VENTILATION REQUIREMENTS IN A RETAIL STORE

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ABSTRACT

This field study was organized to determine the ventilation required to maintain acceptable air quality in a retail store using the ASHRAE Standard 62-1989 performance-based procedure. Pollutant concentrations and ventilation rates were measured in a large retail store during four one-week intervals. The measurement intervals were each separated by three months to allow different weather conditions and mixes of retail stock to be present over the one-year field study in a cold continental climate. Pollutants monitored were formaldehyde, carbon dioxide, carbon monoxide, particle size distributions and concentrations, and selected and total volatile organic compounds. Environmental parameters monitored were indoor and outdoor temperatures, pressure differentials, relative humidities, and ventilation rates (duct flows [L/s] and tracer gas [SF_6] measurements). Total volatile organic compounds was the pollutant class that required the highest ventilation rate to control its concentration. Nonetheless, this rate (0.5 L/s-m^2) is less than those specified in the prescriptive portion of ASHRAE 62-1989 for retail spaces (1.5 L/s-m^2). Unusually high pollutant concentrations were observed for short periods and corresponded with cleaning and maintenance activities.

INTRODUCTION

Both the designer and building owner are concerned about choosing the proper amount of outdoor ventilation air to supply in a building. This is an important issue for the designer who must specify equipment that can supply the proper ventilation required by code. The owner is concerned because the cost of conditioning and moving ventilation air can be a substantial fraction of the total energy cost of the building.

The basis for most ventilation requirements in building codes in the United States is a set of ventilation standards published by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE). This series, designated Standard 62, has been updated about once each decade.

For some building types and uses, Standard 62-1989 [1] uses substantially higher ventilation rates than those contained in the previous version, Standard 62-1981. This is the case for retail spaces. The ventilation rate prescribed in the standard for retail spaces increased from 0.75 L/s-m^2 to 1.5 L/s-m^2 on basement and street level sales floors. The increase is the result of committee judgment about the strength of pollutant sources in retail spaces. The rate chosen is not based on occupant density, the dominant pollutant source for most building types in Standard 62-1989.

This paper describes measurements performed and discusses results obtained from an investigation of the ventilation and indoor air quality performance in an 8700 m^2 retail store located in Stillwater, Minnesota.

The authors employed the performance-based procedure that exists in Standard 62-1989 to examine spaces in which unusually strong or weak pollutant sources exist. This 'performance-based' method, called the indoor air quality (IAQ) procedure, allows a building owner to demonstrate compliance with the standard through field measurements of pollutant concentrations rather than 'prescriptive' ventilation rates. The IAQ procedure included analysis of pollutant and ventilation measurements taken over an entire year to include seasonal changes in weather and in types of products sold in the store.

METHODS

Measurement Strategy

The Standard 62-1989 IAQ procedure calls for measurements of all critical pollutants in order to assure appropriate indoor air quality at a modified ventilation rate. Measurements performed in the retail store were based on discussions with industrial hygienists. Critical contaminants were determined through previous measurements, information about products displayed, cleaning procedures, and occupancy in the retail space. The retail store, completed in mid-1994, had gone through its initial off-gassing phase.

Each group of measurements comprises a measurement set. Each measurement set uses a fixed ventilation rate in the store. Pollutants and environmental conditions were monitored for a 48-hr period during the set. This set was repeated three times in the initial sequence; then two times each at three-month intervals for one year (November 1995 - September 1996). A total of nine measurement sets were completed. The span of measurement periods permits evaluation of pollutants from the varied retail product mixes present during each different season. These periods were also spread out over a one-year period to sample Minnesota's climate with its warm, humid summers and cold winters. The four measurement periods are referred to as first, second, third and fourth quarterly measurement periods.

The multiple measurement sets performed during each of the four quarterly measurement periods correspond to different ventilation rates. The intended ventilation values ranged between 10% and 30% outdoor air. An HVAC Test and Balance contractor set the percentages of outdoor air desired. The actual result was then measured more precisely by tracer gas decays and tested for consistency using conventional flow hood and thermal balance measurements. Thus, for each measurement set, there are corresponding contaminant and ventilation measurements.

Pollutant Measurements

Pollutants measured were formaldehyde [24-hr averages], carbon dioxide (CO_2)[continuous five-minute averages], carbon monoxide (CO) [continuous five-minute averages], particle concentration and particle size distribution [continuous five-minute averages], selected organic compounds and total volatile organic compounds (TVOCs) [48-hr averages]. Environmental parameters sampled included temperature, relative humidity and differential pressures between various points in the store and outdoors. Each parameter was measured continuously; five-minute average values were recorded.

TVOC measurement procedures are of particular interest due to variations between different sampling methods. This study employed a scan for commonly found organic compounds sampled in store at five locations using 3M Model 3500 passive organic vapor badges. Two badges were placed at each interior location for 48 hours. The two badges were combined into one sample during analysis to improve sensitivity. The same procedure was used for the outdoor measurement and control samples. A commercial laboratory performed analysis of the badges.

