganisms increased along the length of the airflow path. There did not appear to be any difference between types (mechanical supply and exhaust; mechanical supply and exhaust air system with recirculated air; mechanical supply and exhaust air system with rotating heat exchangers; mechanical supply and exhaust air system with humidifying unit) of ventilation installations in terms of microorganism contamination (Sverdrup et al 1990).

*se studies*

ew studies have tested the link between ventilation system condition and disease.

strial hygienists were called into a 70 year old building after employees complained of e flu-like symptoms. The initial inspection of the office spaces revealed that airborne bacteria and fungi were 0-150cfu/m$^3$ and surface bacteria and fungi 0-30,000cfu/m$^3$ (CO, $O_3$ and formaldehyde measurements were made but none were detected). Concern over the microbial results led to cleaning of the ducts serving the affected area.

After cleaning the HVAC system, bioaerosol samples were observed in the normal background range (less than 350cfu/m$^3$) and microbial wipe samples were all low (less than 700cfu/square foot). The consultant commented that the HVAC system was dirty in some sections even after cleaning. A second evaluation of the office again found no CO or formaldehyde and low levels of airborne fungi (2-6cfu/m$^3$) and airborne fibres (less than 0.01 fibres/cm$^3$).

Three weeks after the occupants returned to the building following cleaning, a second wave of symptoms was reported. One of the conclusions of the case study was that, due to misunderstanding and over-reaction on the part of the management, the situation was prolonged. By evacuating the office and cleaning the ducts, credibility was given to the environmental hypotheses and symptoms recurred (6).

In another study, Schata el at (1989) tested 150 patients (64 female, 86 male) between 32 and 47 years of age, suffering from various symptoms when in air conditioned rooms. Fungi were isolated from the filters of the air conditioning systems to determine whether these fungi evoked the allergic reactions. Most of the positive results were produced by Penicillium species. 25% of the patients showed positive skin results for Cladosporium herbarium and Alternaria tenius isolated from air the conditioning equipment. Aspergillus species produced a reaction in only 20% of the patients. Schata el at therefore assumed that the "air conditioning disease" was largely an allergic disease caused by sensitivity to mould allergens dispersed by the air conditioning equipment.

Morey et al, 1984 have reported that in one particular building the composition of fungi isolated from rooms with fan coil units differed from the composition of fungi in the outside air. In trying to explain the differences they concluded that the peripheral fan coil units and small air handling units must have acted as reservoirs for viable fungi.

*Stachybotrys atra* is known to colonise cellulosic materials and has been associated with building-related illness on a number of occasions. Dust and lint that had accumulated in the air conditioning ducts of a house in Chicago became colonised by *S. Atra* (burge, 1990). Extensive investigations indicated that this was the only unusual exposure in the house. The occupants suffered from a variety of maladies. Removal of the contamination was claimed to relieve the distress.

One outbreak of aspergillosis has been shown to be the result of contaminated air ducts (Turner et al 1990). Cultures from the exhaust duct were transported to the rooms due to reverse flow in the ducts caused by a fan malfunction.

*Filters - microorganisms and fungi*
Filters are mostly incapable of removing all the pollutants from the external air and, in some cases, the numbers of moulds or yeasts increases after the filter. In practice filters are usually located close to the inlet of a system. As a result they can not protect against the entrainment of dust particles or microorganisms from the components and surfaces of a

HVAC system (Lester et al 1992).

The amounts of fungi and bacteria in filters that had been used for 6 to 24 weeks are given in Table 4 (Martikainen et al 1990).

The characterised fungi belonged to the normal outdoor fungal flora of the area (which was in Finland). The authors report that the water content of the filters was low and correlated with the number of bacteria but not with the number of fungi. This indicated that most of the fungal colonies were from germinated spores and not from vegetative cells.

**Table 4 Bacteria and fungi in filters**

| | |
|---|---|
| Viable bacteria in the filters | $3\times10^3$ to $1.9\times10^5$ cfu/g of dry material |
| Viable fungi | $7\times10^2$ to $2.5\times10^5$ cfu/g |

Considerable variability exists in views about the potential for filters to pollute the supply air. Sverdrup et al (1990) and Hugenholtz et al (1992) report that the least amount of contamination was associated with filters that had recently been changed before sampling. In contrast, Martikainen et al (1990) report that the period of use of the filters did not correlate with microbial content. These conclusions have to be treated carefully because no account was taken of the different climatic and seasonal effects. Airborne microbe levels vary greatly depending on the wind and weather conditions (Martikainen et al 1990).

In one building with fan coil units, filters in both the air handling unit and fan coil unit were heavily laden with dust and debris. Dust from a filter in a small air handling unit contained ~ 3 x $10^7$ viable fungi/g (90% of the isolates were *Penicillium* spp (Morey et al).

## 4.8 Sick Building Syndrome

### 4.8.1 *Possible mechanisms*
SBS may be caused partly by the allergic or irritant effect of airborne contaminants. The contaminants, including micro-organisms, could come from the ventilation ductwork, which acts as a reservoir.

### 4.8.2 *Evidence of vulnerability*
Sick building syndrome (SBS) is now generally regarded as a significant problem in the workplace. The symptoms are irritation of the eyes, nose, throat and skin together with headache, lethargy, irritability and lack of concentration (Raw 1993). Although the cause (or causes) are not clearly known it is widely thought that SBS has multiple causes or classes of causes (for example, the presence of air conditioning, or indoor air quality). It is important, however, at this stage in our understanding to allow for the possibility that, whilst there are probably many combinations of causes in different buildings, in some

buildings there might be a single main cause (Raw 1993). This latter possibility has been exploited by at least one Company who have linked SBS with dirty ventilation systems in a duct cleaning advertisements in a technical Journal.

The probability that a dirty ventilation system is the main cause of SBS can only be partially assessed. American and Canadian experience for example suggests that, in only about 9% of problem buildings, is the condition of the ductwork even under suspicion (Bolsaitis et al 1993).

In a study of costs of office premises (Scope 89) at least one thousand workers in 128 office sites in the UK (representing a floor area of some 6 million sq. ft. and total staff population of 30,000) were surveyed. Only 21% of the buildings were reported to have had complaints which relate to SBS. Of these 82% were concerned with real building issues such as lighting and layout arrangements. This result is broadly in agreement with the American experience in that only a very small proportion could have been associated with SBS.

In a search for the causes of SBS (Harrison et al 1990), the indoor air of fifteen buildings was sampled and analyzed for its microbial and particulate content. With an 88% sample of building occupants completing questionnaires it was established that the highest symptom prevalence rate was in mechanically ventilated buildings. The lowest was in naturally ventilated groups of buildings. However, the highest levels of particles and microorganisms were found in the naturally ventilated buildings. The negative correlation for airborne particulates both between and within ventilation groups suggested that there was no causal relationship between airborne particles and sick building syndrome. Similarly there was a strong negative correlation for airborne microorganisms between levels of bacteria and fungi and symptom prevalence rates which tended to dominate the positive correlations found within each ventilation group (naturally ventilated; mechanical ventilation plus air conditioning). It was concluded that airborne particulates and microorganisms are unlikely to be a major cause of sick building syndrome. In our opinion further work is needed to examine the relationship between non-viable particulates and SBS.

