Multi-family houses

The variation in average ventilation rate in multi-family houses of different ages is moderate. However, as for the single-family houses, the ventilation rate tends to be higher in older houses.

Ventilation rate expressed as (l/(s,inhabitant))

For both single- and multi-family houses the average values of ventilation rate (l/(s,inhabitant)) are very even, ranging from 12 to 18 l/(s,inhabitant) (fig 4). The larger variation in ventilation rate expressed as (l/(s,m²)), (fig 3) is counteracted by the fact that occupants in single-family houses have access to larger livingspace than those in multi-family houses (fig 5).

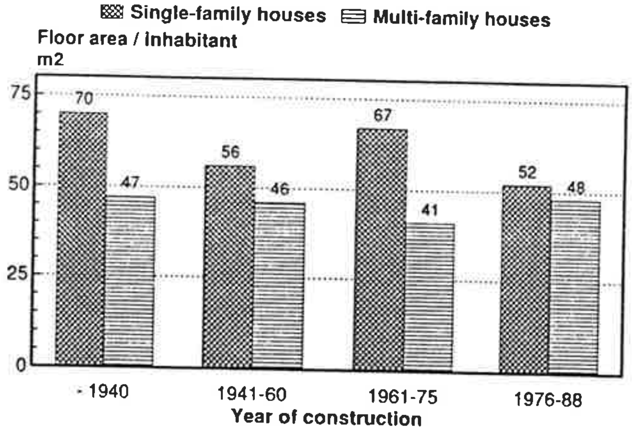

Fig 5 Residential floor area per occupant in Swedish dwellings.

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REFERENCES

1. Boman CA and Sundberg J. Case studies of indoor climate in 100 residential buildings. ELIB-report no.5. Swedish Building Research Institute, Gävle,1993/In Swedish/.

2. Adalberth K, Boman CA, Kronvall J and Norlén U. Correction of tracer gas measurements results for climatic factor. proc 13th AIVC Conference in Nice France, 15-18 sept 1992, air Infiltration and Ventilation Centre, Coventry, UK

THE POLLUTANT CONTROL INDEX: A NEW METHOD OF CHARACTERIZING VENTILATION IN COMMERCIAL BUILDINGS

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ABSTRACT

In many buildings, the traditional indices of ventilation rates are very difficult to measure. The measured indices usually represent only a short time period. Seeking to overcome these limitations, we introduce the local and global pollutant control indices (PCI). These parameters quantify the effectiveness of ventilation in controlling the concentrations of a simulated indoor-generated air pollutant. In the proposed measurement procedure, an indoor pollutant source is simulated by deploying multiple passive emitters of tracer gas throughout the building. Using a programmable sampler, time-average tracer gas concentrations are determined during occupancy periods near locations where occupants breathe. The PCIs are based on the measured tracer gas concentrations and the total tracer emission rate. A new type of passive tracer source has been developed for measurement of PCIs. Further research is needed to evaluate the accuracy of sampling and sample analysis procedures and the reproducibility of measurements within buildings

INTRODUCTION

Traditionally, the rate of ventilation in buildings has been characterized by the rate of outside air supply, normalized by either the indoor volume, the floor area, or the number of occupants. Measurements of these ventilation rates in commercial buildings generally serve one of the following purposes: (a) to determine air flow rates for use in energy-related calculations; (b) to determine if the ventilation rate is adequate for controlling indoor pollutants; and (c) to evaluate the spatial distribution of ventilation within a building. Research on the relationship between ventilation and occupant health in commercial buildings is another, but less common, application for ventilation rate measurements.

