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Indoor Air Quality Update®

A Guide to the Practical Control of Indoor Air Problems, from Cutter Information Corp.

Special Case Study: The DuPage County Courthouse

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Special Case Study: The DuPage County Courthouse

Introduction

In the fall of 1992, officials of DuPage County, Illinois, USA, moved nearly 700 people out of a new office building, the Judicial Office Facility (JOF). It had been occupied for just a little over a year, a period marked by frequent complaints about the building's indoor air quality and numerous illness reports from employees. On March 31, 1992, scores of employees were evacuated from the building and sent for medical evaluation during an episode of acute IAQ problems.

An IAQ investigator examined the building and its systems, and found many problems, including design, operation, and maintenance flaws. While recommending some immediate action to alleviate conditions during the investigation, he also made numerous long-term recommendations, which involved redesigning and updating major systems, improving maintenance, and dealing with chronic problem areas.

The consultant, Dr. Robert C. Brandys of Occupational & Environmental Health Consulting Services, Inc. (OEHCS), Wheaton, Illinois, filed reports amounting to more than 350 pages. These reports are part of the public record of the situation and are on file with the county board. ***IAQU*** has used those records to compile this special report on the building and its problems.

Building and HVAC Design

Although the DuPage County JOF was built in 1990 and 1991, its designers were working in the late 1980s with ASHRAE Standard 62-1981. This standard, formulated with energy savings in mind, required much lower ventilation rates than its successor, ASHRAE 62-1989. Even though the new standard wasn't in effect, debate in the industry had raised doubts about the earlier standard's ability to provide acceptable indoor air.

The upper four stories of the 358,000-square-foot building contain mostly courtrooms, along with their support offices. The basement houses the data processing center and a child support area. Designed to initially house 700 full-time employees, the building also accommodates a varying number of visitors, which averaged 1,761 per day in 1990, with daily totals sometimes considerably higher. Projections indicated that staff would increase to nearly 1,000 and visitors would average over 2,000 by the year 2020.

Air Handling Systems

Four variable-air-volume (VAV) air handling units (AHUs) — AHU-1 through AHU-4 — control the four quadrants of the upper floors. A combination unit — AHU-8 — handles the first-floor cafeteria, while two constant-air-volume (CAV) systems — AHU-5 and AHU-7 — serve the basement area. (VAV systems achieve their heating and cooling tasks by varying the amount of air that is delivered to the space to be conditioned. CAV systems, on the other hand, deliver the same volume of air, but vary the temperature.)

AHU-1 through AHU-4, rooftop units, each have three supply fans and two return air fans. The outside air (O/A) enters through two dampers on opposite sides of each unit. A sight barrier originally enclosed the four units, which are located in close proximity to one another. Heating and cooling coils inside each AHU control the temperature of the air that is released into the supply ducts. This discharge air temperature (DAT) determines the amount of air circulating in the building by affecting the opening and closing of the VAV boxes.

Vortex dampers on the suction side of both the supply and return air fans regulate the amount of air allowed to go to the fans, and therefore the static pressure in the ductwork, depending on the demand created by the VAV boxes.

The minimum setting on the O/A dampers for the JOF was 15%, meaning that, at the very least, the system should have been operating with 15% O/A. Under proper climatic conditions, the settings could increase to 100%, using O/A for heating and cooling and relieving some of the demand on the system.

In the upper floors of the building, the supply air enters office areas through ceiling diffusers, which were designed to alleviate draft problems at work level. Return air exhausts through ceiling grilles or slots next to the fluorescent light fixtures into a return air plenum in the ceiling.

Early Problems with HVAC Units

Building design called for the VAV systems to operate at a DAT of 54°F. However, building operators found that AHU-1 through AHU-4 could cool the building adequately with DATs as high as 57°F or 58°F, which increased the amount of air being circulated. However, at this temperature some areas of the first floor had temperature and/or air supply problems.

In the upper floors, an early inspection of the system revealed that the return air slots in the ceilings of some offices were closed — a potential problem for the return air system and the ventilation in those areas.

AHU-5, the larger of the basement units, experienced a number of trip outs of the return air fan. A readjustment kept the air volume from shutting off the fan, but the situation raised questions of whether the system could handle its design volume and pressures, especially because the basement received sufficient air only when the system's vortex dampers were in the full open position. AHU-7, the smaller CAV unit that serves the data processing area, experienced temperature control problems from early in its operation.

AHU-8, the combination system that handles the cafeteria, had problems in regulating exhaust air, resulting in occasional shut downs caused by overpressurization. An attempt to correct this had involved wiring open the exhaust damper to increase the flow of exhaust air and keep the system operating.

While a no-smoking policy was in effect for all JOF office areas, smoking did occur in some offices and was permitted in other areas. However, ventilation design did not account for this and did not meet ASHRAE's standard for smoking areas.

Building Occupancy

While construction was still in progress, some office employees began working eight-hour shifts in the building. Workers were still applying glues and solvents at this time, and new fixtures and materials were most likely undergoing the normal offgassing that occurs at that stage. Some of the new furniture arrived during construction and subsequently became quite soiled, resulting in attempts at cleaning it before it went into use. While all this was going on, an energy management system regulated the ventilation, and only a limited amount of fresh air entered the building.

Health Problems and History of Complaints

Complaints of IAQ problems began early in the building's operation. Numerous employees reported that they experienced long bouts with colds and flu during the 1991 winter season.

Specific complaints came from the cashier's cages on the first and fourth floors, the clerk's office on the first floor, and the data processing area and child support offices in the basement.

More than 277 persons filed reports of what they considered building-related symptoms between the time the building opened and August 1992. Investigators believe that other instances went unreported, perhaps because some people grew tired of filling out the forms. Headaches and eye irritation led the list of symptoms reported on the forms, followed by throat and skin conditions, and general respiratory distress.

The most serious incident happened on March 31, 1992, when employees in the northeast quadrant of the fourth floor experienced various symptoms: headaches, severe eye irritation, and upper respiratory irritation. About 40 employees required medical attention. Following this incident, maintenance workers sprayed the chairs, carpeting, and ductwork with quaternary ammonium/benzalkonium chloride disinfectant, after which employees began to complain about rashes and other skin problems.

When employee complaints continued after the March 31 incident, building managers called in OEHCS to conduct a full-scale investigation of the IAQ and the HVAC system.

Investigative Focus

At the outset of the investigation, based on an initial survey of the situation, the investigators formed six hypotheses about the IAQ problems. These were:

- The March 31 incident was separate from the JOF's general IAQ problems;
- The data processing and child support areas, being serviced by separate air handling systems, had a somewhat different indoor air quality situation than the upper floors of the building;
- The symptoms reported in the clerk's office on the first floor may have been due to some unusual material in that area or were related to the fact that it was on the end of its air handling system and was experiencing supply problems;
- Other recurring symptoms of a general nature were related to employees' chemical exposure during early occupancy and possible sensitization to these chemicals;

- The courtrooms had a unique IAQ situation due to their highly variable occupancy; and
- Volatile organic compounds (VOCs), typical in new, tight buildings, were probably related to the IAQ complaints.

OEHCS began the investigation by obtaining lists of the chemicals used in the construction of the building or for maintenance in and around the facility. The Material Safety Data Sheets (MSDSs) for the 104 chemicals used indicated that 75 were potentially irritating to the eyes, 74 to the skin, and 82 could cause respiratory problems. Many of the substances could produce multiple effects. OEHCS decided to target these during the building investigation.

Because of the wide variations in occupancy levels, due to the changing levels of court activity, investigators used real-time air monitoring to track conditions during the fluctuations in occupancy. They selected two courtrooms on the fourth floor for this monitoring. They also closed a courtroom, in which occupants had reported numerous complaints during the March 31 incident, and planned detailed study for the room.

The history of respiratory system complaints led OEHCS to consider the possibility of microbial contamination, and investigators also planned to test for bioaerosols.

Sampling occurred on different days of the week over a four-week period to ensure a random sample and to avoid any bias that might come from a routine protocol. Sampling techniques are indicated in Table 1.

One factor that may have affected sampling was the fact that in an effort to immediately relieve some of the complaints — because the building was still occupied at that time — O/A intakes for all systems were set to 100%. This added ventilation most likely resulted in contaminant measurements during the study being somewhat lower than they were under actual operating conditions, when some air handling units were on 30%-40% O/A and sometimes as little as 15%.

Results of HVAC Investigation

A number of problems became evident as a result of the HVAC investigation. Among these were:

- Ventilation requirements;
- The poor quality of the outside air;
- Insufficient air being supplied to various parts of the building;
- Lack of leading air supply;
- Short circuiting; and
- Inadequate humidity control.