In another study (Seppanen, 1991), the normal operation of the buildings included recirculation in the winter months. A questionnaire survey was based on 4 one week periods (that is, 2 weeks with recirculation and 2 weeks operating on 100% outside air). The use of air recirculation (but no humidification) did not cause an increase in occurrence of the following complaints: mucosal irritation, skin reaction, allergic reaction and general symptoms (headache, lethargy) (Seppanen 1991). The study could have been improved however by the inclusion of dust and microbiological measurements.

Raw et al (1993) have attempted to clarify the importance of the cleanliness of surfaces within offices as a determinant of SBS. A series of double blind trials incorporating weekly symptom questionnaires and environmental monitoring were carried out in a 13 year old office building with comfort cooling (induction system) and a high prevalence of SBS. One of the trials involved a "cosmetic" clean of the ventilation system which involved renewing the fresh air filters, cleaning the air handling unit and specific induction unit grilles and nozzles. It was concluded that the ventilation cleaning had no significant benefit with respect to SBS. In contrast, cleaning the office furnishings did reduce symptoms, indicating that the method used in this study was sufficiently sensitive to detect a reduction in symptoms where it occurred.

## 5. STANDARDS

In the course of this study, the literature review indicated that there is insufficient information to establish a ductwork cleaning strategy. A point that comes through clearly however, is that, a number of the authors (12 out of 60) highlight the need for regularly inspecting and cleaning ductwork, although very little direct supportive evidence is presented for such statements. It would appear that in some cases recommendations for cleaning are made as part of a prudent prevention and control policy, for example Brief et al (1988), Samini et al (1990) and Sverdrup et al (1990), in others it represents a commercial view, for example Prokopiw 1988 and Nichols 1992. In the case of Brief et al (1988) the recommended control policy is to periodically inspect HVAC systems and twice yearly clean to remove slime, scale and algae deposits. The recommendation is based on a distillation of the authors experience and a comprehensive review of respiratory hazards associated with HVAC systems.

To date, there is no environmental criterion to determine whether a measured airborne level of fungi or bacteria is a risk factor with regard to human health.

Work carried out by Morey et al, suggests that a level of viable microorganisms in excess of $1 \times 10^3$ viable particles/$m^3$ indicates that the indoor environment is in need of investigation and improvement. However, this is not to say that the air is unsafe or hazardous.

Morey et al, further suggest that two additional quantitative parameters may be helpful in deciding if the indoor environment is in need of improvement. Counts of microorganisms in both stagnant water and in dust found in the HVAC system are needed. Although further studies are required, their preliminary conclusion is that a level of bacteria or fungi $> 1 \times 10^5$/ml in stagnant water or slime and levels of fungi $> 1 \times 10^6$/g in dust suggest that microbial contamination of HVAC system components is excessive.

The standards in Table 5 have been proposed by Serceau et al 1992 based on results obtained by impingement with the Surface Air Sampler (SAS) and sedimentation on petri dishes. Air conditioning systems are reportedly in the Good class.

**Table 5**
**Suggested standard for microorganisms for varying classes of cleanliness**

| CLASS | Germs/m$^3$ * | Germs/30mn * | Mould Fungi & Yeast/m$^3$ | Mould Fungi & Yeast/30mn |
|---|---|---|---|---|
| Excellent (surgery rooms) | <100 | <10 | <25 | <5 |
| Good | 100 - 750 | 10 - 25 | 25 - 250 | 1 - 15 |
| Pretty good | 700 - 1250 | 25 - 75 | 250 - 500 | 10 - 50 |
| Poor (to be avoided) | >1250 | >75 | >500 | >50 |

* Terminology used by Serceau et al

**NADCA 1992 - 01**

*Mechanical cleaning of non-porous air conveyance system components*
The standard provides performance requirements and evaluation criteria for the mechanical cleaning of non-porous ductwork, fans, coils and other non-porous components of commercial and residential air conveyance systems (ACS). This excludes materials such as wood, fibreboard, thermal insulation and concrete. The standard does not apply to hazardous materials such as lead, asbestos or VOCs nor does it apply to microbial contamination which, depending on the type of microbe, may be considered a hazardous material.

General requirements of the standard require that the debris removed during the cleaning shall be contained and precautions must be taken to ensure that debris is not otherwise dispersed outside the ACS during the cleaning process. After ACS cleaning, any areas which could be affected by the cleaning contractor's work must be as clean as or cleaner than their condition prior to the commencement of the cleaning operation.

Where particulate collection equipment is exhausting inside the building, HEPA filtration with 99.97% collection efficiency for 0.3 micron size particles shall be used.

The other areas covered are: where collection equipment is exhausting outside the building; filtration integrity; controlling odours; component cleaning; air-volume control devices and access holes.

NADCA health and safety requirements state (amongst other things) that "no process or materials shall be employed in such a manner that they will create adverse health effects to the building occupants, cleaning contractors or the general public".

*NADCA Vacuum sampling protocol*
Verification of ACS cleanliness should be determined after mechanical cleaning and

before the application of any treatment or introduction of any treatment related substance to the ACS.

A template 15 mm thick, $100cm^2$ sampling area (two 2cm x 25cm slots at least 2.5 cm apart) is secured to the surface to be sampled. Filter medium contained in a cassette is attached to a high volume air sampling pump adjusted to give an airflow of 10 litres per minute. The open area of the template is vacuumed twice (once in each direction) at a rate of not greater than 5 cm/s. The cassette is then sent for gravimetric analysis.

*Verification of ACS cleanliness.*
All non-porous surfaces must be visibly clean and capable of passing the NADCA Vacuum test. The weight of the debris collected by the NADCA Vacuum test shall not exceed 1.0 mg/100 $cm^2$ (which equates to 0.1 $g/m^2$.

Mechanical cleaning must restore the coil-pressure drop to within 10% of the pressure drop measured when the coil was first installed. If the original pressure drop is not known, the coil will be considered clean only if the coil is free from foreign matter and chemical residue, based on a thorough visual inspection.

## 6. EVALUATION OF SAMPLING METHODS AND THE EFFECTS OF HUMAN ACTIVITY ON AIR SAMPLING

The methods and results reviewed in this report cover the use of a wide range of measuring instruments and techniques, especially with regard to the measurement of viable particulates.

There is growing evidence that the determination of reliable values of the numbers of fungal propagules in indoor air is confounded by activity, the source of the contamination, the accuracy of the sampler and the growth medium used.

One cited example illustrates the importance of reliably identifying colonies to species. *Penicillium chrysogenum* was prevalent in both indoor and outdoor samples but more so in the latter. *Penicillium viridicatum* and other *Penicillium* species were mostly found indoors. Merely counting all *Penicillium* would not have indicated an indoor source. *Penicillium viridicatum* is a toxigenic species of the genus *Penicillium* (Miller 1990)

Another serious problem is that although the spores of most moulds persist, the spores of some do not.

Since yeast and fungi develop in the same medium (when using sedimentation techniques) there is competition between these two organisms. In present sites, high quantities of moulds may mask the presence of yeast. Using only sedimentation techniques, this phenomenon is not apparent and may lead to distorted results, and thus reliance solely on this technique should be avoided (Serceau 1992).

Buttner et al (1992) examined the relative efficiencies of selected aerobiological sampling methods and the effect of human activity on retrieval of airborne microorganisms.

Buttner et al evaluated the following aerobiological samplers (activated remotely) for the retrieval of airborne fungi: Two Anderson six-stage viable impactor samplers, two Surface Air System viable impactor samplers, fifteen pairs of 100mm agar filled petri dishes and a single Burkard sporetrap. A total of twelve trials were conducted to evaluate the results of aerobiological sampling.

