#5560

We tested two portable ozone generators currently available on the market to determine how safely they operate. What we found was that both devices tested greatly exceeded hazardous levels in chamber and office environment tests. Both models exceeded the FDA limit of 50 ppb within 15 minutes, and one device exceeded 1,000 ppb in 50 minutes. What the FDA advises is true: you cannot achieve effective oxidation without exceeding safe levels. We concluded that the use of ozone generators in an occupied space was inadvisable.

While the health effects are a real issue, you can't argue ozone's effectiveness. There are systems being developed that use it in a closed loop without releasing it into the occupied space. I think there is promise in that direction, although research is still necessary as to which specific contaminants ozone is best suited as an oxidant. That's where our current research is focused now. Although we haven't prepared our results for release as yet, we have noticed a number of interesting phenomena.

For example, some manufacturers claim that ozone is effective at reducing particulate levels. We have found that ozone effectively increases the particle count. Our theory is that the ozone coalesces particles below detectable size, combining them to form detectable particles. These particles, though larger, are in the respirable range and do not readily drop out of the air.

Conclusions

While there is no clear consensus, there seems to be some agreement as to the following:

1) Ozone is effective at killing microorganisms and at oxidizing many though not all odorous compounds, but:

2) Levels of ozone required to perform these functions are toxic to human beings, and can cause damage to fabrics and other materials. Therefore:

3) Application must be conducted in the absence of people. Industrial-scale ozone application always draws the air stream into an ozone contact container, with some sort of catalyst for destroying the ozone before the air stream continues to the occupied space.

For More Information

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CASE STUDY

Investigating Reentrainment in a Laboratory Complex

The following case study, presented anonymously at the request of the clients, demonstrates the use of tracer gas analysis and a detailed HVAC inspection to determine the pathways of reentrainment of pollutants in a mixed-use university research laboratory complex. Most noteworthy in this case, according to the principal investigator, was the presence of a "red herring" pollutant, assumed by the occupants and building managers to be the cause of reported symptoms. The ensuing investigation demonstrated that this pollutant, while possibly responsible for some of the symptoms, more importantly served to bring more serious existing problems into sharper focus.

Building Description

The 92,000-sq.-ft. laboratory complex at a midwestern US university consists of three interconnected wings. The original four-story wing A

(21,500 sq. ft.) was constructed in 1929 and was renovated during the construction of the five-story wing B (27,000 sq. ft.) in 1946. A third wing, wing C (43,000 sq. ft.), connecting to wing B and containing five floors plus a basement, was constructed in 1963. Major renovations to portions of the HVAC system occurred to wing A in 1946 and 1984; to wing B in 1979, 1982, and 1984; and to wing C in 1967, 1977, 1984, and 1990, just prior to the IAQ investigation. Construction on another six-story, 90,000-sq.-ft. building that will be connected to the complex commenced in October 1989 and is scheduled for completion in late 1991. The building complex houses a mixture of conference/seminar rooms, offices, laboratories, and animal care and exposure facilities.

HVAC System Description

During their inspection of the complex's HVAC systems, the investigators noted that the three wings within the complex had distinct mechanical systems that varied considerably in age, status of operation, and effectiveness. The original wing A had no forced-air HVAC system and relied primarily on infiltration through operable windows and the DX cooling, steam booster coil reheat air handler unit installed in 1946 for air makeup for ventilation and exhaust hoods. The small number of retrofitted water-cooled air conditioners in this wing simply recirculated indoor air and thus did not affect the ventilation balance of the building. During 1979, building renovators manifolded most of the 38 hood exhausts in the building into one of two large exhaust systems that together were designed to exhaust 34,535 cubic feet per minute (cfm).

Wing B's original mechanical ventilation systems heated, cooled, and supplied outdoor air to the building. Nine separate exhaust stacks, which exhausted a total of 5,462 cfm, serviced 14 exhaust hoods.

Wing C was equipped with five separate air handling systems designed to provide 40%-60% outside air during the heating and cooling seasons and 100% outside air when outdoor temperatures were favorable. Most of the wing's 28 laboratory hoods exhausted through the four rooftop ventilation stacks, which were under negative pressure. A static pressure controller, designed to modulate the amount of exhaust air and to maintain constant face velocities as hood sashes or dampers were closed, was disconnected during renovations in 1984. At this time the exhaust stacks were connected to a heat recovery system with a glycol run-around-loop to precondition outdoor air supplied by the tempered air system. Building managers used vane inlet dampers for manual balancing of the exhausts.

