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Factors Affecting the Performance of Ventilation Systems in Large Buildings

by C.Y. Shaw

This Update reviews the results of IRC research on some key factors that influence the performance of a ventilation system in large buildings. It discusses the effects of these factors and provides guidelines for operating the system efficiently.

Achieving good indoor air quality in large residential and commercial buildings continues to be a top priority for owners, designers, building managers and occupants alike. Large buildings — those outside the scope of Part 9 of the National Building Code — present a greater challenge in this regard than do smaller buildings and houses. The challenge is greater today because there are many new materials, furnishings, products and processes used in these buildings that are potential sources of air contaminants.

There are three strategies for achieving acceptable indoor air quality: ventilation, source control and cleaning/filtration. Depending on the building and the specific characteristics of its location, these strategies may be used singly or in combination.

Ventilation is the process of supplying outdoor air to an enclosed space and removing stale air from this space. It can control the indoor air quality by both diluting the indoor air with less contaminated outdoor air and removing the indoor contaminants with the exhaust air.

Source control refers to the use of environmentally friendly building materials and furnishings (such as natural wood), and low-emission floor coverings, paints, adhesives and cleaning products. The primary function of source control is to keep the levels of indoor air contaminants as low as possible by minimizing the use of materials and products that have the potential for off-gassing (i.e., emitting chemical compounds).

Air cleaning is the use of filtration techniques to remove contaminants from both the ventilation (outdoor) and indoor air. It is essential for buildings located in urban centres or near industrial plants where the quality of the outdoor air may be worse than that of the indoor air.

The most frequently used strategy, and in most cases the only one available to building operators, is ventilation. Mechanical ventilation costs money because the outdoor air needs to be heated in winter and cooled in summer. To conserve energy, care must be taken to maximize the efficiency of the ventilation system. In this regard, a number of factors come into play.

Ventilation Performance and Energy Use

The main factors affecting the performance and energy efficiency of a ventilation system are:

- Air distribution
- Air leakage
- Local exhaust

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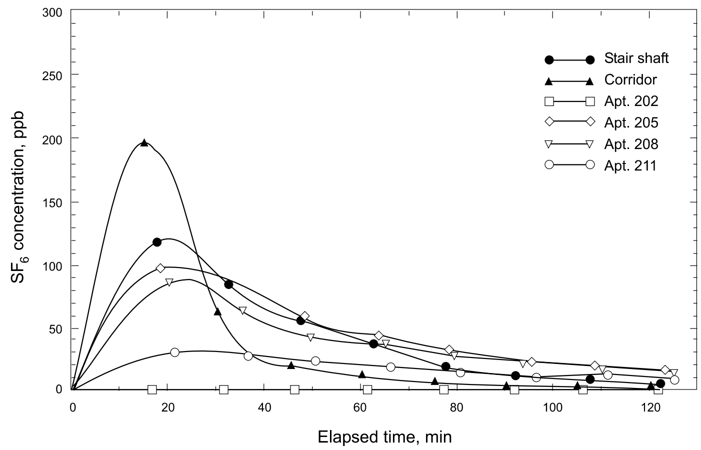

Figure 2. Outdoor air distribution patterns for second floor, winter conditions

Air Distribution

Ideally, all occupied zones of the building should receive adequate ventilation air. This is not always the case, however, especially in residential buildings, as evidenced by an IRC study conducted several years ago in a five-storey apartment building.

The ventilation air in the apartment building was supplied to the corridors. The design concept relied on the pressurization of the corridors to provide ventilation air to the individual apartment units. Exhaust fans installed in the bathroom and kitchen of each unit facilitated the delivery of the ventilation air by lowering the internal pressures.

In addition to the effect produced by fans, the pressures in individual units are generally affected by wind or temperature or both. Wind blowing around and over a building causes variations in pressure around it. Positive pressures prevailing on the windward side increase the pressures in the apartment units on the windward side; negative pressures on the leeward side lower the pressures in the apartment units on the leeward side. Temperature differences between inside and outside also produce variations in pressure across the building envelope as a consequence of differences in the density of the air. This is known as the stack effect. When the inside temperature is higher than that outside, the pressures in the apartment units increase on the lower floors and decrease on the upper floors. Changes in pressure in the apartment units due to wind, temperature, or both, can significantly affect the movement of ventilation air.