The Burkard and Andersen samplers were the most accurate samplers tested for retrieval of spores in the 1.8 - 3.5 µm size range. However, an estimated 25% of the spores were not viable. The Andersen and Surface Air System samplers used could measure only viable spores. The fungal conclusions were therefore underestimated by these samplers.

The Andersen sampler had the highest levels of sensitivity and repeatability followed by the Surface Air System sampler. Depositional samplers had the lowest.

A greater retrieval by one Surface Air System sampler than the other suggested that a single air sample taken from a single location at a discrete point in time may have limited value when the numbers of viable airborne microorganisms are to be assessed.

The Burkard sampler allowed the detection of total numbers of airborne *Penicillium chrysogenum* spores, thus eliminating the reliance on spore viability for detection.

The effect of human activity during sampling resulted in a single increase in the numbers of airborne spores and thus demonstrated a potential limitation of air sampling for adequately assessing microbial contamination in indoor environments.

This work suggests that air sampling, in general, should be undertaken to confirm whether specific reservoirs are producing airborne contamination. In the absence of reservoirs, air sampling may indicate that contamination of other components or fittings, has occurred and that further examination is needed. However, it is unreasonable to expect limited air sampling to prove that contamination is not present.

## 7. THE DUCT CLEANING INDUSTRY

There are now several commercial organisations that offer ventilation system inspection and cleaning services. Representatives of these organisations have indicate that there are three main routes to obtaining cleaning contracts:

- The building manager asks for assistance.
- The duct cleaning firm introduces itself and its services and carries out a survey.
- A pre-commissioning clean of the system is specified in a new build contract.

The most basic form of inspection is often free and consists of a visual inspection at points of access, or a photographic survey carried out using a boroscope. The photographs are presented to the prospective client as "evidence" that the ducts are dirty and require cleaning. The question of how dirty the duct surfaces need to be before they become a potential health hazard is not addressed, probably because the answer to this question is not known. Neither does this method of inspection determine the levels of microorganisms on the surfaces or transmitted into the occupied spaces. Organisations that charge for surveys usually provide a more thorough initial investigation. The need for cleaning and the results to be achieved are based on surface and airborne measurements using contact plates. This method assumes a relationship between a high plate count and a dirty system. Measurements made after cleaning should be near to zero. Airborne fungi tests are carried out in the supply ducts and in the offices. Again a relationship is assumed between a dirty duct and a high fungal count in the offices.

Offices are currently the largest duct cleaning market both by value of the work (60-70%) and by the number of jobs carried out (75-85%). Ductwork cleaning is a labour-intensive operation and the costs involved reflect this fact. In practice 15-20% of building owners choose to have only partial cleaning or cosmetic work carried out, involving cleaning of diffusers and central air handling units (containing dampers, filters, coils, attenuator, humidifier and fan). Partial cleaning is potentially an operation that can be done in-house, essentially because of the readily available access. Partial cleaning contracts may, however, be chosen because facilities managers intuitively feel that the greatest benefit accrues from being able both to both examine components comprehensively and to visually verify the cleaning operation. It is more likely though that the scope of the cleaning operation is limited by cost. Geographically, ventilation ductwork is cleaned nationwide.

Some duct cleaning organisations are careful not to make any direct claims that cleaning the ducts will eliminate SBS. They do, however, imply a connection between dirty ducts and ventilation performance. The general feeling is that a build up of dust is a more frequent problem than high microbiological counts. High on their list of components requiring decontamination are coils, extract ducts and sensors and controls, with the latter being particularly susceptible to dust. Vertical supply ductwork rarely needs cleaning.

In consultations with the duct cleaning industry, the general view was that the amount of dust that could be held in the ventilation system was determined by electrostatic forces. A ventilation system was compared to a sponge in that it has a capacity to accumulate dust and, like the sponge, eventually to become saturated, saturation occurring after perhaps 10-12 years. Dust problems then begin to occur, for instance dust from the ductwork is dispersed into occupied rooms and is evidenced by black streaks around supply diffusers.

In general the duct cleaning industry would consider that current good practice with regard to the treatment of heavily contaminated or degraded parts is as follows:

*Duct materials* - flexible light spring coil type of ducting is usually removed and replaced; more rigid flexible ducting is demounted and cleaned with air brushes. Other ducting materials that are cleaned are: galvanised sheet steel, PVC, brick and Nilflam (fibre-glass sandwiched between Aluminium tape and acoustic lining).

*Sound attenuators* - in the fan chamber are frequently cracked. The possible courses of action are as follows: strip the lining and replace it, seal the lining with PVC or cover it with a metal plate (this may result in a loss of its attenuation characteristics).

*Fans* - are cleaned by spraying degreasant where oil builds up from bearings. The fan blades are never painted because this is liable to throw the blades out of balance and because the paint eventually flakes off.

Duct cleaning, where possible, is carried out by hand and could involve men entering the ducts, wearing respirators. Cleaning proceeds from system inlet to the supply. Much of the cleaning is done using "chimney sweep" brushes (up to 0.6 m2), rotating brushes (square brushes are used in square ducts) and a fan/filter extractor unit to move the dust rather to vacuum it up. The combination of brush and a compressed air nozzle is particularly effective for very heavy layers of dust.

Industry advice is that, after cleaning, systems should be disinfected with a food grade biocide. A fogging machine is used, which leaves a surface coating of the disinfectant.

Claims are made that the application of an antimicrobial agent (an amphoteric amine neutralised organic phosphate) to the interior surfaces of air handling units results in a significant reduction in microbial (both surface and airborne) levels and hence improves the IAQ. However, no mention is made about its possible effect on health (Rhodes et al 1990). Another disinfecting agent, reportedly used in ventilation systems in air conditioning systems in Australia, is a micro-aerosol containing natural tea tree oil as its active ingredient. Bacteria and fungi which can typically be isolated from air conditioning ductwork have shown a 100 fold reduction 24 hours after treatment. According to Vale, safety has been proven in inhalation toxicity tests at ovcr 100 timcs thc normal dose rate.

Heavily corroded ducts are brushed with a wire brush, cleaned, and then coated. If a section of duct is very corroded, it is replaced.

The brush and airline method is ineffective for pre-commissioning cleans. Here wet cleaning, that includes a degreasing agent, is preferred.

## 8. CONCLUSIONS

1. Studies clearly demonstrate that contamination accumulates in ventilation ductwork and that periodic maintenance based on regular inspection of the ductwork is essential, especially within systems that are exposed to heavy particle contamination. With the types and grades of filters currently used, contamination is reported to deposit at the rate of 0.5 to 12 $g/m^2/yr$. The vast majority of the contamination settles on the bottom and other internal horizontal surfaces throughout the ductwork although the uniformity achieved is inconclusive. Surface deposits with a density of between 5 and 10 $g/m^2$ are visible and best described as a thick surface coating. There is very little evidence to suggest that such density levels have affected the volume flowrate of ventilation supply systems. Loss of performance in a system is mostly associated with blocked coils.

2. Reports tend to agree that the bulk of the contamination in ductwork is composed of inorganic dust. The remaining materials are frequently identified as macromelecular organic components, microfungi and bacteria. The focus of research on ductwork contamination has shifted over a period of time from bacteria and dust to the examination of fungal content. Strong supportive evidence has emerged to suggest that certain fungi (all of which have been identified in ductwork) constitute a health hazard. However, from an understanding of the ecology of fungi, an air stream can only become contaminated with fungi or fungal products if there is a reservoir containing living fungi to provide inoculum, and conditions must allow the growth and reproduction of the organism. The normal operating temperatures and humidities in ventilation supply systems are potentially close to being ideal for fungal growth.