Table 1 — Monitoring and Analytical Methods for DuPage County Courthouse

Analyte	Collection Media	Flow Rate	Analysis Method	Reference Method
Particulates	PVC Filters	2 liters per minute (lpm)	Gravimetric	NIOSH S-349/500
Organic Solvents	400 mg Charcoal Tubes	1 lpm	Gas Chromatography	P & CAM 127
Organic Solvents	400 mg Tenax Tubes	1 lpm	GC/MS	EPA TO 1
Formaldehyde	1 N Sodium Bisulfide	1 lpm	UV-Vis	NIOSH 3500
Particulate ID	Bulk Sample	NA	Electron Microscopy	NA
Residue Extraction	Distilled Water	1 lpm	Ion Chromatography	NIOSH
Ethylene Glycol	Glass fiber/silica gel	0.2 lpm	Gas Chromatography	NIOSH 5500
Hydrazine	Tenax Tubes	1 lpm	Gas Chromatography	NIOSH
Microbial (total count)	TSA Agar	40 cfm	Plate Count/ Speciation Std.	Microbial
Microbial (mold/yeast)	Penase Agar	40 cfm	Plate Count/Speciation	Std. Microbial
Carbon Dioxide	Detector Tubes	100 ml	Color Change	Sensidyne #2LL
Carbon Dioxide	2 m C	0.1 lpm	NDIR	EPA
Ozone	Detector Tubes	100 ml	Color Change	Sensidyne #18L
Carbon Monoxide	Electrochemical Cell	1 lpm	Conductivity Change	EPA
Radon	Charcoal	Diffusion	Scintillation Counter	EPA

Source: Dr. Robert Brandys, Occupational and Environmental Health Consulting Services

Ventilation Requirements

ASHRAE 62-1981 required 5 cfm/person for office space and 7 cfm/person for meeting and waiting rooms. ASHRAE 62-1989, on the other hand, requires 20 cfm/person for office spaces. OEHCS questioned whether the office requirements are appropriate for such places as courthouses.

The report says that office waiting rooms usually involve a more professional clientele, with possibly better personal hygiene, than is likely in a courthouse. OEHCS says that transportation waiting rooms more accurately reflect the variation in the types of people present as plaintiffs or defendants. This would also reflect the types of persons present in line at the cashier's cages and in the hallways outside the courtroom.

Patient rooms in hospitals, according to OEHCS, probably more closely reflect the anxiety levels and increased metabolism of persons concerned over potential jail terms and fines. Therefore, the investigators recommended that the higher hospital standard of 25 cfm/person be used for the courthouse.

Outside Air Quality

The outside air quality concerned investigators because the AHUs are located so close together on the roof and because the air intake dampers are so near the exhaust dampers. (See Figure 1.) Initial tests showed that the carbon dioxide (CO_2) levels in the incoming air supply averaged 25% higher than in the ambient air.

The situation was aggravated by the sight barrier, which prevented the wind from removing the exhaust air and also from diluting it before it was reentrained by the air intake dampers. The barrier also caused fresh air to be drawn across the surface of the roof, where it picked up chemicals being offgassed by construction materials in the roof. Also, the cafeteria exhaust system discharged horizontally across the surface of the roof.

The OEHCS report calculated, using a hypothesis that intake air contained 50% exhaust, that O/A dampers would have to open to double their design minimum just to meet the ASHRAE 62-1981 standard to which the building had been designed.

After officials removed portions of the sight barrier early in the investigation, intake air quality improved, but exhaust air still entered the system.

Air Changes per Hour

Air changes per hour (ach), the number of times a volume of air equal to the volume of the room is delivered, is an important HVAC measurement. While there is no standard, OEHCS considers between 6 and 10 ach to be good practice.

The four rooftop AHUs have a combined capability of moving 340,000 cubic feet per minute (cfm) of air. Because the four floors they serve have an area of 290,000 square feet (ft^2), the system could theoretically deliver 7.0 ach with vortex openings at 100%. However, since earlier operation had dictated vortex openings considerably less, it was likely that the building had experienced air flow in the neighborhood of 2.7 ach. Had the building been operated at the design DAT, this figure might have been even lower.

Once initial changes were made at the beginning of the IAQ investigation, air flow increased to 3.8 ach, but even this could drop if a VAV box were to close in a particular space for any significant time.

Closed VAV Boxes

Some VAV boxes within the building closed completely on many occasions when there were few people in the building. The problem didn't seem to occur during medium or heavy occupancy loads, but seemed to be especially prevalent in the courtrooms and other areas served by AHU-1. Apparently the problem occurred when the cooling demand in some areas was satisfied or when stored cooling from the morning operation of the system remained. The upshot of these closings was that these areas were without fresh air supply.

Two major incidents created short-term interruptions in the O/A supply. During one incident in November 1991, a 10-minute system shutdown sent CO_2 levels above the ASHRAE limit of 1,000 parts per million (ppm). During OEHCS's investigation, one of the AHUs went off line. Because of a 10-minute delay built into the system before restart, CO_2 levels increased and did not resume normal patterns until two hours later.

Leading Air Supply for Variable Occupancy

Both ASHRAE 62-1981 and 62-1989 require that when contaminants are independent of occupants and their activities, outside air must be supplied to a space before occupancy, so that occupants will encounter acceptable air at the start of occupancy. An exception to this would be allowed where peak occupancies of less than three hours occur.

A survey of court records showed that, at some times, very large court calls brought a capacity crowd to some courtrooms for extended periods, eliminating the possibility of allowing the exception. Measurements showed CO_2 levels in some courtrooms peaked above 1,000 ppm.

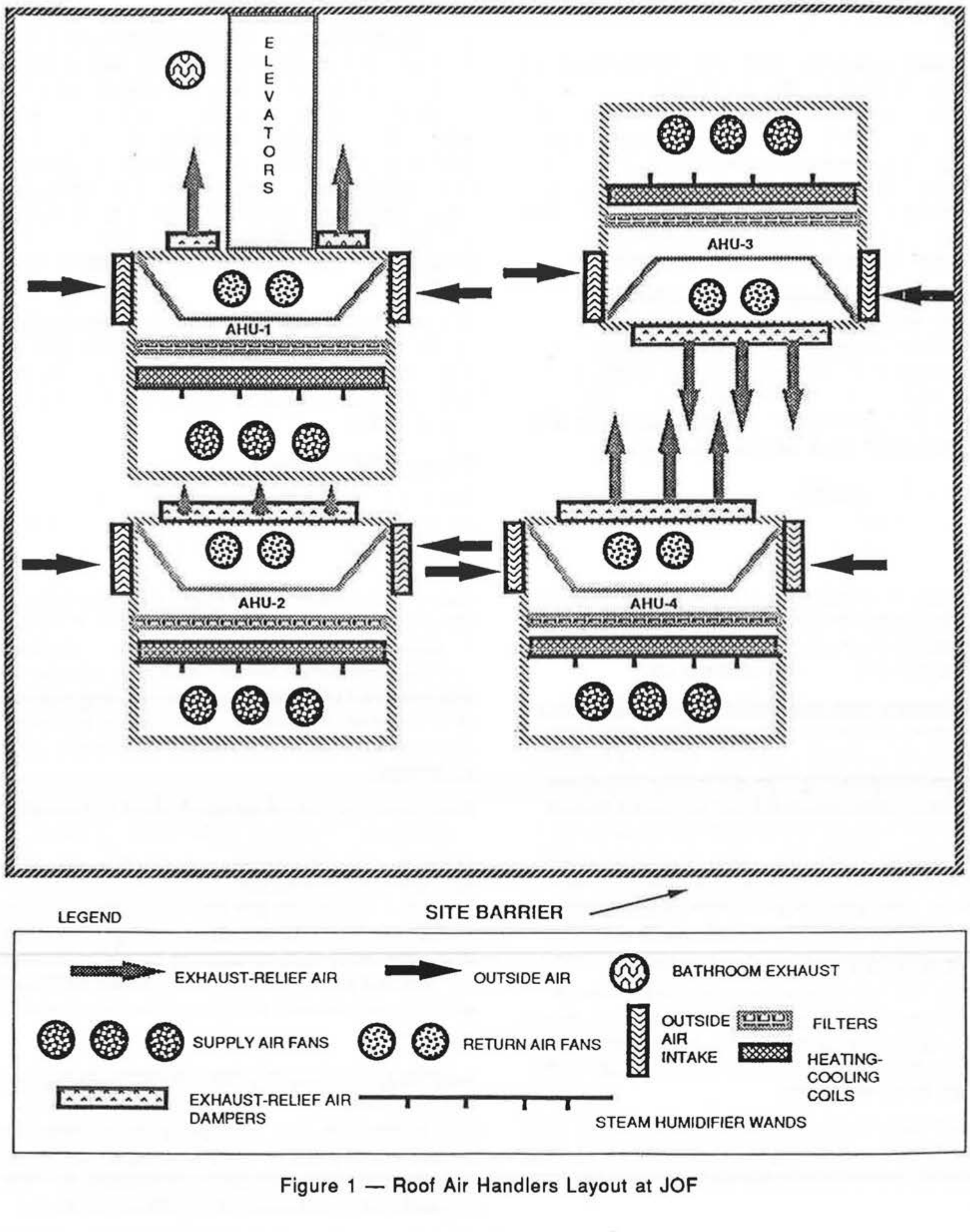

Figure 1 — Roof Air Handlers Layout at JOF

In testing for contaminants, the investigators found that courtroom fixtures and furnishings were offgassing irritating chemicals (see IAQ Investigation below) and thus the courtrooms require a leading air supply.

