#4017

MEASURING CARBON DIOXIDE LEVELS AS AN INDICATOR OF POOR BUILDING VENTILATION: A CASE STUDY

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ABSTRACT

In September 1984, investigators from the National Institute for Occupational Safety and Health (NIOSH) conducted a health hazard evaluation of building-related health complaints reported by occupants of a three-story office building, known as the "500 Building," located in downtown Birmingham, Alabama. From interviews with the building maintenance supervisor and the building heating, ventilating, and air-conditioning (HVAC) design engineer, the NIOSH investigators learned that to conserve utility costs, the building owner had elected not to install outside makeup air ducts on the building's HVAC systems. NIOSH evaluated this ventilation deficiency by measuring the buildup of carbon dioxide (CO_2) during normal working hours. Results from direct reading measurements revealed that indoor CO_2 concentrations reached 3000 parts per million (ppm), or 10 times the outdoor CO_2 level by mid-afternoon. Results from self-administered questionnaires completed by 85 building occupants found 69 (86%) of the occupants had experienced what they believed were building related health problems. Occupants on the second floor had the greatest percentage of complaints (92%). This floor also had the highest CO_2 build-up (3000 ppm at 4:00 p.m.). The most frequently reported symptoms were eye irritation, sinus congestion, headache, sneezing, and nose or throat irritation. To alleviate these complaints, NIOSH recommended compliance with ASHRAE Standard 62-1981, which specifies that mechanical ventilation systems should supply at least 20 cubic feet of outside air per minute per building occupant.

INTRODUCTION

The NIOSH Hazard Evaluations and Technical Assistance Branch (HETAB) provides, on request, medical, nursing, and industrial hygiene technical and consultative assistance to federal, state, and local agencies; labor; industry; and other groups or individuals to control occupational health hazards and to prevent related trauma and disease. Although the NIOSH Health Hazard Evaluation Program was originally established to evaluate industrial work environments, since 1971, NIOSH has conducted more than 350 indoor air quality investigations in response to complaints from building occupants or to reports of suspected building-related illnesses.

In June 1984, NIOSH received a request for a indoor air quality investigation from the chief of the Facilities Management Branch, Internal Revenue Service (IRS), in Birmingham, Alabama. The IRS employees had complained of health problems soon after moving into their new three-story office building in January 1983. Typical of the symptoms reported were headache, watery eyes, nasal congestion, and skin irritation. Although IRS supervisors believed initial complaints were probably the result of odors noted from the new interior furnishing, such as carpets, fabric-covered partitions, wood furniture, etc., employees continued complaining throughout the summer. In September 1983, the IRS asked the Birmingham Area Office of the Occupational Safety and Health Administration (OSHA) to inspect the building environment.

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In January 1984, OSHA took illumination measurements and collected air samples inside the building for carbon monoxide (CO), carbon dioxide (CO_2), ozone, formaldehyde, and volatile organic compounds. OSHA found CO_2 levels ranging from 1500 to 2500 ppm, and formaldehyde concentration ranged from 0.035 ppm to 0.063 ppm. Only trace levels of CO were found. Tests for ozone yielded negative results, and volatile organic compounds were below the limit of detection for the sampling and analytical method used. One air sample taken during a followup inspection in March 1984 detected 0.13 ppm formaldehyde on the second floor.

Because the airborne concentrations of the toxic substances sampled by OSHA were below OSHA's Permissible Exposure Limits (PELs), and because many complaints by building occupants were made to the OSHA inspector, OSHA recommended that the IRS request a NIOSH Health Hazard Evaluation. OSHA's other recommendations to the IRS were: (1) determine if the building was being supplied with outside air ventilation at the rate recommended by ASHRAE, and (2) vacuum the new fabric covered office partitions to remove any loose fibers that might otherwise become airborne.

DESCRIPTION OF ON-SITE NIOSH INVESTIGATION

On September 24, 1984, NIOSH held an opening conference with the Birmingham IRS Facilities Management branch chief and an employee representative from the National Treasury Employees Union. NIOSH was assisted during the survey by a representative from the Alabama Department of Public Health.

Accompanied by the building management facilities engineer, NIOSH toured the building and inspected the HVAC systems. This activity was mostly a visual inspection of the roof-mounted condenser units and exhaust fans and inspection of the ceiling-mounted evaporator blowers and associated ductwork. Special attention was directed at the means by which the HVAC systems introduced outside makeup air into the building. Airflow volumes from HVAC ceiling diffuser outlets were randomly checked with a direct reading flow-hood to evaluate the balance of the HVAC supply air distribution.

