PRE-OCCUPANCY INDOOR AIR QUALITY MEASUREMENTS
IN ENERGY-EFFICIENT, CALIFORNIA STATE OFFICE BUILDINGS

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ABSTRACT

During the late 1970s and early 1980s, the State of California designed, built and occupied a series of innovative and state-of-the-art, energy-conserving office buildings. Indoor air quality complaints in the first completed structure led to air quality monitoring in that building and in the remaining structures prior to occupancy. Investigators applied a variety of measurement methods and protocols. Those investigations including air quality measurements and some of their results are described in this paper.

The results of the investigations were used to identify remedial actions where required, and they helped reassure potential occupants with indoor air quality concerns. A "building closeout" procedure was developed and adopted for new state office buildings. The program also increased awareness of the importance of collaboration between design, construction and management personnel in order to achieve acceptable indoor air quality in new buildings.

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INTRODUCTION

While numerous reports of indoor air quality measurements in occupied non-residential buildings have been published, very little has been written about monitoring newly-constructed or renovated buildings prior to occupancy (1,2,3,4). As a practical matter, designers, builders and building owners can obtain little instruction from the published literature regarding procedures for evalutation and conditioning of buildings prior to initial occupancy. This paper reports on some of the State of California's experience in the early 1980s and the current practices which result from that experience.

During the late 1970s and early 1980s, the State of California designed, built and occupied a series of innovative and state-of-the-art, energy-conserving office buildings. Five of these buildings were in Sacramento, and one each in San Jose, Santa Rosa, and Long Beach (see Table 1). These office buildings' designs incorporated numerous energy conservation technologies such as diverse daylighting schemes, several solar shading approaches and devices, energy-efficient electric lighting sources, open and enclosed atriums, and solar domestic hot water systems. These and other design features were intended to enhance indoor environmental quality as well as the buildings' energy efficiency (5).

The eight buildings ranged in size from 8.9 x $10^3 m^2$ to 3.25 x $10^4 m^2$

(96,000 ft^2 to 350,000 ft^2). They were mostly three to four stories in height, primarily open office plans, and they had higher than typical floor-to-ceiling heights for improved daylighting. Their pre-construction projected annual building energy consumption ranged from 433 to 627 MJ/(yr x m^2), (38 to 55 kBTU/(yr x ft^2), approximately half of the typical new office building energy consumption immediately preceeding that period (5). While no systematic evaluation of the actual energy consumption of the buildings has been performed, available data indicate that consumption is at or near the expected range (6).

As a result of complaints in the first of these buildings to be completed, air quality was evaluated in several of the buildings, and standardized procedures were developed for checking out completed buildings before occupancy. This paper reports on three of those evaluations. The monitoring is viewed as an integral part of the process of completing and initially occupying the buildings.

Air quality monitoring.

The first completed structure was the Gregory Bateson State Office Building in Sacramento. As a result of complaints after initial occupancy at the Bateson Building, air quality sampling was undertaken there and in several of the other buildings. The California Department of Occupational Safety and Health (Cal/OSHA) conducted most of the monitoring through its Consultation Service, a non-enforcement arm of the agency which provides advice to building operators as well as industrial and commercial concerns. The Office of the State Architect (OSA) conducted some of the HVAC supply air measurements. Each building and pre-occupancy evaluation was unique, and no standardized monitoring program was employed. The procedures and methods described here represent approaches which may be instructive in similar circumstances.

BATESON BUILDING.

Background.

The Gregory Bateson State Office Building was the pride of the administration of Governor Jerry Brown. It was a hybrid active-passive solar design, energy conserving building. Its low-rise configuration, central atrium, operable windows, balconies, and many other features were intended to create an extraordinarily habitable environment. Its plan and urban setting were intended to begin the revitalization of much of downtown Sacramento.

At the well-publicized dedication ceremony in May, 1981, Brown invoked the late Bateson's thought and declared that the building was consistent with Bateson's philosophy and values. The Governor declared its environment a healthy, pollution-free one. Even as he spoke, fumes from the sealer used on the paving in the atrium were noticeable in the air; and, some of the early occupants were considering what to do about the carpet and furniture fumes in their offices.

