BUILDING ASSESSMENT TECHNIQUES FOR INDOOR AIR QUALITY EVALUATIONS

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Techniques for indoor air quality evaluations are presented and discussed. The techniques presented first focus on procedures to determine effective ventilation rates and pathways of air movement within the building. This is followed by a discussion of assessment techniques to identify potential sources of air contaminants. These sources can then be categorized with respect to their originating location. Air contaminants can arise from within the building, outside the building, from the mechanical ventilation system, or from localized exhaust systems.

The procedures associated with these techniques include the survey of carbon dioxide concentrations to determine effective ventilation rates and outdoor air makeup, the use of enthalpy balance to determine mixing ratios and visual determinations using air current tubes. This technique is useful for building evaluations where there is no identifiable suspected source of air contaminants causing complaints or situations where there is an identifiable suspected source but unknown pathways of transmission. This paper will draw upon illustrative case studies to show how the parameters discussed have contributed to various cases of degraded indoor air quality.

Introduction

The performance of effective indoor air quality (IAQ) evaluations depends on the ability to understand the interactions of the variables affecting IAQ. These variables include the effective ventilation rates within the building and the introduction of air contaminants from either within the building, outside the building, or from within the mechanical or unoccupied spaces of the building. The techniques presented in this paper for performing building assessments focus initially on determinations of the effective ventilation rates and then consider the potential sources of air contaminants.

Assessing Actual Building Ventilation Rates

The concept of Effective Ventilation Rate (EVR) refers to the actual removal rate of air contaminants from the occupied spaces in the building. One procedure for determining the effectiveness of the ventilation system involves the measurement of carbon dioxide CO_2 concentrations throughout the building. In addition to measuring CO_2 levels in the occupied spaces, measurements should be obtained of the concentration of CO_2 in the supply air to assess the proportion of outdoor air coming from the mechanical HVAC system versus the building enclosure infiltration. When using this procedure, measurements of the outdoor (background) concentrations of CO_2 must be obtained.

The procedure which is used to assess an "Effective Ventilation Rate" (EVR) is based on monitoring carbon dioxide concentrations in the building. Modeling of this building can then be performed relying on the assumptions that the source strength is proportional to the occupancy rate, the outdoor concentration is fairly constant, and the only removal mechanism is with the exhaust or exfiltrated air. The concentrations of CO_2 present in a building therefore can provide a measure of how well the ventilation system is diluting and removing air contaminants generated within the building (1). In this analysis, it is the people occupying the space that are the source of the CO_2 being measured.

In evaluating situations where the pollutants of concern are generated within the building, it is useful to quantify the EVR. The fundamentals of this procedure are found in the ASHRAE handbook (1). This technique can provide a measure of how well the ventilation system is diluting and removing air contaminants generated within the building. For this analysis, care must be taken to ensure that no combustion sources are present in the occupied space which would interfere with the method. In one building evaluation, for instance, elevated CO_2 levels were traced to an improperly vented gas-fired water heater.

Mechanical Systems

For mechanical HVAC systems, a useful procedure is to perform an enthalpy balance at the mixing box adjacent to the outside air dampers. The term enthalpy refers to the internal (sensitive plus latent) energy in a mixture of moisture and air. Knowing the enthalpy of the outside air, the return air, and the resulting value for the combination of these two air streams permits the determination of the relative proportion of outside air to return air at the time of measurement. Accurate, stable, calibrated sensors are needed.

This technique only assesses the outdoor air introduced into the mechanically driven air handling system. The shortcoming of this approach is that it ignores the outdoor air introduced by infiltration. Also, merely determining the amount of outdoor air introduced into the mechanical system does not assess how effectively the dilution air actually reduces the concentration of contaminants in the occupied zone. The uncertainty here relates to the concept of "ventilation effectiveness" which is a function of the geometry of the locations of the supply and return air registers and the temperature of the supply air with respect to the room air.