Existing techniques for determining ventilation rates in commercial buildings include tracer ga decays or stepups (1), measurements of post-occupancy carbon dioxide (CO_2) decay rates (2) measurements of air flow rates (3), and mass-balance estimates based on measured CO_2 concentrations and estimates of the rates that occupants generate carbon dioxide (2). Although ventilation rates may be temporally variable and long-term average ventilation rates are often desired, none of these measurement techniques provide an average ventilation rate for an extended time period (several days), unless the measurement process is repeated many times. Only the tracer gas and CO_2 decays account properly for air infiltration and exfiltration. The tracer-gas techniques are very labor intensive, impractical to implement in many buildings, and require stable ventilation rates because the processing of tracer gas data is based on steady-state mass balances (1). Direct measurements of air flow rates, for example using flow

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hoods, pitot tubes, or hot wire anemometers, are labor intensive, often obtrusive, and often inaccurate when air velocities are low or the velocity profiles in airstreams are irregular. Post occupancy CO_2 decays are only applicable when all occupants leave the building within a short period. Estimates of ventilation rate based on CO_2 mass balances are often inaccurate because of uncertainties in both occupancy and the rates of CO_2 emissions by occupants and because indoor CO_2 concentrations usually do not stabilize (2).

Practical techniques of measuring the quantity of ventilation in commercial buildings over extended time periods are clearly needed. In response to this need, this paper introduces a simple new concept for characterizing effective ventilation rates in buildings and describes the measurement technique under investigation.

THE POLLUTANT CONTROL INDEX

The obstacles to practical measurements of the traditional indices of ventilation rate include temporally varying air flow rates, irregular velocity profiles in airstreams, imperfect mixing of the indoor air, air infiltration and exfiltration, and the complex nature of the ventilation systems in commercial buildings. These obstacles are not easily overcome. However, for most applications other than energy calculations, normalized flow rates of outside air are not needed. Instead, we need indices of the effectiveness of ventilation in controlling the concentrations of indoor-generated air pollutants. Indices are needed that apply at specific locations and, on average, for entire buildings. The two indices described subsequently are based on a measurement technique that is not subject to the limitations and measurement difficulties of the traditional measurement techniques.

The two new indices are the local and global pollutant control index, denoted PCI_l and PCI_g, respectively. These parameters are analogous to time-average pollutant concentrations, thus, lower values of PCI imply better ventilation. For reproducible measurements, the pollutant source is simulated by multiple (e.g., 100) passive tracer gas sources distributed throughout a building at a height of 1 m and spaced approximately uniformly per unit floor area. The sources emit tracer gas continuously at approximately a constant rate, much like building materials emit pollutants (but unlike pollutant emissions from occupants). Indices of the effectiveness of the ventilation in controlling pollutants from other types of simulated pollutant sources (e.g., an intermittent source) could easily be defined.

Indoor tracer-gas concentrations are measured by collecting air/tracer samples on sorbent tubes (4) near the breathing zone of selected occupants. In contrast to existing passive tracer techniques with continuous passive sampling, samples are collected actively using pumps only during the period of occupancy. Sample collection during occupancy on multiple days should be possible.

PCI_l is based on a measurement of a time-average tracer gas concentration during the period(s) of occupancy (e.g., a work day or work week) near individuals' breathing locations. It is calculated based on the equation

$$PCI_l = KC_{avg} \qquad (1)$$

where C_{avg} is the time-average tracer gas concentration at the measurement location and K is a scale factor. K normalizes for building-to-building variation in the strength of tracer sources per unit floor area and adjusts the PCI so that it equals 100 for a reference-case building with perfectly mixed indoor air and continuous ventilation at the minimum rate specified in ASHRAE Standard 62-1989 [10 l/s-occupant and 7 occupants per 100 m^2] (5). The scale factor is determined from the equation

$$K = \frac{70\,A_{floor}}{N\,E_{avg}} \qquad (2)$$

where A_{floor} is the floor area, N is the number of tracer gas sources, and E_{avg} is the average emission rate of tracer sources during the period of deployment in the building.

PCI_g is identical to PCI_l except that it is based the average of multiple measurements of tracer concentrations from sampling locations distributed approximately uniformly throughout the building.