Direct reading colorimetric detector tubes (both long-term and short-term) were used to measure the buildup of CO_2 and CO inside the IRS offices at several locations on the first, second, and third floors. These small glass tubes contained chemicals that changed color in the presence of specific airborne gases or vapors the tubes are designed to measure. The approximate concentration of the measured gas (in this survey CO and CO_2) was determined by reading the length of the color change inside the tube after a measured volume of air was pulled through the tube. The tubes had a relative standard deviation of 10% to 15%.

IRS employees working in areas with a history of occupant health complaints were asked to complete and return a self-administered questionnaire. The questionnaire was used to identify the most frequently noted symptoms or health complaints and to obtain comments from the occupants concerning their general impression about the quality of the air in their assigned work areas.

FINDINGS

The building housing the IRS was a 99,000 square feet brick structure with small non-opening windows on three sides. The IRS offices were located in the newer half of the building and occupied all three floors (18,000 square feet per floor). This new section was constructed to the adjoining older half in 1981. The old and new sections shared a common wall and first floor breezeway. In the IRS section of the building, HVAC equipment consisted of 48 individual evaporator/blower units mounted above the suspended ceiling on each floor (16 per floor). Each unit supplied air ducted through five to six ceiling diffusers. One ceiling air return was provided for each unit. During the walk-through survey of the building, NIOSH investigators discovered that the evaporator/blower units were not configured with outside makeup air ducts. Small louver-covered openings in the west outside wall, first believed to be a source of outside air, only permitted natural ventilation of the utility space above the suspended ceilings. Because all supply and return air was ducted to the blower units, the air circulated through the building was 100% return air. It was later learned that the former building owner had elected not to install outside air systems to save on utility costs. When the General Services Administration (GSA) leased the building for the IRS, their "Solicitation of Offers" did not specifically require outside air. Furthermore, their solicitation stated that outside air intake during heating and cooling seasons "shall be reduced to the greatest extent feasible." However, the GSA solicitation did suggest that a "10% outside air intake will be adequate for general office space." GSA has now revised the solicitation for offers to require outside air ventilation but only at the minimum rate of 5 cfm/person.

The lack of outside air ventilation for this building permitted an excessive buildup of CO_2 in the building. As monitored with direct reading detector tubes, the indoor CO_2 levels reached a peak concentration of 3000 ppm on the second floor by 4:00 p.m. This concentration was 10 times that found outdoors, where CO_2 is normally about 325 ppm. Peak readings on the first and third floors were 1060 ppm and 2300 ppm, respectively. For carbon monoxide, only trace amounts (less than 3 ppm) were detected (see Table 1).

Eighty-five IRS employees completed and returned the self-administered NIOSH questionnaire. Of the 85 employees who returned a questionnaire, 69 (86%) reported building related health complaints. The most frequently reported symptoms were eye irritation, sinus congestion, headache, sneezing, and nose or throat irritation (see Table 2). As shown below, the floor with the greatest percentage of complaints was the floor with the highest buildup of CO_2.

	# Interviewed	With Complaints	Carbon Dioxide Levels
1st Floor	12	67%	900-1060
2nd Floor	63	92%	1000-3000
3rd Floor	10	80%	2000-2300

CONCLUSIONS

The symptoms and health problems reported by these IRS employees are typical of complaints frequently reported by occupants of poorly ventilated buildings. The American Society for Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) recommends in its ASHRAE Standard 62-1981 that office buildings receive at least 20 cubic feet per minute (cfm) of outside air per person, if smoking is permitted (ASHRAE 1981). Measuring the buildup of CO_2 in a building is an easy-to-monitor index of a building's ventilation efficiency. The indoor CO_2 level is sensitive to both the level of human activity in a building and the ability of the building's HVAC outside air systems to dilute the resulting indoor air contaminants. Although NIOSH recommends an occupational exposure limit for CO_2 at 10,000 ppm (NIOSH 1976), and ASHRAE recommends ventilating buildings to control CO_2 to less than 2500 ppm (ASHRAE 1981), it has been suggested that indoor air having CO_2 concentrations from 600 to 1000 ppm or higher are associated with occupant discomfort (Bell and Khati 1983; Rajhans 1983). In 1974 the Japanese passed a law requiring that indoor air CO_2 levels be kept below 1000 ppm (NTIS 1974). This is also the indoor air limit recommended by the World Health Organization (WHO Working Group 1979).

The buildup of CO_2 in the IRS offices measured by NIOSH during this investigation supports our conclusion that the building did not receive adequate outside air ventilation for controlling the potential buildup of indoor air contaminants, such as tobacco smoke or volatile organic compounds.