Consequently, OEHCS found that while the building and its use required leading air, the systems couldn't provide it in many parts of the building.

Complicating the situation was the fact that the system operated early in the day with a DAT below room temperature in order to cool other areas of the building. This caused the courtrooms to become overcooled, and the stored cooling delayed the opening of VAV boxes for a considerable length of time after the courtrooms filled to capacity. It wasn't until the rooms warmed up sufficiently that the VAV boxes would open to allow supply air into the space.

Also, the investigators noted that to achieve standard ventilation rates not only must the proper parameters be in the design, but building operators must have the documentation necessary to achieve the desired results. The investigators said they were unable to locate any such documentation when they reviewed system documents during the study.

Short Circuiting

Short circuiting occurs in an HVAC system when supply air flows into the return air grille or plenum without mixing with room air. This can aggravate a situation where a system is not supplying enough air of sufficient quality in the first place.

Investigators suspected that this phenomenon was taking place in the JOF, primarily based upon the fact that light fixtures, which served as return air vents, were often located adjacent to the supply air diffusers. In fact, this is a common occurrence in buildings that have both supply and return air outlets in ceiling fixtures.

CO_2 tests confirmed these suspicions, when the tests showed that CO_2 levels in the various AHUs didn't track the occupancy of the building. In other words, areas with greater occupancy should have had higher CO_2 levels, given the same amount of supply air. This wasn't the case.

Investigators hypothesized that perimeter heating was increasing short circuiting. Early in the day, as perimeter offices heated up, their VAV boxes opened to maintain temperature. Consequently, much of the air circulating in the building was not mixing, but was short circuiting to the return air grilles in exterior offices after being heated. When the investigators turned off the perimeter heating system, CO_2 levels became consistent.

One effect of the short circuiting was that it reduced the ach in rooms in the center of the building, while increasing ach in the perimeter rooms, primarily because a principal air return duct runs along the perimeter.

In the JOF, some of the courtrooms were experiencing almost no airflow through the return air ductwork, meaning fewer ach and an even greater reduction in the amount of fresh air being delivered. This was aggravated by the previously discussed O/A quality problems due to the roof units reentraining exhausted air.

Humidity Control in the JOF

Relative humidity plays a big role in indoor air quality, both in terms of the respiratory and skin conditions it can cause, and in the way building occupants perceive the air quality. As humidity decreases, many people experience episodes of dryness, either in the eyes or on the skin. As humidity levels increase, it becomes more difficult for the lungs and the skin to cool the body through evaporation.

Humidification

One factor in the March 31 incident was the humidifier in AHU-1, which was the only one adding humidity to the building. A series of events led to the incident. It had rained immediately before and, due to a faulty sensor that was giving an erroneous low-humidity reading, the system was adding humidity to already saturated air. Also, the system was operating on 100% outside air and was not cooling it.

The result was a visible cloud that spread through the areas served by AHU-1. A complicating factor in this incident involved contaminants in the system that were dispersed by the cloud. The complete incident will be discussed later in this report.

Tests of the humidifier system during the IAQ investigation showed water in the condensate return line, something that would be expected due to a clogged return line. A clogged strainer, which investigators discovered, could have limited the water return to the boiler. In fact, once the strainer was removed and cleaned, the system began operating.

In addition, investigators found insufficient high-temperature hot water to maintain humidity boiler pressure at 10 pounds per square inch (psi). When they closed the three-way valves to the perimeter heat exchangers, the pressure increased. Consequently, they recommended replacing the three-way valves with two-way valves to increase the pressure permanently.

While tests did not show direct water carryover to the steam wands, visible deposits on the water-level sight glass indicated past problems with high levels of dissolved and suspended solids. Investigators used Lake Michigan water during their tests. As this is considerably softer water than the well water previously used, they recommended using the lake water to avoid water treatment chemicals, until the reliability of the system could be established.

Dehumidification

While HVAC systems need to control excess humidity in outside air, they also have to be able to remove humidity produced by the people and plants within a building. Excess humidity, in addition to its adverse effect on cooling the body, can increase the emission of contaminants from building materials and can also cause re-emission from materials that have absorbed pollutants earlier.

Many humidity readings recorded by investigators fell in the high end of the comfort range or above — 60%-76%. Incident reports of employee symptoms appeared to have tracked the humidity levels, increasing when the relative humidity increased.

One problem with the building was that humidity sensors inside the return air ductwork were recording levels lower than the actual humidity in the occupied space. This was due in large part to the short-circuiting problem, as the lower-humidity supply air was entering the return air ducts before mixing with the more humid room air.

Individual Problem Areas

Some areas within the JOF experienced more problems than others. Many of these problems, while caused by the overall problems with the HVAC system, were exacerbated by design characteristics of the individual spaces in relation to the total system design.

Among the spaces reporting the most problems were some courtrooms, the cashier's cages on the first and fourth floors, and the basement facilities, including the data processing area and the child support area.

Courtrooms

The JOF courtrooms, in three sizes, can accommodate between 50 and 101 persons at maximum capacity. Using the expected occupancy and the total volume of the rooms, outside air requirements range from 18.6% of maximum design volume supply to 86%. This depends on the courtroom size and whether the ventilation conforms to the ASHRAE 62-1981 or 62-1989 standard.

If ventilation is according to the 1981 standard (7 cfm/person in meeting and waiting rooms), then minimum O/A damper settings should be no less than 18.6% and as high as 24%. However, if ventilation is set to the 1989 standard for hospital rooms, as recommended by OEHCS, then minimum settings should be no less than 66.5% and as much as 86%. All of these figures are higher than the 15% specified in system design.

In addition, these calculations assume that VAV boxes are fully open, something that was not the normal case in the JOF.

Another problem with the courtrooms was in the ach delivered to the spaces. With VAV boxes fully open, the rooms could receive between 8.8 ach and 10.9 ach. However, with the boxes open only 50%, which may have been closer to the average operating condition, the rooms would receive between 4.4 ach and 5.5 ach.

The report notes that low occupancy of the rooms could make things even worse. Because two-thirds of the maximum cooling demand was due to occupants, with only a few people in the room, the VAV box would be open only 33%, reducing the air change rate to around 3.4 ach.

Air Handling Unit-1

AHU-1, the system that operated nearest to its capacity, controlled areas of the building that reported the most IAQ complaints.

Calculations show that to meet 1989 standards, AHU-1 should have operated with a minimum O/A damper setting between 19.6% and 27%, which was not the case. Also, these figures assume that the air was evenly distributed within the areas, something else that was not necessarily the case.

Court Clerk's Office

The court clerk's office served by AHU-1 was the source of many of the IAQ complaints. Calculations show that various areas within the office area required minimum O/A damper settings far above the 27% that was calculated for AHU-1 as a whole.

For example, the office area itself would need a 66.5% setting, while the conference room needed 73.1%. Two areas — the cashier's cage and the waiting areas — require 125% and 130% respectively, meaning the design volume cannot meet the 1989 standard.

Another problem occured under a heavy cooling load. When the static pressure on the second floor sensors dropped below two inches of water, the air supply to the first-floor clerk's office decreased to a negligible level, raising questions of whether the system could supply sufficient air to the first floor.

The report notes that this can be overcome by lowering the DAT, which would increase the static pressure, but this would close VAV boxes in some areas. This indicates that the system has conflicting control needs.

A study of the air change rate in the clerk's area also revealed that under the best of circumstances — 100% VAV box opening — the office area and the cashier's cage would receive less than 6 ach. In fact, the cashier's cage was receiving only 3 ach. With a 50% box opening, this would drop to 1.5 ach.

Since AHU-1 was operating close to capacity most of the time, investigators concluded that it couldn't supply the air volume needed in the clerk's area.

The situation in the cashier's cage was even worse. In addition to the low air change rate, the controller for the VAV box was located in an adjoining room that was rarely occupied and had little demand for cooling. Attempts to correct this situation by setting the VAV box to 100% resulted in the room becoming overcooled. The thermostat called for less air and eliminated any net gain in air volume delivered to the cashier's cage.

A second attempt included setting a minimum opening on the VAV box at all times. While this improved the situation slightly, the area still received insufficient air.

Air Handling Unit-5 (Basement)

AHU-5, a constant-air-volume system, serves the child support areas in the basement. Investigators discovered that the return air grille was partially closed. Opening this improved the situation slightly, but when they tried to increase the air supply, they found that at least in one area the ductwork was too small to allow any more air into the space.

To adequately ventilate the areas served by AHU-5 to the 1981 standards, O/A dampers should have had a minimum opening of between 5% and 24%, depending on the individual space. To meet the 1989 standard, those minimums should have been between 14.3% and 68.6%. OEHCS concluded that specifying 15% O/A as a minimum was in conflict with the actual requirements.

While the calculated air change rate for these basement areas was above 6 ach, some questions arose as to the actual rate. One basis for the questions was repeated trip-outs of the return air fan due to motor overload, indicating that the fan, as installed, was incapable of moving the amount of air required by the area. Reducing the air volume solved the trip-out problem, but also decreased the number of air changes.