MEASUREMENT SYSTEM

To measure the PCI, the pollutant source must be simulated with a tracer gas, the source emission rate must be known, and the time-average concentration of tracer gas near breathing locations must be measured. We initially intended to measure the PCI using the perfluorocarbon tracer (PFT) system developed at Brookhaven National Laboratory (6). This system consists of small permeation sources of PFTs that can be distributed throughout buildings and diffusion-tubes containing a solid sorbent for continuous diffusive sampling of the PFTs. The quantity of PFT on the sorbent tubes is determined by thermal desorption and analysis using a gas chromatograph with an electron capture detector (GC-ECD). Experiments with this system, using small pumps for active sampling during occupancy (in place of the normal continuous diffusive sampling), yielded unsatisfactory results.

An alternative measurement system is being evaluated. Laboratory tests indicate that several PFTs [perfluorotolulene (C_7F_8), metaperfluorodimethylcyclohexane (C_8F_{16}), perfluoromethylcyclohexane (C_7F_{14}), and perfluorobenzene (C_6F_6)] are readily measurable with a gas chromatograph-mass spectrometer (GC-MS) system. Compared to the GC-ECD, the GC-MS is much less subject to errors resulting from interference by compounds other than the PFTs. However, with the GC-MS system available in our laboratory, larger tracer gas quantities, between a few and several hundred nanograms of tracer, are required for analysis.

With the GC-MS system used for sample analysis, passive PFT sources with higher emission rates than the currently available sources are required for practical measurements of the PCI. A potentially suitable type of source was described in a paper by Stymne and Eliasson (7). The source is based on the permeation of PFTs (which are liquids at room temperature and pressure) from small glass vials with a crimp-on caps and Teflon septa. The PFT diffuses from the inside of the vial through the septa. Stymne and Eliasson abandoned this type of source because of imprecise emission rates. However, we suspected that the imprecision could be a consequence of their use of Teflon septa (which are not very compressible and, thus, form a poor seal) and on the use a crimp-on top for the vial which is designed only for a specific septa thickness. Consequently, we have evaluated sources consisting of glass vials with screw-on caps and numerous combinations of PFTs and septa materials.

Table 1 characterizes several types of sources that have performed well in laboratory tests. In general, we are using silicone septa and a glass vial with a volume of approximately 7 ml. The relative standard deviation in the emission rates of identical sources ranges from 4% to 12%. The emission rates of the different source types range from approximately 1 x 10^{-3} to 5 x 10^{-2} g/day. The lifetimes of the new sources range from one month to a few years. The tracer emission rates increase by about 4% for each degree centigrade increase in temperature. Although a complete independence of emission rate on temperature would be ideal, the PCI concept requires only a repeatable well-characterized source. In addition, many real pollutant sources emit pollutants at rates that increases with temperature.

The sources are easy to produce. Liquid PFT is added to the vial and the cap is screwed on the vial with septa inserted in the cap. An adhesive is applied to the threads of the vial to keep the cap tightly installed.

Table 1. Characteristics of tracer gas emitters.

Tracer	C_7F_8	C_7F_8	C_7F_8	C_7F_{14}	C_7F_{14}	C_8F_{16}	C_8F_{16}	C_6F_6
Septa Material	Silicone	Silicone	Silicone	Silicone	Silicone	Silicone	Silicone	Teflon
Septa Thickness (mm)	1.6	2.4	3.2	1.6	2.4	1.6	2.4	0.25
Emission rate @ 25^{o}C (g/day)	0.051	0.042	0:030	0.0052	0.0044	0.0030	0.0025	0.0013
Lifetime @ 25^{o}C (days)	33	41	57	325	383	569	687	1344
RSD in Emission Rate (%)	4	4	4	5	5	8	9	12
% Change per ^{o}C	4	4	4	4	4	4	5	4
Time Constant*	1 - 2	< 1	1 - 2	4 - 5	4 - 6	5 - 7	-------	2 - 5

* time constant for the change in emission rate after the source is subjected to a step change in temperature

Currently, we are evaluating a sampling procedure based on pumping air containing PFTs through tubes containing multiple solid sorbents (4). The samples are thermally desorbed and analyzed on a calibrated GC-MS yielding a PFT volume. Dividing the PFT volume by the volume of air drawn through the sample tube yields the concentration of PFT. The procedure has been evaluated by sampling and analyzing an airstream with controlled PFT concentrations. The results to date are encouraging. Experiments to determine maximum and minimum sample volumes, and the effects of sample storage are planned.