Presenting Problem/History of Complaints

In late December 1989 and early January 1990, occupants of the laboratory complex, including full-time employees, students, and part-time laboratory workers, began to complain of the very noticeable smell of diesel exhaust fumes from construction activities in an area adjacent to the laboratory complex. In early February, nine employees sought treatment for symptoms ranging from eye and throat irritation to central nervous system effects. Throughout the month more employees complained of effects that they attributed to diesel exhaust fumes.

During the second week of March, university officials took measures to reduce exposure to diesel exhaust fumes by stopping diesel operations on the construction site during the day and ordering the installation of catalytic converters on the equipment. They temporarily closed the building and relocated air intakes to reduce the intake of fumes from the construction area.

At the same time that facilities managers were attempting to remediate the apparent problems associated with the diesel fumes, they began chiller maintenance, including the release of 100 lbs. of Freon 113 (trichlorotrifluoroethane) from the basement chiller units. After the building reopened, occupant complaints and clinic visits increased. University officials closed the complex for three days in mid-March when they measured Freon 113 levels ranging from 17-120 ppm in various parts of the building.

By late March, Freon 113 levels measured in the building were less than 2 ppm. When the AC sump in the basement, into which Freon 113 may have been drained, was emptied and flushed, however, several individuals reported symptoms of dizziness.

In all, 60 of the complex's 111 full-time employees registered health and comfort complaints during February-April 1990. The majority of complaints came from occupants of wing C. During the next month university officials and facilities managers retained an environmental health and engineering consultant firm to begin an investigation.

Investigative Focus

In June 1990, a university committee requested that the consultants evaluate and make recommendations for the elimination of problems associated with:

- The air distribution systems;
- Biological contamination;
- Ductwork contamination; and
- Sumps, drains, and other potential sources of contamination.

To accomplish this, the investigators:

- Reviewed the ventilation systems, including control and operation strategies, pressure differentials and air flow balances, and exhaust hood operations;
- Performed tracer gas tests to determine air migration routes;
- Administered an environmental/health effects questionnaire to occupants;
- Performed environmental measurements for: volatile organic compounds (VOCs), nitrogen dioxide, formaldehyde, Freon 113, mercury, carbon monoxide, and microbiological contaminants.

As a result of the consultants' findings and ensuing recommendations, the university performed a considerable amount of remedial work in wing C. In August 1991, the consultants returned to do a followup investigation.

Test Results and Findings

HVAC Investigation

Inspection of the complex's HVAC systems revealed that many of the components did not operate as originally designed. The investigators attributed much of this to improper maintenance and makeshift exhaust connections. Measurements of flows and building pressure through the mechanical systems of the three wings revealed that the complex exhausted about twice as much air as its systems supplied. Table 3 presents the flow summary of the complex at the time of inspection.

Wing A appeared to operate at the greatest deficit. The investigators concluded that wing A's reliance on windows and steam-coiled makeup transoms did not provide the pressurization required for laboratory buildings. They found that wing B was operating with a slight excess supply of outdoor air since only four of the nine rooftop exhaust stacks were operating.

The investigators focused much of their attention on wing C, the site of most of the occupants' complaints. This wing appeared to be exhausting 20,000 cfm more than its systems supplied, despite the fact that the equipment installed should have been capable of providing a proper balance of makeup air, according to the inspectors. Further inspection revealed that the pressure control system of the tempered air system was not operational. Improper operation of hoods by individuals making adjustments to dampers and fans was contributing to the problem as well.

The HVAC inspection further revealed that the imbalance between exhaust and outdoor air was causing relatively large pressure differences between wings C and B, wing C and the ambient environment, and the hallway and the stairwell within wing C.

Tracer Gas Studies

A series of tracer gas tests involving the release of sulfur hexafluoride at numerous locations throughout wings C and B revealed a number of problems:

- Significant air transfer occurred between the animal facilities and adjacent areas despite the

Table 3 — Laboratory Complex Flow Summary

Wing	Total Measured Exhaust (cfm)	Total Measured Outdoor Air Supply (CFM)	Total Measured Excess Exhaust (CFM)
A	30,951	0	30,951
B	6,434	11,493	-5,059
C	56,302	35,963	20,339
Total	93,687	47,456	46,231

Note: cfm = cubic feet per minute

fact that the HVAC systems were designed to isolate the animal facilities. The investigators attributed this to reentrainment of the air from the animal facilities into the return air of one of the air handling units.