Another thing that decreased IAQ for areas served by AHU-5 was the fact that air exhaust vents and air intake vents were located adjacent to one another in a concrete pit outside the building. During southerly or westerly winds — or stagnant wind conditions — air exhausted from AHU-5 and AHU-7, as well as from the mechanical room, would flow directly over the air intake for AHU-5. These conditions, according to weather records, occur about 35% of the time.

Also, increased filtration would help eliminate particulates that are found in the O/A taken in at ground level. However, the filter banks were too small to accommodate the larger, more effective filters. Even if the filter banks were replaced to fit the new filters, fans for the system were already operating at maximum level and would suffer overloads if higher-efficiency filters were added.

High relative humidity also proved to be a problem for the basement. Investigators not only found residue from water discharge in the system, but actually observed water rather than steam coming from the humidification wands.

This resulted in significant mineral deposits in the ductwork and damaged the insulation.

Because of the number and severity of the problems in the basement, OEHCS recommended that, as a temporary move, child support and clerk's office personnel relocate from the basement to unused space on the first floor, which received its air from AHU-4, a unit capable of handling the increased load.

Air Handling Unit-7 (Data Processing)

The data processing area had no exhaust ductwork to vent air outside the building. Designers had apparently assumed that positive pressure would force excess air to leak out through the concrete block wall into other areas of the building. Consequently, stale air and contaminants were not effectively vented from the space.

An exhaust fan, installed shortly after the IAQ investigation began, allowed up to 50 cfm for each person in the data processing center. However, another design limitation prevented adequate air flow into the space. In attempting to operate the system at 100% outside air, investigators found that the system could handle only 5,000 cfm, rather than the 10,000 cfm for which the system is rated. The reason for this was an undersized O/A duct.

This was aggravated by the fact that the system also contained an O/A takeoff for the sally port, a passageway through the building. This meant that when the sally port required outside air to reduce carbon monoxide, the fresh air supply to the data processing center dropped even further. This duct was not designed into the system, but was added on when it was discovered that the sally port had no fresh air supply.

AHU-7, like AHU-5, also had problems with entraining exhaust air. When winds came from the south or the east, or were stagnant, exhaust from AHU-5 and the mechanical room would flow directly over the O/A intakes for AHU-7. Weather data showed that these conditions could exist about 35% of the time.

Like AHU-5, this system required more efficient filters, but lacked filter banks of sufficient size or the fan power to accommodate the increased resistance.

Both basement systems also lacked any dehumidification capability, resulting in high humidity levels in those areas.

Basement Mechanical Room

The mechanical room, also located in the basement, contained the hot water system, heat exchangers for the perimeter heat and air handling systems, and the air handling systems for the basement area.

Some chemical leakage is normal in these rooms, and usually a separate exhaust fan vents the chemical odors outdoors. However, the JOF mechanical room had both supply and return air openings into the basement air handling system, which meant the chemical odors spread to the data processing area.

Investigators recommended closing the return air duct and using exhaust fans to vent the mechanical room. However, the exhaust fans had to work full time to achieve sufficient odor control. Also the negative pressure in the air handling system ductwork was so great — partially due to the small size of the outside air duct — that it drew odors from the mechanical room into the system.

Results of IAQ Investigation

The IAQ assessment focused on contaminants in the building's air, including airborne particulates, VOCs, and microorganisms.

Investigators ruled out radon and asbestos as problems within the building and determined that neither dust mites nor microorganisms posed a problem at the time of the investigation. However, they cautioned that mites or microorganisms could become problems without adequate maintenance. The basement area had flooded during construction, and investigators said this could have left spores that would grow under ideal conditions, such as excess humidity. Dust mites live on protein matter such as shed skin cells and dander, and could become a problem after a prolonged period of occupancy, unless maintenance was sufficient to remove the mites and their remains.

Particulates

Airborne particulates, as the OEHCS reports notes, affect IAQ in two ways: they act as primary physical irritants to the eyes and upper respiratory tract; and they absorb other chemicals from the air and concentrate them, so that the chemicals, as well as the particles, become irritating.

Initial tests showed that in the JOF about 90% of the airborne particles were less than 10 microns (μ) in diameter. Tests throughout the building showed particle counts ranging from 11 micrograms per cubic meter ($\mu g/m^3$) to 90 $\mu g/m^3$, while normal particulate levels in the outside air ranged from 40 $\mu g/m^3$ to 60 $\mu g/m^3$.

The levels measured within the building were well within the limit of 5,000 $\mu g/m^3$ established by the US Occupational Safety and Health Administration (OSHA), but some readings were above the US Environmental Protection Agency's clean air standard of 75 $\mu g/m^3$.

One interesting note is that particulate levels remained constant throughout the testing period. However, during that period, building operators installed new high-efficiency filters, which should have caused the levels to drop.

Investigators concluded that most of the particulates within the building came from the building itself. Suspected sources were dust and other materials stirred up by people walking across rugs and carpets, as well as debris left behind on furniture that had been in the building during the final construction stages.

Tobacco Smoke's Contribution

Although the courthouse was designated a no-smoking building in the office areas, some office workers did smoke. Also, smoking was permitted in public areas, such as corridors and waiting rooms. Smoking areas require higher ventilation standards than nonsmoking areas and the JOF's ventilation system didn't account for the added burden.

The fact that the environmental tobacco smoke (ETS) entered other areas with no, or inadequate, filtration may have accounted for some of the elevated particulate levels.

Residue on Chairs and Carpeting

Internally generated particulates are uncommon in new buildings, as a buildup of dust and dirt usually causes this situation. As mentioned above, some furniture was in the building while construction was still going on and became soiled. Reports indicate that these were vacuumed to remove the dirt, but some particles could have been left behind.

In addition, following the March 31 incident, chairs and carpeting were sprayed with a quaternary ammonium/benzalkonium chloride solution as a disinfectant.

Subsequent tests of the chairs showed that, when rinsed with distilled water, the resulting water had a pH in the range of 1-3, indicating a highly acid condition. With subsequent rinsing, the pH moved toward 7, a neutral solution, meaning that some buffering agents may have created the neutral solution in time.

Investigators hypothesize that in the March 31 incident, sulfates in the air contaminated the chairs and carpeting. Then, they assume, two scenarios may have taken place. When workers applied the quaternary ammonium/benzalkonium chloride solution to the chairs, the solution evaporated quickly, leaving crystallized compounds. Or, the solution reacted with the sulfates already on the chairs and produced salts that, when meeting moisture, formed an acid solution. The investigators theorize that a combination of these two scenarios may have occurred.

In effect, when employees sat in the affected chairs, moisture from their bodies would react with the crystals to form the acid solution. As the reaction continued, buffering ions formed, and the solution increased in pH toward the neutral range.

The investigators concluded that this reaction caused the rashes and skin irritation reported by employees. It would explain why reports of these reaction increased after the application of the disinfectant in early April.

Microscopic examination of the material extracted from chairs and carpeting showed significant amounts of dirt and other materials, with some furniture showing more than others. Fiber glass or other fibers were also present and indicated a source within the building.

The investigators hypothesized that the fibers came from either the sound absorbing lining in the ductwork or insulation above the ceilings.

In July, OEHCS sampled for dust and dust mite allergens. This involved vacuuming sections of carpet and some chairs. Investigators found significant amounts of dirt and other materials in all areas, despite a recent cleaning. The dirtiest was the first floor clerk's office public lobby.

OEHCS concluded that cleaning efforts had been unsuccessful, or that dirt from the carpets had recontaminated the chairs, and recommended a general recleaning.

Vertical panels also gave off visible particles when they were rubbed, and OEHCS recommended that these be cleaned during maintenance.

The investigators also recommended upgrading vacuum cleaners to high-efficiency models for greater dust removal and filtering. They suggested that future testing evaluate whether the cleaning efforts are successful.

Fibers in Return Air Plenum

A considerable layer of dust above the ceiling tiles and on top of other fixtures in the ceiling areas also showed a significant number of fibers and other dirt. This material posed a danger to occupants because it could become airborne if disturbed during maintenance activities.

In that event, the fibers and other materials could become entrained in the return air supply. The investigators felt that increased filtration — added as a result of this study — should suffice to remove the fibers. In the short term, since the HVAC system was being operated on 100% O/A, nearly all of the return air was being discharged from the building and not returned to the system.

One danger that remains, however, is that moving ceiling tiles or fixtures could disturb the dust and recontaminate areas below. OEHCS suggested that in future maintenance activities, tiles be moved as little as possible and that they be vacuumed before being reinstalled.

Contaminants

OEHCS conducted tests for a variety of contaminates, including microbial growth, carbon monoxide (CO), CO_2, VOCs, asbestos, and radon.

Asbestos and radon posed no problems for the courthouse. Microbial testing involved drawing a known volume of air through a microbial sampler and collecting the microbes or spores on agar gel sampling strips. The strips were incubated for 36 hours at 37°F and the microorganisms were counted.

American Council of Government Industrial Hygienists (ACGIH) bioaerosol guidelines call for concentrations of microbes to fall below 500 colony forming units per square meter (cfu/m^3) for individual organisms and 1,000 cfu/m^3 total. Testing in various areas of the JOF showed the counts to be 4-37 cfu/m^3, with most readings falling in the high 20s. This indicated little problem from microbial growth.