Premature-occupancy problems.

Many of the early occupants complained about poor indoor air quality. Much media, state government, and occupant attention was focused on energy conservation as a causal factor. In fact, many of the problems occurred because the building was occupied prematurely - before its environmental control systems were fully operational, balanced and tested. Some of the building's innovative design features were not fully functioning for as long as a year after the initial occupancy. Defective hardware and incorrect installation of controls in the building's heating, ventilating, and air-conditioning (HVAC) variable air volume (VAV) system resulted in valid air quality complaints, and many occupants expressed concern about what might be in the air. The press focused public and governmental attention on the problems, and the attendant publicity heightened occupant fear and tension.

HVAC problems.

Complaints diminished during the fall of 1981. As time passed, the change of seasons and the progressive completion and initiation of more of the HVAC, shading/sun control and daylighting system components resulted in new and different complaints. Almost a year after initial occupancy, an ad hoc group reviewed the building's history and discovered that a number of the original design features were altered or non-operational for budgetary or other reasons.

Improper installation or faulty HVAC hardware was implicated in many of the complaints. The faulty devices included thermostats and sensors which controlled the variable air volume system operation and the installation of the sensors and controls. Roughly 80% of the variable air volume control boxes were broken, either by occupants who tampered with them in order to obtain more ventilation, or otherwise. Much of the evidence came from ventilation system inspection and supply volume measurements rather than from air quality sampling (7). Eventually the building systems were completed and put into operation, and the complaint level subsided to a normal rate.

Air quality monitoring.

There were several rounds of testing conducted in the building. Measurements were made of air concentrations of formaldehyde, carbon monoxide, carbon dioxide, oxygen, total hydrocarbons, polynuclear aromatic hydrocarbons, total dust, respirable particles, and radon. Interviews with selected building occupants and research into the potential causes of the complaints were also conducted. State of California health department and Cal/OSHA staff conducted the work (8,9,10,11).

In 1984, a reported case of Legionnaire's Disease affecting one of the building's occupants caused concern about the rock bed thermal storage system, one of the building's dramatic, albeit, not publicly-visible, energy-conservation technologies. Air samples were negative for B. legionella pneumophilia.

Most of the air quality measurements were made using established industrial hygiene sampling and analytical methods. The equipment, knowledge, methods and standards normally used in industrial settings were applied. The absence of applicable indoor air quality standards and sampling methods influenced the results and the conclusions drawn from them.

Monitoring results.

Reports filed by the industrial hygienists did not identify significant contamination problems. The measured concentrations were generally far below prevailing occupational limits and reportedly consistent with the range of Cal/OSHA measurements in other office buildings. In accordance with its legislative authority and usual industrial hygiene practice, the levels used for comparison by Cal/OSHA were those developed for use in industrial settings.

Air flow measurements at the supply air registers revealed that ventilation system performance did not meet specifications in some areas. In one case, reverse flow was measured at -2.8 L/s (-5.9 CFM) per person "average fresh air" for an area allocated to 171 people. Another area for 96 people received a measured average flow of 1.8 L/s (3.9 CFM) per person. Other levels ranged from 4.5 to 18.4 L/s (9.6 to 39.0 CFM) per person. The building totals were 7.3 L/s (15.4 CFM) per person for 1224 occupants.

Discussion.

The results of air quality monitoring did not indicate the presence of air contamination at levels above legal limits nor at levels known to cause irritation and health effects. However, ventilation system measurements revealing the absence of adequate supply air and even negative flows at some of the air distribution registers did indicate potential air quality problems.

It is worth noting that only two of the eight measured HVAC supply volumes indicated deficiencies. Total building measurements or calculations were not adequate to pinpoint the faulty areas. It is also significant that several rounds of air quality measurements did not identify problems, even though outside air supply volumes were inadequate in some locations.

These findings were suprising to building operators. The HVAC measurement results supported some occupants' complaints and were important in focusing attention on the need for remedial work. Ultimately, a large number of defective VAV components were identified and corrected.

One of the building's designers suggested that the HVAC problems stemmed from a change in the occupancy pattern. The original design intent was for an open space office environment for the anticipated tenant agency. But different government agencies occupied the building, and many of them required private office spaces, at least for some of their personnel. Thus, the balancing and control of the HVAC system became difficult with the originally designed system (7).

