INDOOR AIR POLLUTANT MOVEMENT IN A SINGLE STOREY HOUSE BASEMENT UNDER A RANGE OF AIR CIRCULATION CONDITIONS

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A study has been conducted to monitor the concentration, distribution, and transport of indoor airborne contaminants in a basement of a detached house. Using a tracer gas (N_2O) to simulate a single airborne contaminant, this study examines the effect of air temperature distribution in the basement on air circulation and air mixing within the basement over a range of building operating conditions.

Tracer gas data were collected from a single-storey unoccupied residential building with basement using a microcomputer-based data acquisition system. The data acquisition system was designed to monitor tracer gas concentrations taken from a number of locations in the basement. To examine stratification effects in a basement, testing included discharging tracer gas from perimeter line and single point source locations and monitoring the tracer gas concentration at various heights in the basement. Various air circulation strategies were tested which use fans to increase air circulation in the basement.

Results show that, unless auxiliary mixing fans located on or near the floor are used, or the furnace fan with supply air outlets located near the floor is operated continuously, significant spatial variations in tracer gas concentrations may exist.

INTRODUCTION

In any building, there may exist several indoor air pollutants including tobacco smoke, biological contaminants, combustible by-products, formaldehyde, and organic chemicals from household cleaners. Radon gas, which is naturally occurring and present in most soils, is sometimes found in high concentrations in basements of residential buildings. Exposure to elevated levels of one or more of these air contaminants over an extended period of time can lead to serious health problems for residents.

To reduce energy costs and increase human comfort, improved building products and construction techniques have been developed to reduce ambient air infiltration, and thus, heat loss or heat gain. With a decrease in natural ventilation or air infiltration and unless additional forced ventilation is provided, the ventilation rates may be insufficient to remove air contaminants in buildings [1,2]. On the other hand, even buildings with leaky envelopes may experience high levels of indoor air contaminants. For example, houses with internal sub-grade air pressures less than atmosphere can have radon gas drawn in from the soil gas surrounding the basement. Houses with cracked or leaky basement foundations have an increased potential for the infiltration of radon gas into their basements. In addition to air infiltration and ventilation, other factors influencing air contaminant concentrations include the contaminant source strength and location, building construction, geometry, and forced ventilation and internal air circulation, and environmental conditions. While several studies have been conducted to develop control methods for reducing high concentrations of air contaminants such as radon gas [3-5], insufficient tests have been performed to characterize the quality of air in buildings [6].

Depending on the location of the observer in a house, the air quality of a house may or may not appear to be acceptable. For example, air contaminant concentrations may exceed recommended levels in some areas of a house where source strengths are high combined with low or ineffective ventilation [7]. Since house basements usually have cold floors and warm ceilings [8], temperature gradients in basements inhibit convective air circulation and mixing. This inefficient air ventilation and mixing, combined with the fact that a primary entry point of radon gas is through the basement foundation, may result in radon gas concentrations much greater in the basement than elsewhere in houses.

It is the objective of this study to present tracer gas data, used to simulate air contaminants in a house, to assess the movement of indoor air in a test house operated under typical forced and free air circulation modes of operation. Special attention is given to basement air circulation and ventilation where air stratification effects, due to significant vertical temperature gradients, inhibit the removal of contaminants.

METHODOLOGY

Tests were performed in an unoccupied single storey detached house in Saskatoon, Saskatchewan, to examine the distribution of a tracer gas within that space for a variety of ventilation modes of operation. The building envelope consists of wood framed walls (38x140 mm or 2x6 in) with fibreglass batt insulation (3.5 RSI or 20 R), continuous interior vapour barrier extending below the headers, and a stucco exterior finish. Three bedrooms, a kitchen, living room, two bathrooms, and closet and storage areas are located on the main level. The basement, shown in Figure 1, consists of a concrete foundation with floor level about two meters below grade. In the basement, the perimeter walls have no insulation or air barrier and neither the walls nor the floor are painted. A stairwell leading to the basement partially divides the basement into two sections: north and south. The north section contains a natural gas fired forced-air furnace. To minimize interference caused by the furnace fan air circulation with the measurement of typical basement airflows and temperatures, the majority of sampling was performed in the south section of the basement. The total floor area and volume of the basement is 109 m^2 and 281 m^3, respectively.