However, OEHCS felt that certain factors held the possibility of future microbial contamination. The first was the fact that exhaust air from the kitchen was entering the air handling system, resulting in the possibility of organic matter accumulating in the ductwork.

The second was the high humidity levels in the building — sometimes as high as 78% — which would support the growth of microbial organisms.

Carbon Monoxide and Carbon Dioxide

Carbon monoxide, when tested with real-time monitoring over a period of five days, measured less than two parts per million (ppm), levels that basically reflected the levels found in outside air. Researchers discontinued monitoring.

CO_2 levels, on the other hand, posed more of a problem. Investigators calculated that because as many as 3,000 people occupy the building on some occasions, they could generate as much as 10,410 ft^3 of CO_2 in an eight-hour period. To dilute this to 500 ppm, which is half of the ASHRAE upper limit of 1,000 ppm, would require up to 125,000 cfm of fresh O/A, considering the CO_2 content of outside air and the variability in air mixing within the building. Tobacco smoking within the building would add to this requirement.

Investigators, as noted previously, recommended setting the damper openings to 100% O/A, which should have alleviated the CO_2 problems for most of the building. Courtrooms, however, proved to be another story because of their highly variable occupancy rates.

Therefore, OEHCS monitored the CO_2 levels in three of the courtrooms to determine the extent of the problem, if any. During the one-month sampling period, CO_2 levels in the courtrooms remained below 1,000 ppm except on four occasions, which occurred during the morning court calls, when occupancy was highest.

Because these happened after the system was operating on 100% O/A, the investigators formed five hypotheses:

- Overcrowded courtrooms: The courtrooms were at about 105% of occupancy at these times; however, this should have been within design parameters.
- Delayed opening of VAV boxes: Overcooling from the previous evening could have delayed the box openings. However, this would occur early in occupancy, and the high CO_2 levels were recorded later in the morning.

- Overcooling by VAV boxes meant short open times and limited air delivery: Some of these high CO_2 levels occurred after the DAT was increased to 60°F, 5° above the original design. This should have caused the VAV boxes to stay open longer than they did, leading investigators to question whether there is adequate air supply for the room under maximum loading conditions.
- Insufficient fresh air entering the room: Before the investigation, the air handling system was operating on 10%-20% O/A. After that increased to 100%, the courtrooms were receiving 4 to 5 times more fresh air than before. The elevated CO_2 levels led investigators to question whether the air supply was adequate, even at a maximum O/A rate.
- Improper VAV box operation: In one of the courtrooms studied, investigators discovered that a VAV box was sticking and not opening fully during operation. They discovered the same problem in several other areas. After they had remedied the situation in the affected courtroom, they measured no more elevated CO_2 readings. However, case loads subsequent to the repair didn't seem as heavy as before, so they couldn't tell if that solved the problem.

All of these considerations led OEHCS to question the total air volume to the courtrooms and whether short circuiting, or improper mixing, was at the root of the problem.

CO_2 levels in the rest of the building were well within accepted guidelines, averaging about twice the levels in ambient air, and considered normal for office occupancy.

Ozone

Investigators didn't detect any ozone in the building, but noted that the Chicago area experiences elevated ozone levels about 18 times a year. This ozone could be brought into the building, especially with the HVAC system operating at 100% O/A.

Also, since copiers and facsimile machines are a potential source of ozone within the building, OEHCS recommended that the machines be serviced regularly and filters changes be based on the number of copies made.

Formaldehyde

While investigating one courtroom, OEHCS discovered that the wood paneling on the walls and furniture was actually a pressed wood core with a real wood veneer. Since pressed wood is known to emit formaldehyde from the urethane formaldehyde resin used in manufacture, investigators decided to test emissions.

They measured the emissions in the room and from pieces of paneling tested in a polyethylene enclosure, and found levels to fall between 0.01 and 0.07 ppm. This is below the OSHA permissible exposure limit of 0.75 ppm, but above the 0.05 ppm level established by the Canadian Department of Health and Welfare for residential indoor air.

Because formaldehyde emissions are greatest when the materials are new and decrease over time, it is reasonable to assume that the emission rate was greater earlier in the building's life. Also, since outside air ventilation rates were also considerably lower, formaldehyde levels in the building could have been substantially higher earlier in the building's history, when many of the complaints began to surface.

OEHCS concluded that the current levels of formaldehyde were not significant for most persons, but could be a problem for people who are sensitive to the chemical.

Amine Compounds

After investigators noticed a slight ammonia-like odor in the basement mechanical room and data processing center, they reviewed the chemicals that were used and determined that the high-temperature hot water system contained hydrazine and morpholine. Both are amine-containing compounds and scavenge free oxygen in boiler water to reduce corrosion.

Because hydrazine is a hazardous chemical, OEHCS used the OSHA method specific for hydrazine and found that all readings were less than the limit of detectability, and therefore less than the OSHA limit of 0.13 milligrams per cubic meter (mg/m^3). OEHCS used the OSHA standard, since no indoor air quality standard currently exists.

However, if the hydrazine is below the limit of detectability, it is also below the odor threshold of 3 mg/m^3, and cannot be responsible for the odors. Investigators theorized that some other low-molecular-weight amine compound accounted for the odor, perhaps a decomposition product of hydrazine and morpholine.

The odor could also have been related to the quaternary ammonium disinfectants applied to the furniture and carpeting. However, there is no simple air testing technology to determine which amine compound is in the air.

Table 2 — Proposed NATO Target Guidelines for TVOCs in Indoor Air

Chemical Class	Concentration in μg/m³
Alkanes	100
Aromatic hydrocarbons	50
Terpenes	30
Halocarbons	30
Esters	20
Alderhydes and ketones (Except formaldehyde)	20
Others	50
Target guideline value (sum of TVOCs)	300

A third possibility is the use of urea fertilizer in the ground outside the air intake for the data processing center. Urea can break down, giving off amine radicals.

In response to all of these possibilities, OEHCS made a number of recommendations:

- Continuously operate exhaust fans in mechanical rooms;
- Remove mulch from the lawn outside the air intake;
- Limit grass cutting in front of the air intake to weekends;
- Prohibit lawn chemicals from the area near the air intake; and
- Review the design of the air handling system and the air intake for the basement.

Investigators also noted the odor of ethylene glycol in the basement, although tests failed to show any levels greater than the level of detectability, meaning that if the substance was present, it was well below the OSHA standard of 50 ppm.

They concluded that the odor probably came from trace compounds of commercial-grade antifreeze. This is used in the fresh air pre-heat coils to prevent freezing in the winter and had been spilled in the basement and on the 4th floor.

OEHCS recommended that an independent air supply duct for the mechanical room be added to increase the effectiveness of the room's exhaust.

Volatile Organic Compounds

Sampling in selected courthouse areas for VOCs showed several occasions when the total VOCs (TVOC) exceeded 160 μg/m³, levels at which irritation and discomfort can generally be expected, according to NATO guidelines. OEHCS didn't use the OSHA guidelines because they are hundreds of times higher than NATO's and investigators felt they didn't apply to this situation. However, once the O/A intake was increased to 100%, TVOC levels dropped by 60%-80%, and there were no measurements above 160 μg/m³.

One area of concern for investigators was the concentrations of specific classes of VOCs. NATO has established target guidelines for these classes, as Table 2 shows. When investigators analyzed the VOCs that were found in the JOF, they broke them down by class and determined the concentration of each chemical that was greater than 0.5% of all the VOCs detected. The results are shown in Table 3.

OEHCS determined that the total aromatic concentrations approached 40 μg/m³. This indicates that despite the 100% ventilation with O/A, these concentrations are at about 80% of the NATO guidelines. If O/A were reduced to 80%, using the present air handling system, these levels could rise above the guidelines and cause irritation.

Table 3 — Distribution of VOCs Found in DuPage County Courthouse

Chemical Class	Percent
Aldehydes and ketone (excluding formaldehyde)	
2-Butanone	1
Aromatics	
Toluene	26
Ethyl benzene	8
Xylene	17
Cumene	3
TOTAL	54
Halocarbons	
1,1,1-Trichloroethane	4
Tetrachloroethylene	2
TOTAL	6
Alkanes	
2,2,5-Trimethylhexane	12
3-Methyl, 5-propylnonane	9
2,2,6-Trimethyl octane	7
Tridecane	9
Undecane	1
2,2,6-Trimethyldecane	1
TOTAL	39

Source: Dr. Robert Brandys, Occupational and Environmental Health Consulting Services

Another factor to consider is that these levels were measured nearly a year after the building opened and workers had moved in. It would be safe to assume that, given the normal offgassing of VOCs from new furniture and building materials, added to the limited outside air ventilation, VOC levels earlier in the building's history were considerably higher.

OEHCS also called in a toxicologist, who studied the VOC levels and employee complaints and determined that many of the symptoms reported "are the result of chronic low-level multiple chemical exposures present in the DuPage County Court Building." The toxicologist's report can be found in Appendix A.