The IRC study was conducted during winter to assess the maximum influence of stack effect using the tracer gas method, which requires a small amount of harmless tracer gas (SF_6) to be injected into the supply-air duct. Air samples were taken at six locations on each floor to measure the tracer gas concentrations (Figure 1). Detection of the tracer gas at any of the six locations provided evidence that air from the ventilation system was reaching them.

Immediately after the tracer gas was injected into the ventilation system, concentrations were detected at five of the six sampling stations (Figure 2). The concentration was highest in units 208 and 205, followed by unit 211. Little or no tracer gas was detected in unit 202. This suggests that the units on one side of the corridor were receiving much more ventilation air than the building design called for. The units on the other side (represented by unit 202) were receiving little or no ventilation air because the pressures in these units were high enough to prevent it from entering via the corridor.

These units were likely relying solely on air leakage (see discussion below) for ventilation.

As the ventilation air must be preheated in winter, units relying on air leakage require additional energy to heat the air leaking in. The occupants of these units would experience cold drafts and would likely resort to raising the thermostat to increase their comfort, thus further increasing energy use.

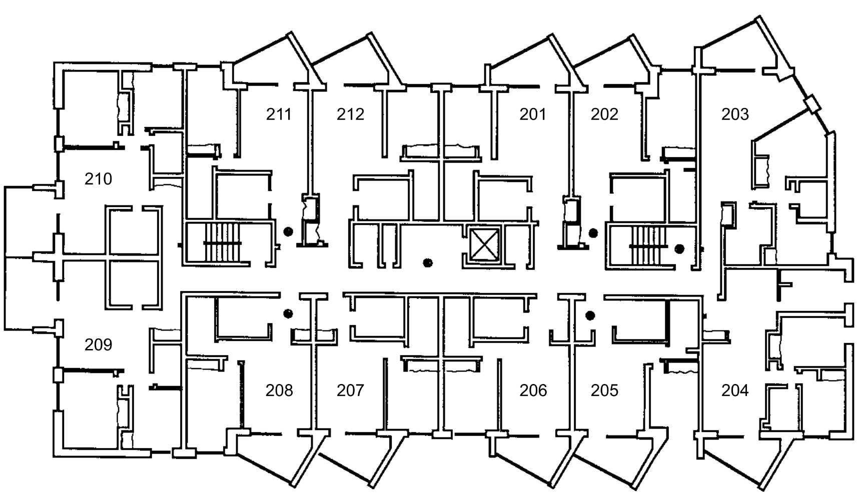

Figure 1. Typical floor plan

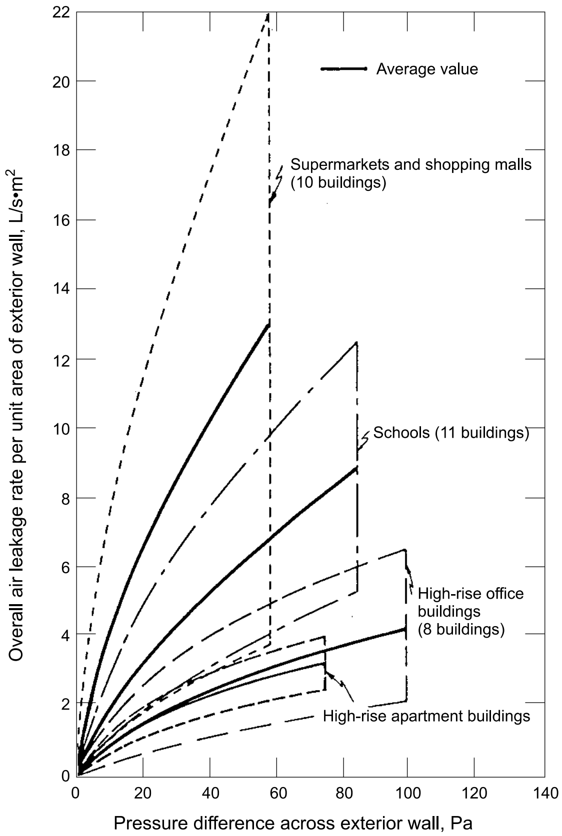

Figure 3. Airtightness measurements in various types of buildings

Air Leakage

Air leakage is the infiltration of air through the building envelope. The amount of air leakage depends on the airtightness of the building envelope and the pressure difference across it caused mainly by wind and temperature differences between the inside and outside.

