TABLE VIII. CORRELATIONS BETWEEN ENVIRONMENTAL QUALITY AND PREVALENCE OF VARIOUS SYNDROMES: ON 9 SELECTED FLOORS

	SYNDROMES				
	Irritant	Toxic	Skin	Stress	Building illness
Temperature - departure from 22°C	.182	.406	.469	-.217	.285
Temperature - within day range	-.343	.081	-.207	-.489	.360
Humidity - departure from 50% RH	-.349	.300	-.165	-.210	-.290
Humidity - within day range	.149	-.365	-.034	-.178	.663
Total particulates	.445	.323	.223	.054	-.150
Organic vapours	-.359	.059	-.495	-.219	-.216
Ventilation - uniformity	-.251	-.230	-.350	-.217	-.218
Ventilation - fresh air	.131	.485	-.034	-.163	-.298
Environmental score (mean of ranks)	-.115	.225	-.153	-.476	.066
Rank of score	-.173	.189	-.382	-.465	-.101

TABLE IX. MEAN ENVIRONMENTAL MEASUREMENTS AND "BUILDING ILLNESS" (16 CASE-CONTROL PAIRS) *

	Cases *	Controls
	mean values	
Temperature:		
(1) Absolute difference from 22°C	1.5°C	1.3°C
(2) Within day range (°C)	0.7°C	0.7°C
Humidity:		
(1) Absolute difference from 50% RH	24.00%	25.00%
(2) Within day range (% RH)	2.00%	1.00%
Total particles (per cc)	1.12	1.55
Organic vapours	0.55 mg/m^3	0.54 mg/m^3

* Were defined in September 1983 on similar but not identical criteria to later building illness syndrome.

RELATING HEALTH AND ENVIRONMENTAL STUDIES IN A TIGHT BUILDING SYNDROME INVESTIGATION

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A two-phased study was undertaken to investigate health and environmental complaints in a large, modern, sealed office complex. An account of the epidemiological investigation and the associated environmental study has been presented earlier at this conference (McDonald et al).

The health surveys of present and past employees were conducted to fully characterize the nature and magnitude of the complaints. Preliminary analyses of the current employee questionnaire data were used in establishing the environmental sampling protocol. A limited environmental study was conducted to identify environmental factors which might be responsible for the complaints of the complex's occupants.

Incidence and prevalence rates of a pre-defined "irritation-type" syndrome were examined on a floor-by-floor basis in all towers of the complex. Ten floors were selected for environmental investigation. The environmental survey of these "good" and "bad" floors, as characterized by low and high frequencies of an irritation syndrome, consisted of two areas of study -ventilation and the measurement of specific air quality parameters.

Two ventilation parameters, outdoor air supply and air distribution, were investigated. The volume of outdoor air supplied to a floor was determined using the Pitot traverse method on each supply duct. Effective ventilation rates were determined with the rate of decay tracer gas method using sulfur hexafluoride (SF_6) as the tracer. The effective ventilation rates, determined at eight sites on each of the selected floors, were used to interpret outdoor air distribution on the floor. Temperature, relative humidity, total particulates, and organic vapour levels were also measured at the same sites on the selected floors.

A case-control series of seventeen pairs, matched for age and sex, and associated with the presence or absence of symptoms, was established in order to study differences in indoor air quality measurements at the level of the individual work sites.

As related in the health questionnaire, respondents with no complaint about the environment had few complaints about their health and vice-versa. There was little indication, however, that the type of symptom (individually or in groups) and type of environmental complaint were correlated in any meaningful way.

The environmental survey indicated that ventilation was better with a uniform office configuration on a floor.

The limitations of the environmental investigation in light of the available resources are discussed. The limitations of the health study are reviewed. Data interpretation and the correlation of health and environmental results are examined in relation to these limitations, the parameters measured, and the weighting of the same in the final analyses.

Lessons learned from this investigation, which can be applied to future studies, are summarized.

Introduction

Background to Problem

In the last decade interest and concern relating to indoor air quality has heightened. This can be linked to the construction of tightly sealed buildings in the wake of the energy crisis of the early 1970s. These sealed structures are totally dependent on a mechanical ventilation system for air supply and distribution. The occupants of these structures are increasingly voicing a variety of non-specific health symptoms, and problems relating to the ventilation, noise, and thermal comfort of the indoor environment. The typical symptoms of nasal, eye, and throat irritation, accompanied by headache, dry skin and lethargy, have been called the "Sick" or "Tight Building Syndrome" (1,2,3,4).