March 31 Incident

While the March 31 incident, in which a number of employees required medical attention, was not part of the ongoing problem, investigators felt it had its roots in numerous deficiencies in the building's HVAC system.

The humidifier system used sodium sulfite and potassium hydroxide to alleviate the buildup of solids at the steam discharge ports. These entered the system through meters and were added with every 10 gallons of water.

One theory proposed by OEHCS was that the sulfite, being highly reactive, quickly converted to a sulfate. In fact, an examination of the boiler water showed that it contained 956 milligrams per liter (mg/l) of sodium sulfate, compared to mg/l of sodium sulfite. Since there was no other source of sulfate in the building, OEHCS concluded that the humidifier water must have been the source of the sulfate later discovered in the chairs.

On March, 31, only the humidifer in AHU-1 was adding humidity to the building. Although it had only recently rained, apparently a malfunctioning sensor indicated a need for humidity. In addition, AHU-1, which serves the courtrooms on the fourth floor, was drawing in 100% O/A and was not cooling it. When the humidity was added to this already saturated air, it formed a visible cloud.

The theory concludes that the sulfate in the humidifier steam water reacted with the humid air to form an acid particulate that was highly irritating to those employees who came in contact with it.

Conclusions

At the end of the investigation, OEHCS made a number of conclusions about the design and operation of the air handling systems for the JOF; the indoor air quality as related to contaminants; and a determination of whether the evidence supported the original six hypotheses.

The Six Hypotheses

The study data appeared to support the hypotheses, as follows:

1) The March 31 incident was a separate situation caused by:

- A humidifier malfunction;
- The use of sodium sulfite as a water treatment chemical;
- A combination of unusual weather conditions;
- Air mixing problems on the roof; and
- Conflicting operational functions of the air handling system.

2) The data processing and child support areas, being serviced by separate air handling systems, had a somewhat different indoor air quality situation than the upper floors of the building. The differences included:

- A lack of exhaust air ducting in the data processing area;
- Ground-level air intakes;
- Constant-air-volume design vs. a variable-air-volume design; and
- Possible transmission of chemical odors from the mechanical room.

3) The symptoms reported in the clerk's office on the first floor may have been due to some unusual material in that area or may be related to the fact that the office is on the end of its air handling system and is experiencing supply problems.

- Significantly higher dust and dirt levels were present in the carpeting in this area.

4) Other recurring symptoms of a general nature were related to chemical exposure during early occupancy and possible subsequent sensitization to these chemicals.

- Formaldehyde and VOC concentrations were most likely significantly higher during early occupancy of the building. Volatile aromatic organic hydrocarbon levels can still be above recommended guidelines with insufficient makeup air. Formaldehyde can cause chemical sensitization in approximately 20% of the exposed population.

5) The courtrooms had a unique IAQ situation due to the highly variable occupancy.

- Carbon dioxide readings showed peak concentrations above 1,000 ppm on three occasions during testing, indicating a potential fresh air supply problem.

6) VOCs, typical in new, tight buildings, were probably related to the IAQ complaints.

- Total VOCs measured in two courtrooms on two days were above recommended guidelines. Further analysis of individual classes of VOCs showed volatile aromatic organic hydrocarbon levels can still be above the recommended guidelines with insufficient fresh make-up air.

Design and Operation

OEHCS compared the design and operation of the JOF to the 1981 and 1989 ASHRAE ventilation standards. A number of deficiencies showed up during the investigation. Some of the most important ones were:

- The initial design may not have complied with ASHRAE 62-1981 for outside air at all times in all spaces of the building because the specifications allowed the O/A dampers to close to a 15% opening. Based on linear air volume to damper position assumptions, an opening of no less than 24% should have been allowed. Changing the damper to 100% O/A appears to meet ASHRAE 62-1989, but only under normal climatic operating conditions.
- The air handling systems for the upper floors were not designed to meet the ASHRAE 62-1981 requirement for leading air supply in occupied spaces, "when contaminants are generated in the space, independent of occupants or their activities."
- The current air handling system can generally supply a sufficient amount of O/A to meet ASHRAE 62-1989 with the O/A dampers set at 100%. Under climatic extremes, this may not be the case.
- The ventilation system for the upper floors does not provide 6 to 10 ach in all spaces of the building at all times. This reduces the amount of O/A being brought into a space, limits the effectiveness of mixing the O/A with the air in the building, and reduces the amount of contaminated air exhausted from the building.
- The building can't remove excess humidity from the air without overcooling the building and virtually stopping airflow in some spaces.
- AHU-1, which services the northeast quadrant of the building, operates at maximum capacity at nearly all times. This section of the building also has the highest occupancy level. This limitation reduces the amount of ventilation to the first floor clerk's office. If the parameters are changed to ventilate the first floor offices, this reduces the ventilation to other spaces in this quadrant.

IAQ Assessment

A single chemical failed to appear as the cause of the symptoms among building occupants. However, OEHCS noted a number of chemicals that played a part in the situation.

- Formaldehyde levels appear to have been substantial during early occupancy, possibly causing eye and upper respiratory tract irritation.
- VOCs from furnishings and building materials were probably high during early occupancy. This continued for several months and some were still measurably above recommended levels during the study.
- Volatile aromatic hydrocarbon concentrations approaching the NATO guidelines still occur in some areas of the building, even at 100% O/A settings.
- Particulate levels generated in the building were higher than desirable on some occasions, possibly due to construction debris and other particulate materials in ductwork, furniture, and carpeting. Particulates can absorb various hydrocarbons and can become even more irritating when inhaled or in contact with skin or eyes.
- Fibers, dirt, and other chemicals used in the building appear to be related to the incidence of rashes.
- The application of benzalkonium chloride disinfectant compounds appears to have contributed to the rash symptoms.
- Sodium sulfate in the humidifier water appears to be the chemical that caused the symptoms experienced in the March 31 incident.
- Amine breakdown products from boiler treatment chemicals add to the total level of irritating chemicals in the air in data processing.
- CO_2 levels in courtrooms and possibly other areas of the building could exceed the recom-

mended guidelines, when O/A dampers are not 100% open.

Other Conclusions

OEHCS identified three other potential causes of the rash symptoms within the building:

- Fibers from fiber glass insulation and mineral wool fibers from the ceiling tiles were detected in the environment and on furniture and carpeting.
- Benzalkonium chloride disinfectants used on the chairs and carpeting resulted in a complex chemical reaction that initially produced a very low pH solution on contact with moisture. The low pH could irritate the skin. Also, the potential release or generation of particulates from the furniture or carpeting could result in irritating particles.
- Dirt and debris in the chairs and carpeting could have produced a physical irritant that alone, or in combination with chemicals present in these materials, could have contributed to or caused some of the reported rashes.

The investigation also determined that several possible factors were *not* involved. These include:

- Microbial agents;
- Carbon monoxide;
- Ethylene glycol; and
- Radon.

Recommendations

OEHCS made a number of recommendations based on what investigators discovered during their indoor air quality assessment and review of the design and operation of the HVAC systems.

Air Handling Systems

Investigators recommended numerous changes in the HVAC systems to ensure that the building conforms to ASHRAE 62-1989. These recommendations appear in full in Appendix B and are summarized below:

- Completely reassess the design and operation of the ventilation system;
- Install a dehumidification system;
- Install new humidity and temperature sensors;
- Put new controllers on VAV boxes;
- Provide local reheat, as necessary;
- Establish isolated zones for each system;
- Set minimums for VAV boxes;
- Rebalance all air handling systems;
- Upgrade AHU-5 and AHU-7;
- Install an extra ventilation system to increase capacity in areas served by AHU-1;
- Install a new HVAC computer and software;
- Establish an alternative environment or special air supplies for chemically sensitive individuals;
- Change the horizontal discharge of the cafeteria exhausts to vertical; and
- Install air filters of 60% or higher efficiency.

Air Quality Assessment

OEHCS made a number of recommendations to reduce the incidence of symptoms in the building. Many recommendations were started or implemented during the study itself. The status of the recommendations, as of the time of the report, were as follows.

Fully Implemented Recommendations

- Increase fresh air damper settings to 100% at all times;
- Rinse chairs to attempt to remove contaminating chemicals;
- Wash carpeting to remove chemicals and accumulated dirt;
- Decrease the use of potentially irritating chemicals; and
- Restrict pesticide use in the building.

Recommendations Related to Cleaning

- Develop and implement maintenance and construction procedures to reduce dirt and fiber generations when moving ceiling tiles or generating dust;
- Wash vertical panels to remove accumulated particles;
- Develop and implement a cleaning plan for furnishings;
- Implement a preventive maintenance program to insure that ozone filters on office equipment are periodically replaced; and
- Review the use of, and research possible chemical substitutes for, hydrazine as the oxygen scavenging chemical in the high-temperature hot water system.

APPENDIX A — Toxicologist's Report

Human Health Effects Assessment: DuPage County Courthouse

Introduction

Over the past several months, numerous complaints if illness have been registered by the office employees at the DuPage County Courthouse Building (DCCB). Employee complaints surfaced after relocating to the newly built DCCB facilities.