Leaky buildings are more costly to heat and more difficult to ventilate properly than relatively airtight buildings. Figure 3 shows the results of airtightness measurements made some 25 years ago in various types of buildings, including eight office complexes. Five of these were re-tested about twenty years later to determine whether their airtightness values had changed. One of the re-tested buildings was found to be about 40% more airtight owing to extensive renovations (Figure 4). Based on the recorded energy consumption for the same three winter months before and after the renovations, the 40% improvement in airtightness translates into an energy saving of 11%. These data are strong evidence that designers and owners can profit by knowing how airtight a building really is.

Cold drafts are usually a good indication that air leakage is occurring. When this is the case, sealing cracks and openings in the exterior wall and around windows will improve airtightness.

Contamination Source/Local Ventilation

When powerful contamination sources are present in a building, leading to occupant complaints, the building operator may be inclined to increase the ventilation rate to speed up the dilution process. An IRC study indicated that such a strategy is rarely effective, even when energy use is not a concern.

The study took place in an area where a number of photocopiers were located together and staff were complaining of poor air quality. In the study, air samples were taken in this area throughout the day. The results show that two large peaks — indicating high concentrations of volatile organic compounds (VOC's) — occurred at 9 a.m. and at 2 p.m., corresponding closely with the periods when most of the photocopying was being done (see Figure 5).