3. There is a dearth of information on the possible effect of ductwork condition on sick building syndrome.

4. A growing body of information suggests that conventional particulate filters can become a source of odour and viable particulates sufficient to contaminate the supply air. An important factor is the amount of water available, the literature recommending that ventilation systems should be designed and built so that filters remain as dry as possible.

5. While there are no environmental criteria to determine whether a measured airborne level of contaminants is a risk factor (in fact the literature is almost completely lacking in any quantitative evaluation of risk) there is at least a preliminary proposal for an air quality standard to indicate when an indoor environment is in need of improvement. Additionally, there is a standard on acceptable surface particulate levels in ductwork issued by NADCA (USA). Much could be gained from combining and developing these criteria into a UK consensus document of standards applicable to contract cleaning.

6. Discussions with commercial cleaning organisations suggest that they vary greatly in the service they offer. In one case the service provided was seen as no more

than an extension to office cleaning, although another demonstrated a commitment to a comprehensive and checkable service. Whatever the commitment, there is great similarity and simplicity in the preferred methods of cleaning which involves the use of men with brushes in conjunction with fast moving air streams. Some of the actions and operations applied to cleaning are very subjective, for example the factors influencing, say, whether to clean or disinfect, or when to seal surfaces. A strongly held view in the cleaning industry is that access arrangements in most existing ventilation systems are totally inadequate. The consequence of this is that some 50% of the cost of the first clean of a system results from providing and installing the necessary access. Presumably, subsequent cleaning should be substantially cheaper. Pre-commissioning cleaning suffers from the same lack of standards.

7. The potential impact of poorly maintained ventilation systems on the air conditioning industry cannot be ignored. On the basis of current knowledge and a broad interpretation of the effect of the recent workplace health and safety regulations, there is likely to be demand-led change for non-polluting components in ventilation systems. Growing interest in the performance of particulate filters suggests that they may be at the forefront of change.

## 9. RECOMMENDED FURTHER RESEARCH

The review highlights the need for further work to be carried out in the following areas.

(1) The preparation of a code of practice for the safe and effective operation of ventilation systems. Among other things this might include the following:

- Air system management
- Cleaning and disinfecting procedures (including pre commissioning)
- Monitoring and control (including agreed criteria for initiating and checking decontamination).
- Risk assessment
- Training.

The following studies are required to underpin the development of the code of practice;

(i) Develop the Morey and Serceau proposed standards for viable particles into a practical guide for indicating when duct cleaning is necessary from a health and safety point of view. The main effort in the work will be to establish preferred strategies for when, where and how to carry out the necessary sampling.

(ii) Extend and enhance the NADCA surface dust standard to provide a comprehensive cleaning standard for both dust and viable particles for a range of situations. New data are required to establish (either by experiment or by the distillation of commercial experience) acceptable criteria for levels of dust and viable particles in relation to the working environment.

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(iii) Field trials in ventilation systems to establish:

- The efficacy of cleaning procedures.
- The efficacy of different classes of biocides/fungicides.
- The efficacy and safety of surface preparations.

(2) Develop a design guide for the provision of minimum access arrangements in ventilation systems.

(3) Work directed to improving the quality and effectiveness of maintenance of ventilation systems;

(i) The development of rapid test methods for use in a fast moving air stream to determining the presence of fungi and bacteria.

(ii) The development of new ways of indicating filter life, based on their potential to pollute rather than relying on pressure drop.

In addition to the above, longer term fundamental studies are needed, such as the following:

(4) Research on microbially produced toxins and their health effects under conditions of low dose exposure.

(5) Development of models of the ecology of ventilation systems and the factors that affect the nature and numbers of microorganisms.

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## APPENDIX 1 Terms and mechanisms (Reproduced from the WHO Series 3)

There are many diseases that have been associated with problems of indoor air quality. The following may sometimes be associated with or caused by biologically derived aerosols, as well as having causes unrelated to the building environment. The first four conditions below will be grouped together since the role of biologically derived aerosols is similar for each. They may be acute or chronic, and may deteriorate or improve in relation to biological aerosol exposure.

*Rhinitis* involves the nasal mucosa, and often results in itching or sneezing, and running or blocking of the nose. It may be due to infection (the common cold), allergy (e.g. hay fever) or nonallergic causes such as dryness or coldness of the air pollutants. It is commonly related to the indoor environment.

*Sinusitis* involves the sinuses. It causes pain or fullness in the face and may be associated with headache. It has causes similar to those of rhinitis.

*Otitis* is inflammation of the lining of the external (otitis externa) or internal (otitis media) parts of the ear. It may cause pain, and otitis media impairs hearing. The condition may be due to infection, allergy or nonallergic mechanisms.

*Conjunctivitis* involves the conjunctival mucosa. It causes itching, soreness, watering and discharge from the eyes. Its causes are similar to those associated with rhinitis.

*Pneumonia* is an infection of the gas-exchanging part of the lung resulting in consolidation of the lung. The condition is acute, and may be fatal. Most cases are unrelated to indoor air quality. Legionnaires' disease is a pneumonia caused by a specific bacterium (*Legionella pneumophila)*. It accounts for less than 5% of community-acquired pneumonia. *Legionella* pneumonia may be building-related in about 30% of cases, mainly in hotels and hospitals.

*Asthma* is variable airways obstruction with bronchial irritability. It may be precipitated by biologically derived aerosols. Most of those affected have multiple trigger factors, such as exercise and cold air, irritants such as smoke and particulates, and allergens and drugs. Asthma symptoms related to particular buildings may deteriorate within minutes or hours of exposure, and may improve after leaving the building. Asthma may occur or reoccur 6-12 hours after exposure to an allergic stimulus in a building. This represents the late phase of dual-phase asthma, in which inflammatory factors may lead uniquely to a late-phase response or to a dual response commonly seen after exposure to industrial allergens or to other allergenic stimuli such as house dust. Virus infections can precipitate acute attacks of asthma and may sometimes be the initiating cause.

*Alveolitis* is an inflammation of the gas-exchanging parts of the lung resulting in breathlessness. It may be acute, coming on about 4-12 hours after exposure. Chronic exposure may lead to permanent lung damage. It may be caused by allergic or nonspecific mechanisms. In the present context only allergic alveolitis will be considered.

Most building-related alveolitis is caused by contaminated humidifiers, containing many fungi and bacteria. In most cases the disease appears to be caused by soluble products rather than single whole organisms. Individual outbreaks have been related to any of the following organisms.

| | |
|---|---|
| Thermophilic bacteria | *Merulius lacrymans* |
| *Micropolyspora faeni* | *Trichosporon cutaneum* |
| *Cytophagia allerginae* | *Flavobacterium* spp. |
| *Aspergillus fumigatus* | *Bacillus subtilis* |
| *Penicillium* spp. | *Aureobasidium* spp. |
| *Cephalosporium* spp. | *Thermoactinomyces vulgaria* |

Humidifier fever is an influenza-like illness developing 4-8 hours after exposure to aerosols from microbiologically contaminated humidifiers. Recovery occurs within 1 to 3 days despite continuing exposure. It classically occurs on the first day of re-exposure after a break of one or more days. It is often associated with headache and fatigue. Antibodies are found to *Acanthomoeba polyphaga* and *Naegleria gruberi*. The current evidence is that the antibodies are cross-reacting, and not the cause of the disease. Endotoxins are suspected to be the dominant cause of occupational cases.