The complaints develop shortly after arriving at the workplace, usually within one to one and one-half hours, and generally subside or disappear upon leaving the workplace air. Workers indicate the irritations and illnesses surface when at the workplace. No such symptoms occur over the weekends. Complaints were registered most frequently by women; data processing workers at the lower level and employees on the fourth floor appear to have the greatest number of complaints. The most frequent complaints reported were:

• Frequent continuous headaches	104
• Upper respiratory irritation	99
• Dry, burning, itching eye irritations	90
• Itching, burning rashes on skin/body	83
• Nausea, upset stomach	67
• Lethargy, tiredness	46
• Lightheaded, dizzy feeling	42
• Shortness of breath	36
• Chest pain	30
• Metallic or acid taste in the mouth	21
• Swollen glands	5
• Nosebleeds	4
• Diarrhea	3
• Neurasthenia, numbness of hands	2

Air samples were collected the the DCCB and subjected to gas chromatographic-mass spectroscopy analysis. The analyses were directed to determination of thirty of the most common volatile organic chemicals, as well as a number of nonvolatile organics. The results of the analysis indicate ten volatile organic chemicals were found to be present at the low micrograms per meter level (see Table 1), but above detection limits. Several additional nonvolatile compounds were also reported to be present. Compounds identified as C_7 through C_{16} skeletons were found present in the sample analysis, but were not examined in the health assessment.

Discussion

The acute toxicity of well-defined chemical exposures is generally easily recognized and the causative factor readily identified. However, in chronic and subchronic low-level exposures, establishing causality is frequently not so clear cut. However, an exception exists when there is a preponderance of evidence that logically supports this and no other conclusion. That logic is present in this situation and follows a certain pattern, described below.

1) In examining these symptoms, it is apparent the biological systems involved are highly consistent among the exposed employees. They indicate the mucous membranes of the eyes and upper respiratory system, the exposed skin surface, the central nervous system, and the cardiovascular system were most frequently involved. Gastrointestinal disturbances were few. However, it is indicative of a chronic toxicological event.

2) In this situation, the reported symptoms of the employees are highly consistent. The syndromic effects reported by individuals working on different floors are similar and the same biological systems are involved in the complaints. Large numbers of employees suffer a complex of symptoms that are consistent. The continued complaints and presenting symptoms are quite real. The large numbers of employees reporting similar illness is indicative of real exposure situations.

3) The effects and symptoms have an unmistakable temporal relationship. The complaints began at a time when the employees moved over to the new DCCB office building, and this is known as Sick Building Syndrome — a syndrome that produces headaches, rashes, itching of the skin, irritation of respiratory systems, and narcosis in human inhabitants. It appears a short time after reporting to work and generally disappears or subsides after leaving the workplace. It is not usually present on weekends when no exposure to the workplace has occurred.

4) The chemicals identified in the DCCB and listed in Table 1 can cause adverse effects to human skin, respiratory systems, mucous membranes, to the central and peripheral nervous systems, and can elicit responses in other organs if the exposure is sufficiently chronic. These effects have been demonstrated and/or reported to occur in humans and/or in experimental animal models, either during accidental or experimental exposures. Each chemical alone has the capacity to initiate several of the symptoms. Although presently measured in low levels, these chemical species were previously present in higher concentrations. Ventilation systems have been recently modified to increase removal of odors and vapors.

5) An additive and synergistic potentiation is also at play, since the adverse effects occur at simultaneous exposures of low levels of the organic chemicals. Ten of the chemical agents have the same or similar irritant and narcotic qualities, and are present concurrently. Inhalation of these organic solvent vapors and/or cumulative deposition of chemical agents on the skin and mucous membranes produce a chronic exposure. Acting together, the chemicals produce an effect which is greater than if each were acting alone. Higher exposure levels are usually reported as being necessary to initiate such acute effects; however, concurrent exposure to multiple chemical agents at low levels will initiate similar and greater effects.

Conclusion

Based upon the above, and with a reasonably high degree of biomedical certainty, it is my opinion that the symptoms and illnesses reported by the employees at the DCCB are the result of low level multiple chemical exposures present in the DCCB.

Respectfully submitted,

Joseph K. Prince, Ph.D., M.P.H.

5/28/92

Table 1 — Chemicals Found in the Air of the JOF

Chemical	Also Known As	Use	Positive Responses	High Concentration	Symptoms of Exposure
Benzene		Solvent	2	0.09	Hematopoietic, carcinogen
2-Butanone	Methyl ethyl ketone	Solvent	1	1.0	Irritates eyes, skin, and mucous membranes, causes narcosis.
Carbon disulfide		Solvent	3	1.0	Damage to central/peripheral nervous system; axon neuropathy, headaches, dizziness.
Ethylbenzene		Solvent	8	1.2	Skin and mucous membrane irritant; narcotic effects. Used in styrene synthesis.
4-methyl-2-pentanone	Methyl isobutyl ketone	Solvent	1	2.2	Irritant to eyes, mucous membranes, and skin; has narcotic effect. Causes weakness, headache, and nausea.
Styrene		Solvent	8	4.0	Irritant to eyes and mucous membranes; central nervous system depressant. Causes headache, nausea, and fatigue.
Tetrachloroethane		Solvent	7	1.2	Causes dermatitis; narcotic.
Toluene		Solvent	6	7.9	Central nervous system depressant. Causes headache, dizziness, nausea, mild fatigue, weakness.
Trichloroethane		Solvent	8	3.3	Central nervous system depressant.
Trichloroethene		Solvent	8	0.2	Central nervous system depressant.
o,m,p-Xylenes			7	4.6	Irritant to eyes, mucous membranes, and skin. Can cause narcosis.

Source: Dr. Robert Prince

APPENDIX B — Complete List of Recommendations

Problems and Recommendations for DuPage County Courthouse Air Handling System

Potential Problem	Interim Corrective Action	Long-term Corrective Action
Building has been operated with ventilation equipment turned off on weekends and evenings, allowing offgassing chemicals to build up overnight. This resulted in airborne chemical levels that may cause potential chemical sensitization of employees, particularly those with previous allergy histories.	Computer control program was overridden to keep fans operating at all times.	Reprogram to keep fans operating permanently.
Variable-air-volume boxes installed with no minimum settings as required by design. This resulted in closing of boxes and **no** air circulation in rooms. This caused a buildup of chemical concentrations that may elicit reactions in sensitive employees, and high CO_2 levels that may affect other employees.	Discharge air temperature was increased to 60°-61°F to maintain boxes full open as much as possible without leading to overheating (insufficient cooling) in building areas.	Reset all VAV boxes to minimum air volumes specified by new design review of minimum settings based on occupancy and heat load.
Insufficient fresh make-up air causes CO_2 levels to exceed 1,000 ppm in courtrooms.	Fresh air dampers were set to 40% minimum, based on air testing.	Reprogram control software to never go below this setting when building is occupied or to be occupied within 4 hours.
Energy management system computer controls appear not to have been designed to insure that CO_2 levels do not build up in building.	See above.	See above.
Air handling units are placed in close proximity to each other. Some recirculation of exhaust air into fresh air grilles occurs to all units, especially AHU-1.	Removed sight barriers to increase fresh air circulation between units.	Evaluate the possibility of redirecting exhaust air flow or remote ducting of fresh air intakes. Make necessary upgrades.
Sight barriers decrease mixing and dilution of return air; decrease flow of fresh air for fresh air intakes; increase pickup of gases from roof. This recirculation potential is also partially the result of centrally locating all rooftop units.	Removed sight barriers.	If sight barriers are required, install remotely located barriers which allow easy air flow.
Insufficient ventilation to dilute offgassing chemicals from new building materials causes reactions in chemically sensitive individuals.	Fresh air dampers set to 100% fresh makeup air.	Continue 100% fresh makeup air until building sufficiently offgasses (up to five years).
Insufficient air changes per hour in areas where duct size is a limiting factor.	Increased static head pressure in the air handling systems from 2.25 to 2.5 water gauge to force more air through system in areas where duct size is a limiting factor.	Reassess design and upgrade ventilation to provide 6 to 10 air changes per hour in all occupied spaces.
Variable-air-volume boxes may be of insufficient capacity in some areas as reflected by employee comfort complaints.	Reassess cooling and fresh air ventilation needs based on occupancy and cooling load.	Install larger VAV boxes where necessary (e.g., grand jury room).
Dehumidification subroutine program causes discharge air temperature to decrease to 50°F, resulting in overcooling of system and room. VAV boxes close and air circulation on Floors 1 to 4 becomes minimal. Chemical concentration buildup to possibly significant levels that may lead to chemical sensitivity and symptoms.	Dehumidification program disabled.	Redesign system to provide actual dehumidification without cooling and reheat.
Humidity level sensors do not reflect actual levels of humidity in the building due to improper location and recirculation of supply air at ceiling level. This leads to falsely low humidity indication. System operation overhumidifies, leading to more rapid release of irritating polar organic compounds.	Turned off humidification system control.	Relocate sensors. Install fuzzy logic.