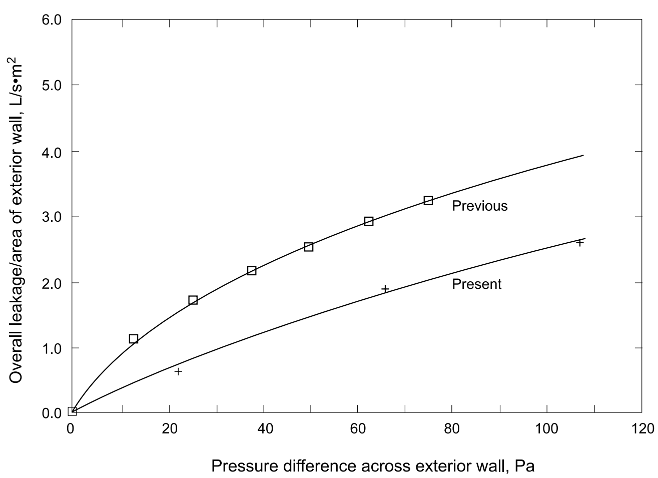

Figure 4. Airtightness values for office building following renovations

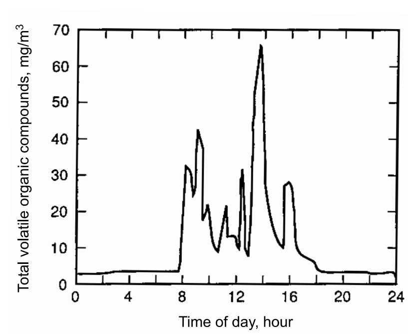

Figure 5. TVOC profile produced by copying machines in an office space

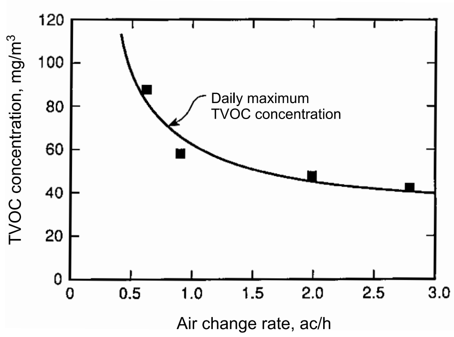

Figure 6. Dilution capability of ventilation air

To determine whether dilution alone could eliminate this pollution problem, the ventilation rate in the building was increased six-fold from 0.5 to 3 air changes per hour. This action decreased the VOC level by 50% from 90 ppm to 45 ppm (Figure 6). However, this reduced level still significantly exceeds the concentrations of between 0.1 and 5 mg/m^3 found in 200 samples taken by IRC researchers in Canadian residential and office buildings. The study clearly showed that ventilation alone does not ensure acceptable IAQ where a prominent source of contaminants is present. It is necessary to remove the contaminants at the source by using local exhaust and to rely on ventilation for the rest of the required improvement in air quality. In the case of an identifiable contaminant source such as a photocopier, the exhaust of the photocopier should be directly connected to the outside.

Energy-Efficient Control of Ventilation

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) recommends ventilation rates for buildings based on the maximum (design) number of occupants. For buildings that are typically occupied only during certain times — office buildings, for example, are occupied only during the day — it may be possible to control ventilation rates on the basis of the number of occupants at a given time. A demand-controlled ventilation system, using occupant-generated CO_2 as the control index, is one approach that can be used in office buildings.

CO_2 Demand-Controlled Ventilation

Studies in office buildings have shown that the concentration of CO_2 increases and decreases with the number of occupants. Thus, it should be possible to control ventilation rates based on measured CO_2 concentrations.

The feasibility of using CO_2 concentrations as a method of controlling the ventilation rate in a building depends on whether or not the following three conditions can be met:

- The CO_2 concentration must be proportional to the actual number of occupants at a given time.
- The CO_2 concentration should be the same on all floors, and there should be suitable locations for placing the CO_2 sensors, where the concentrations of CO_2 are representative of those throughout the building.
- The CO_2 concentration must be proportional to the building's air change rate.

To verify whether a building is likely to meet these conditions, IRC conducted a study in a 22-storey office tower with an interior volume of approximately 113,700 m^3. The building has seven all-air constant-volume supply-air systems and two return-air systems. Four of the supply-air systems provide air to the interior zones of the east and west floors. The remaining three systems provide air to the south perimeter, the east and east half of the north perimeter, and the west and west half of the north perimeter.

The results shown in Figure 7 confirm that the CO_2 concentration varies according to the number of occupants. The concentration is low during the night, begins to rise as the employees arrive in the morning and peaks around noon. It drops somewhat during the lunch hour, then picks up as the employees return to work and peaks again around 4 p.m. Once the occupants

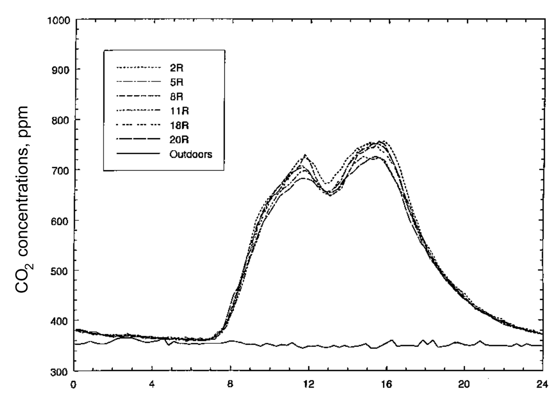

Figure 7. Typical weekday CO_2 concentrations measured at different times of the day