Perhaps the greatest benefit of the efforts to resolve problems encountered at the Bateson Building was the heightened governmental, public and design professionals awareness of the potential for indoor air quality problems in new office buildings. For many people, the Bateson Building became synonymous with indoor pollution. While this reputation may have been undeserved, it served to provide the press with a recognizable handle for stories on the elusive issues of indoor air quality which surfaced elsehwere.

Attention focused on air quality problems at the Bateson Building served to motivate state government to develop procedures to provide air quality assurance prior to occupancy. The protracted dealings with employee concerns at the Bateson Building taught state officials that the cost of indoor air quality problems was high in terms of the time and effort required to ameliorate building system problems and occupant concerns. Additionally, there were significant technical and economic burdens attendant to remedial activities. Thus, a more aware and dedicated Office of the State Architect and Department of General Services initiated a more formal process of pre-occupancy evalution for the remaining buildings.

STATE OFFICE BUILDING, LONG BEACH.

Background.

The California Veterans Memorial State Office Building, Long Beach, (CVMSOB) was the subject of an extensive sampling program. Because of the unavailability of Cal/OSHA personnel to do the work and the presence of a potentially significant air contamination problem, researchers from the Center for Environmental Design Research, University of California, Berkeley, were contracted to develop and implement a sampling program. The program was intended to explore the impact of major components of the building and its contents on indoor air quality. It was hoped that the process would result in improved understanding of the general issues related to indoor air quality in office buildings. However, due to the nature and magnitude of the contamination problems, much of the effort was focused away from the general objectives.

The building consisted of 14,500 m^2 of conditioned floor area on four floors. The building's office spaces were served by eight separate, roof-mounted HVAC systems. The interior spaces were primarily open office environments, as per the design intent. However, many private offices were installed, as in the Bateson Building, contrary to the original program and building design.

Pentachlorophenol contamination.

In the Fall, 1981, the Office of the State Architect was advised by a manufacturer of pentachlorophenol (PCP) that the extensive PCP use as a wood preservative on structural beams and columns partly inside the building might cause comfort or health problems for occupants. As a result, PCP monitoring was conducted during the initial sample collection period. The levels detected (mean = 0.027 mg/m^3) were deemed unacceptable. Repeat sampling confirmed the earlier findings. Remedial work was conducted including sealing exposed portions of PCP-treated wood on the interior of the building and improving HVAC performance. Considerable sampling for PCP was done in conjunction with the remedial work (12, 13).

Sampling Program.

Three sampling rounds were originally planned:

1) after carpet installation, before ventilation system operation;

2) pre-occupancy, with operation of the HVAC; and,

3) after occupancy.

Ultimately, several additional rounds were conducted in connection with the PCP investigation and remedial activities.

Certain building materials were investigated, particularly the free-standing partitions, carpet, and carpet adhesives, to assess their potential impact on indoor air quality. The selected materials were investigated due to widespread concern regarding the formaldehyde and other volatile organic chemical (VOC) content of many partition and carpet system components.

Air sampling was conducted for various substances including total hydrocarbons, carbon monoxide, carbon dioxide, nitrous oxides, formaldehyde, total oxidants, total suspended particles, and total respirable particles. Results and methods are summarized in Table 2.

Results

Air levels of all monitored substances were below established TLVs and NAAQS levels (see Table ?). Formaldehyde concentrations measured during the pre-occupancy and post-occupancy sampling did exceed 80 ppb in at least one location. The estimated air exchange rate at the times samples were collected was toward the upper end of the range of normal operation. It was considered probable that under minimal outside air supply and VAV conditions, formaldehyde concentrations might exceed 0.1 ppm. However, no measurement confirmed this.

Bulk sampling of building materials was also done during the pre-occupancy period. No standards were available for comparison. The results were obtained to provide baseline information for possible subsequent work.

PCP results were also well below the TLV of 0.5 mg/m^3 during all sampling periods. However, health officials had advised that the levels found (0.03 mg/m^3) during pre-occupancy sampling might result in discomfort and health effects. Post-remedial PCP levels were <0.01 mg/m^3.