Potential Problem	Interim Corrective Action	Long-term Corrective Action
The humidification system steam supply boiler uses high-mineral-content well water with sodium sulfite and potassium hydroxide mineral deposit preventor. Sodium sulfite, potassium hydroxide, and mineral particulates are released directly into the supply air system during humidification without filtration to remove particulates. Overhumidification (see above) exacerbates excessive particulate release. This results in high levels of potentially irritating particulates in the indoor air (the major cause of the March 31 incident).	Turned off humidification system.	1. Install system to supply high-quality water for steam generation. 2. Relocate steam wand upstream of air filters.
Return air fans set to 10% underdriven to "pressurize" the building for energy conservation. This results in less air changes per hour and less exhausting of chemical-laden air.	Reset computer so that exhaust fans are equal to supply air fans.	Rewrite control program to make permanent.
Computer readings of return air fans and dampers in air handling units appear to inaccurately reflect percent makeup air and exhaust air volumes based on percent damper openings. This results in less fresh air entering building than readings appear to indicate.	Recalibrate based upon air balance measurements.	Rewrite computer program to reflect actual percents.
The building's relative humidity (RH) gets too high. On days when RH exceeds 40%, rashes and other symptoms develop on sensitive and possibly other employees. High humidity promotes increased offgassing of polar organic compounds, many of which are irritating.	Reengineer air handling systems to provide dehumidification.	Install dehumidification system.
Air filters in the system are only roughing (30%) filters. These are not sufficient to provide effective filtration of particulates in the building. Excessive particulates irritate the eyes and upper respiratory tract. In addition, they can absorb chemicals in the air and concentrate them so that they are more irritating.	Increase filters to 60% at a minimum. Increase to 80% filters, if possible (especially in AHU-1). (Completed April 1992, AHU-1 through AHU-4.)	Redesign AHU-5 and AHU-7 to handle higher efficiency filters.
The fiberglass sound-absorbing duct lining appears to be shedding fibers in some sections. Linings may be damaged. Mineral fibers may also be present in dust above ceiling tiles. (The ceiling tiles contain mineral fibers.) These fibers may be the cause o' the small "red dot" dermatitis as observed in some indi\ iduals.	Increase air filtration efficiency as shown above.	Diffusor filters may be necessary in some areas.
Air handling system control computer power loss results in shutdown of most air handling systems, leading to buildup of chemicals that cause reactions in chemically sensitive employees. (This has happened twice since study started.)	Turned system back on.	Put computer on uninterruptible power supply system or install fail-safe controls to keep fans operating at all times.
Air handling system control computer results in loss of program override for fresh air, discharge air temperature, and static head.	Turned system back on. Reprogrammed new settings.	Put computer on uninterruptible power supply.
Computer failure was not indicated on any constantly monitored location.	Install system failure warning alarm to JOF guard station and central plant.	None determined at this time.
System has automatic 10-minute time delay before fan restart cycle begins.	Decrease to 1 minute or less, if possible.	None determined at this time.
Computer control program for energy management and system control is not user friendly.	1. Increase training for more personnel. 2. Have technicians available for immediate service.	Replace with user-friendly system.
Air handling systems do not appear to be properly balanced, based on both supply and return volumes.	Assess air volume needs, based upon maximum occupancies.	Rebalance systems.
Interconnection of all return air systems occurs in the escalator area. This means that each system cannot be individually balanced. Return air may be entering from another system.	Install barriers in escalator perimeter ceiling areas to isolate each return air system.	Rebalance system.

Potential Problem	Interim Corrective Action	Long-term Corrective Action
Return air flow through ceiling plenum ducting does not go to furthest point in systems. This means that return air negative pressure can be minimal at ends of systems.	Reevaluate system design.	Extend return air ducting as necessary.
Tight building construction minimizes infiltration of fresh air into the building, reducing number of air changes per hour. Fresh air leaks on a localized basis.	Evaluate effectiveness of overdriving return air fans in relation to supply fans and effects on basement air handling systems. Some leakage would improve indoor air quality at this time.	Balance in the future.
Temperature sensing of the building to control air temperature and perimeter heating only occurs on the second floor. This makes it difficult to insure proper ventilation on all floors and individual areas.	Assess additional instrumentation needs and controls for various floors and areas.	Install as necessary.
Systems do not appear to have sufficient reheat capability to bring in 100% outside air during winter months to meet ASHRAE 62-1989.		
VAV control boxes do not have individual control capability from computer, making it more difficult to alter air volumes into rooms.	Assess impact of upgrading building controls.	Install new VAV controllers in necessary areas.
Computer that controls the air handling systems can't develop algorithms to improve the management of the air handling system.	Install VAV controllers.	Install controller software on "up-to-date" computer.
Building does not have leading air supply as required in ASHRAE 62-1989.	Induce artificial cooling load early in workday by allowing building temperature to increase to 70°F overnight. Optimize time period where DAT is decreased to 60°F to maintain maximum vortex openings during startup.	Install leading air supply in all areas of the building.
Courtrooms do not have leading air supply, as required in ASHRAE 62-1989.	Set minimums on courtroom VAV boxes.	Install leading air supply capability, possibly through new controls.
Building humidification system may not be sufficient to maintain comfort range with increased outside air during wintertime.	Assess system capability.	Upgrade as necessary.
Recommendation Specific to AHU-1		
AHU-1 operates at a higher vortex opening (100% vs. 40%) than other systems. This may indicate insufficient maximum capacity, as compared to other systems.	Reassess design.	Implement necessary upgrades.
AHU-1 has almost no return air flow measurable on transition ducts from some fourth floor rooms. Return air system is split on fourth floor, which is different than any other floor in the building.	Increase static pressure to 3.0 inches.	Reassess design. Upgrade return air ducting.
Recommendations Specific to AHU-5		
Return air damper to office area found partially closed.	Fully opened damper.	Balance system based on supply and return air.
System capacity may not be sufficient in some offices.	Reassess system capacity as part of dehumidification and filter size upgrade. Increase air changes per hour in areas where air quality complaints have occurred.	Install necessary upgrades. Balance system based on supply and return air.
Humidification system malfunction has deposited large quantities of water mineral deposits, sodium sulfite, and potassium hydroxide in ductwork. Material is probably generating particulates that could be irritating to sensitive employees.	Clean ductwork. (Completed April 1992.)	Reevaluate need to humidification.

Potential Problem	Interim Corrective Action	Long-term Corrective Action
System unable to accommodate upgraded filters.	Redesign air handling unit to handle larger air filters.	Install new filter banks and upgrade fan motor.
Basement air handling system does not have dehumidification capability.	Evaluate design changes to system to include dehumidification.	Install new equipment as necessary.
Recommendations Specific to AHU-7		
History of fan vortex control problems resulted in tying the vortex vanes in full open position. Reduced air volume in the past may have allowed chemical levels to build up to undesirable levels in data processing area.	Wired dampers full open.	Permanently remove vortex dampers.
No return exhaust ducting was present in the system design. System could only supply fresh air, but could not discharge contaminated return air. Lack of exhaust ducting limited amount of fresh air input.	1. Set system to 100% fresh air. 2. Installed continuous exhaust air system.	Assess volume balance of system for climatic extremes. Program into controls.
System was not properly balanced, resulting in lower air flow volumes at the end of runs.	Readjusted dampers to provide more air at end of runs.	Fine tune air balance.
Discharge air temperature set too cold, resulting in cold drafts and cold complaints.	Increased discharge air temperature.	Install better control system.
This system supplies the computer mainframe room and the office areas. Each area has drastically different cooling needs, making balancing the system very difficult. Improving balance will increase overall air quality in the area.	Install local exhaust hoses on mainframe computer cabinets to directly exhaust hot air to the return air plenum.	Reevaluate the system, based on these changes. Upgrade system design.
Return air damper failure reduced system capacity over 30%.	Repair damper. (Completed in three days.)	Install flow warning indicator.
System unable to accommodate upgraded filters.	Redesign air handling unit to handle larger air filters.	Install new filter banks and upgrade fan motor.
Air handling system does not have dehumidification capability.	Evaluate design changes to system to include dehumidification.	Install new equipment as necessary.
Recommendations specific to other areas.		
Mechanical room was not designed to be maintained under negative pressure. This design would have helped keep odors or chemical vapors from entering the office area. Leaks and spills have deposited a number of odors.	1. An exhaust fan was installed to keep the area under negative pressure. 2. Large exhaust fans are being operated to ventilate the area until the odors are gone.	Review design needs of basement air handling units, based upon current use and personnel levels.
The hot water from the main boiler contains hydrazine and morpholine, known irritants and sensitizers. As hydrazine is a known carcinogen, release of these materials needs to be strictly controlled.	Replace hydrazine/morpholine additive with an FDA acceptable boiler additive. Now that the county has Lake Michigan water, boiler scale should be less of a problem.	Use less toxic and irritating chemicals throughout all service piping system. Dispose of waste water as a hazardous waste.
The cafeteria exhaust fans on the roof discharge horizontally. Even though these are almost 100 feet from the fresh air intakes for the upper floors, under certain conditions, odors reenter the building.	Install vertical discharge ducts on the exhaust fans.	Use the future sight barriers to act as a wall, forcing this exhaust air to a higher elevation for more dilution.

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