COMMERCIAL BUILDING VENTILATION RATES AND PARTICLE CONCENTRATIONS

B.H., Turk, D.T., Grimsrud, J.T., Brown, K.L., Geisling-Sobotka, J., Harrison, R.J., Prill
Indoor Environment Program, Lawrence Berkeley Laboratory, Berkeley, CA 94720, USA

Abstract

Ventilation rates have been measured in 38 commercial buildings that represent a variety of use types, sizes, ages, and mechanical system configurations. A single tracer (SF_6) test was conducted once at 36 buildings over a two to four hour period based on mechanical system operation for a prior two-week period. Two buildings were tested a second time under different environmental conditions. Whole building ventilation rates ranged from 0.3 ach to 4.2 ach for the 40 building measurements with an average value of 1.5 ach. Several pollutants were also monitored in the buildings for 10-day periods during working hours. Respirable suspended particles was the pollutant group that most frequently approached or exceeded elevated levels and was usually associated with local tobacco smoking.

Introduction

In the relatively short period of time since the issue of air quality inside non-industrial structures has become a concern, most exposure studies have focussed on the indoor residential environment (3, 6-8). Yet for employed men and women, 23-32% of their time is spent in non-residential indoor locations (4), including places of business, restaurants, and places of employment. The same percentage may also be appropriate for children of school age. Although the atmosphere in the industrial workplace may be monitored and regulated, commercial and institutional buildings (offices and educational facilities) generally are not.

In 1981 the Pacific Northwest Power Planning and Conservation Act authorized the Bonneville Power Administration (BPA) to undertake cost effective conservation programs to help meet the BPA load obligations. These program measures may include recommendations for reductions in infiltration and the mechanical ventilation rate in commercial and institutional buildings. Since little is known about existing ventilation rates and pollutant concentrations in commercial buildings, this study was undertaken to provide information to BPA about existing indoor environmental conditions in commercial and institutional buildings in the Pacific Northwest. Specific study objectives were:

1) Characterize a variety of indoor pollutant concentrations and ventilation rates in 38 commercial and institutional buildings in the Pacific Northwest. Buildings were to be selected to represent existing stock and not necessarily exhibit symptoms of poor air quality.

2) If possible, demonstrate relationships between observed indoor pollutant levels and ventilation rates.

Study Design

Study sample

Thirty-eight buildings were selected for participation in this study to represent a sample of the ages, uses, sizes, and ventilation characteristics of Pacific Northwest Buildings. None was selected because of previous indications of air quality problems or complaints. Two of the buildings were monitored a second time under different seasonal conditions for a total of 40 building measurements.

The sample was equally divided between two distinct climate zones: the moderate Pacific Northwest coastal region that includes Portland and Salem, Oregon; and the more extreme climate of the continentally-influenced inland region that includes Spokane and Cheney, Washington. Winter condition measurements were made in 14 Portland-Salem buildings and in seven Spokane-Cheney buildings. Six Portland-Salem buildings and four Spokane buildings were monitored during spring conditions, while the remaining nine buildings were measured during the summer in Spokane.

Buildings ranged in size from 860 to 34,300 m^2; in age from 0.5 to 90 years; in occupancy from 34 to 2500 persons; and in HVAC systems from 0 (natural ventilation) to 32 air handlers. During the project 1,700,000 person-hours of monitoring were accrued.

Pollutants monitored

Formaldehyde, water vapor, radon, nitrogen dioxide, respirable suspended particles (RSP), polycylic aromatic hydrocarbons, carbon dioxide, and carbon monoxide were measured in each building during periods that the buildings were occupied. This discussion is restricted to measurements of RSP.

Respirable suspended particles were collected on an in-line one-micron 37-mm diameter teflon filter after passing through a Dorr-Oliver 10-mm nylon cyclone with a size-segregating cut point of 3 microns. Sample air through the system was maintained at 1.7 LPM independent of filter particle loading up to 12,500 Pa pressure drop. Air flow through the filters continued during occupied hours and was stopped when the building was vacated. The combined weight of particles on all filters from a site was used to determine the average RSP concentration for that site.

Measurement protocol

Each building was monitored for approximately 10 working days over a two-week period during occupied hours. The minimum sampling time of 75 hours was chosen to give adequate detection sensitivity for the formaldehyde passive sampler. Three to twenty inside sampling locations were chosen (based on the size of the building) to include a distribution of various ventilation conditions, floor heights, structural configurations, occupant activities, and proximity to observed pollutant sources. Smoking sites were defined arbitrarily as areas where at least one person smoked tobacco products within a 10-m radius of the sample location. Site selection was intended to represent common building environments. In buildings with a restrictive smoking policy, an RSP sampling system was placed in the major smoking area, usually a cafeteria or designated lounge space. It is important to note that because of limitations on available instrumentation, sample site locations were not randomly selected. Therefore, results presented are not true spatial averages but rather means of all variously-grouped samplers.