Determination of Air Movement Pathways and Ventilation Efficiency

The determination of air movement pathways through a building can most readily be accomplished by the performance of tracer testing. Releasing a tracer such as sulfur hexafluoride, near the site of a suspected source with subsequent analysis of samples collected throughout the building is the basic technique (2). This provides an assessment of how rapidly that quantity of tracer is removed from the release area and also a determination of the pathways of air movement through the structure. Another technique for determining air movement pathways is the use of air current tubes. These devices produce a neutral density visible cloud which will follow the air streams into which they are released. Following the identification of these locations, tracer gas can be released at these penetrations to determine the areas of the building impacted by infiltration from this source. In this procedure, air samples are collected in the building in Tedlar bags. The contents of these sampling bags are then analyzed for the amount of tracer present. The presence of tracer in these samples can document the existence and location of pathways of air movement through the building.

Assessment of Building Contaminants

After assessing the effective ventilation rate for removing air contaminants from the occupied spaces and the pathways of air movement into and through the building, the next step is to assess the presence of air contaminants themselves. First it must be recognized that the sources of these air contaminants can either be from within the occupied spaces of the building, from outside the building, or from within the mechanical system or other unoccupied spaces in the building. Since the determination of the effective ventilation rate provides a measure of how effectively pollutants generated from within the occupied spaces are being removed from these spaces, it is useful to perform an emissions inventory to estimate the possible sources of the indoor air contaminants.

Sources Within the Building

The following is a listing and discussion of some of the typically more important indoor air contaminants to be considered.

Particles

The first source of particles to be considered is the presence of smoking activity. Qualitative assessments can, of course, be made by simple observation. Quantitative assessments can be based on measurements of concentrations of respirable particulate matter (RSP). This technique is effective since about 95% of the smoke generated from cigarettes is in the respirable range (< 7 um). Care must be taken in interpreting these results since cigarette smoke may not be the only source of RSP in a given area. Portable equipment currently exists for near real-time determinations of RSP concentrations, thus allowing walk-through surveys to be conducted. In evaluating the impact of tobacco smoke, two mechanisms for elevated concentrations of RSP have been observed, local generation and transport by the HVAC system.

Combustion Gases

The inventory of potential sources must include all combustion sources. Combustion oxides (often respiratory irritants) are generated by combustion processes. These oxides include carbon monoxide, carbon dioxide and nitrogen dioxide. Real-time portable monitors are available for all 3 oxides, and passive integrating samplers are available for nitrogen dioxide.

Ozone

The potential for ozone may be related to the quantity of electrostatic copiers in the building, or other high intensity UV processes. Real-time portable ozone monitors may be used to conduct surveys if suspect processes are in use.

Biological Sources

The presence of mold and fungi can often be related to evidence of high humidity (in excess of 55% RH) which would foster the growth of these organisms. This assessment should include not only the occupied spaces but any humidification equipment, or mechanical systems. Specific types of equipment implicated in past evaluations as sources of microbial aerosols include water spray systems, humidifiers that use recirculated water, cold mist vaporizers and fan coil units (4). Sampling for the concentrations of viable organisms in occupied spaces typically involves drawing the room air across an agar medium. Analysis of this culture plate involves incubation and subsequent counting of the number of colonies formed. Other biological indicators may include the presence of insects. This procedure involves microscopic examination for insect hairs or parts.

Organic Chemicals

The complexity and diversity of the organic chemicals introduced into many indoor environments can make assessments of these compounds difficult, and air cleaning for their removal impractical. Hence, we must rely on the effectiveness of the ventilation system for the removal of the off-gas from building materials and office equipment alike. Survey methods are available for identifying potential sources, and sophisticated, expensive analyses such as GC/MS or MS/MS can be performed to determine the components of the organic soup in modern office buildings.

Fibers

The presence of fibers, including fiberglass and asbestos may be related to the presence of acoustical or insulation materials often located within the ceiling plenum of a building or in mechanical rooms. If there is frequent construction activity and access to these areas, there may be increased risk of exposing the whole building to air contaminants from these areas.

Sources from Outside the Building

This section discusses sources of air contaminants which originate outside of the occupied spaces in the building and are drawn into the building either through the mechanical system or through infiltration.