Government agencies, university research groups, and private consulting firms in North America and Europe are now receiving frequent requests, associated primarily with the office environment, to investigate health and/or environmental complaints from the building occupants.

The non-specific nature of the complaints has led to a variety of approaches to the problem. The presence of numerous contaminants in an office environment, all at low levels, has been previously confirmed (2,3). However, the task of linking these with the non-specific health complaints occurring, poses a formidable problem. The fact that the office environment is a

continually changing entity (i.e. floor plans, contaminant sources, ventilation rates), poses a problem in defining a standard method of investigation. Many studies have been undertaken to date, using a variety of approaches, with the vast majority of the findings being inconclusive. Some outbreaks have been investigated strictly from an environmental standpoint, attempting to identify a particular causal agent with no description of complaints nor their patterns (5). Other investigators conduct environmental tests with subsequent epidemiological surveys (6), treating the two as completely separate entities. These approaches have been unsuccessful in fully characterizing the complaints, their cause(s), and relating them to existing environmental conditions.

A two-phased investigation relating epidemiologic and environmental studies, in order to study employee complaints in a large, modern, sealed office complex, has been previously described at this conference (7), of which certain elements will be elaborated here. Data interpretation and the correlation of health and environmental results are examined in relation to: the limitations imposed by available resources, the parameters measured and the weighting of the same in the final analyses.

The problems in the complex began in 1977 with the first occupancy of the office buildings. Since that time, the employees have voiced complaints characteristic of the Tight Building Syndrome. Prior to the McGill University investigation (1983-84), various other studies had been undertaken on the premises. These included: air sampling for particulates, organic contaminants, carbon monoxide, formaldehyde; temperature and relative humidity measurements; a limited health survey by a local employee group; verification of mechanical system performance, functional diagnoses and facilities maintenance. Various modifications to lighting and air handling systems had been undertaken within the complex but their consequences in relation to health complaints had never been established.

The initial proposal involved three facets to be conducted over a two-year period: (1) description; (2) search for causes; and (3) control. The descriptive aspect would ascertain past and present frequencies of specified symptoms in both current and past employees of the complex. This would be done in relation to such variables as age, sex, place and type of work, personal habits, etc. Subsequently, a fairly extensive series of environmental measurements would be undertaken to test whether there was any difference in the level of measurable environmental parameters in workplaces of employees with high and low frequencies of various types of health complaints. It was anticipated that both the health and environmental surveys would indicate the need for certain controls. It was hoped to then test the effectiveness of these controls once introduced.

At the request of the client, an abridged version of the original proposal (July 27, 1982) was subsequently submitted (September 6, 1982). The time frame of the study was reduced to one year and, consequently, the environmental surveys were limited and the control aspect of the study was discarded.

The ensuing investigation had two components:

(1) an epidemiologic survey (a) to characterize the nature of the health complaints in present and past employees and (b) to determine whether a pattern of complaints existed in relation to place (i.e. floor, tower, type of office), time, and personal characteristics of the employees (i.e. age, sex).

of possible causative factors related to employee complaints.

Ventilation System Design

"Les Terrasses de la Chaudière" complex consists of three office towers and a hotel. The office buildings are referred to as East, Central and North and are 19, 7 and 28 storeys respectively. For purposes of the environmental study, the East building was considered as two towers, East-1 and East-2, based on the design of the air handling system. The outside air intakes and conditioning units for the East and North buildings are located in the penthouse while the intake for the Central building is located at ground level. In addition, East-1 and East-2 have two auxiliary air handling units on the 14th and 10th floors respectively, to supply the additional ventilation capacity needed on the larger lower floors of the terraced structure. Upon entering the HVAC system, outdoor air passes through a set of 20% efficient fibreglass pre-filters and a second set of 60% efficient filters (based on ASHRAE Atmospheric Dust Spot Efficiency Tests) (8). A plan-view of the complex is presented in Figure 1 and indicates the outdoor air supply and exhaust units.

The HVAC design in the complex is a variable air volume (VAV) system. Floors are divided into two zones, interior and peripheral, the peripheral consisting of all areas within 3.7 m (12 ft) of the exterior wall. Design stipulates a supply of 0.76 lps/m^2 (0.15 cfm/ft^2) outside air and 3.4 lps/m^2 (0.67 cfm/ft^2) recirculated air.

