CONTAMINATED AIR IN A MULTI-STORY RESEARCH BUILDING EQUIPPED WITH 100% FRESH AIR SUPPLY VENTILATION SYSTEMS

Behzad S. Samimi, MSPH, Ph.D., CIH
Department of Occupational and Environmental Health
Graduate School of Public Health
San Diego State University
San Diego, California
U.S.A. 92182-0405

INTRODUCTION

A considerable number of employees working in a multi-story biological research establishment were complaining about multiple symptoms, primarily of respiratory tract. The symptoms were chiefly irritation of mucous membranes as well as allergic reactions including: nose bleed, itchy eyes and lacrimation, asthmatic condition, and hay fever. There were also other complaints about occasional odor of diesel fumes within the building, musty odor resembling sewer gas in at least one office and air becoming stuffy in some offices when doors were kept shut; in the lather locations, employees complaints were primarily stuffiness, occasional headache and lethargy, particularly during the p.m. hours. The great majority of employees claimed that they experience the symptoms shortly after reporting for work in the building but are relieved from their symptoms after they leave the building and as long as they are away from work.

The objectives of this investigation were: (1) to determine whether the employees physical symptoms were caused by air contaminants in the building, (2) to identify the types and the sources of such air contaminants and (3) to recommend corrective measures to resolve the problem.

MATERIALS AND METHODS

1. **Preliminary Survey:** As the first step in the investigation, employees working within the affected area were interviewed. The primary objective was to determine whether or not the symptoms were work related. The interview was conducted individually with each employee and was consisted of two parts. At first, the employee was given the opportunity to explain the ground for complaints and then was asked to answer a number of pre-determined questions.

A walk-through survey of the building including the HVAC systems was conducted in order to look for presence of potential sources of gaseous air contaminants, i.e. formaldehyde and other organic vapors, carbon monoxide, ozone, etc. This included search for presence of new walls, floor coverings, partitions and furniture, open combustion, duplicating machines, etc. Preliminary inspection of the HVAC systems also included search for evidence of bacterial and fungal growth within the systems and visual signs of particulate contamination.

The final step was to set up a sampling strategy and to determine the sampling and analytical equipment and techniques needed for the study.

2. **Inspection of the HVAC Systems:** There were eleven large HVAC units designed to supply 100% filtered fresh air to all units of the building with no air recirculation. The return air was handled by separate fan systems which discharged the air from each room or laboratory directly onto the roof top. Only five out of the eleven HVAC units in the building which ventilated the affected area were included in this survey.

Various components of the HVAC systems were carefully inspected in order to identify the defective components or operations. This included thorough inspection of the interior of ducting systems, pre-filters, charcoal filters and after filters, pre-heat, cooling and reheat coils.

3. **Air Sampling and Analysis:** High-volume air samplers were used to collect air samples for airborne particulate from (1) general air in rooms, laboratories, and hallways and (2) air supply ducts. All samples were analyzed gravimetrically followed by phase contrast microscopy (PCM) and polarizing light microscopy (PLM). Representative samples of particulate collected from the air supply ducts were also analyzed by scanning electron microscopy / energy disperssive spectroscopy (SEM/EDS).

Wipe samples were also collected from particulate deposited within the air supply ducts (including the re-heat coils), on the face of the air dampers and along the door gaps of rooms with negative pressure. These samples were also examined by PCM, PLM and SEM/EDS to identify the particulate content.

No air samples were needed for carbon monoxide, formaldehyde and other organic vapors due to absence of potential sources of these air contaminants within the building. However, concentrations of carbon dioxide were monitored throughout the building.

4. **Measurement of Thermal Comfort:** Elements of thermal comfort, i.e. temperature, relative humidity and air movement were measured three times a day during the study.

5. **Survey of Ventilation and Air Flow Patterns:** The rates of air supply to ,and return air from, every room and laboratory in the affected area of the building were measured using a calibrated flow hood. By comparing the rates of supplied air and exhaust and use of Smoke Tubes, the presence of negative or positive pressure in a room or laboratory was verified and recorded. The information was used to determine the air movement pattern throughout the building.

RESULTS AND DISCUSSION

1. **Air Supply and Thermal Comfort:** There was a strong evidence that the employees symptoms were most likely work related, because the great majority (80%) of employees either did not have the symptoms, or noticed significant improvement, while being away from work, particularly during weekends.

Considering the design of the ventilation in this building as providing continuous flow of non-circulated fresh air, it seemed likely, from the beginning of this study, that the cause of employees health problems in this case would be different from the common cause of "sick building syndrome", i.e. inadequacy of fresh air supply to the occupants, which is frequently seen in many energy efficient buildings.