*Bronchopulmonary aspergillosis* is a complicated specific form of asthma due to allergy to the fungus *Aspergillus fumigatus*. It can cause acute blockage of major airways and lung infiltrates. It is rare. The same fungus can cause asthma, rhinitis and alveolitis, may produce mycetomas in scarred lung tissue, or may be invasive in immunocompromised patients.

*Contact dermatitis* is an acute or chronic inflammation of the skin of variable severity due to allergic, toxic or irritant effects. Most causes relate to physical contact, but aerosols may be the cause (airborne contact dermatitis)

*Atopic eczema* is a chronic relapsing itching skin rash, variable in expression in genetically predisposed individuals. It commonly first occurs in infancy or early childhood. It is sometimes aggravated by biologically derived aerosols.

*Contact urticaria* is an acute or chronic, itching skin rash with variably sized wheals and swelling. It has allergic and nonallergic causes, sometimes caused by biologically derived aerosols.

*Mycotoxicosis* is a rare toxic response to products from certain moulds, producing fatigue and irritability and inflammation of the heart. One building-related outbreak was associated with *Stachybotrys atra* but there are many mycotoxin-producing species that need to be considered.

*The sick building syndrome* consists of a number of symptoms that are common in the general population, but may in a temporal sense be related to a particular building. A substantial increase in the prevalence of the symptoms above background levels provides the link between the building and its occupants.

The main symptoms are:

- eye, nose and throat irritation
- sensation of dry mucous membranes, skin erythema
- mental fatigue, headache, nausea, dizziness
- high frequency of airway infection and cough
- hoarseness, wheezing, unspecified hypersensitivity.

The causes of sick building syndrome are many. It is epidemiologically related to sealed buildings, non-openable windows, tight-enclosure dwellings, increased temperature and dust levels, and passive cigarette smoking. There is also a likely role for biologically derived aerosols.

*Allergy* is an undesirable physiological event mediated via a variety of immunological mechanisms induced by specific allergens.

*Pseudo-allergic reactions* are similar reactions without immunological specificity. They may be caused by the direct release of mediators, direct complement activation, psychoneurogenic effects or enzyme defects.

There is epidemiological evidence that more workers have symptoms in buildings with humidifiers and chillers than in those without such equipment (*18*) and that very dry air (relative humidity less than 30%) which is common in heated premises in very cold climates, increases many sick building symptoms. Humidifiers and chillers may become contaminated with microorganisms and are an important potential source of them. Experimental exposure of individual symptomatic workers to humidifier antigens can induce headache, rhinitis and lethargy, as well as asthma and alveolitis; similar exposures do not cause symptoms in previously unexposed workers.

Table 3. Relationship between agents and disease with respect to severity, frequency and rate

| | | | Agents[c] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Disease | Severity[a] | Frequency[b] | Viruses | Bacteria (including endo-toxins) | Fungi | Pollen | Animal dander and excre-tions | Mites[d] and excre-tions | Other arthro-pods | Amoebae | Actino-mycetes and thermo-philics | Plant con-stituents |
| Rhinitis<br>Sinusitis<br>Otitis<br>Conjunctivitis | 2 | 4 | 4 (infec tions) | 0 | 3 (aller-gens) | 3 | 4 | 1-4 | 2 | 0 | 1 | 1 |

[a] Severity: 1 = trivial: 2 = interfering: 3 = restricting activities 4 = incapacitating: 5 = serious. fatal

[b] Frequency: 1 = rare 2 = low frequency 3 = medium frequency 4 = common

[c] Attributable rate: 0 = none 1 = rare 2 = low 3 = medium 4 = high

[d] House dust mites as a cause of asthma and rhinitis relates largely to climate. They are found predominantly in humid environments, they are rare in desert and cold environments.

[e] Pontiac fever is a specific type of humidifier fever caused by various bacteria including Legionella pneumonia

Source Rom. W.N. ed (3) and Turner-Warwick M (4)

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## APPENDIX 2 THE FUNGI (Reproduced from Harriet A Burge (35)

*Ecology*

Fungi can be regarded as simple plants. The body of a fungus is referred to as mycelium, a matt or web of branching, interwoven, microscopic threads (hyphae) which grow in and on the substance from which they derive their food.

Moulds are simple fungi from several different groupings in the fungal classification system. There are three principal features common to all fungi:

(1) They have simple food requirements, being sustained by only small amounts of simple sugars and other organic matter including starches, fats and cellulose;

(2) They produce vast numbers of minute, seed-like airborne spores; and

(3) They can grow very quickly under suitable conditions.

In general, fungi prefer dampness rather than standing water, most fungi are able to use non-living organic material (saprophytes), a few are pathogens. It is important to remember that any substrate, indoors or out that contains reduced carbon compounds and other nutrients and is damp will support the growth of fungi. Vegetative spore production is often induced by the onset of unfavourable conditions.

Fungi produce a variety of compounds, and all are potentially antigenic and allergenic. In most cases, sensitization to antigens (and allergens) occurs via the airborne route. Two types of diseases that are caused by airborne fungal antigens are allergic disease (asthma and rhinitis and hypersensitivity pneumonitis. In addition, some fungi can grow in the thick secretions that can build up in the lungs of some asthmatic patients. These fungi do not actually invade the human tissue, but grow in the mucus and produce antigens (and possibly toxins) that cause disease. The *Aspergillus fumigatus,* a ubiquitous environmental fungus that is also an opportunistic infectious agent.

The systemic mycoses, where the fungus becomes disseminated throughout the body in an otherwise normal host and the opportunistic infections, where the fungus can invade human tissues only when the hosts defenses are impaired. One such fungi *Cryptococcus neoformans* which can be abundant in dry, shaded (indoor) pigeon droppings, surviving with little competition in this alkaline, high-salt environment.

*Irritants*

The fungi produce volatile organic compounds during degradation of substrates that cause the typical "mouldy" odor associated with fungal growth, as well as a wide variety of other odors. These substances can be irritating to the mucous membranes, and some evidence is accumulating that they may cause headaches and possibly other kinds of acute toxic symptoms.

Note that fungi need not be alive and culturable to be antigenic, and toxins remain in the environment long after the fungus is dead.

## APPENDIX 3 SUPPLY DUCTWORK HYGIENE: A scoping study of contamination in four buildings

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C Wiech } BRE
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Completed: September 1993

## INTRODUCTION

As part of a review of published literature on ventilation system hygiene it was considered essential to have some indication of the contamination levels obtaining in UK systems. A small scoping study was therefore undertaken to assess the airborne and surface levels of microorganisms and solids in the air handling units in four occupied buildings. Although measurements were made using routine sampling and analytical methods it cannot be assumed that the assessment was sufficient to judge the health risks associated with each system. In the report the buildings are referred to as WCH, SE, PH and LS.

## AIMS

The aims of the assessment were:

- To investigate the nature, prevalence and distribution of contaminants in the air handling units.

- To determine the effect of the contamination on supply air quality.