Discussion

None of the substances measured except PCP provided indications that indoor air quality problems might exist. Yet ventilation system data clearly indicated the potential for discomfort, irritation, and adverse health effects.

Monitoring for pentachlorophenol was repeated at various times. That work occasioned numerous additional sample collection days. A by-product of the intensified sampling program was an unexpected understanding of the role of various key actors and building components in the installation and commissioning of the ventilation system. In effect, pentachlorophenol served as a tracer gas, and much of the PCP sampling data indicated poor ventilation system performance. Unexpected deficiencies in the HVAC system design, installation and operation were found and corrected as a by-product of the PCP remedial work.

In conducting the PCP sampling, the building HVAC system was operated under various protocols. This was done, among other reasons, to simulate worst case and various typical conditions of building ventilation. The discovery of defective ventilation system performance led to greater concern about the ability of the system to meet design specifications under the various protocols. During the extensive testing, the ventilation systems' inability to respond properly to operator control was detected, and control system deficiencies were corrected.

Investigation of airflows in and out of the "package HVAC units" on the roof was conducted because entrainment of exhaust air in the supply air stream was suspected. The configuration of the units on the roof was such that exhaust from several units could easily be entrained in the supply of adjacent units under prevailing wind conditions. Smoke tube tests validated this concern, and modifications were made to direct exhaust air away from adjacent intakes.

Intake control vanes in the units were also identified as a source of problems due to their ability to close entirely under minimum outside air conditions. Therefore, they were adjusted so that a portion of each set would always remain open, thereby guaranteeing that a minimum quantity of outside air would be supplied to the building at any time.

In summary, apart from the PCP contamination, many of the potential indoor air quality problems would not have been found by air testing alone. Inspection and measurement of HVAC units and components was more fruitful in pre-occupancy evaluation. The unintended "tracer gas" functionof the PCP measurements was also useful.

CALIFORNIA ENERGY COMMISSION BUILDING, SACRAMENTO.

Background.

The California Energy Commission (CEC) Building, across the street from the Bateson Building in Sacramento, was scheduled for completion and occupancy in mid-1982. Staff at the Energy Commission were particularly aware of the indoor air quality problems at the Bateson Building and in new office buildings elsewhere through their work on building energy conservation standards. Opposition to the adoption of residential building standards focused Commission and staff work on indoor air quality problems in houses. And staff work on non-residential standards development and environmental impact assessment required considerable investigation of indoor air quality problems related to energy conservation measures. A request was made for Cal/OSHA investigation and for scheduling occupancy "....after building construction is completed, so that building materials have had an opportunity to off-gas volatile consitituents, and after the HVAC system is completely installed, checked and balanced" (14).

A comprehensive protocol for ventilation testing and monitoring indoor air quality at the CEC Building was proposed by Thomas J. Phillips, of the CEC's Environmental and Siting Office staff (15). That protocol was not followed by Cal/OSHA staff. However, it is summarized here as Tables 3 and 4 because it represents an early and still valuable effort to formulate a pre-occupancy evaluation scheme.

<u>Air quality monitoring</u>.

Sampling was conducted by Cal/OSHA. Samples were collected and analyzed for formaldehyde, CO, CO_2, and volatile hydrocarbons. A sample of the air supply registers were checked for air flow. The evaluation included the following:

a) Initial walk around to determine sources of possibly harmful materials which could be released into building air;

b) Air samples in various locations in the building, representative of areas of high occupancy density, to determine levels of harmful materials in building air;

c) Spot-check of HVAC register balance to assure system balance according to design specifications (16).

Results.

The results were reported as no "significantly elevated levels of contaminants." One supply air register out of 27 checked was more than 10% below design specifications. During the visit, one of the two major mechanical systems was not operating, but was subsequently repaired.

Discussion.

Early occupancy problems included complaints of cigarette smoke and of odors eventually traced to the caulking used at glazed openings. The findings of the pre-occupancy evaluation were not particularly useful in identifying these problems in advance. Initial occupancy changed the nature of the air quality, the contaminant loading, and the load on the HVAC system. More thorough evaluation of the HVAC system might have been more productive than the air quality monitoring that was done.