The results of ventilation survey (summarized in Tables I and II) showed that due to ample supply of outside air and low density of occupants throughout the building, the concentrations of carbon dioxide, as expected, were quite low ,i.e. slightly above the outdoor level. Only in some offices with negative pressure, air supply rate of less than 160 SCFM and with both air inlet and exhaust grilles on ceiling, the CO_2 concentrations, with occupants present, ranged 400 - 550 ppm (considerably higher than all other units of the building). The employees complained of lethargy and stuffiness when doors remained closed for an extended period of time. However, this was apparently as a result of inadequate air distribution due to negative pressure and short route between the inlet and exhaust ducts. It seems likely that carbon dioxide accumulation in these offices might have reached even higher levels in the past.

Temperature and relative humidity were also notably higher in these rooms, evidently due to the same reason of inadequate air distribution.

TABLE I: THE RATES OF SUPPLY AND RETURN FRESH AIR IN VARIOUS UNITS OF THE BUILDING

Type of Units	No of Units	Average Air Flow in SCFM (Range)		Pressure Status	SCFM Per Employee
		Supply	Return		
Office	10	273 (105-635)	443 (126-936)	Negative	110-317
Office	9	272 (155-410)	227 (144-268)	Positive	155-395
Laboratory	4	680 (500-833)	1356 (1152-1560)	Negative	167-390
Workshops	2	-	-	Positive	-

SCFM: Standard Cubic Feet per Minute

TABLE II: ELEMENTS OF THERMAL COMFORT AND CONCENTRATION OF CARBON DIOXIDE IN VARIOUS BUILDING UNITS

Type of Unit	No. of Unit	Pressure Status	Temperature Range (^oF)	Relative Humidity (%)	CO_2 Range (ppm)
Office	10	Negative	74.5 - 79.5	59 - 62	400-550
Office	9	Positive	72.0 - 75.5	58 - 60	325-350
Laboratory	4	Negative	72.0 - 76.0	59 - 61	325-350
Workshops	2	Positive	72.0 - 74.0	58 - 60	325-350

TABLE III: THE RESULTS OF SAMPLING AND ANALYSIS FOR AIRBORNE PARTICULATE

Sampling Location:	Sampling Data:			HVACs #	Concentration: in Ug / M^3
	Number	Time (Min)	Volume (Liter)		Mean (Range)
Office General Air	2	165-180	4042-4480	2/7	23.4 (15.6-31.2)
Air Supply Ducts	11	127-372	3111-9114	2/7/11	71.1 (14.2-131.5)
Hallways and Doors Open to Outside	3	235-383	5757-9383	NA	71.7 (29.9-98.7)
Machine and Electronic Shops	3	135-330	3307 8085	7	86.2 (61.8-125.8

2. **Air Contaminants:** In the absence of significant levels of gaseous air contaminants as the cause of employees illness, attentions were focused on collection, assessment and identification of the types and sources of airborne particulate in the building. The results of air sampling are summarized in Table III. The results of identification of airborne particulate as well as wipe samples are summarized in Table IV. These results indicate presence of multiple types of airborne particulate introduced into the building by the following sources:

TABLE IV: THE RESULTS OF IDENTIFICATION OF AIRBORNE AND SETTLED PARTICULATE SAMPLES BY PCM, PLM, AND SEM/EDS TECHNIQUES

Type of Sample	Location of Sampling	No. of Samples	Major Particulate Content in Order of Prevalence:
Air	Offices	2	Cellulose Fibers; Fiberglass; Mineral Dust; Pollen; Smoke; Aluminum and Iron Oxide Flakes Animal Hair.
Air	Air Supply Ducts	8	Cellulose fibers;*Fiberglass; Aluminum and Iron Oxide Flakes Charcoal Particles; Pollen; Mineral Dust; Mold; Animal hair Insects, etc.
Air	Machine and Electronic Shops	3	Fine Metal Oxides; Mineral Dust Cellulose Fibers; Fiberglass, etc
Air	Hallways and Doors Open to Outside	3	Mineral Dust; Organic Particles Variety of Pollen; Smoke and Soot Particles.
Wipe	Offices (Door Gap and Damper Grille)	2	Cellulose Fibers; Mineral Dust; Organic particles; variety of Pollen; Fiberglass Fibers, etc.
Wipe	Inside Air Supply Ducts & Dampers	5	Fiberglass Fibers*; Cellulose Fibers; Mold Clusters; Aluminum and Iron Oxides; Charcoal Particles; Animal Hair; Pollen.
Bulk	Duct Liner (Fiberglass)	2	Fiberglass Liner Loaded With Dust Particles (Fiberglass & Cellulose Fibers, Metal Oxides, Mineral Dust, Pollen, etc.) and Mold Clusters; Animal Hair.
Bulk	Reheat Coil	1	Aluminum Oxide Dust; Fiberglass & Cellulose Fibers; Mineral Dust
Bulk	After Filters**	3	Cellulose Fibers; Charcoal Part-icles; Mineral Dust; Pollen; Insects; Molds, etc.

