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The building had a constant-air-volume ventilation system with an economizer. A single air intake was on the 11th floor. During the study, fresh air volume was supposed to vary weekly on each floor from 10 cubic feet per minute per person (cfmpp), the Montreal standard; to 20 cfmpp, the ASHRAE standard; and 50 cfmpp, a standard proposed by the Ontario Department of Labour. The building operator and engineer, the only ones who knew the ventilation level each week, overrode the economizer cycle and used the building's heating and cooling systems, rather than outside air, to maintain temperature and humidity.

Measuring the Results

Each Wednesday during the six weeks of the study, the researchers measured temperature, humidity, and CO_2 three times at 10 work sites on each floor. They measured outdoor air supply using the CO_2 measurements and sulfur hexafluoride (SF_6) tracer gas decay.

At the beginning of the study, workers in the experiment filled out a baseline questionnaire and completed additional queries on each Wednesday afternoon in one of two formats: a direct probe and an open-ended questionnaire. The questionnaires tested worker symptoms in response to environmental changes, and whether the respondents had been "unblinded," that is, whether they knew what changes in ventilation levels they were experiencing.

Researchers discovered that building leaks frustrated their attempts at restricting outdoor air intake to 10 cfmpp. The lowest they could achieve was 20.4 cfmpp. Neither did they reach 50 cfmpp, achieving only 33 cfmpp one week and 47.5 cfmpp the other.

This led them to recommend that future studies using this technique limit the attempt to the two extreme levels, bettering the chance for a greater variance.

Both time and the questionnaire type were important in results reported by the subjects. Those respondents who used an open-ended questionnaire reported fewer symptoms as the study went on, ranging between 11% and 36% lower than those respondents with direct probe questionnaires.

Researchers conclude from the temporal phenomenon that future researchers should allow for the variation when designing a study. The researchers also suggest that the choice of a questionnaire was crucial. Those subjects who used the open-ended style questionnaire reported 22% fewer symptoms in general than those with the direct questionnaire.

The team also discovered through work site measurements that exposure to building conditions is not homogeneous for all workers. Therefore, they recommend local work site measuring for a more accurate reading.

For more information, contact: Dr. Robyn M. Tamblyn, Lady Meredith House, Clinical Epidemiology, 1110 Pine Avenue West, Montreal, PQ H3A 1A3, Canada; (514) 398-3324.

CASE STUDY

*[In each issue **IAQU** presents a case study on an investigation of indoor air problems in a particular building. The editorial staff relies on information provided by the environmental consultants involved in the investigation. **IAQU** presents a variety of approaches to investigation and mitigation implemented by consultants with a broad range of experience, philosophies, and expertise. Inclusion of a particular case study in the newsletter does not imply **IAQU**'s endorsement of the investigative procedures, analysis, or mitigation techniques employed in the case. **IAQU** invites readers to submit comments, suggestions, and questions concerning any case. At the discretion of the editors, correspondence may be presented in a future issue.]*

Wet-Process Copier Fumes Elevate TVOC Levels in Four Buildings

We usually present a case study that examines problems and solutions in a single building. However, this case involves four buildings, all located in Canada, where the IAQ problems stemmed from copying machines. The recommended solutions differed according to the individual situation in each structure, as did management's response.

All four buildings are located in the province of Quebec, where the winter season is cold and windy (low of -20°C, -4°F) and the summer season is hot and damp (high of 30°C, 86°F).

Table 3 — HVAC Investigation Techniques

Ventilation Factors	Testing Method	Sampling Method
Fresh Air Change Rates	Tracer gas decay using sulfur hexafluoride (SF_6) and gas chromatography, or anemometer	Automated system collected samples from each floor, or velocity measurements were made at the total system air duct
Air Distribution	Balometer	Measurements at diffusers by direct-reading balometer
Reentrainment of Exhaust Air	Injection of SF_6 into exhaust system	Sampling by direct-reading instruments at outdoor intakes of each HVAC system
Installation and Operational Problems With HVAC Systems	Visual inspection	Visual inspections and walk-through
Thermal Comfort/Relative Humidity	Spot readings of relative humidity, air velocity, and dry bulb and radiant temperatures recorded at 2.75 inches, 29.5 inches, and 73 inches above floor level	All the instruments are installed on a cart and data are recorded by a technician pushing the cart through all selected stations

None of the buildings had windows that could be opened. In each case, building occupants had reported problems for a number of years, but no one had investigated previously. Also, in each case, symptoms affected more than 50% of the occupants and included: difficulty concentrating, tendency to fall asleep, lack of energy, dry throat problems, and sneezing and coughing.