Ventilation measurements were made using a tracer gas decay technique with SF_6 as the tracer gas. The protocol is similar to the procedures described in ASTM E741-83 (2) and used by Persily and Grot (5), and others for measuring total ventilation rates in buildings. A gas chromatograph (GC) with an electron capture detector (ECD) was placed at a location central to the building. Small diameter (1.6mm ID) polyethylene tube lines were run from three to nine locations that, when practical, coincided with pollutant sampling sites. To seed SF_6 into the building, the outside air dampers were closed while the air handling system continued to recirculate interior air. A known amount of SF_6 was slowly metered into each of the mixed air chamber(s) and distributed throughout the building by the supply fan to achieve a building target concentration of approximately 1000 ppb.

The ventilation systems were operated at 100% recirculation for 30 to 90 minutes after tracer injection to achieve admixing. In buildings with little or no mechanical ventilation, windows were closed while the pure SF_6 was manually distributed through the interior space. Good mixing of the SF_6 was assumed when concentrations at the sampling sites in the building were within 10% of one another. Unfortunately, in buildings with more than two mechanical ventilation systems, the SF_6 injection system was inadequate to easily achieve and maintain uniform mixing. Once the space was determined to be well-mixed, the outside air dampers were opened to a position that was typical of conditions during the pollutant monitoring period (during the monitoring period technicians had recorded the outside air damper positions twice daily). Building air was then pulled by a pump through the sample tubes to the GC/ECD where a valve under microprocessor control sequentially selected sample tubes at one minute intervals. As the outside air diluted the SF_6 in the building, the GC/ECD analyzed samples containing constantly declining concentrations and recorded this data on a strip chart.

Measurement Results

Ventilation values

The arithmetic mean for all 40 air exchange measurements is 1.5 ach while the median is 1.3 ach. Building average values ranged from 0.3 to 4.1 ach. A comparison of measured whole building L/s-occupant values with those present in the ASHRAE ventilation standard 62-1981 (1) showed that five buildings of the 40 measurement sets are at or below the recommendation for ventilation when smoking is present. On the other hand, most buildings have values that are considerably above the values recommended in 62-81.

Ventilation rates are classified by building type in Figure 1. The results show a reasonable consistency throughout building types. The error bars define the range of values observed for particular buildings with the building average shown. The curly brackets give the average of each building type; the standard error or standard deviation of the mean value is given by the width of the bracket. The points along the left vertical axis give the average values of the measurements taken in the various seasons of the year. The uniformity of results is surprising as is the magnitude of the ventilation values displayed. This group of buildings is overventilated in most cases.

Particle concentrations

Within the sample of 40 building tests, the range of building average RSP values ranged from below detection limits to 67 $\mu g/m^3$ with an arithmetic mean of 31 $\mu g/m^3$ and a geometric mean of 27 $\mu g/m^3$. Fitting a lognormal distribution to a histogram of measured values allows us to estimate that 7% of the sites in a similar sample of buildings would exceed the NAAQS of 75 $\mu g/m^3$ for total suspended particles (TSP). Since RSP is only a fraction of the TSP burden, this is a conservative estimate of the number of sites with a problem related to RSP. For comparison, the California standard for PM_{10}, i.e., particles less than 10 μm in diameter is 30$\mu g/m^3$. Values from this study suggest that 32% of the values in this survey of RSP exceed the CA PM_{10} standard. Note that if just smoking sites are considered, 25% of the values exceed the TSP NAAQS value of 75 $\mu g/m^3$.

Figure 2 is a histogram of measurement results at individual sites separated into smoking, non-smoking, and outside locations. Geometric means and geometric standard deviations for each group of sites are given in Figure 2 as well.

Comparison of RSP concentrations and building ventilation rates show that a correlation between RSP concentrations and ventilation rates is non-existent in this study

sample. Building RSP concentrations are dominated by local sources rather than ventilation processes.

Discussion and Summary

Respirable suspended particles was the pollutant class monitored in this study that most often exceeded conservatively recognized guidelines. Most of these occurrences were related to local tobacco smoking. Building mean RSP ranged up to 67 $\mu g/m^3$ with one smoking site reaching 308 $\mu g/m^3$. We estimate that 25% of smoking sites in a similar sample would have smoking sites whose concentrations exceed the 75 $\mu g/m^3$ annual average concentration for outdoor TSP under the National Ambient Air Quality Standards.

The one-time ventilation measurements from all buildings average 1.5 ach and ranged from a low of 0.3 to 4.1 ach. Buildings with low ventilation rates were not usually associated with indoor air quality problems, although local ventilation may fall below ASHRAE recommendations of 2.5 L/s-occupant in non-smoking areas and 10 L/s-occupant in smoking areas.