During the heating season buildings usually behave like chimneys. This thermal stack effect is created by the escape of buoyant heated air at the upper levels of the building which create negative pressures capable of causing infiltration at the lower levels of the building. Therefore, because of this induced upward flow, and the normal supply of fresh air to the building, the following items can be identified as potential sources of air contaminants to the building.

Radon

The potential for radon can be crudely assessed by a few questions as to the radon content of the soil geology, sources of water, and building materials. More definitive assessments can be provided by detectors such as track-etch cups or more expensive real-time monitors. The release of radon into a building may be related to the infiltration of soil gas, the use of certain stone and masonry products or ground water supplies.

Loading Docks

Loading Docks are considered as potential sources of air contaminants for some buildings. The combination of idling diesel vehicles, and penetrations at the loading dock, under the influence of typical negative pressures can draw pollutants into the building's interior.

Parking Lots

Parking Lots and Roadways are considered as potential sources of air contaminants for some buildings because of the accumulation of carbon monoxide and carbon dioxide from idling vehicles. This is especially true for multi-level parking facilities in congested areas. These may be considered large area sources for pollutants such as carbon monoxide.

Cooling Towers

Cooling Towers are considered potential sources of air contaminants because they often harbor biological growths which may be infectious to people.

Localized Exhaust Systems

Localized exhaust systems should be evaluated as potential sources of air contamination. If their points of emission are close enough to air intakes or infiltration sites, the contaminants may be drawn in with the outside air. In evaluations of this type algorithms have been developed and published for estimating air intake contamination from nearby exhaust vents. The parameters for evaluating the impact on IAQ are discussed in greater detail below.

Sources Related to the Building Mechanical System

Location of Air Intakes

Location of air intakes can contribute to the contamination of indoor air quality if they permit re-entry of emissions from the building itself or from other sources.

Humidity Control

Humidity control is mentioned here since any humidification device involving recycled and/or standing water is subject to stagnation and is a potential source of contamination from micro-organisms, including various fungi.

Location of Supply and Exhaust Registers

Location of supply and exhaust registers contribute to the determination of ultimate indoor air quality by their varying abilities to remove contaminants from the occupied zones. If both supply and exhaust registers are located in the ceiling or in the same wall, short circuiting may occur. This may allow contaminants to remain undiluted within the stagnant zone. A floor-supply/ceiling-exhaust geometry, in combination with a buoyant contaminant, can however, facilitate the rapid removal of contaminants from this space.

Building height is included as a factor affecting indoor air quality because the taller a building, the greater the potential for pressure which the air distribution system must overcome in order to distribute air throughout the structure. In many buildings with roof mounted equipment, the return air riser behaves like a chimney drawing more air than intended out of the lower levels. With improper design, the return fan output overtakes the supply fan, and the building air pressure becomes negative to the outdoors on the lower floors, and over pressurized on the upper floors. If the air pressure in a space is greater than what the supply fan can deliver the occupants on the upper floor levels then receive no air. Another serious ramification of this problem is that the return air volume can exceed the supply fan volume. The outside air opening becomes a building exhaust port; even though the outside damper may be wide open, <u>no</u> fresh air is introduced.

Parameters for Localized Exhausts

The evaluation of localized exhausts, such as fume hoods or process emissions, cuts across the distinctions between the above subtopics and therefore requires a systems approach to deal with several interrelated factors.

Capture Efficiency

The capture efficiency of the localized exhaust system refers to the ability to prevent the air contaminant being controlled from being released into the room itself. This can be assessed to some extent by the use of air current tubes.

Negative Pressurization

The over pressure of a room containing a source requiring a localized exhaust system creates the potential for leakage of contaminants to other areas. As above, the assessment of pressurization can be determined using air current tubes. For a localized exhaust system to function properly there must be some provision for a make-up system.