Individual floors have at least one ventilation core, consisting of one or two air handling units. Conditioned outdoor air enters the mechanical room from the supply shaft through constant volume air valves. Each mechanical room acts as a mixing plenum for the outdoor air and the recirculated air which is drawn from the floor ceiling space. This mixture of supply air passes through another set of 60% efficient filters located in each air handling unit. Supply air is discharged by the air handling unit through ducts containing heating and cooling coils for the peripheral zones, and cooling coils only for the interior zones. Conditioned air is delivered to VAV valves in the ceiling space via fibreglass duct work and then supplied to the occupied space through linear ceiling diffusers. Air from the floor space is directed in part towards the washroom and general exhausts, the remainder being recirculated (~80% recirculation).

Room temperature, 21.0 - 25.0°C (70-77°F), is controlled by thermostats located in the ceiling space. The VAV valves in the periphery are designed to operate at a minimum of 40% capacity. Interior VAV valves were originally designed to fully close and supply no air when setpoint temperatures were satisfied. However, as a result of numerous complaints by building occupants, all VAV valves have been set to ensure a minimum 40% open position at all times in order to increase the local air supply (9).

Methodology

The basic principles of epidemiology were applied to this study of Tight Building Syndrome. That is, the knowledge of disease distribution (symptoms) was used in order to elucidate causal mechanisms, explain local disease occurrence, and describe the natural history of the disease (10). The nature and magnitude of the health and environmental complaints in the indoor environment were described in relation to a variety of specified parameters (age, sex, work location, type of office, time of onset, progression, etc.). In a subsequent step, patterns of complaints were investigated using the resources of occupational hygiene monitoring so as to generate hypotheses relating to causal agents. Sampling procedures and instrumentation have been fully described elsewhere (7).

Health Survey

A preliminary analysis of the current employee questionnaire data allowed us to look at frequencies of reported health complaints in relation to tower and floor. Incidence and prevalence rates of a pre-defined "irritation-type" syndrome were examined on a floor-by-floor basis in all towers of the complex.

Five floors with a high frequency and five with a low frequency of complaints were selected for environmental evaluation in relation to ventilation and indoor air quality parameters.

A case-control series (matched for age and sex) was also established. Cases were defined as individuals experiencing irritation-type symptoms starting in their present work location; controls had no such complaint. Three individuals were also identified as having irritation-type symptoms starting in a previous work location but not reported at their present site. Consequently, they served as their own control. The case-control series was studied in relation to indoor air quality measurements; no ventilation studies were undertaken at specific work sites.

The environmental sampling protocol and the parameters selected for study were established after having: considered the results of the previous studies; conducted a detailed walk-through of the complex; and undertaken the floor classification in relation to office type present.

The ten floors and seventeen case-control pairs were given to the environmental team with no information other than the floors and towers to be studied and individual work sites for cases and controls. They had no "a priori" knowledge of the health status of the individuals nor the types of complaints on the floors and sites investigated.

Environmental Study

Two ventilation parameters, outdoor air supply and air distribution, were evaluated. The volume of outdoor air supplied to a floor was determined using the Pitot traverse method on each supply duct. Effective ventilation rates were determined by the rate of decay tracer gas method using sulfur hexafluoride (SF_6) as the tracer. The effective ventilation rates, determined at eight sites on each of nine selected floors, were used to interpret outdoor air distribution on that floor. Temperature, relative humidity, total particulates, and total hydrocarbon levels were also measured at the same sites on each of the floors as well as at sixteen paired work

locations. Practical considerations did not allow measurements on one of the floors and one of the seventeen pairs of sites selected by the health team.

Results

Health Survey

A high proportion of employees at Les Terrasses de la Chaudière reported health and environmental complaints related to their place of work. These problems were typical of those experienced in other Tight Building Syndrome investigations - irritation of the eyes, nose and throat, complaints of drowsiness, difficulty in concentration, headache, as well as frequent complaints associated with ventilation, noise and lighting of the office environment.

All parts of the complex were affected regardless of tower, floor, aspect, interior or periphery, or proximity to office machines.

Only minor differences in the frequency and nature of the complaints were noted in relation to employee age, sex, or seniority. There was, however, a systematic tendency for those who worked in cubicles to be more frequently affected than comparable persons in closed offices or open areas.

There was no evidence that work in the complex had an adverse effect on pregnancy outcome.