Air contaminants in houses may originate from single point sources, such as CO from a gas-fired appliance, or a line source, such as radon gas entering through cracks located in the basement foundation. In this study, tracer gas was injected along the wall/floor interface to simulate radon gas infiltrating into the basement through the crack frequently occurring along this interface. N_2O tracer gas was used to simulate a single airborne contaminant.

Experiments performed in the basement included acquiring tracer gas data to estimate the effect of temperature distribution on air circulation in a basement. Also, the use of the central forced-air recirculation fan to improve air mixing within the basement was examined for two cases; 1) supply air outlets in their normal location (near the basement ceiling), and 2) supply air outlets relocated close to the basement floor. Finally, the use of auxiliary mixing fans to enhance air circulation and mixing in the basement was assessed through tracer gas measurements.

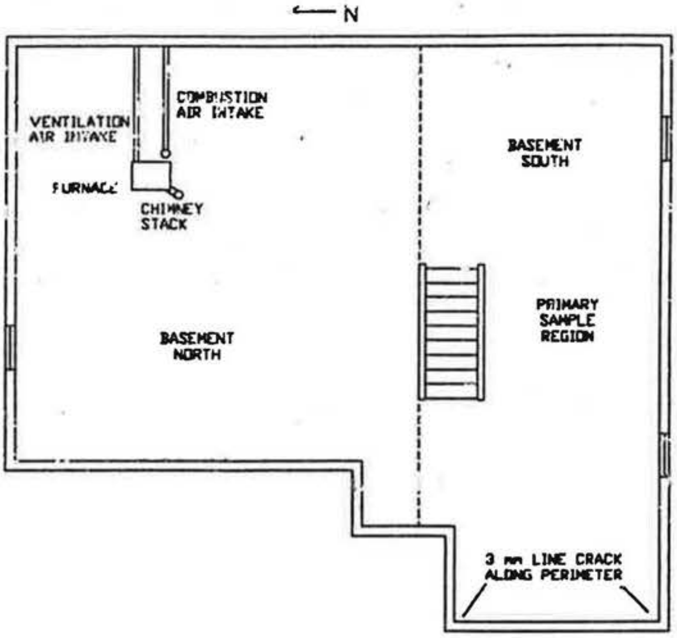

Figure 1. Basement floor plan.

MEASUREMENT SYSTEM

Since air contaminant concentrations in a room may vary spatially and temporally, special attention must be given to describe the spatial and temporal conditions during testing as well as the measurement of tracer gas. To account for temporal and spatial variations in tracer gas or air contaminant measurement, a microcomputer-based data acquisition system, shown in Figure 2, was developed to monitor accurately tracer gas concentrations [9]. A central MS DOS computer with customized software combined with a data logger provide periodic measurement of various air properties. The sampling frequency of the system was selected to record transients in the data, while post-processing of the data enables time average concentrations to be computed over extended periods of time.