## METHOD

Measurements were made of airborne and surface dust and microorganism levels in the supply ductwork at the following locations:

(a) before filter
(b) fan chamber
(c) supply diffuser

## 2. MEASUREMENTS

### Airborne dust

Airborne dust in the supply air was sampled using a Malvern - APC 300-5 laser particle counter. This gives a quantative assessment of the numbers of dust particles contained in a one cubic foot sample of air (p/ft3) at the test location. The unit was set to count particles above 0.3 microns in size (1 micron is 1.000th of a mm)

**Airborne microorganisms**
Petri-dishes containing selective media were exposed at three sites along the ventilation ducts: at the intake, after the filter and at the entry point in the room. The plates were held at right angles to the air flow for between 5 and 30 minutes. The air in the room was also monitored by exposing the plates on a table or similar surface for 30 minutes. The plates were incubated at $25^0$C for 4 days for bacteria or at least 7 days for fungi. Any resultant biological growth was either identified to genera level in the case of the fungi or subcultured onto three semi-selective media: Mannitol Salt agar (selective for Gram positive cocci), Pseudomonas selective media (selective for pseudomonads) and MacConkey agar (selective for bile resistant bacteria).

**Surface dust**
Dust on the surface of ductwork was collected using preweighed sticky backed labels. The size of the label was $39cm^2$.

**Surface microorganisms**
Dust samples were collected using dry sterile culture swabs (Sterilin). Any material present was resuspended into 2 ml of Travers resuspending medium (peptone 10g, insitol 20g, tween 80 1ml, distilled water 1000ml) and serial dilutions prepared. Duplicate 0.1ml aliquots were spread plated onto selective media used for the air samples and the plates were incubated for the same time periods.

## 3. BRIEF DESCRIPTION OF SYSTEMS

### BUILDING WCH

A three year old building situated in a town centre with a constant volume single zone system with central air handling unit situated in a roof plant room. The system supplies tempered air to the working spaces through insulated steel ducts located above false ceilings to floors Ground plus 2. Air is supplied and extracted at ceiling level through multi vaned diffusers and grilles.

The air handling unit consists of bird mesh, inlet damper, bag filters (grade EU7), heating coil and supply fan.

*Comments*

Badly fitting filters with the potential for significant air leakage. Filter life and performance could be enhanced by eliminating sagging of the bags.

### BUILDING SE

A five year old building situated on a trading estate with variable air volume (VAV) system serving floors Ground plus 3. Two central air handling units (North and South zones) are situated in a roof plant room and supply air to the working spaces through insulated steel ducts located above false ceilings to slot supply diffusers. Air is extracted through the ceiling void.

Each air handling unit consists of inlet damper, recirculation damper and mixing zone, multi pocketed folded paper filters (high efficiency), heating and cooling coils, reverse flow silencer and supply fan.

*Comments*
Good filter arrangement, potentially leak-tight.

In VAV air conditioning systems, the airstream entering the supply ductwork is mostly a mixture of outdoor air and recirculated air. At the time of the visit the control dampers took up positions that resulted in a supply airstream of 100% outdoor air.

## BUILDING PH

A seven year old building situated on the edge of a small town with variable air volume (VAV) system serving floors Ground plus 5. The central air handling unit is located on the roof behind a 2m high mansard. Air supply to the working spaces is through steel ducts located above false ceilings to slot supply diffusers. Air is extracted at high level.

The air handling unit consists of pre-filter, bird mesh, inlet damper, recirculation damper and mixing zone, bag filters (grade EU7), heating and cooling coils, wetted element humidifier and supply fan.

In VAV air conditioning systems, the airstream entering the supply ductwork is mostly a mixture of outdoor air and recirculated air. At the time of the visit the control dampers appeared to be set to provide a supply airstream of 20% outdoor air and 80% recirculated air.

## BUILDING LS

A twenty year old building in the centre of London with induction system with central air handling units serving floors Ground plus 5. The air handling units are located two floors below ground level with their inlets drawing outdoor air from a plenum chamber at the same level. Air supply to the cill line induction units is through insulated steel ducts around the perimeter and concealed behind the induction unit casing. Air is extracted at high level.

Outdoor air is mechanically drawn into the building at road level, pre-filtered and ducted to the plenum chamber. The air handling unit drawing air from the plenum chamber consists of inlet damper, bag filters (grade unknown), heating coil, spray humidifier chamber (decommissioned), cooling coil, eliminator plates and supply fan. The fan compartment floor is insulated against noise transmission with glass fibre board (MMMF) covered with a tough impervious outer skin.

*Comments*
The condition of the fan chamber section of the high pressure air handling unit could be improved from the point of view of its effect on air hygiene.

The lower fixings of some of the eliminator plates are beginning to corrode.

A loose white powdery substance has accumulated in certain parts on the floor of the fan chamber. It is assumed that these derive from the operation of the humidifier.

The tough outer skin to the sound insulation layer on the floor of the unit has worn through at one place exposing the MMMF substrate. Fibre shedding is thus a possibility.

A greasy layer has formed at the inlet of the supply fan.

Data under the heading "Induction" relate to **one unit only**. Superficial examination of other induction units suggested that the test unit was fairly typical in respect of dust coverage and general condition.

## 4. RESULTS

### 4.1 Airborne dust

**BUILDING: WCH**

| PARTICLE SIZE | LOCATIONS<br>Number of particles | | |
|---|---|---|---|
| micron | before filter | fan chamber | diffuser |
| <2 | 22,000 | 12,600 | 8,000 |
| >2 | 2,960 | 1,830 | 1,690 |

Note.

The particulate content of the air was measured for particles >1.0 micron per cubic foot of air.

**BUILDING: SE**

| PARTICLE SIZE | LOCATIONS<br>Number of particles | | |
|---|---|---|---|
| micron | before filter | fan chamber | diffuser |
| <2 | 304,300 | 114,500 | 104,500 |
| >2 | 8,440 | 7,600 | 966 |

Note.

Only a small portion of the building was occupied at the time of the measurements. The dust content of air exhausted from the building was found to be 110,000p/ft3, substantially less than the 312,800 p/ft3 in outdoor air.

**BUILDING: PH**

| PARTICLE SIZE | LOCATIONS Number of particles | | |
|---|---|---|---|
| micron | before filter | fan chamber | diffuser |
| <2 | 477,400 | 180,500 | 169,200 |
| >2 | 1,590 | 280 | 137 |

Note.

The resultant mix of outdoor air 166,400 p/ft3 and recirculated air 799,500 p/ft3 produced a supply airstream with 479,000 p/ft3.

**BUILDING: LS**

| PARTICLE SIZE | LOCATIONS Number of particles | | |
|---|---|---|---|
| micron | before filter | fan chamber | diffuser |
| <2 | 357,500 | 588,100 | 1,210,000 |
| >2 | 7,076 | 5,920 | 6,850 |

Note.

The dust content of outdoor air exceeded 1,400,000p/ft3. However, the dust content of the air in the plenum chamber, that is, the supply to the air handling units, was of the order of 360,000p/ft3. The reduction is attributed to the pre-filters, however, these were not examined.