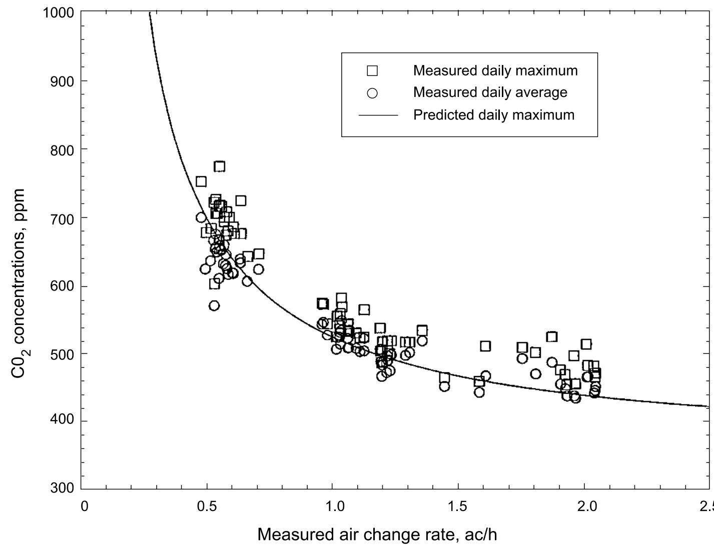

Figure 9. Comparison of daily maximum CO_2 concentrations and daily average CO_2 concentrations at various air change rates

begin to leave, the concentration drops continuously until it reaches the nightly level.

On all test floors, the CO_2 concentrations measured at various locations on the occupied floor agreed closely with the concentration measured at the return-air shaft of that floor, suggesting that the latter measurement provides a good indication of the CO_2 concentration for the entire floor.

Then once it was determined that the CO_2 concentrations measured at the return-air intakes of individual floors were the same from one floor to another, measurements were taken at the tops of the two main return-air shafts. Figure 8 shows that the measurements at the tops of the shafts agreed closely (within 2%) with the values at the return-air intakes on individual floors, indicating that they are representative of the CO_2 concentrations throughout the building. The finding also indicates that the tops of return-air shafts are suitable locations for CO_2 sensors.

The final step in the above study was to establish the relationship between the measured CO_2 concentration and the air change rate. Figure 9 shows the daily maximum and the daily average CO_2 concentrations at the various air change rates (ventilation rates). The results suggest that a good correlation exists between the measured CO_2 concentrations and the air change rates. Thus, this relationship can be used as the basis for controlling the building's ventilation rate.

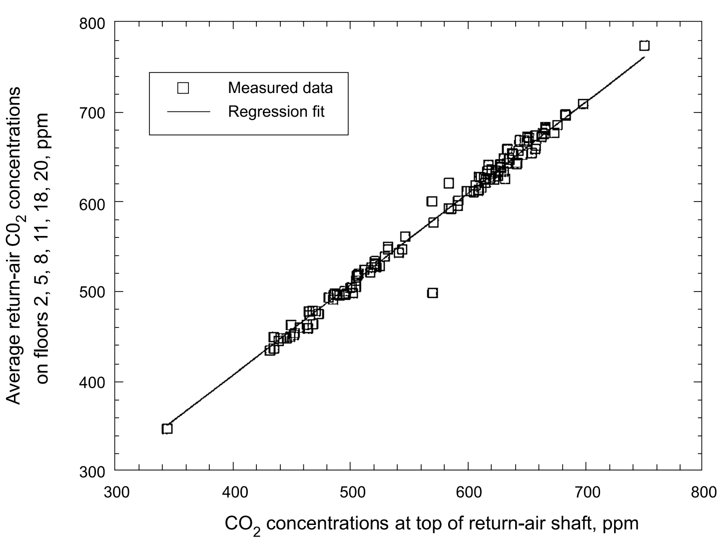

Figure 8. Comparison of CO_2 concentrations measured at the top of the return-air shafts and at return-air intakes on individual test floors

Summary

The information in this Update has been presented to help building designers, owners and managers understand how certain key factors affect the performance and energy efficiency of the ventilation system.

Improving the airtightness of older buildings will reduce air leakage and cold drafts, and help reduce energy use by improving the performance of ventilation systems.

To reduce energy use, it is necessary to reduce contamination sources as much as possible either by using environmentally friendly furnishings, materials and products, or by exhausting contaminants at the source, if possible. General ventilation should then be used.

For buildings where the number of occupants varies significantly with time, such as office complexes and schools, it may be possible to further improve energy efficiency by controlling their ventilation rates based on the actual number of occupants at a given time.

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