Table 2 — Surface Fungal Concentration (cfu/g x 10^3)

Organism	Status	Number	Mean	STD	Min.	Max.	Case/Control
Aspergillus	Case	213	2,886	19,009	ND	180,000	0.8
	Control	228	3,593	11,959	ND	83,300	
Cladosporium	Case	213	1,217	6,130	ND	41,700	0.2
	Control	228	6,943	48,900	ND	678,300	
Penicillium	Case	213	1,341	4,890	ND	43,300	1.6
	Control	228	843	2,950	ND	26,400	
Stachybotrys	Case	142	10,587	71,449	ND	770,000	156
	Control	153	68	450	ND	5,233	
Other Fungi	Case	213	10,314	31,900	ND	250,000	1.3
	Control	228	7,738	29,746	ND	270,000	
Total Fungi	Case	213	26,345	80,200	ND	770,000	1.4
	Control	228	19,185	65,400	ND	740,000	

Source: NIOSH

Stachybotrys concentrations were higher in the case homes; in this instance, 156 times higher. The mean concentration of *Stachybotrys* in case homes was 10,587,000 cfu/g versus 68,000 cfu/g in controls. Table 2 shows the surface fungal concentrations.

The report concluded that the infants who contracted hemosiderosis were exposed to significantly higher *Stachybotrys* concentrations than those in control homes.

These results underscore the heightened concern that some IAQ researchers have concerning fungal contamination resulting from moisture in the indoor environment.

To obtain a copy of the NIOSH study or for more information, contact NIOSH at (800) 35-NIOSH.

CASE STUDY

[In each issue, ***IAQU*** *presents a case study on an investigation of indoor air problems in a particular building. The information in the cases comes from various sources, including published material, reports in the public record, or, in some instances, reports supplied by the consultants involved in the case.* ***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.]*

Do Green Buildings Provide Better IAQ? It Depends...!

Designing "green buildings" is one of the latest trends in the industry. Usually, the term means structures that have a minimal impact on the environment, and, as an added benefit, will provide a healthy and comfortable indoor environment for occupants. As this is a relatively new concept, it remains to be seen whether the efforts in this direction will, over the long term, achieve the desired results.

To test the theory behind the green building concept, researchers from the US National Institute of Standards and Technology (NIST) monitored conditions in one such building. They found that designing such a building requires tradeoffs between things like increased ventilation and the environmental impact of the added energy necessary to achieve it. They also found that the best design is still subject to the day-to-day operation practices in the building.

Stuart Dols, Andy Persily, and Steven Nabinger from NIST conducted the research and reported on their findings at the ASHRAE IAQ '96 conference in a paper, *Indoor Air Quality in Green Buildings: A Case Study.*

Audubon Building

The building in question is the headquarters for the National Audubon Society (New York City), on which we reported in a previous issue (see ***IAQU***, June 1994), and which was the subject of a book, *Audubon House: Building the Environmentally Responsible, Energy-Efficient Office* (New York: John Wiley & Sons, Inc., 1994).

The Audubon Society undertook the project because its previous office space had become too expensive, but also because IAQ problems in the previous building had caused numerous occupant complaints, including typical sick building syndrome symptoms — headache, fatigue, and respiratory distress.

To serve as a new office building, the society acquired a century-old building and began a complete renovation designed to provide more outdoor air (O/A) than is required by current codes and standards. The design also specified low-emitting products and aimed at an energy consumption that would be 62% lower than a merely code-compliant building.

Building Description

The nine-story building (the ninth story was added during renovations) contains nearly 100,000 square feet (ft^2) of occupied space. The society, however, uses only Floors 4-9. Floors 4-8 each contains about 7,400 ft^2 of occupiable space, while Floor 9 has only a conference facility and a large mechanical equipment room. Floors 1-3 are leased to retail and office operations.

The ninth-floor equipment room houses the major mechanical systems including the main O/A intake fan that provides air for all the lower floors through a single vertical shaft. Mechanical rooms on each floor receive the O/A from the vertical shaft, and supply air handlers on each floor mix O/A and return air (R/A) and deliver the conditioned air to the occupied space.