In a commercial building, the measurement process is relatively simple. The number of tracer sources to be deployed is determined based on an assumed typical ventilation rate and the size and configuration of the building. The sources, which are stored and transported at a typical indoor temperature, are weighed and then deployed in the building, spaced approximately uniformly per unit floor area. A sample flow rate is selected based on the expected indoor PFT concentration, the desired duration of the period of sampling, and the acceptable range of PFT volumes on the sorbent tube. Sample pumps with appropriate flow rates controlled by programmable time switches are deployed at the desired measurement locations with sorbent tubes attached. Sampling occurs according to the programmed schedule, then the sorbent tubes and PFT sources are removed. The sources are re-weighed and the PFT emission rates are determined from the changes in weight. An average emission rate for the building is calculated. The sorbent tubes are analyzed in the laboratory, and the PCI values are calculated.

The measurement system and procedures are similar to those developed previously by Dietz and Cote (6) and used primarily in residences. The major difference is that tracer gas concentrations are measured only during occupancy to determine PCIs while Dietz and Cote (6) employ continuous passive sampling to measure time-average tracer gas concentrations. However, the PCI is a fundamentally different parameter than the ventilation rates measured by Dietz and Cote. The PCI is an index of the effectiveness of pollutant control while the ventilation rates are average outside air flow rates based on steady state mass balances. Steady state mass balances are more appropriate for residences than for commercial buildings which often have highly variable ventilation rates.

ADVANTAGES AND UNRESOLVED MEASUREMENT ISSUES

The advantages of this measurement technique, compared to the traditional measurements of normalized outside air flow rates, are numerous. Valid measurements do not depend on stable air flow rates, perfect mixing of the indoor air, a known or stable occupancy, or a small rate of air infiltration or exfiltration. The PCI can be measured for an extended period of occupancy (e.g., a forty hour work week). If the building ventilation system is shut down at night, the measured PCI values incorporate the impact of the reduced night-time ventilation on pollutant exposure during the period of occupancy. The users of the tracer sources and samplers do not need to be experts in tracer gas techniques or experts in building ventilation. Finally, the labor required to measure PCIs is less than that associated with the performance of tracer gas stepups and decays.

Despite the apparent advantages of the measurement approach, we cannot recommend the use of PCIs until extensive evaluations are completed. The performance (e.g., precision, accuracy, sample storage stability, and potential limitations) of the measurement system will be evaluated in much greater detail. The evaluation will include experiments to determine the extent of tracer adsorption and desorption from indoor surfaces. This adsorption and desorption must be negligible compared to the rate of tracer removal by ventilation.

The measured values of PCI must also be shown to be relatively independent of the specific locations of tracer gas sources. Different patterns of deploying tracer gas sources evenly per unit floor area must yield the same values of PCI, within acceptable limits. Local values of PCI are more likely than global values to be dependent on specific tracer source locations. If mixing of the indoor air is relatively complete within air volumes with a scale comparable to the distance between sources, the PCIs should be independent of the specific locations of sources. Based on our prior tracer gas studies, we expect adequate mixing in many types of buildings. This issue will be investigated by simultaneously deploying sources of different types of tracer gas in different locations within the same building and comparing the measured values of PCI associated with each tracer gas. Measurements in numerous buildings with different types of ventilation (e.g., mechanical with and without recirculation and natural) will be required to determine if PCI measurements that are independent of tracer source locations can be made with a practical number of sources deployed.

SUMMARY

In many buildings, normalized rates of outside air supply (the traditional indicators of ventilation rate) are very difficult to measure accurately. In addition, these measured ventilation rates are generally representative of only a short time period. For many applications, indices of the effectiveness of ventilation in controlling indoor pollutant concentrations are at least as useful as traditional ventilation rates. We have defined two such indices--the local and global pollutant control indices. Through the use of tracer gas sources to simulate real sources of pollutants, practical measurements of these indices should be possible. Further research is required to develop and validate the measurement technique described in this paper.