The investigative teams, while differing from case to case, generally consisted of several engineers and engineering students from the same consulting company. This team followed a general IAQ inspection routine, as well as the study of specific contaminants, such as VOCs, lead, and microorganisms.

The HVAC investigation techniques (outlined in Table 3) included:

- Measurements of fresh air change rates using tracer gas decay;
- Direct-reading balometer measurements of air distribution;
- Measurement of exhaust reentrainment;
- Visual HVAC inspections; and
- Spot readings of humidity, air velocity, and temperatures.

The IAQ assessment of each building (outlined in Table 4) consisted of:

- Infrared detection of CO and CO_2;
- Charcoal-type filters connected to air pumps to measure total volatile organic compounds (TVOCs);
- Passive dosimeters installed for three days to measure formaldehyde; and

Table 4 — IAQ Assessment Techniques

Contaminant	Measurement Technique	Accuracy	Measurement Locations
Carbon Monoxide (CO)	Infrared detector	Range: 0-100 ppm; Precision: 1% full scale	Selected workstations and outside air
Carbon Dioxide (CO_2)	Infrared detector	Range: 0-5,000 ppm; Precision: 1% full scale	Selected workstations and outside air
Total Volatile Organic Compounds (TVOCs)	Charcoal-type filters connected to air pumps	Range: 0-100 ppm; Precision: 2.5 ppb	Selected workstations and outside air
Formaldehyde (HCHO)	Passive dosimeters installed for three consecutive days	Range: 0-100 ppm; Precision: 1% full scale	Selected workstations and outside air
Suspended Particulates	PVC filter analyzed by gravimetry	Precision: 5 $\mu g/m^3$	Selected workstations and outside air

- PVC filters analyzed by gravimetry to indicate suspended particles.

Case 1

Building and HVAC Description

This tight glass office building and courthouse of unknown age consists of four stories, plus the basement, and features both closed offices and open areas with partitions. No recent renovations had been done. Two H-type systems with variable fresh air volume provide HVAC for the facility. Approximately 100 people occupy the structure on a permanent basis, and up to 300 clients visit at a time.

HVAC Investigation

Investigators reported that the HVAC system appeared to be very clean with evidence of a good maintenance program.

Indoor temperature varied from 20.3°C to 25.8°C (69°F to 78°F), and the relative humidity (RH) varied from 20% to 59%. Workers in the building, however, reported that in winter the RH stayed around 20%, leading to numerous complaints of dryness. The air change rate, approximately 10.2 liters per second per person (l/s/p), complied with ASHRAE's standard of 10 l/s/p. The air distribution rate was 240 l/s/p, five times higher than what is required by Quebec law.

Suspecting reentrainment of automobile exhaust, the researchers also conducted a fume test at the parking lot, sampling by direct-reading instruments at each HVAC intake. These indicated that some exhaust fumes were being reentrained.

IAQ Assessment

Indoor and outdoor concentrations of CO registered zero particles per million (ppm), but shot up to as much as ten ppm when automobile exhaust was introduced into the building. The average, however, was less than the nine ppm limit specified by ASHRAE.

CO_2 concentrations ranged from 375 to 650 ppm indoors and 350 to 450 ppm outdoors, both well under the 1,000 ppm ASHRAE standard. Neither formaldehyde nor suspended particles presented any problems.

TVOCs ranged from 504 to 2,816 $\mu g/m^3$, as measured by charcoal-type filters connected to air pumps. These levels fall well below the American Industrial Hygienists Association's (AHIA) recommended limit of 5,000 $\mu g/m^3$. Most VOC contamination came from the wet-process photocopiers.