Volatile organic compound (VOC) measurement results were broken down into more than 25 different chemical components. Only those VOCs with concentrations above the detection limit were reported. These included toluene, butoxyethanol, ethanol, isopropanol, methyl-ethyl-ketone (MEK), cyclo-hexanone, benzene, d-limonene, and acetone.

Ventilation Measurements

Ventilation rates were measured using SF_6 tracer decays [3]. Measurements were made at multiple points in the main retail area of the store and additionally at locations within the zone above the retail area's suspended ceiling and in the stockroom. This coupled, three-zone system is defined by a set of coupled differential equations that define the ventilation in the store [4]. Measured SF_6 data are modeled by inserting flow values into these differential equations from which the airflow from outdoors into each inside zone can be calculated. The combination of these values yields the total outdoor air supplied to the store by the ventilation system and through infiltration. These measurements were verified independently using both flow hood measurements and temperature differences between the outdoor air, return air and mixed air streams.

MEASUREMENT RESULTS

The contaminant levels seen in this store differed as expected within a quarterly test period because of the changes made to the ventilation rate. Comparisons between quarterly test sets with similar ventilation rates indicate a variance in the measurements that are due to weather, cleaning practices and mix of products in stock and on display. The application of these findings to other stores in this retail chain is possible because the air distribution systems, products displayed and management practices are consistent across all stores.

Temperature, humidity, CO and CO_2 were measured continuously. The variations over a day relate to human activity. The amount of outdoor air measured by tracer gas decay was determined for several tracer-gas injections and the average is presented. Except for temperature and humidity there is an inverse relation between the concentration measured and the flow rate of outdoor air.

Temperature and Relative Humidity

Indoor air temperatures averaged between 20 and 23 °C during store open hours (8:00 AM to 10:00 PM) during each season of the year. Relative humidity measurements varied greatly from season to season (10% - 60%). Averages in winter for relative humidity were below the desired level of comfort.

Differential Pressure

Differential pressure measurements revealed that the retail area of the store consistently remains at a higher pressure than outdoors even during the nighttime hours when HVAC use is curtailed. The retail area of the store also remains at a consistently higher pressure than the stockroom and the area above the retail area's suspended ceiling. Average values between the retail space and outside for various ventilation rates were approximately 15 Pa for 10% outdoor air and 30 Pa for 20% outdoor air.

Particle Concentrations ($PM_{2.5}$)

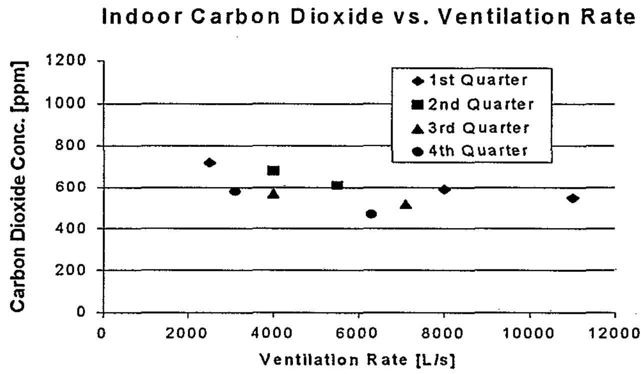
Measurements of average values of three-micron particles were less than 6 $\mu g/m^3$ during all measurement periods. Typical nightly maximum $PM_{2.5}$ concentrations ranged from 10 to 20 μg/m^3. However, concentrations exceeded 50 μg/m^3 on several occasions. As discussed in the CO section the nightly operation of a propane-powered burnisher was a strong source of carbon monoxide and particles. These concentrations were very low after the nightly peaks were diluted. No other obvious sources of particles were identified.

Formaldehyde (HCHO)

Formaldehyde concentrations during each of the quarterly measurement periods remained below 40 μg/m^3 (33 ppb) for all outdoor air settings. The concentration of concern is 120 μg/m^3 (100 ppb).

Carbon Dioxide (CO_2)

Daily increases in carbon dioxide were observed during store hours as occupancy increased; however, CO_2 concentrations remain below 1000 ppm for all ventilation rates tested.



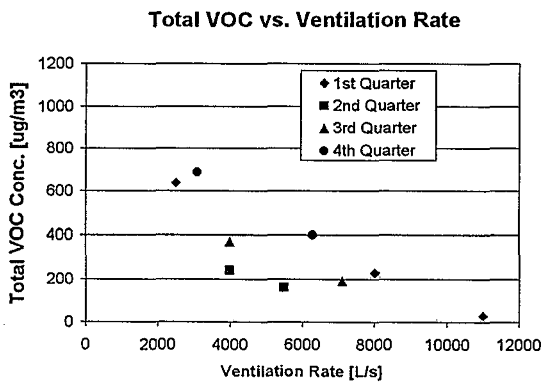
Carbon Monoxide (CO)

Twenty-four hour averages of CO varied between 2 and 6 ppm. Separating these results into periods when the store was open and closed, we found that the store-open values ranged between 1.5 and 4 ppm while the store-closed average values ranged from 3 to 9 ppm. A closer examination of the store-closed results showed nighttime peaks that were related to the use of a propane-fired floor burnisher. This caused storewide concentrations to reach 20 ppm and, on one occasion, 59 ppm. No other obvious sources of CO were noted in the store.