BUILDING CLOSE-OUT PROCEDURE.

The Office of the State Architect (OSA) initiated development of a standard process of "closing out" a building, from the design standpoint. In 1984, that process resulted in the issuance of guidelines, attached as Appendix 1. Key features of those guidelines are a thorough inspection of the ventilation system, balancing, bake-out, and air quality monitoring (17).

SUMMARY.

The comparability of results among buildings was limited by the inconsistency in investigatory protocols; by the timing of the measurements in relation to the building completion and furnishing process as well as seasonal variations; and, by the lack of standardization in the operation of ventilatiion systems in the various buidings. Nonetheless, the results for most of the measured parameters in all three buildings are generally consistent. Thus, the variations identified above either combine to cancel each other out, the testing is not sensitive or accurate enough to detect differences, or other factors produce the apparent consistency. This suggests that the various designs employed do not produce significant differences in the air quality parameters studied.

The acquisition of data on the several buildings facilitated comparisons which provided an improved context for evaluation of the measurement results. Since very little had been published on measurements in new office buildings at the time, and virtually no data was available on pre-occupancy measurements, the data base developed in the various buildings began to serve as a baseline for comparison of subsequent measurements.

Measured air supply volumes varied from design volumes in many locations and on many locations. These differences appeared to be more significant than air pollutant levels. In all three of the buildings described above, deficiencies in ventilation system operation were discovered as a result of the indoor air quality concerns. It is likely that many buildings are completed without proper or complete air balancing, and the early occupancy period serves as a "shakedown" period.

Of particular note were the thermostat and VAV box problems experienced at Long Beach and Bateson. Additionally, some of the design flaws at Long Beach included potential re-entrainment of exhaust air including both toilet and office area exhaust entrainment in office area supply air intakes. Modifications of the intake air damper systems at Long Beach were also necessary to assure minimal quantities of outside air under all operational conditions. Yet these changes would not have been made prior to occupancy without the pre-occupancy evaluations beyond the usual air balance work of the mechancial contractor.

The results of the investigations identified remedial work where it was required, where the normal building closeout procedures do not. And, perhaps of equal importance, they helped provide reassurance to potential occupants with indoor air quality concerns.

CONCLUSIONS

1. Pre-occupancy air quality evaluations can be difficult and not definitive if the subject buildings' HVAC systems are not properly operating and balanced at the time of evaluation.

2. During pre-occupancy monitoring (and perhaps later) ventilation system inspection and performance measurements can be more useful than air quality measurements in determining the potential acceptability of indoor air quality to occupants.

3. Pre-occupancy monitoring can be effective in identifying construction flaws which are not easily identifiable using traditional construction inspection methods.

4. Air sampling prior to occupancy of newly completed buildings can provide a preliminary screening only if the following conditions are met:

a.) Proper operation of HVAC system under the operational protocol(s) in effect at the time(s) of the sampling.

b.) Ventilation system supply volumes are within acceptable limits of design and normal operational parameters.

c.) Air distribution is reasonably similar to that which will occur in the furnished and occupied structure.

d.) Thermal control is within design limits.

5. Post-occupancy evaluation (POE) air quality monitoring is useful in following up on problems or potential problems identified during the pre-occupancy monitoring or through complaints of occupants. POE can examine the impacts of occupant activities on building system operation and performance.

APPENDIX A: BUILDING CLOSEOUT PROCEDURE (16)

The following criteria should be taken into consideration when testing and analyzing the indoor air quality in new buildings:

1. Scheduling of testing shall be coordinated with the contractor, Office of the State Architect (OSA) and Cal/Osha. The coordination of all testing in the field shall be done by the construction inspector assigned to the project with prior approval of the OSA project manager. The procedures and the equipment to used shall be reviewed by the project manager to insure that the testing will not void any warranties or infringe on contracts between contractors and the State. The testing procedures must be designed to operate within the physical limitations of the building's equipment.

2. The criteria used for air quality sampling to evaluate the building should be set up by Cal/Osha only. The quantity testing will be done by using OSA and industry standard methods.