Building design attempted to avoid some common IAQ problems. The O/A intake was located on the top floor on the building's southern side — its most exposed side — in an effort to provide the best possible O/A. Also, the intake was positioned under a large overhang to minimize moisture intake.

At the time we originally reported on the building, the specifications said the HVAC system could bring in as much as 30 cubic feet per minute per person (cfm/p) of O/A with a design rate of 26 cfm/p. A prefilter with a 35% dust spot efficiency rating leads to a bag filter with an 85% efficiency rating in an effort to eliminate most particles. The filtered O/A then goes to each floor for mixing in an attempt to provide better zone control.

Heating and cooling comes from a gas-fired chiller/heater on the top floor. Gas was the fuel of choice because it is less expensive than electrical energy and has less environmental impact than an oil-fired unit. The society's consultants determined that this configuration would eliminate emissions from the oxides of sulfur and nitrogen. Also, the chiller operates with lithium bromide, eliminating ozone-depleting chlorofluorocarbons.

The chiller/heater provides 180 tons of cooling and 1.7 million Btu/hour of heating. A six-step cooling system circulates the chilled water to air handling units (AHUs) on each floor. Hot water circulates through pipes along the building's perimeter.

The variable air volume (VAV) system responds to static pressure sensors that control variable frequency drives to slow fan motors and conserve energy. Each floor has additional sensors to monitor environmental conditions and send information to a central computer.

The building was also designed for two supplemental systems: one to draw in O/A during nighttime hours to precool the building with virtually no energy use. Also, during moderate temperatures, an economizer cycle was designed to reduce the heating and cooling load.

Material Selection

In our original report on the building, ***IAQU*** described the attention that designers paid to material selection. Among the criteria were the emission potential of each material balanced against the cost and environmental impact on the material's entire lifecycle. Consequently, some materials met IAQ criteria, but were rejected because they caused environmental damage during their manufacture, or posed a potential environmental threat during disposal.

The building's original floors were damaged and required new subflooring. Rather than specify a typical interior-grade plywood, which contains urea-formaldehyde, the designers chose Homasote™, which is made from recycled newspaper and a low-toxicity bonding agent.

For the carpeting system, designers specified a 100% wool carpet woven from three different types and colors of undyed wool. This came from a European manufacturer which, at the time, was the only manufacturer that could provide baseline information on the environmental performance of the carpet. The padding was jute, a natural product, in place of synthetic pads.

Paint selection proved difficult, because at the time the design was in progress paints made from natural pigments were prohibitively expensive. However, at that time, the first of the odor-free commercial paints appeared on the market and was chosen for the project.

Designers avoided pressed-wood furniture as much as possible, choosing instead steel, rubber, and non-CFC foam products. For some products, the designers were able to work with manufacturers to achieve environmentally acceptable designs.

One operational matter involved acceptable cleaning agents. At the time the building opened, environmental consultants reported difficulty in finding nontoxic cleaning agents for some tasks. The plan was to use toxic agents only when necessary and only on a spot basis, avoiding widespread use.

The NIST Study

To evaluate the IAQ characteristics in the buildings, the NIST researchers monitored indoor conditions over two consecutive work days in the late fall. To do this, they concentrated on three main areas:

- Ventilation performance: O/A flow rate and pressure relationship between zones;
- Pollutants: carbon dioxide (CO_2), carbon monoxide (CO), formaldehyde, particulates, and VOCs; and
- Thermal comfort: temperature, relative humidity, and percent predicted dissatisfied (PPD).

To measure the O/A flow rates, the researchers used a hot-wire anemometer to perform a velocity traverse of the O/A delivery duct for each zone. They then multiplied the average velocity by the cross-sectional area of the duct at the traverse location to obtain the airflow rate. They used the resulting rate to determine both per-person ventilation rates and pollutant source strengths.

They determined pressure relationships between zones using smoke tubes to indicate how air flowed between zones. The researchers evaluated the relationships between the occupied spaces of all floors and the stairways, elevators, recycling shafts, and restrooms. Some lower floor spaces were unavailable, but the major pathways to and from the shafts were accessible.