### 4.2 Surface dust

**BUILDING: WCH**

| Sampling position | LOCATIONS Weight of dust (mg) | | |
|---|---|---|---|
| | **before filter** | **fan chamber** | **diffuser** |
| Bottom | 3.1 | 40.0 | - |
| Top | 11.4 | 8.3 | - |
| RHS | 26.1 | 9.2 | - |
| Diffuser blade | | | 11.5 |

**BUILDING: SE**

| Sampling position | LOCATIONS Weight of dust (mg) | | |
|---|---|---|---|
| | **before filter** | **fan chamber** | **diffuser** |
| Bottom | 8.1 | 5.1 | - |
| Top | 0.4 | 1.9 | - |
| RHS | 3.1 | 3.3 | - |
| Diffuser blade | | | - |

**BUILDING: PH**

| Sampling position | LOCATIONS Weight of dust (mg) | | |
|---|---|---|---|
| | **before filter** | **fan chamber** | **diffuser** |
| Bottom | 25.0 | 36.0 | - |
| Top | 7.8 | 4.2 | - |
| RHS | 3.1 | 0.0 | - |
| Diffuser blade | | | - |

**BUILDING: LS**

| Sampling position | LOCATIONS Weight of dust (mg) before filter | fan chamber | diffuser |
|---|---|---|---|
| Bottom | 16.3 | 38.0 | - |
| Top | 7.2 | 3.0 | - |
| RHS | 10.3 | - | - |
| Diffuser blade | | | 17.2 |

**4.3 Microbiological Investigation**

Table 1 Bacterial and fungal loading

**BUILDING: WCH**

| Sample description | Time exposed (mins) | Bacterial count* | Fungal count* |
|---|---|---|---|
| Outside air | 5 | 23.0 | 8.0 |
| Filtered air | 5 | 9.3 | 0.3 |
| Room supply air | 15 | 2.0 | 0.3 |
| Room air | 30 | 20.3 | 0.7 |

**BUILDING: SE**

| Sample description | Time exposed (mins) | Bacterial count* | Fungal count* |
|---|---|---|---|
| Outside air | 10 | 2.0 | 6.7 |
| Filtered air | 10 | 4.7 | 5.7 |
| Room supply air | 30 | 9.7 | 7.7 |
| Room air (**) | 30 | 4.0 | 1.0 |

**BUILDING: LS**

| Sample description | Time exposed (mins) | Bacterial count* | Fungal count* |
|---|---|---|---|
| Outside air | 5 | 34.0 | 22.7 |
| Filtered air | 10 | 101.3 | 16.3 |
| Room supply air | 15 | 1.3 | 1.3 |
| Room air (**) | 30 | 9.0 | 15.0 |

**BUILDING: PH**

| Sample description | Time exposed (mins) | Bacterial count* | Fungal count* |
|---|---|---|---|
| Outside air | 10 | 4.0 | 8.0 |
| Filtered air | 5 | 15.0 | 12.7 |
| Room supply air | 15 | 1.0 | 1.0 |
| Room air (**) | 30 | 14.0 | 4.7 |

* number of colonies appearing on the plates (average of three replicates for unit time (5 mins) except for room air)

** relates to an <u>unoccupied</u> room

Table 2 Fungal composition of air samples

**BUILDING: WCH**

| Sample description | Outside air | Filtered air | Supply air | room air |
|---|---|---|---|---|
| Fungi | (%) | (%) | (%) | (%) |
| **Alternaria** | 4.17 | 0.00 | 0.00 | 0.00 |
| **Aspergillus** | 4.17 | 0.00 | 0.00 | 0.00 |
| **Aureobasidium** | 4.17 | 0.00 | 0.00 | 0.00 |
| **Cladosporium** | 41.67 | 0.00 | 0.00 | 0.00 |
| **Helminthosporium** | 4.17 | 0.00 | 0.00 | 0.00 |
| Mycelia sterilia | 25.00 | 100.00 | 100.00 | 0.00 |
| **Penicillium** | 0.00 | 0.00 | 0.00 | 50.00 |
| **Phoma** | 4.17 | 0.00 | 0.00 | 0.00 |
| **Ulocladium** | 4.17 | 0.00 | 0.00 | 0.00 |
| Yeasts | 8.33 | 0.00 | 0.00 | 0.00 |

**BUILDING: SE**

| Sample description | Outside air | Filtered air | Supply air | Room air |
|---|---|---|---|---|
| Fungi | (%) | (%) | (%) | (%) |
| **Aspergillus** | 0.00 | 0.00 | 8.70 | 0.00 |
| **Aureobasidium** | 5.00 | 9.52 | 13.04 | 0.00 |
| **Cladosporium** | 55.00 | 38.10 | 34.78 | 0.00 |
| **Fusarium** | 5.00 | 0.00 | 4.35 | 33.33 |
| **Helminthosporium** | 15.00 | 14.29 | 13.04 | 0.00 |
| Mycelia sterilia | 10.00 | 0.00 | 4.35 | 0.00 |
| **Tricoderma** | 0.00 | 4.76 | 0.00 | 0.00 |
| Ulocladium | 5.00 | 9.52 | 0.00 | 0.00 |
| Yeasts | 5.00 | 23.81 | 21.74 | 66.67 |

BUILDING: LS

| Sample description | Outside air | Filtered air | Supply air | Room air |
|---|---|---|---|---|
| Fungi | (%) | (%) | (%) | (%) |
| **Aureobasidium** | 1.47 | 2.04 | 0.00 | 9.30 |
| **Botrytis** | 2.94 | 0.00 | 0.00 | 4.65 |
| **Cladosporium** | 66.18 | 14.29 | 75.00 | 67.44 |
| **Fusarium** | 2.94 | 2.04 | 0.00 | 0.00 |
| **Helminthosporium** | 5.88 | 0.00 | 0.00 | 4.65 |
| Mycelia sterilia | 0.00 | 2.04 | 0.00 | 2.33 |
| **Penicillium** | 1.47 | 0.00 | 0.00 | 0.00 |
| **Phoma** | 0.00 | 4.08 | 0.00 | 4.65 |
| **Tricoderma** | 1.47 | 0.00 | 0.00 | 0.00 |
| **Ulocladium** | 1.47 | 0.00 | 0.00 | 0.00 |
| Yeasts | 16.18 | 75.51 | 25.00 | 67.44 |

BUILDING: PH

| Sample description | Outside air | Filtered air | Supply air | Room air |
|---|---|---|---|---|
| Fungi | (%) | (%) | (%) | (%) |
| **Aureobasidium** | 4.17 | 2.63 | 0.00 | 0.00 |
| **Botrytis** | 0.00 | 5.26 | 0.00 | 0.00 |
| **Cladosporium** | 41.67 | 57.89 | 33.33 | 57.14 |
| **Fusarium** | 0.00 | 0.00 | 0.00 | 7.14 |
| **Helminthosporium** | 0.00 | 2.63 | 33.33 | 0.00 |
| Mycelia sterilia | 4.17 | 2.63 | 33.33 | 7.14 |
| **Penicillium** | 25.00 | 0.00 | 0.00 | 0.00 |
| **Phoma** | 4.17 | 7.89 | 0.00 | 0.00 |
| **Ulocladium** | 0.00 | 2.63 | 0.00 | 0.00 |
| Yeasts | 20.83 | 18.42 | 0.00 | 28.57 |

Table 3 Distribution of bacterial growth types within air samples

**BUILDING: WCH**

| Sample description | Outside air | Filtered air | Supply air | Room air |
|---|---|---|---|---|
| Media | (%) | (%) | (%) | (%) |
| Mannitol Salt | 25.00 | 100.00 | 100.00 | 0.00 |
| Pseudomonas | 8.33 | 0.00 | 0.00 | 0.00 |
| MacConkey | 41.67 | 0.00 | 0.00 | 0.00 |

**BUILDING: SE**

| Sample description | Outside air | Filtered air | Supply air | Room air |
|---|---|---|---|---|
| Media | (%) | (%) | (%) | (%) |
| Mannitol Salt | 14.49 | 14.34 | 16.67 | 0.00 |
| Pseudomonas | 55.07 | 39.43 | 33.33 | 0.00 |
| MacConkey | 10.14 | 0.00 | 0.00 | 0.00 |