3. When attempting to "bake off" or raise the internal temperature to an abnormal degree in a new building in order to stimulate off-gassing of the various materials within the building, consideration must be given to the design of the HVAC systems which include the internal heat loads of people, lights, and equipment to supplement loads provided by the mechanical equipment. When performing the subject test, the buildings must be fully illuminated and other systems should be operating, where feasible, to raise the temperature as high as possible. The required to raise or lower temperatures m;ust be established and accounted for in the scheduling of the

process. In addition, the cost of utility services (gas and electric) to accomplish the testing and the method of payment must be established.

4. Adequate time to conduct the tests must be allowed. When a building nears completion, the pressures to install tenant materials and equipment and to move in the building must be resisted to permit proper testing. A period of approximately 30 days should be allowed to complete proper testing.

5. Any chemical additives to be used routinely in the operation of HVAC equipment, should be sent to Cal/Osha for review and recommendation before additives are used.

A typical building test procedure is as follows:

1. HVAC and electrical systems are inspected to determine that:

a) HVAC system has been finaled as per contract.

b) HVAC system has been balanced completely as per contract specifications.

c) Electrical and energy systems have been finaled as per contract.

2. Building interior shall be cleaned and is free of standing water before testing.

3. Movable screens, furniture and other fixtures shall be installed prior to test (if included in project).

4. Set the HVAC system to operate at maximum heat mode for 12 to 24 hours with full illumination. Time required to heat structural mass may be more than 24 hours.

5. Set the HVAC system to operate at normal operation mode for 12 to 24 hours after a predetermined temperature has been reached.

6 Set the HVAC system to operate at maximum heat mode for 12 to 24 hours

with full illumination after a predetermined temperature has been reached.

7. Set the HVAC system to operate at normal mode for 24 hours minimum after a predetermined temperature has been reached.

8. Set up air sampling devices according to Cal/Osha criteria.

9. Take air quantity tests on HVAC system as directed by Cal/Osha with all systems on full cool in order to read maximum air flow as per industry standards.

10. Cal/Osha forward all test results to OSA.

11. Take concurrent tests of external atmospheric air in order to make comparisons.

Each project varies in its schedule and complexity. The above procedure should serve as a minimum guide and be modified, as required, to produce the most reliable test for each situation.

References

(1) National Academy of Sciences, Indoor Pollutants, National Academy Press, Washington, D.C., 1981.

(2) Berglund, B., T Lindvall, J Sundell, eds., Indoor Air, Volumes 1-5: Proceedings of the 3rd International Conference on Indoor Air Quality and Climate, Stockholm, Sweden; August 20-24, 1984.

(3) Meyer, B. 1983. Indoor Air Quality. Reading, Massachusetts: Addison-Wesley.

(4) Wadden, RA and PA Scheff, 1983. Indoor Air Pollution: Characterization, Prediction, and Control. New York: John Wiley & Sons.

(5) Davis, S., "Designing for Energy Efficiency: A Study of Eight California State Office Buildings", Department of Architecture, University of California, Berkeley, California, 1981.

(6) Levin, H. and Wasserman, B., Proceedings, Research and Design '85, American Institute of Architects, Washington, D.C. pp. 261-265.

(7) Matthews, S. Memo to B. Wasserman, State Architect, April 14, 1982.

(8) Seabury, J. Memo to B. Wasserman, State Architect, May 29, 1981.

(9) Diamond, P., Memo to R. Johnson, Department of Health Services, July 24 1981.

(10) Wesolowski, J. Memo to B. Myers et al, Department of Health Services, April 22, 1982.

(11) Seabury, J. Memo to D. Janssen, Department of General Services, May 13, 1982.

(12) Levin, H., Reserch and Design '85; General Proceedings, Washington, D.C.: American Institute of Architects, 1985, 375-382.

(13) Levin, H., and J. Hahn, Environment International, Volume 12, 1986, pp. 333-341.

(14) Geesman, J., California Energy Commission, Memo to E. Jones, Cal/OSHA Consultation Service Chief, July 1, 1982.

(15) Phillips, T., California Energy Commission, Memo to N. Wilson, California Energy Commission, August 20, 1982.

(16) Seabury, J., Cal/OSHA Consultation Service, Memo to C. Grimes, Deputy State Architect, November 16, 1982.