CO_2 and CO measurements came from both automated systems and portable monitors. The automated system operated continuously for the two days at locations in the R/A streams on Floors 4-8, supply air streams on Floors 4, 6, and 8, and the O/A on the building's roof. The system took samples once every 20 minutes. The researchers used the portable monitors at various locations throughout the occupied zone and from the O/A.

Passive samplers measured average formaldehyde concentrations over an eight-hour period each day. Samples came from two areas in the open office space of each zone, as well as O/A. The researchers took five-minute samples for particulates using a monitor based on a piezo balance. This device collects particles from 0.01 micrometers (μm) to 10 μm in diameter.

VOC Sampling

The researchers measured VOC concentrations on both days. Samples came from Floors 4, 5, 7, and 8 on both days. On the first day, the researchers sampled the sixth floor twice — once in the morning and once in the afternoon — and took two outdoor samples, one before and one after the indoor measurements. On Day 2, they sampled the sixth floor seven times throughout the day and they sampled the O/A five times.

All indoor samples came from the R/A duct just inside the mechanical room of each floor. Outdoor samples came from just outside the O/A intake grille. Sampling equipment consisted of a portable pump and tubes filled with Tenax® sorbent, and the researchers used gas chromatography/mass spectrometry to analyze the results.

To estimate source strength, the researchers assumed that the indoor TVOC concentrations were at equilibrium and that there were no VOC sinks in the building. They then used the following equation:

$$S = (C_{in} - C_{out}) \times Q_{oa}/A$$

where S is the source strength per unit of floor area (mg/m^2/hr), C_{in} is the indoor TVOC concentration, C_{out} is the outdoor TVOC concentration, Q_{oa} is the O/A flow rate into the zone, and A is the zone floor area.

Results

In measuring the O/A intake rates, the researchers discovered that, except for the seventh floor, the rates were well below the design rate of 1,150 cfm/floor. The seventh floor was slightly higher than design.

The researchers then counted the occupants on each floor and calculated the per-person ventilation rates, which were all equal to or higher than the current ASHRAE standard of 20 cfm/person, except for the sixth floor, which was considerably lower. Table 3 shows the O/A intake rate and the calculated per-person O/A ventilation rate for each floor.

Smoke tube testing indicated that on the lower floors air generally flowed from the occupied space into the stairway and main elevator shaft, but moved in the opposite direction on the upper floors. The opposite scenario took place with respect to the freight elevator shaft. The change in direction occurred between the fifth and seventh floors.

Air also tended to infiltrate the building at the main entrance and exited from a ninth-floor doorway. However, restrooms were under negative pressure relative to the adjoining occupied space, which is what the design called for.

CO_2 monitoring showed that the average levels for both days reached a high of about 700 parts per million (ppm), except for the sixth floor, which reached concentrations about 900 ppm. This corresponded to the lower per-person ventilation rates on the sixth floor.

CO, formaldehyde, and particulates were all well below levels of concern. TVOC concentrations on the first day averaged about 500 $\mu g/m^3$ above the outdoor concentration and, on the second day, about 150 $\mu g/m^3$ above the outdoor levels. Table 4 shows the TVOC concentrations.

One notable TVOC reading was on the sixth floor on the first day of the study. The researchers noted that if this reading were excluded, the average indoor concentration for the first day would still be about 270 $\mu g/m^3$ above the outdoor concentration — almost twice the difference they found on Day 2. They hypothesized that a significant, but unidentified, VOC source existed on the sixth floor on the first day.

Thermal comfort measurements showed fairly consistent readings on both days, with temperatures between 70°F and 77°F and relative humidity from 20% to 35%. All of the percent predicted dissatisfied measurements were below 10%, which indicated acceptable thermal conditions.