* Fiberglass fibers were loaded with dirt and fungi growth
** Past pre-Filter and Activated Charcoal Filter

(a) HVAC Systems: All eleven HVAC units in the building were installed at the time of construction in 1967. All units provided 100 % filtered outside air without recirculation. HVAC units that supplied air to some of the research laboratories and the animal surgery rooms, were equipped with three-level particulate filtration system which consisted of: (1) cardboard-framed cotton pre-filters (12"x12", 25-35% efficiency), (2) carbon module (activated carbon) and (3) after filters the same type as the pre filters. Other HVAC units had a two-level filtration compartment consisting of pre-filters and after-filters of the same types stated above.

A major problem noted was softening and collapsing of pre-filters as well as after-filters cardboard frames due to high moisture content of intake air at the air handlers. As a result, under the pressure of the air stream, the filters often collapsed, i.e. became crooked in place or fell off the metal retainer leaving large gaps for passage of unfiltered unconditioned outside air.

The interior of all air supply ducts were lined acoustically with flexible 0.5 inch-thick x31 density fiberglass duct liner. Over the years of operation, outdoor airborne particulate including mineral and organic dusts, pollen, animal hair from a nearby stack, smoke and soot from diesel trucks unloading on a nearby unloading dock, etc. either entered the building atmosphere or were deposited onto the duct liner.

Animal hair were originated from the exhaust pipe of the adjacent animal holding unit of the same building. Maintaining high negative pressure within the animal holding unit and separate ventilation system, prevented entry of animal hair into the research unit through doors and hallways; however, due to failure of the particulate filtration system on HVACs, animal hair exhausted from the animal holding unit near the HVACs' air intake port, entered the research unit with outside air. Animal hair was one the particulate contaminants found in air samples.

Cellulose fibers were also being emitted from both pre and after filters made of primarily cotton. Activated charcoal filters also contributed to the particulate emission by gradual release of carbon particles through the perforated retainers; this occurred apparently as a result of vibration of the system and presence of gaps in the after-filter units as explained earlier.

Gradual corrosion and oxidation of aluminum fins of the re-heath coils installed within the air supply ducts generated a significant amount of aluminum oxide dust which considerably added to the particulate emission from the HVAC systems.

The most troublesome airborne particulate, however, seemed to be the fiber glass fibers being originated from the air supply duct liner, apparently as a result of gradual deterioration of the duct liner over the years. Due to relatively high humidity and retention of resulting moisture by the duct liner, fungal and bacterial growth also occurred within the duct liner. The duct liner, as a result, became a dust storage depot from which particulate air contaminants were continuously emitted into the building atmosphere (see Table III).

(b) Shops: An additional source of air contamination of building atmosphere was resulted due to improper air balance between various components of the building. For example, the machine and electronic shops were maintained under positive pressure. As a result, there was a continuous flow of air from these shops into the hallway and ultimately into the rooms and laboratories with negative pressure. During metal cutting, grinding, welding and soldering operations, due to lack or failure of local exhaust hoods in the shops, metal fumes and odors were spread, particularly to the nearby rooms.

(c) Outdoors: Negative pressure within the hallways (compared to outdoor), also caused continuous infiltration of outside air through several doors around the building that were normally left open during the summer days.

As a result, continuous flow of unfiltered air into the rooms with negative pressure left visible marks of settled dust within these rooms. Dust accumulation was particularly notable along the door gaps and on the return air grilles where, apparently due to high air velocity, inertial impaction played a major role in stopping the particles.

Diesel fumes from trucks unloading on the receiving dock entered the building through the same route. Excessive negative pressure in some offices resulted in suction of air from spaces beyond the wall boards through the cracks and openings such as electric power outlets. At least in one office, a musty odor, possibly from a decomposing rodent body, was noticeable, particularly when door was kept shut for a while.

CONCLUSION AND RECOMMENDATIONS

The results of this indoor air quality study has clearly demonstrated the presence of notable quantities of airborne particulate as the most likely causes of employees health problems in this building. Laboratory analyses of dust samples showed abundant presence of particulate such as pollen, fiberglass, mold, animal hair, etc. that are known as irritant and/or allergenic. The causes of dust contamination were: (1) use of improper, i.e cardboard-framed, filter elements under high humidity condition over many years which resulted in collapse of filters and excessive dust contamination of the air supply duct liner, (2) lack of a proper inspection and maintenance schedule, for the HVAC units and (3) failure in proper air balancing of the building components.

The recommended corrective measures included:

(1) Cleaning and encapsulation or replacement of the contaminated ducts.

(2) Improvement of the particulate filtration system by using more efficient and rigid filters. The recommended filters were FARR 30/30, 4-inch depth totally rigid pleated or RIGA-FLOW XL,(40-45%) 6-inch depth with galvanized steel frame as pre filters and RIGA-FLOW 15 (60-65%) or RIGA-FLOW 100 (80-85%) 6-inch depth as after filters. The synthetic backing of these filters also minimizes fiber emission from the filters.

(3) Proper air balancing of building components, i.e. maintaining shops and laboratories under negative and offices and hallways under slight positive pressure.

(4) Adopting and implementing a proper schedule for regular inspection and maintenance of the HVAC systems.

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