Environmental Studies

Environmental sampling was conducted over a three-month period in the winter of 1983-84. The results are summarized in Table 1.

Temperature and Relative Humidity

Temperature measurements, made twice daily, detected a range of 19 to 26.5°C on the nine floors monitored and 21.0 to 25.5°C at the 16 pairs of selected work sites. Temperatures, on the whole, did not vary significantly throughout the day (±1.5°C), and exceeded the 20.0 - 23.6°C range recommended by ASHRAE (11) on relatively few occasions. Relative humidity was found to range from 13 to 39% throughout the complex. The majority of the measurements were in the 25 to 35% range with little intra-day variation.

Total Particulates and Hydrocarbons

The average concentration of the organic and particulate contaminants measured on each of the nine floors was higher than that found in the outdoor air. Although the concentrations found were quite low, this build-up is to be expected for internally sourced pollutants in a building whose ventilation system uses a large percentage of recirculated air.

The concentration of particulates on the nine floors ranged from 2.2 to 21.6 ug/m^3. By comparison, the range of particulates observed at the 32 individual work locations throughout the complex was 2.2 - 33.4 ug/m^3.

Airborne fungal spores, primarily of the Aspergillus type, accounted for approximately 80% of total airborne particulates. Concentrations ranged from 0.9 to 25.9 ug/m^3.

The measurement of total hydrocarbons, based on a C-8 alkane calibration, was found to be extremely low (< 0.01 - 2.64 mg/m^3) and exceeded 1.0 mg/m^3 on relatively few occasions.

Ventilation

The supply of outdoor air was found to be adequate on six of the nine floors investigated. It was observed that some of the constant volume air valves, controlling the supply of outdoor air into the mechanical rooms, were not set to design specifications.

On some of the floors, air distribution was found to vary significantly, and was seemingly related to the overall office design of the floor. Floors having a uniform office concept, that is primarily open or private offices, were found to have a good air distribution.

Health and Environmental

As intimated in the health questionnaire, respondents with no complaint about the environment had few complaints about their health, and vice versa.

There was some suggestion that the employees on the five "better floors" (based on the environmental survey) had fewer symptoms than those on the other four floors but, overall, no correlation could be demonstrated between environmental measurements and the prevalence of health complaints. However, a combination of inadequate air supply and poor distribution, accompanied by periods of high temperature and low humidity, particularly in cubicles and other poorly ventilated work locations, could be responsible for initiating illnesses of the type described in the health survey.

Discussion

A most difficult aspect in investigating any Tight Building Syndrome outbreak is the interpretation of results.

In this study, subjective responses characterizing health and environmental problems were elicited in a questionnaire inquiry. The scope of these complaints was large, and to link them to a possible causal agent or agents - of which the list of possibilities is vast - posed a formidable problem.

A revision of the initial proposal, at the request of our client, resulted in the favouring of the characterization of the complaints. As mentioned, the occupational hygiene component measuring stressors in the indoor environment which might possibly provoke these complaints, was limited.

A preliminary assessment of available health data from the current employee questionnaire inquiry allowed for a maximization of the hygiene resources by focusing on areas of the complex meriting investigation. This, of course, does have limitations.

The environmental assessment described the conditions at the time of the survey. It was limited to a winter investigation and as conditions in the complex have changed over time (modification to air handling systems,

changes in floor design, etc.), they can only reflect the present-day situation and do not necessarily reflect conditions throughout the year, or in the past. On the other hand, the health complaints cited had started six years previously in some cases and had persisted with time.

In the ranking of floors as well as specific work sites, and the linking of these to health complaints, each of the environmental parameters measured was assumed to have an equal influence on the quality of the office environment. To date, there is no justification to weight otherwise, but perhaps a different weighting would have strengthened the correlations. It is of interest to note that positive correlations were observed for the parameters of ventilation, relative humidity, and total particulates, all of which, in theory, can provoke the list of complaints seen within the complex. Had these parameters been weighted more heavily, correlations of health and environmental data might have been more striking.

Parameters such as low frequency noise, lighting, and carbon dioxide levels, could have conceivably contributed to, or been the cause of, the complaints, but they were not examined in this investigation. The parameters selected for study were determined after careful consideration of the results of previous studies, the need to establish a baseline for future investigations, and making the best use of resources to this end.

Smoking in the workplace is another issue which may have been selected for study. That is, the relationship of environmental pollutants to the number and location of smokers in the area, as well as complaints elicited as a result could be examined subsequently.