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REFERENCES

1. Fisk WJ and Faulkner D. Air exchange effectiveness in office buildings: measurement techniques and results. In Preprints of the International Symposium on Room Air Convection and Ventilation Effectiveness, July 22-24, Tokyo, pp. 282-295, Society of Heating, Air Conditioning, and Sanitary Engineers of Japan. Proceedings to be published by ASHRAE, Atlanta.
2. Persily AK and Dols WS. Field measurements of ventilation and ventilation effectiveness in a library building. Proceedings of the 11th AIVC Conference "Ventilation System Performance", vol. 2, pp. 293-314. Published by the Air Infiltration and Ventilation Centre, Coventry, Great Britain.
3. Sheet Metal and Air Conditioning Contractors National Association, Inc.(SMACNA) HVAC systems: Testing, adjusting, and balancing. SMACNA, Tysons Corner, Vienna, Virginia, 1983.
4. Hodgson AT, Binenboym, J, and Girman JR. A multisorbent sampler for volatile organic compounds in indoor air. Proceedings of the 79th Annual Meeting of the Air Pollution Control Association, Minneapolis, Paper 86-37.1, 1986.
5. American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc. ASHRAE Standard 62-1989, Ventilation for acceptable indoor air quality. ASHRAE, Atlanta, GA, 1989.
6. Dietz RN and Cote EA. Air infiltration measurements in a home using a convenient perfluorocarbon tracer technique. Environment International 1982;8(1-6):419-433.
7. Stymne H and Eliasson A. A new passive tracer gas technique for ventilation measurements. Proceedings of the 12th AIVC Conference "Air Movement and Ventilation Control Within Buildings", Ottawa, 1991;3:1-18.

EVALUATION OF DRAUGHT RISK FROM OUTDOOR AIR INTAKES ABOVE THE WINDOW

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ABSTRACT

The air movement caused by three air inlets above the window was measured. The designs were a slot diffuser, a radial ceiling diffuser and a multinozzle radial diffuser. The test room had a triple glazed window and a convective heater below the window. The results show that it is possible to achieve acceptable thermal comfort using air flow rates up to 8 litres per second, at outdoor air temperatures of 0 °C and -20 °C when the draught criterion is based on a 20 percent level of dissatisfied occupants. A supply velocity of more than 2-3 m/s should be used. The curtains and their supports have an unfavourable effect on air movement and draught risk. Jet theory can be used to draw general conclusions regarding the effects of the supply air velocity and mixing properties of the diffuser.

INTRODUCTION

Exhaust ventilation systems without mechanical air supply are common in Finnish residential buildings. In order to obtain a fresh air flow rate that is adequate for living rooms and bedrooms, air inlets should be installed in the outer wall of these rooms. However, during cold periods, draught is a serious problem when using this system. This study aims to find the principles underlying draughtless outdoor air intake.

TEST CASES

Three air inlets were selected for full-scale tests after preliminary analysis using jet flow equations and computational fluid dynamics. The test room is shown in Figure 1. It is 4 m long and 3.5 m wide, the window having a triple glazing and an area of about 1 m^2. The heater below the window is of the convective type: the convective part of the total heat output was more than 90 %.

All three supply air devices (Fig. 2) were installed above the window in the central plane of the room. In the first case the cold air is blown upwards from a 1 metre long slot which is located 0.32 m below the ceiling. In the second case a radial ceiling diffuser just below the ceiling is used. The third case is a multinozzle radial diffuser installed 0.2 m below the ceiling, with the nozzles directed 28 degrees upwards. This case was measured in another, nearly similar test room. In the radial case, additional tests were performed using curtains and their different supporting systems. The pressure losses of air inlet devices were small in order to achieve the highest possible supply air velocity using the available, usually small pressure difference across the external wall. The values of the supply air velocity given in this report were calculated by dividing the air flow rate at a density of 1.2 kg/m^3 by the free area of the supply opening.