Recommendations for Mitigation

Investigators recommended increasing humidity in winter and relocating the fresh air intake that was responsible for reentraining auto exhaust. They also suggested that the clients duct the wet-process copiers. The clients adopted all recommendations. While no followup has been conducted yet, building owners, management, and the employee unions have been very satisfied with the results, and report an alleviation of the symptoms that prompted the investigation.

Case 2

Building and HVAC Description

A tight glass structure, this office building, approximately 30 years old, consists of four stories plus the basement, totalling about 10,266 m^2. Two HVAC systems provide 100% fresh air for the 500 occupants who worked in both closed offices and open areas with partitions.

HVAC Investigation

The HVAC investigation revealed that the fresh air change rate varied from 20.5 to 96.4 l/s/p, depending on the floor that was under study. Even at the minimum, this was well above the 10 l/s/p recommended by ASHRAE. The air distribution varied from 42 to 421 l/s/p, again depending on the floor. Investigators found that crowding on some of the floors meant the occupants of these floors did not receive enough air.

Tests indicated no problem with reentrainment of exhaust air, and the HVAC system seemed to be well maintained, although the diffusers were a little dirty. Indoor temperatures varied from 19.2°C to 24.1°C (67°C to 76°F), while RH varied from 20% to 50%. At the time of the testing, outdoor RH was around 90%.

IAQ Assessment

In studying the air quality, the investigators found that concentrations of CO presented no problem, as they were between 0 and 2 ppm. Outdoor concentration was null at all times. CO_2, however, presented more of a problem. Concentrations varied from 420 to 1,025 ppm, with the higher levels on the crowded floors. Outdoor CO_2 levels ranged from 375 to 450 ppm.

TVOC levels registered much higher, with concentrations ranging between 1,014 and 41,668

$\mu g/m^3$. Suspended particles ranged from 20 to 81 $\mu g/m^3$.

Recommendations for Mitigation

Investigators determined that wet-process photocopiers, all from the same manufacturer, accounted for the elevated TVOC level. To remedy this, they recommended replacing them with dry-process copiers. The team also suggested distributing more air in the crowded zones and adding secondary filters in the ventilation system.

The clients followed most of the recommendations, according to the investigating team. They did not replace any of the copiers, but relocated some of the wet-process copiers within the copying areas; however, a six-month followup test showed TVOC levels remaining close to what they were before mitigation. The clients remain concerned about the TVOC levels, and are studying the options available to reduce the high TVOC levels.

Case 3

Building Description

This 47-year-old office building had been retrofitted with HVAC systems in the early 1970s. Consisting of four stories plus a basement, the building contains 9,550 m^2 of surface area and provides both closed offices and open office areas with partitions for a total of 350 permanent employees.

Three HVAC systems are in place. One provides 100% fresh air ventilation and a sprinkler-type humidifier. The second is an independent unit, and the third, a recirculation unit with ventilator and heating element.

HVAC Investigation

Investigators found the air change rate to be anywhere from 11.2 to 135.3 l/s/p, depending on the HVAC system. However, the total air distribution rate was between 0 and 118.3 l/s/p, depending on the floor being considered. Car exhaust fumes from the parking lot were entering the fresh air intake.

The team reported that the HVAC system appeared to be well maintained. Indoor temperatures varied from 19.8°C to 24.4°C (68°F to 76°F) and RH ranged from 37% to 57%. The outdoor RH at the time of testing ranged from 52% to 90%.

IAQ Assessment

Air quality measurements showed CO concentrations ranging from 0 to 10 ppm, while outdoor concentrations were between 0 and 1 ppm. Indoor rates were higher at traffic hours due to car exhaust. CO_2 levels indoors registered from 400 to 800 ppm, and outdoors from 350 to 400 ppm.

However, TVOC concentrations ranged between 1,780 and 58,843 $\mu g/m^3$, mostly due to contamination from the unducted wet-process copiers. Formaldehyde varied from 19 to 37 $\mu g/m^3$ and particulates ranged from 6 to 44 $\mu g/m^3$.

Recommendations for Mitigation

Despite the age of the building, the ventilation systems were relatively new and well maintained. The consultants recommended, however, that the systems be balanced to correct the wide variations in air distribution rates. The large number of wet-process photocopiers and the lack of ducting for them led to the high level of VOCs. The investigating firm reports that TVOC levels were the highest its staff has seen in the 100 buildings it has investigated, reaching 59 mg/m^3.