It must also be remembered that the Les Terrasses "situation" had been widely publicized in newspapers (local and national), home journals, and within the complex itself (union newsletters, in-house committees). Hence, we would expect employees to be more "aware" of any health problem experienced. This dictated a need to localize areas where complaints started and to examine these sites in relation to the environmental stressors present. The population studied, though, was highly mobile in that about 30% of current employees reported having occupied more than three work locations in the complex. The localization of the start of complaints, as well as the indication of work locations occupied on a floor plan, are further complicated by the terracing of the office structures. This problem was somewhat alleviated by citing examples in the information sessions conducted during the questionnaire distribution phase.

The task of comparing information from a self-administered and a telephone-administered questionnaire also complicated data interpretation. In the end, each of these results was reported separately and similarities and differences were examined with caution.

All of these factors may bear heavily on the fact that the correlations between the health complaints and environmental conditions were not striking. The contribution of each, independently or collectively, was impossible to evaluate due primarily to the fact that the investigation was undertaken at a very late stage in the "ensemble" of the problem. Their contribution to the confounding of any link of health complaints and environmental conditions can only be surmised.

Conclusions

The methodology, using an extensive epidemiologic health study to focus on areas of the complex meriting environmental investigation, made the

best use of the resources available within the contract. It enabled a complete characterization of the nature and extent of the health and environmental complaints within the complex. It also permitted a baseline of health and environmental measurements to be established, which is necessary for the evaluation of the impact of any environmental changes subsequently undertaken. Furthermore, it allowed some speculation to a causal component of the complaints - inadequate outdoor air supply and distribution accompanied by periods of elevated temperature and low relative humidity.

In the wake of complaints, investigations should be conducted immediately in order to: avoid the confounding of issues; establish and characterize a baseline state from both a health and environmental perspective; and provide effective solutions which should be followed up and subsequently evaluated. Labour and management working as a team, both playing an active role, are more likely to successfully deal with office environment problems than either group working independently.

The possible components of a Tight Building Syndrome situation necessitate the multi-disciplinary approach. Epidemiologic, air quality engineering, toxicologic, medical, architectural and psychologic components must be considered in any complete investigation. Epidemiology is necessary to characterize the complaints; air quality engineering incorporates the tools of ventilation engineering and occupational hygiene to quantitate the environment in terms of ventilation parameters and indoor air contaminants; toxicologic and medical principles are used to correlate health complaints and existing environmental conditions; architectural principles such as building materials and design must be examined; and psychological implications of the situation in relation to productivity and discomfort need to be considered.

Presently, the etiology of Tight Building Syndrome remains unknown. The potential effects of indoor pollutants on health, the synergistic and antagonistic effect of these pollutants on health, the applicability of current standards/guidelines etc. to a non-industrial environment, and smoking versus non-smoking and its effect on the indoor environment, are all issues meriting future investigation.

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Table 1. Environmental Results

Sites	Temperature °C	Relative Humidity %	Total Particulates ug/m³	Total Hydrocarbons mg/m³	Outdoor Air Supply lps/person (cfm/person)	Outdoor Air Supply lps/m²(2) (cfm/ft²)
9 floors	19.0 - 26.5	20 - 39	2.2 - 21.6(1)	<0.01 - 2.64	7 - 14 (14 - 29)	0.5 - 1.0 (0.10 - 0.20)
Outdoor air			5.5 - 18.3	<0.01 - 0.09		
32 individual work locations (16 pairs)	21.0 - 25.5	13 - 33	2.2 - 33.4	0.01 - 1.78	-	-

Guidelines

ASHRAE(3,4)	(winter) 20.0 - 23.6 (summer) 22.8 - 26.1	50	75	-	10 (20)	0.7 (0.14)
Public Works Canada(5)	(winter) minimum 20 (summer) maximum 26	20 - 60	75	-	10 (20)	0.7 (0.14)

(1) Estimate based on ACGIH TLV for Nuisance Dust of 10 mg/m³ or 1059 p/cc (30 mppcf)
(2) Based on an average population density of 7 persons/100m² where smoking is permitted
(3) ASHRAE Standard 55 - 1981: Thermal Environmental Conditions for Human Occupancy
(4) ASHRAE Standard 62 - 1981: Ventilation for Acceptable Indoor Air Quality
(5) Public Works Canada: Environmental Standards for Office Accommodation