Discussion

The researchers noted that so-called "green buildings" face some of the same obstacles as ordinary buildings — actual operating conditions don't always satisfy design goals. In the current case, despite careful design to avoid elevated VOC

Table 3 — Outdoor Air Intake Measurements

Location	Average Occupancy	Day	Time	Outdoor Air Intake Rate	
				cfm	cfm per person
Floor 4	14	Day 1	12:00	297	21
			16:00	275	20
		Day 2	11:00	297	21
			16:00	318	23
Floor 5	17	Day 1	15:00	699	41
		Day 2	11:00	509	30
			15:30	678	40
Floor 6	24	Day 1	10:00	297	12
			17:00	360	15
		Day 2	9:00	360	15
			14:00	297	12
			16:00	318	13
			17:00	297	12
			20:00	339	14
			21:00	318	13
Floor 7	24	Day 1	14:00	1,271	53
		Day 2	10:00	1,377	57
			15:00	1,208	50
Floor 8	17	Day 1	11:00	720	42
			16:00	657	39
		Day 2	10:00	1,038	61
			15:00	784	46

Source: Dols, Persily, and Nabinger

Table 4 — Total Volatile Organic Compounds (TVOC)

Location	Day 1				Day 2			
	Time	TVOC Concentration (μg/m³)		Source Strength (mg/m²/hr)	Time	TVOC Concentration (μg/m³)		Source Strength (mg/m²/hr)
		Indoor	Outdoor			Indoor	Outdoor	
Floor 4	14:00	210	80	0.1	12:00	230	100	0.22
Floor 5	15:30	560	80	0.83	16:30	230	100	0.22
Floor 6	11:00	490	80	0.3	8:00	280	60	0.19
	16:00	1,790	80	1.54	11:00	190	60	0.12
	—	—	—	—	13:00	260	70	0.14
	—	—	—	—	15:00	270	70	0.15
	—	—	—	—	17:00	250	100	0.11
	—	—	—	—	19:00	290	100	0.16
	—	—	—	—	21:00	260	120	0.11
Floor 7	15:00	310	80	0.73	14:00	230	70	0.45
Floor 8	12:00	160	80	0.14	10:00	110	60	0.13

Source: Dols, Persily, and Nabinger

levels, unexpected occurrences can introduce VOC sources into the building on an episodic basis.

Also, despite a design that specified higher ventilation rates, some areas of the building showed rates below current standards at the time the measurements were taken. The researchers noted that this was most likely an operational, rather than a design, issue. They also noted that the results applied only to the time the measurements were being taken and may not have reflected the situation at other times.

It's important to note that the flow rates and TVOC measurements were those that existed on the day that these measurements were taken and may not reflect ongoing conditions. Also, despite the fact that some O/A rates were lower than design, there is no indication of any complaints from building occupants.

For more information, contact Andy Persily, Building and Fire Research Laboratory, NIST, Gaithersburg, MD 20899, USA; (301) 975-6418, Fax: (301) 975-4032.

NEWS AND ANALYSIS

FAA Lowers Allowable CO_2 Concentration for Commercial Aircraft

The US Federal Aviation Administration (FAA) has lowered the allowable carbon dioxide (CO_2) concentration in airplane cabins from 30,000 parts per million (ppm) to 5,000 ppm. The FAA announced the new rule and its rationale in the *Federal Register* (Vol. 61, No. 232, December 2, 1996).

The agency said it chose the 5,000-ppm limit because it found no documented health or safety issues with a limit lower than that. In fact, according to the FAA's own rationale, current aircraft usually maintain a much lower level. The 5,000-ppm limit would correspond to an outdoor air (O/A) ventilation rate of 2.25 cubic feet per minute (cfm) per person. The FAA said current aircraft O/A rates now vary from a low of 7 cfm/person to over 20 cfm/person.

Some studies have shown that CO_2 concentrations during boarding and deboarding, when CO_2 levels could be expected to be much higher than in flight, ranged from 2,000 to 2,550 ppm — again well below the new limit.

In performing its cost benefit analysis of the rule, the FAA calculated that the cost of going from 30,000 ppm to 5,000 ppm would be about 1.43 cents per person per hour. However, since no aircraft currently operate at that concentration and, in fact, all operate below 5,000 ppm, the rule change will results in no incremental costs.