Discharge Parameters

The air contaminants from a localized exhaust system can re-enter the building at another location if the stack is not tall enough to discharge out of the aerodynamic wake of the building. The requirements for source receptor distances, stack height, and discharge velocity can be evaluated using algorithms of dilution achieved (6). All too often, short stacks are selected for aesthetic considerations. This is an invitation for the air contaminants discharged to be drawn back into the building.

Summary and Conclusions

The presence and location of various potential sources both inside and outside of the building can be performed by observation. However, in order to determine how the ventilation system or systems of a building are performing, it is necessary to use more sophisticated approaches. The evaluation of a ventilation system requires the measurement of at least one component of the gas stream. Options for this evaluation include both compounds that are normally present in the occupied spaces or a compound that is specifically introduced into the occupied spaces for the purpose of this evaluation, such as sulfur hexafluoride.

If the evaluation of ventilation rates and the determination of air movement pathways are not sufficient to deduce the source of air contaminants, further specific measurements of sources and contaminant concentrations may be employed.

The techniques and procedures described have been used by the authors to investigate several buildings with histories of occupant complaints. Solutions have been developed from these investigations which have eliminated the problems and reduced the occupant complaints to more normal levels, or eliminated them completely.

References

1. ASHRAE Handbook, 1981 Fundamentals, Chapter 22 "Ventilation and Infiltration", p. 22.1 (1981).

2. ASTM Standard E 741-80. Standard Tracer Dilution Method for Infiltration Measurement (1980).

3. P.R. Morey and R.E. Rundus, HVAC System Operational Parameters Affect Airborne Fungal Levels in Occupied Spaces", Proc. 3rd International Conference on Indoor Air Quality and Climate, Volume 3, Sensory and Hyperreactivity Reactions to Sick Buildings, Stockholm, Sweden, August (1984).

4. D.J. Wilson, "A Design Procedure for Estimating Air Intake Contamination from Nearby Exhaust Vents", ASHRAE Transactions, Volume 89, Pt. 2A & B, No. 2769 (1983).

Case Studies

I. Five Story Arts and Science Building

Occupants of a renovated university building complained of welding fumes from the basement lab reaching the Dean's office, although a welding fume collection system had been installed.

The use of respirable particle sampling equipment and subsequent elemental analysis confirmed the anomaly of elevated iron levels in two locations besides the lab a hallway, and the Dean's office. The use of SF_6 tracer confirmed the existence of two pathways of air movement which were allowing the fume to be carried to the office space, an elevator shaft and penetrations for electrical cables.

The use of enthalpy balance techniques confirmed the improper functioning of an HVAC System which prevented the office area from receiving adequate outside air during the majority of the system's operation. A CO_2 survey also pinpointed a back drafting gas hot water heater.

Subsequent redesign of the fume removal system, sealing of the elevator shaft, and modifications to the HVAC System corrected the problem. Measurements were performed after the modifications were made to ensure their adequacy.

II. Multi-Story Health Care Facility

Occupants complained of diesel exhaust odors periodically throughout the day, particularly one floor. The use of tracer measurements confirmed the pathways of exhaust fumes from loading dock activity. These pathways (penetrations) were sealed eliminating the problem.

III. Two Story Office Building

Occupants complained of a history of the smell of gasoline within the building associated with "high water" periods. The use of an organic "sniffer" confirmed the existence of hydrocarbon contaminated water flowing under the building. The sources of fume leakage into the basement were identified and sealed.

Tracer gas measurements were used to map the air movement between the basement and first floor and the identified penetrations were sealed. The use of calibrated temperature sensors revealed a malfunctioning mixed air sensor. This sensor was causing the outside air damper to remain closed a high percentage of the year. The mixed air sensor was recalibrated. The HVAC controls were modified to include minimum position potentiometers and the control strategy was changed to maximize the amount of outside air provided during temperate weather.

Several water leaks were identified in the heating system and repaired to minimize the potential for biological activity associated with high localized humidity.

After alterations were made to the building, the duplicating equipment was identified as the most detectable point source of organics within the building.

Because of the high particle measurements that were recorded in the break rooms, localized exhaust was recommended. A rigid schedule of maintenance for the break room air cleaner was also outlined.