Total Volatile Organic Compounds (TVOC)

Elevated concentrations of d-limonene help explain a larger than expected TVOC result during the fourth quarter period. D-limonene is a constituent in some cleaning products. A cleaning product containing d-limonene was used extensively by store employees during this measurement period. One constituent of the TVOC signal is the d-limonene from this source.

TVOC concentrations were below the threshold of concern for all tests. A concentration of TVOC greater than 1000 μg/m^3 is an indication of concern and further testing should be done to identify the individual volatile organic compounds causing the high reading.



In this store TVOC is the most useful measurement parameter due to its higher toxicity and its clear response related to changes in ventilation rate. Therefore, TVOC would be the best candidate to confirm appropriate design application in similar stores.

Ventilation Rates

Results of the ventilation measurements obtained using tracer decay were consistent with results obtained by flow hood measurements and temperature based measurements within the ducts during testing periods. Control of outdoor air quantity is not a simple adjustment. Nonetheless, the damper settings resulted, on average, in outdoor air rates that were close to those intended.

DISCUSSION

In this study we have elected to use the guideline limits recommended in the public review draft of the revised Standard 62. These are listed in Table C-1 of Appendix C in the public review draft [2]. There are no federally mandated standards for indoor air pollutants in the United States. Common practice and building codes use the guidelines described in Section 6.2.1 of ASHRAE 62-1989. The guidelines listed apply the National Ambient Air Quality Standards (NAAQS) to the indoor environment and also add four pollutants: CO_2, chlordane, ozone and radon. These are listed in Table 3 of ASHRAE 62-1989. The procedure then suggests that additional pollutants and guidelines be selected from Appendix C of ASHRAE 62-1989.

The following table presents the guideline limits from the 1996 ASHRAE 62 public review draft for those contaminants chosen as pollutants of concern for this study.

Table 1: Guideline Limits for Pollutants of Concern

Contaminant	Concentration of Interest		Note
CO	9 ppm		average 8 hour exposure
HCHO	120 $\mu g/m^3$ (100 ppb)		30 minute exposure
Odors (CO_2)	1000 ppm		
Particles (PM_3)	50 $\mu g/m^3$		24 hour exposure
Total Volatile Organic Compounds (TVOC)	$C < 300$ $\mu g/m^3$ $300 < C < 3000$ $\mu g/m^3$ $C > 3000$ $\mu g/m^3$ $C > 1000$ $\mu g/m^3$	complaints unlikely complaints possible complaints likely trigger further analysis	Semi-quantitative measure of indoor pollution. For $C > 1000 \mu g/m^3$ determine individual compounds.

Analysis of TVOC concentrations in stores in different locations would provide a leading indicator contaminant test of acceptability. Low TVOC concentrations would indicate that other contaminants will be low, and adequate ventilation is present assuming no unusual or obvious source. TVOC concentrations that exceed the guideline could be the result of inadequate ventilation, excessive source strength or both. Thus, the TVOC test indicates acceptability but does not identify a cause (excessive source strength or inadequate ventilation or both) if it fails.

This study has been designed to assess the ventilation requirements in a large 62,000 gross cubic meter store (with a retail volume of 35,000 cubic meters). For retail spaces, the ASHRAE 62-1989 prescriptive method calls for 1.5 $L/s\text{-}m^2$ of outside air to be supplied. By employing the ASHRAE 62-1989 performance-based method to this retail space, it was found that the ventilation rate could be lowered to approximately 0.5 $L/s\text{-}m^2$ while maintaining critical pollutant levels well below guideline values. The performance-based method requires critical contaminants to be defined and measured while ventilation rates are adjusted across varying retail stock and outdoor weather conditions. This procedure results, not only in good indoor air quality, but energy savings and, therefore, reduced operational expenses for the retail store. Retail chain stores commonly found in the U.S. create one building model and replicate it widely. Ventilation system design changes for the model store will result in a reliable and high quality of indoor air as well as significant energy savings across a retail chain.

Drawbacks for the performance-based method are unmeasured or unforeseen large contaminant sources. In this study a gas/propane powered floor burnisher was occasionally observed to increase CO levels significantly during low-ventilation, store-closed hours. These high pollutant levels were also observed to carry over into store-open hours. Similarly, strong cleaning solutions, high in VOCs, were observed to increase pollutant levels above acceptable values during store-open hours. For the performance-based method to be successful, contaminants with high source-strengths must be avoided consistently.

ACKNOWLEDGMENTS

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