- Tests in wing C detected significant reentrainment of pollutants from the basement into upper floors; the outdoor air intakes for the AC units were within 30 feet of the exhaust fan of the basement mechanical room.
- The investigators did not find significant pollutant transfer from the sewage system or sewage vent system.
- Certain outdoor wind conditions promoted reentrainment of hood exhaust into wing C.
- The drainage system and sump pits that serviced the basement mechanical room in wing C were capable of transferring significant quantities of pollutants into the general building environment. Pollutants appeared to be drawn through the elevator shaft into the upper floors due to pressure differences.
- The transfer of airborne contaminants from wings A and B into wing C appeared to be substantial.
- There also appeared to be substantial transfer of pollutants from wing C into wing B.

Air Contaminant Measurements

The investigators monitored the laboratory complex for a series of contaminants that might be implicated in the health effects reported by occupants. Testing included monitoring for:

- VOCs
- Total volatile organic carbons
- Mercury vapor
- Bioaerosols
- Formaldehyde
- Nitrogen dioxide
- Carbon monoxide
- Freon 113 (trichlorotrifluororethane)

Table 4 presents details of the methods and results of these tests. The only significant results were:

- Elevated benzene concentrations, which though not in excess of the OSHA permissible exposure limit (PEL) of 1 ppm, exceeded the World Health Organization's (WHO) guideline of 0.3 ppb;
- Thermophile actinomycetes in two rooms in wing C supplied by a single tempered air unit.

Neither of these findings, however, explained the sick building complaints registered by the occupants, according to the investigators.

Chemical Survey

The investigators conducted a cursory chemical survey in laboratory spaces to detect gross chemical storage problems. While, in general, laboratory users appeared to be employing proper chemical storage practices, a few exceptions surfaced. The investigators were particularly concerned about the storage of chemicals in hoods and underneath open sinks, and the leakage of contaminants from shipments of biological specimens in wing C.

Conclusions

The investigators found no significant results in their airborne contaminants testing that would satisfactorily explain the symptoms reported by occupants during the months preceding the investigation. They noted, however, that events that occurred at the time of the initial complaints, namely the influx of diesel exhaust fumes from the construction equipment and the spillage of Freon 113, were not duplicated during the time of the testing. The relatively low concentrations of pollutants measured during the investigation were not, however, an indication that the complex was safe to occupy, according to the investigation team.

Serious exhaust system deficiencies and ventilation imbalances within the complex coupled with the presence of potentially harmful chemical pollutants in use in the laboratories could lead to serious pollutant exposure upon resumption of activities in the building. While complaints about diesel exhaust fumes and Freon 113 exposure first focused university officials' attention on possible reentrainment problems in the laboratory complex, the situation was, in fact, potentially more hazardous given the ineffectiveness of the ventilation system for a building with intensive laboratory usage.

According to the investigators, the lack of a comprehensive program of laboratory safety and health in the complex resulted in poor coordination of mechanical systems in terms of installation and maintenance, poor maintenance in many laboratories, improper chemical handling and storage procedures, and potential safety problems for personnel. Additionally, transfer

Table 4 — IAQ Investigation

Contaminant(s)	Testing Procedure	Findings	Comments
VOCs (39 speciated)	Tenax sampling cartridges used in accordance with the EPA's TO-1 IAQ sampling and analysis protocol	only significant results of the VOC tests were for benzene concentrations, which, though not in excess of the OSHA permissible exposure limit of 1 ppm, exceeded the World Health Organization's (WHO) guideline of 0.3 ppb	The consultants did not consider this result of significance since the measured concentrations were typical of most buildings and residences in the US where benzene is a common component and office products as well as tobacco smoke
Total Volatile Organic Carbons	Century OVA-128 flame ionization detector	all non-detectable results	
Mercury Vapor	Bachrach Model MV-2 detector	all non-detectable readings	
Bioaerosols	Andersen N6 impactor and culture on malt extract agar and tryptic soy agar	no overt airborne fungal or microbial contamination, except for thermophile actinomycetes in two rooms in Wing C supplied by a single tempered air unit	Further inspection revealed a deteriorating internal fiberglass lining with mold growth. The investigators concluded that the concentrations of mold detected would only cause adverse effects in individuals with pre-existing sensitivities.
Formaldehyde	chromotropic acid method 3,500 specified by the National Institutes of Occupational Safety and Health (NIOSH)	no formaldehyde concentrations that exceeded the occupational threshold limit values or IAQ guidelines set by ASHRAE (62-1981R) or WHO	
Nitrogen Dioxide	exposing passive diffusion samplers (Palmes Tubes) for four to five days followed by spectrometric analysis	no significantly elevated concentrations of nitrogen dioxide	Results indicated that no combustion source was affecting the area during the sampling period.
Carbon Monoxide	Interscan 400 direct reading instrument	background levels	Samples taken at locations overlooking the construction area may have been misleadingly low due to the small amount of equipment on the construction site at the time.
Freon 113	charcoal tube sampling in accordance with NIOSH's analytical method 1020	no measured concentrations greater than the limit of detection; all results three orders of magnitude less than occupational and ASHRAE guidelines	