The problems investigated by NIOSH in this building are not uncommon. With the increased emphasis on energy conservation, building owners and managers are encouraged to limit outdoor air ventilation to reduce the costs of operating their building HVAC equipment. This is a generally accepted practice, because many building codes do not specifically require outside air ventilation. For example, the Southern Building Code requires mechanical ventilation for buildings that have a total openable window area of less than 8% of the total floor space. However, the code does not specifically require the installation of a mechanical outside air ventilation system, or specify a minimum outside air volume to control indoor air quality.

RECOMMENDATIONS

To control health complaints from occupants of poorly ventilated buildings, NIOSH recommends that building owners and managers make every effort to comply with ASHRAE Standard 62-1981 by insuring that office buildings dependent on mechanical HVAC systems deliver at least 20 cfm of outside air per person or at least 5 cfm per person if smoking is prohibited. Assuming an average occupant density of seven people per 1000 square feet of office space, these recommended rates are respectively equivalent to 0.14 cfm and 0.035 cfm per square feet of occupied floor area.

Where direct outside air volumes cannot easily be measured, a test of the peak indoor CO_2 concentration can be used as an indirect indicator of the air quality in an occupied space. If CO_2 concentrations exceed 1000 ppm, additional outside air should be provided.

Unless building managers begin to realize that occupant comfort is not simply a matter of maintaining a comfortable indoor air temperature and learn to accept the need for providing a "quality" indoor air environment, complaints of discomfort or even more serious health problems will continue to be reported by affected building occupants. The resulting loss in worker productivity and the likely tenant dissatisfaction with the quality of the office spaces occupied should not be overlooked by conscientious building managers or profit oriented building owners.

REFERENCES

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TABLE 1
Carbon Dioxide Levels
September 25, 1984

LOCATION	SAMPLING TIMES	CONCENTRATION
First Floor:		
-Financial Mgt. Br.	11:35	900 ppm
	11:15 - 4:00	1060 ppm (LTDT)
Second Floor:		
-Revenue Agents Area	10:20 - 1:20	1320 ppm (LTDT)
	1:20 - 4:30	1745 ppm (LTDT)
-Personnel	9:15	1000 ppm
	9:30	1200 ppm
	3:25	2700 ppm
	4:00	3000 ppm
	9:05 - 11:05	2140 ppm (LTDT)
	11:06 - 1:10	2130 ppm (LTDT)
-Special Processing	11:15	2300 ppm
	3:00	2700 ppm
Third Floor:		
-Executive Suites	11:15	2300 ppm
	4:15	2000 ppm

Note: LTDT = as measured with long term detector tube

TABLE 2
Internal Revenue Service
Birmingham, Alabama

Questionnaire Results
September 25, 1985

DEMOGRAPHIC DATA	NUMBER REPORTING(%)		
Total Questioned	1st Floor 12 (100%)	2nd Floor 63 (100%)	3rd Floor 10 (100%)
Non-smoker	7 (58%)	55 (87%)	8 (80%)
Others nearby smoke	7 (58%)	20 (35%)	6 (60%)
Smoker	5 (42%)	8 (13%)	2 (20%)
Allergies	7 (58%)	13 (22%)	4 (40%)
Contact lens wearer	0 (0%)	7 (11%)	2 (20%)
HEALTH COMPLAINTS			
Poor air circulation	8 (67%)	46 (73%)	6 (60%)
Too hot or cold	3 (25%)	36 (57%)	6 (60%)
Dust in Air	1 (8%)	22 (35%)	2 (20%)
Odors	1 (8%)	8 (13%)	1 (10%)
Other complaints	0 (0%)	0 (0%)	1 (10%)
No complaints	4 (33%)	5 (8%)	2 (20%)
SYMPTOMS EXPERIENCED			
Eye irritation	4 (33%)	37 (59%)	3 (30%)
Sinus congestion	6 (50%)	35 (56%)	4 (40%)
Headache	2 (17%)	30 (48%)	6 (60%)
Sneezing	5 (42%)	25 (40%)	1 (10%)
Nose or throat irritation	4 (33%)	25 (40%)	2 (20%)
Runny nose or watery eyes	2 (17%)	25 (40%)	1 (10%)
Fatigue	3 (25%)	17 (27%)	4 (40%)
Skin rash	1 (8%)	10 (16%)	1 (10%)
Cough	0 (0%)	10 (16%)	1 (10%)
Chest tightness	0 (0%)	10 (16%)	1 (10%)
Dizziness	1 (8%)	9 (14%)	0 (0%)
Wheezing	0 (0%)	3 (5%)	1 (10%)
Nausea	0 (0%)	1 (2%)	0 (0%)