(17) Hansen, J., Deputy State Architect, Memo, "Building Closeout Procedure," to A/E Supervisors, Consultant Services Supervisor, Sacramento, April 11, 1984.

Table 1. California State Energy Efficient Office Buildings

Designation	Name/Agency	Location
Site 1A	Bateson Building	Sacramento
Site 1B	California Energy Commission	Sacramento
Site 2	Water Resources	Sacramento
Site 3	Employment Development Department	Sacramento
	Justice Department	Sacramento
Santa Rosa		Santa Rosa
San Jose	Aflfred Alquist Building	San Jose
Long Beach	California Veterans Memorial State Office Building	Long Beach

Table 2. Air quality monitoring at Long Beach

Material/substance	Method: Collection/Analysis	#	Results: Range	Mean	Units
02/19/82 NO VENTILATION	T = 14.4-25.0 C	RH = 47-54%			
Indoor air/PCP	Ethylene glycol/GC-ECD	6	15.1-50.0	30.7	ug/m^3
Wood beam/PCP	Bulk extract/GC-ECD	1	1870		ppm
Carpet/Formaldehyde	Bulk extract/GC-MS	1	<1.49		ppm
Indoor air/VOCs	Charcoal tubes/GC-MS	2	7.03-8.41		mg/m^3
Carpet/chlor'd Hydrocarbons	Bulk/GC-MS	1	1.08		ppm
Carpet/total hydrocarbons	Bulk/GC-MS	1	<10		ppm
C. adhesive/THC	Bulk/GC-MS	1	7450		ppm
06/04/82 HVAC ON	T = 23.3-27.2 C.	RH = 51-58%			
Indoor air/PCP	Ethylene glycol/GC-ECD	6	7.1-44.5	27.2	ug/m^3
IA/organic vapors	Charcoal tubes/GC-MS	3	0.69-0.78	0.73	ppm
IA/formaldehyde	NIOSH P&CAM 125	7	13.1-85.3	61	ppb
IA/carbon monoxide	Direct/FID	9	0		
IA/carbon dioxide	Direct/FID	9	384-518	443	ppm
IA/NO_x	Direct/	9	22-29	24	ppb
IA/particulates	High volume/gravimetric	2	29.4-37.4		ppb
IA/Oxidants	Direct/FID	7	6.5-15.6	10.0	ppb
IA/Non methane HC	Direct/GC-FID	9	1.73		ppm
02/07/83 HVAC ON	T = 20.5 - 24.4 C.	RH = 52 - 59%			
Indoor air/PCP	Ethylene glycol/GC-ECD	6	7.1-44.5	27.2	ug/m^3
IA/THC	Charcoal tubes/GC-MS	3	0.24-1.66	1.28	ppm
IA/formaldehyde	NIOSH P&CAM 125	7	10-81	32	ppb
IA/carbon monoxide	Grab/colorimetric	7	0-3	0.86	ppm
IA/carbon dioxide	Grab/colorimetric	7	300-600	440	ppm
IA/particulates	High volume/gravimetric	1	25.75		ppb
IA/NO_x	Grab/colorimetric	7	20-60	36	ppb

Table 3. Ventilation testing at Site 1B (15).

Test	Approach	Frequency/Duration
Zone Ventilation Index	Duct temperature measurements and calculations	Once each for heating and cooling modes, before and after occupancy.
Air Mixing	Smoke sticks, temperature measurements; tracer gas measurements.	Pre-occupancy: once each for heating and cooling modes when initial balancing occurs after partitions are installed.

Table 4. Indoor air quality monitoring at site 1B (15)

Radon daughters	Long term integration	40-hr. work week, time-weighted ave.
Formaldehyde	Short-term peak measurement	Every 3, 8, and 24 hours for 1 week.
Organics	Long term integration, identify 15 most abundant compounds	40 hour work week, time weighted ave.
Carbon monoxide	Short term peak and long term integration	" "
Carbon dioxide	" "	" "
Respirable particulate matter, fibers, and PAH	Short term peak and long-term integration	" "
Supporting information		
Temperature		
Relative humidity		
Ventilation: air flow rates and air mixing (see Table 3)		