and reentrainment of airborne contaminants from basement areas and hood exhausts into other areas of the building and into outdoor air intakes created potentially hazardous conditions.

Recommendations

In light of their findings, the investigators recommended the following remedial actions:

- Isolation of the basement equipment drain sump from the elevator shaft in wing C;
- Promulgation and enforcement of acceptable laboratory practices;
- Extension of rooftop exhaust stacks on all wings;
- Rehabilitation of all laboratory fume hood systems;
- Rebalancing of the wing C HVAC systems;

- Disconnection and capping of certain hoods from the exhaust systems in wings A and B;
- Rehabilitation of certain portions of the ventilation systems in wings A and B;
- Replacement of air handling systems in wings A and B;
- Balancing of the new systems in wings A and B;
- Development and implementation of preventive maintenance procedures; and
- Hiring of a facilities manager with engineering experience.

Followup Study

During an inspection of the laboratory complex 14 months after the initial investigation, the consultants found that the university had completed the majority of the recommended remedial measures "in a satisfactory manner." The university's remedial measures included:

- Implementation of a preventive maintenance program;
- Improvements in laboratory hoods;
- The establishment of a comprehensive, unified program of laboratory safety;
- Rebalancing of the wing C supply and exhaust air systems;
- Replacement of a check-valve in the elevator shaft of wing C;
- Relocation of outside air intakes;
- Raising of hood exhaust stacks;
- Sealing of chemical sumps;
- Installation of HVAC filters;
- Cleaning of wing C mechanical systems; and
- Bringing the wing C ventilation system into compliance with original design specifications.

Testing of the pressure relationships in the complex, particularly in wing C, showed that the improved systems should provide a safe working environment for all occupants. To maintain this level of safety, however, the consultants recommended that occupants observe the following safety precautions:

- Refraining from propping open laboratory doors;
- Keeping hood sashes in set positions except during transitory conditions;
- Refraining from using hoods for storage of chemicals and laboratory equipment to avoid impeding air flow;
- Keeping windows closed; and
- Refraining from blocking or altering air supplies or air return diffusers.

"It is essential that people realize that they have control over their safety and they must use common sense to ensure it. It is equally important that they realize that the functioning of each laboratory unit impacts the general building environment and that they must take responsibility for maintaining a safe environment for all," the consultants wrote in their followup report. Hiring a facilities manager to oversee procedures and equipment, which was not accomplished by the time of the followup visit, is essential to ensuring the continued safe operation of the facility, they added.

The environmental consultants that investigated this case invite comments, questions, and suggestions pertinent to this case or other cases. For more information, contact: John McCarthy, Environmental Health & Engineering, Inc., 7 Wells Avenue, Suite 2, Newton, MA 02159, USA; (617) 964-8550, Fax: (617) 964-8556.

INFORMATION EXCHANGE

US Agency Introduces IAQ Correspondence Course

State and local environmental health professionals, who have added indoor air problems to their responsibilities, can now arm themselves with "the information needed to recognize, evaluate, and control IAQ problems" through a correspondence course sponsored by the National Environmental Health Association (NEHA). The 120-page *Introduction to Indoor Air Quality: A Self-Paced Learning Module* and accompanying 297-page reference manual were written by Associate Professor Ingrid Ritchie of the Indiana University School of Public and Environmental Affairs, under a grant from the Bureau of Health Professionals of the US Public Health Service and the Indoor Division of the US Environmental Protection Agency (EPA).