**BUILDING: LS**

| Sample description | Outside air | Filtered air | Supply air | Room air |
|---|---|---|---|---|
| Media | (%) | (%) | (%) | (%) |
| Mannitol Salt | 6.87 | 0.00 | 0.00 | 6.25 |
| Pseudomonas | 17.18 | 78.01 | 24.05 | 6.25 |
| MacConkey | 65.29 | 14.18 | 25.06 | 68.75 |

**BUILDING: PH**

| Sample description | Outside air | Filtered air | Supply air | Room air |
|---|---|---|---|---|
| Media | (%) | (%) | (%) | (%) |
| Mannitol Salt | 42.16 | 57.91 | 25.64 | 55.56 |
| Pseudomonas | 20.59 | 18.43 | 0.00 | 29.63 |
| MacConkey | 25.49 | 0.00 | 0.00 | 0.00 |

Table 4 Bacterial and fungal loading of surface dust

**BUILDING: WCH**

| | Sample description | | Bacterial count* | Fungal count* |
|---|---|---|---|---|
| 1 | Inlet | bottom | 3.0 | 6.0 |
| 2 | Inlet | nearside | 2.5 | 3.0 |
| 3 | Inlet | top | 1.0 | 0.0 |
| 4 | Fan chamber | bottom | 2.5 | 1.5 |
| 5 | Fan chamber | top | 0.0 | 9.5 |
| 6 | Fan chamber | side | 0.0 | 0.0 |
| 7 | Fan | impeller | 1.5 | 1.5 |
| 8 | Exhaust grille in office | | 6.5 | 0.0 |
| 9 | Exhaust grille in office | | 5.5 | 3.0 |
| 10 | Supply diffuser in office | | 2.5 | 7.0 |
| 11 | Supply diffuser in office | | 0.0 | 3.0 |

**BUILDING: SE**

| | Sample description | | Bacterial count* | Fungal count* |
|---|---|---|---|---|
| 12 | Inlet | bottom | 3.0 | 6.5 |
| 13 | Inlet | top | 1.5 | 6.0 |
| 14 | Inlet | nearside | 0.0 | 2.5 |
| 15 | Inlet | side (door) | 1.0 | 5.0 |
| 16 | Fan chamber | top | 0.0 | 4.0 |
| 17 | Fan chamber | bottom | 1.5 | 5.5 |
| 18 | Fan chamber | silencer | 0.0 | 3.0 |
| 19 | Fan chamber | nearside | 2.5 | 0.0 |
| 20 | Supply diffuser in office | | 1.0 | 2.0 |
| 21 | Exhaust grille in office | | 1.0 | 5.0 |

**BUILDING: LS**

| | Sample description | | Bacterial count* | Fungal count* |
|---|---|---|---|---|
| 22 | Inlet | nearside | 1.0 | 0.0 |
| 23 | Inlet | farside | 2.0 | 7.5 |
| 24 | Inlet | bottom | 0.0 | 6.5 |
| 25 | Inlet | top | 3.5 | 2.5 |
| 26 | Fan chamber | (**) | 30.0 | 4.0 |
| 27 | Fan chamber | Bottom | 0.0 | 4.0 |
| 28 | Fan chamber | nearside | 0.0 | 4.0 |
| 29 | Fan chamber | top | 0.0 | 5.0 |
| 30 | Fan chamber | (***) | 1.0 | 3.5 |
| 31 | Induction unit | Drip trap | 1.0 | 5.5 |
| 32 | Induction unit | Side | 1.5 | 3.0 |
| 33 | Induction unit | Coil | 3.0 | 1.5 |
| 34 | Induction unit | grille | 2.0 | 4.0 |

**BUILDING: PH**

| | Sample description | | Bacterial count* | Fungal count* |
|---|---|---|---|---|
| 35 | Inlet | bottom | 30.0 | 10.5 |
| 36 | Inlet | top | 15.0 | 6.0 |
| 37 | Inlet | Horiz. bar | 0.0 | 3.0 |
| 38 | Inlet | Vertical | 1.5 | 3.0 |
| 39 | Fan chamber | top | 0.0 | 4.0 |
| 40 | Fan chamber | bottom | 2.0 | 1.0 |
| 41 | Fan chamber | nearside | 0.0 | 5.0 |
| 42 | Access hatch | splitter | 3.0 | 1.5 |
| 43 | Access hatch | vertical | 0.0 | 2.0 |
| 44 | Access hatch | horiz. | 1.0 | 1.0 |
| 45 | Supply diffuser in room | | 0.0 | 1.0 |
| 46 | Supply diffuser in room | | 0.0 | 7.0 |

* number of colonies appearing on the plates inoculated with the neat resuspension (average of two replicates)

** Hole in sound insulating layer

*** Spray eliminator plate after humidifier

## CONCLUSIONS

1. Based on the numbers of particulates, the air supplied to the rooms via the air conditioning system was cleaner than outdoor air in buildings WCH and SE, but just as dusty in buildings PH and LS. Dust concentration data suggest that in buildings PH, WCH and SE fine particles were being deposited in the ductwork, whereas in building LS fine dust was being removed from the ductwork and deposited in the office spaces.

2. Dust densities on the floor of the fan chamber in building WCH, PH and LS (surface of the insulation layer on the floor of the fan chamber) were of the order of 10g/m2. Such densities are easily visible and best described as a thick layer. Dust densities were considerably less than this on all other surfaces in the chambers.

3. Dust densities on the floor of the fan chamber in building SE were of the order of 1g/m2. Dust layers at this density are difficult to identify by eye, the surfaces merely appear dull. Dust densities were less than this on all other surfaces in the chamber.

4. The airborne bacterial and fungal loading data suggest that the filter in building WCH is operating effectively although inspection suggested otherwise since there were large gaps between the filter and its support framing. In buildings SE, LS and PH the air after the filter contains more bacteria and roughly the same or higher number of fungi than the incoming air. This observation was borne out by an examination of the fungal composition and bacterial type composition. The condition may be due to one or all of the following:

   In building PH

   - The recirculated air is more heavily polluted with bacteria and fungi than the outdoor air.
   - The filter is ineffective or contaminated.
   - The coils and/or humidifier are contaminated.

   In building LS

   - The filter is ineffective or contaminated.
   - The coils and/or humidifier are contaminated.

   In building SE

   - The filter is contaminated.
   - The coils and/or silencer are contaminated.

5. It is interesting to note that in two buildings SE, and LS, the percentage of yeast in the air increased dramatically after the filter. At both sites a greater than 4-fold increase was noted. In building PH the level of yeasts remained relatively constant.

Only in building WCH was there an effective removal of yeast and other fungi.

6. Generally, very low levels of fungi and bacteria were obtained from the samples of the "supply air to the room", this may have been due to the method of measurement. Sampling fast moving air by inserting a solid object in the air stream is complex and difficult to predict. This can result in dramatically different impaction rates for particles such as spores, dependent on the size and orientation of the collection plate. Certainly the variation between plates exposed at the same time was larger than hoped, which does indicate some degree of variability due to the method of sampling.

7. Examination of the samples taken from the contamination layers on the internal surfaces of the air handling units indicates that there is no biological growth occurring. Of the forty-six samples taken from the ducts in all four buildings, sixteen yielded no bacteria colonies and five yielded no fungi. Only three sites yielded more than an average of 10 bacteria per plate when inoculated with the neat resuspendate and only one site yielded more than an average of 10 fungi per plate. If active biological growth was present, the plates at this dilution would have been entirely swamped.