Acknowledgments

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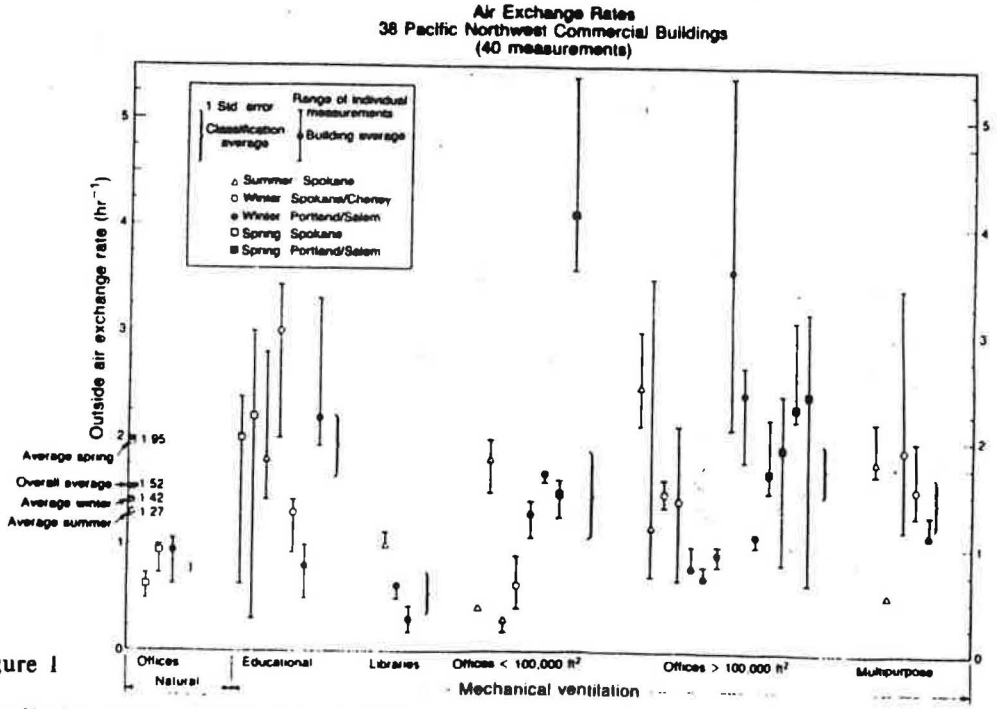

Figure 1

Ventilation rates classified by building type. Buildings with natural ventilation are grouped at the left portion of the figure. The vertical line for each building defines the range of values observed for particular buildings with the building average shown. The curly brackets give the average of each building type; the standard error or standard deviation of the mean is given by the width of the bracket. The points along the left vertical axis give the average values of the measurements taken in the various seasons of the year.

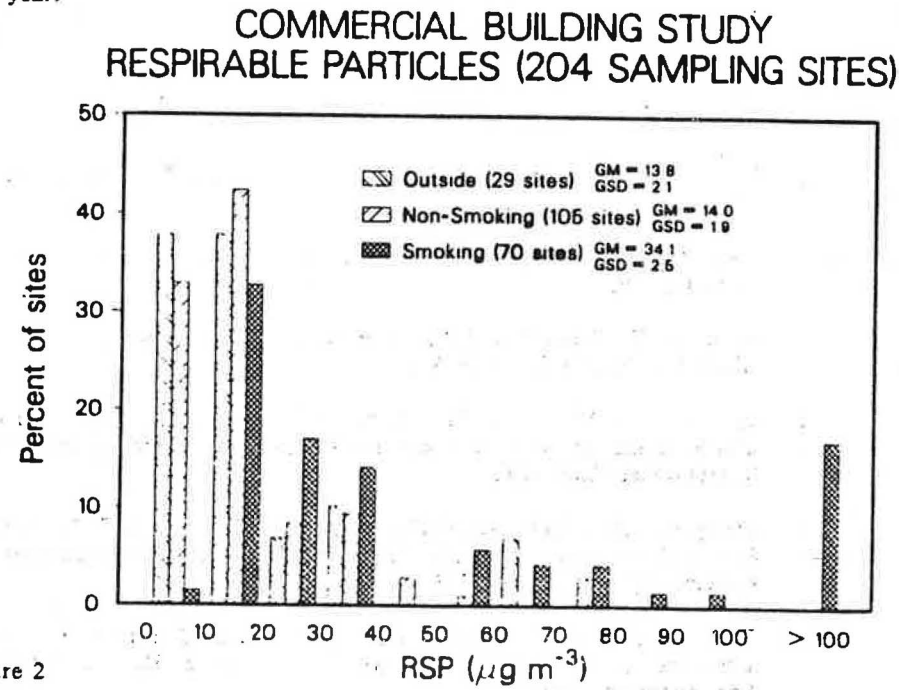

Figure 2

Measurement results at individual sites separated into smoking, non-smoking, and outside locations.