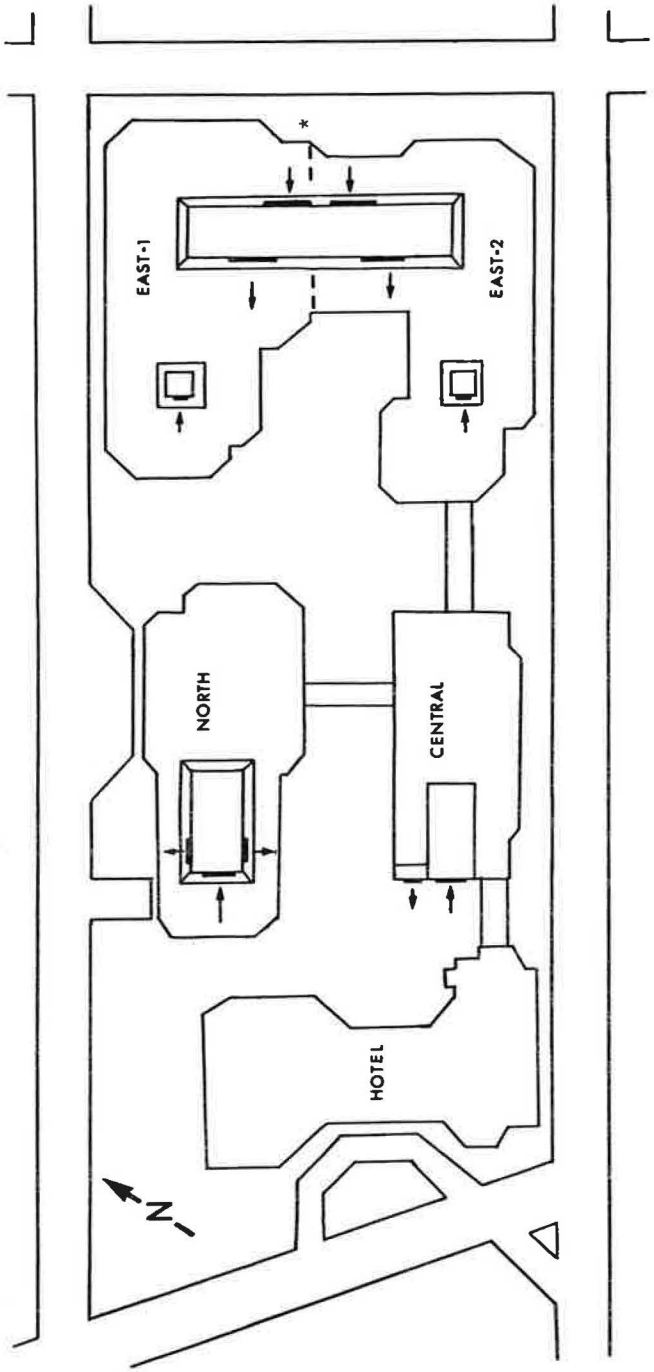

Figure 1. Plan-view of Les Terrasses de la Chaudière complex indicating outdoor air supply and exhaust units.

Note: * Illustrates division of East towers for purposes of the environmental survey.

A METHOD FOR THE OBJECTIVE EVALUATION OF INDOOR AIR QUALITY USING A PASSIVE MONITORING SYSTEM COUPLED TO BIOASSAYS

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In order to obtain objective data on the biological effects of indoor air quality, passive samplers were placed at 287 sites within 18 different buildings and at 33 sites within 7 homes. The contaminants trapped by these samplers were tested for toxic effects with the *Panagrellus redivivus* bioassay. Two types of samplers were used, an absorbent sampler containing activated Molecular Sieve 13X, to trap contaminating organic vapors, and a liquid sampler containing a physiologically balanced buffer, to trap contaminating viable and non-viable particles. Two distinct classes of toxic effect were detected; *inhibition* of growth and *stimulation* of growth. Inhibition of growth is a toxic response to contaminants in the air, while stimulation of growth reflects conditions of increased microbiological contamination. Both types of effect correlated with health complaints within the tested buildings. Inhibition by vapors was detected in 16.7% of the tested sites, while stimulation was found in 8% of the tested sites. Inhibition caused by particulates was observed in 16.9% of the sites tested, while stimulatory particulates were found in 6.2% of these sites. Where corrective measures were taken at the identified problem sites, worker complaints decreased.