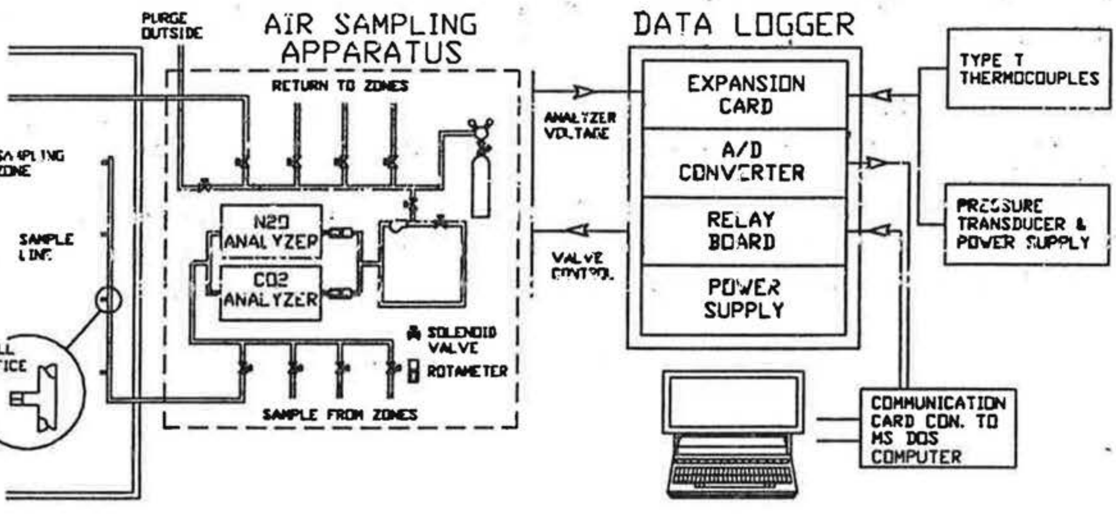

Figure 2. Schematic diagram of data acquisition system and gas sampling apparatus.

Included in the system shown in Figure 2 is a gas sampling apparatus. Solenoid valves, controlled by the microcomputer and a relay board, are located within the gas sampling apparatus. This apparatus allows sampling of tracer gas from one to four zones or from one to four sample locations within one zone. Other components of the data acquisition system include pressure transducers used to measure internal pressure differences (accuracy of ±0.25 pa) and pressure difference across the building envelope, and thermocouples for measuring internal and external temperatures (accuracy of ±0.2°C).

Spatially averaged tracer gas samples are obtained by sampling from multiple orifices along a horizontal, straight-line sampling tube. Tracer gas enters through each small orifices (0.25 mm diameter) spaced at 1.2 m intervals along a copper tube (4.8 mm I.D.), as shown in Figure 2. As the gas sample is drawn in through an orifice, flow is turbulent, allowing the gas sample to mix with air stream within the copper tube, providing a well mixed measurement of tracer gas along a line. To simulate an air contaminant originating from a line source such as the wall/floor interface line in the basement, line discharge tubes, designed similar to the line sampling tubes, were used to discharge tracer gas along the perimeter of the basement. Both the line sampling and line discharge tubes were designed so that the pressure drop across each orifice is much greater than the pressure drop due to flow along the copper tubing, ensuring a uniform sample flow rate or discharge flow rate through each orifice along the length of the tube.

EXPERIMENTAL RESULTS

N_2O tracer gas was injected into the basement either as a pulse or at a continuous rate and monitored over time (after conditions are quasi-steady for the constant rate of injection tests). Five test conditions were examined. They include tracer gas measurement for test conditions with:

1) only natural or free convection air circulation in the basement and main floor of the house for a tracer gas introduced as a multiple-point source near the floor of a basement,
2) only natural or free convection air circulation in the basement and main floor of the house for a tracer gas introduced from a single point source, 1500 mm above the floor,
3) the use of the forced-air recirculation furnace fan to enhance air circulation,
4) the relocation of the supply air outlets close to floor level in the basement to improve air mixing in tests similar to (2), and
5) the use of auxiliary mixing fans to enhance air circulation in the basement.

The location and method of injection used and the tracer gas sample locations for the five test conditions listed above are given in Table 1. Test conditions 1, 2, and 3 are considered to be typical operating conditions for air movement and circulation in a basement while test conditions 4 and 5 are considered to be modified or atypical operating conditions for basement air circulation. The tracer gas profiles for each test are presented in Figures 3 through 7.

Figure 3 shows tracer gas concentrations for the first test condition indicated in Table 1 where air circulation in the basement is due to natural convection alone. It is evident from this figure that a stratification of basement air tracer gas exists. Since the tracer gas was introduced at the perimeter of the floor of the basement, tracer gas concentrations measured close to the floor are higher than those measured at the other sample locations.

When tracer gas was introduced from 1500 mm above the floor in the second test condition (Figure 4), the concentrations close to the floor are the lowest of the four sample locations. From both sets of results, the tracer gas varies by as much as 20% in the vertical direction.

Table 1. Test conditions for tracer gas test.