Consequently, investigators recommended that the clients eliminate or duct the wet-process copiers or try to concentrate them in negative pressure rooms. As there was some migration of CO from the outdoor parking into the fresh air intake, they also suggested relocating the intake.

The team reports that the client is still studying the recommendations, due to an unwillingness to change more than 50 copiers. The client feels that ducting them is difficult and impractical. Meanwhile, the unions are upset over the high TVOC levels. The situation is still unresolved.

Case 4

Building and HVAC Description

This 11-story building of undetermined age has both closed offices and open work areas with partitions, as well as conference rooms and printing rooms. It houses 600 employees on a permanent basis and accommodates up to 900 clients. The HVAC system consists of one ventilation system per floor, each with variable fresh air volume and constant total air volume.

HVAC Investigation

The investigating team reported that the walk-through inspection showed the HVAC system to be well maintained. Air change rates varied from 7 to 31 l/s/p, depending on the floor. This

meant some floors, due to overcrowding, were below the ASHRAE standard of 10 l/s/p. Air distribution varied between 84 and 156 l/s/p, which is in compliance with Quebec law.

Indoor temperatures varied from 21.4°C to 28.3°C (70°F to 83°F) and RH ranged from 37% to 61%. The investigation was carried out during summer months.

IAQ Assessment

Indoor concentrations of CO and CO_2 were below ASHRAE limits. CO measured from 0 to 4 ppm indoors and 0 to 5 ppm outdoors. CO_2 levels ranged from 380 to 950 ppm indoors and 320 to 650 ppm outdoors.

TVOC levels were high, ranging from 301 to 5,663 $\mu g/m^3$, as was formaldehyde, which varied from 17 to 81 $\mu g/m^3$. Dust levels were also elevated, as each floor had only a very-low-efficiency filter.

Recommendation for Mitigation

The investigators recommended that the client duct the wet-process copiers to reduce the TVOC levels. They also suggested adding a second layer of filters to alleviate the dust problem and adjusting the ventilation dampers to provide more air to the crowded floors. The team recommended a bake-out to try to resolve the elevated levels of formaldehyde.

The clients followed all recommendations and report they are pleased with the results. However, the investigators have not yet conducted a followup.

One interesting note in this case is that the photocopier suppliers were angry over the recommendations and threatened to sue the IAQ investigators.

Conclusion

In all four cases, the main culprits were the unducted wet-process photocopiers, although some buildings had poor air distribution as well.

Wet-process photocopying uses toners, dispersants, and developers that are nearly pure aliphatic petroleum distillate solvents with some trace compounds. Among the VOCs found in this process are isodecane, xylene, 2,2,4-trimethyl octane, branched alkanes, nitropyrene, phthalates, and isocyanates.

Each time a copy is made, a small amount of solvent disperses in the air. If a copier is making 1,500 copies a day, it could account for as much as 25 grams of TVOCs per hour. With insufficient air exchange rates and a high number of copiers, this can result in significant TVOC buildup.

An interesting note is that the investigators in these four cases found that the highest TVOC levels were found in buildings using a particular brand of photocopiers. They suggested that manufacturers should test their machines for emissions before putting them on the market.

However, many of the problems could have been avoided by correct placement and ducting of the copiers at installation.

For More Information

The same firm conducted all four investigations. Contact: Van Hiep Nguyen, President, Auger, Donnini & Nguyen, Inc., 1801 McGill College, Suite 800, Montreal, PQ H3A 2N4, Canada; (514) 849-5607, Fax: (514) 849-8366.

NEWS AND ANALYSIS

FTC Guidelines Set Limits for Environmental Claims

Whenever marketers make objective environmental claims, either implicit or explicit, they must be backed up by reliable evidence. That's the main gist of marketing guidelines issued recently by the US Federal Trade Commission (FTC).

While the guidelines are not legally enforceable, they are an interpretation of laws administered by the FTC, which stressed that the guidelines also do not preempt any state or local consumer laws.

In addition to the provision that any environmental claims should be supported by competent scientific evidence, the guidelines suggest:

- Qualifications and disclosures should be sufficiently clear and prominent to prevent deception;