Test Condition	Method of Injection	Location of Injection (mm above floor)	Location of Samples (mm above floor)	Reference Figure #
1. no mixing fans no furnace fan	constant injection	0 (perimeter) multiple-point	150,600,1200,1800 multiple-point	3 & 8
2. no mixing fans no furnace fan	constant injection	1500 single-point	150,600,1200,1800 multiple-point	4
3. no mixing fans furnace fan on	constant injection	0 (perimeter) multiple-point	150,600,1200,1800 multiple-point	5
4. no mixing fans furnace fan on supply air outlets relocated	constant injection	0 (perimeter) multiple-point	150,600,1200,1800 multiple-point	6
5. mixing fans on no furnace fan	pulse-type injection	1500 single-point	1000 single-point north & south centre	7 & 9

Figure 5 shows tracer gas profiles for the third test condition where the forced-air recirculation fan was used to enhance the mixing of air in the basement. In this mode of operation, four furnace air supply ducts jetted unheated air down from the ceiling at about 40 L/s each. Only one return air inlet was located in the basement. Flow through this return air inlet was almost negligible (not readable by airflow hood). These results suggest that the operation of a furnace fan with this configuration of supply and return ducts, does little to enhance mixing of air in the lower half of the basement. For a tracer gas supplied at the perimeter of the basement floor, local concentrations may be significantly higher in areas where air mixing rates are low such as the lower half of the basement.

In the fourth test condition, the supply air outlets in the basement were extended from the ceiling to floor level using 12 cm diameter flexible ducting. As shown in Figure 6, results were changed significantly. In this case, the tracer gas concentrations measured at the four sample heights are nearly the same at each level (ie. less than 5% difference is seen at any time). These small variations in tracer gas concentrations measured at each height suggests that mixing of air in the basement has increased dramatically.

Figure 7 shows results from a tracer decay test which used auxiliary fans to enhance air circulation in the basement. Two fans located on the basement floor supplied approximately 890 L/sec of air. The total volume of the basement was 281 m^3. The differences in the measured tracer gas concentrations are negligible.

During the tracer gas tests presented above, the air temperatures were measured at the four sample heights to show the thermal stratification of air in the basement. Figure 8 shows the temperature profile for the first test condition where any air movement is due to natural convection alone. These temperatures were obtained at the same time as the tracer gas data presented in Figure 4. Figure 9 shows the temperature profiles for case where mixing fans were used to enhance air circulation in the basement where the corresponding tracer gas data are given in Figure 7.

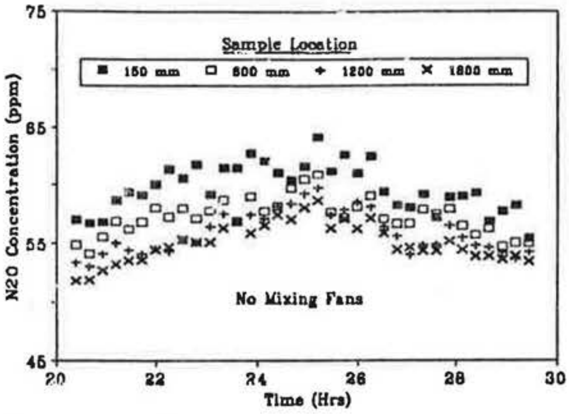

Figure 3. Tracer gas concentration profile for a stratified basement with perimeter discharge at floor level.

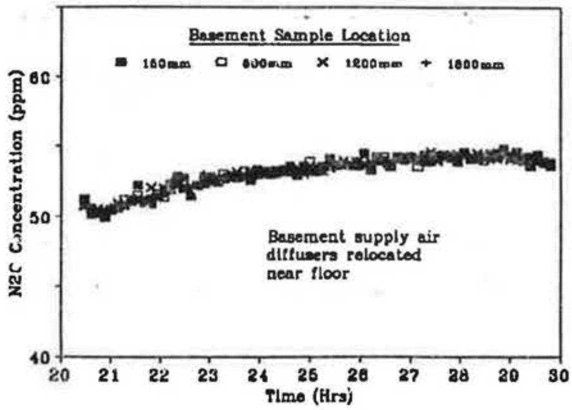

Figure 6. Effect of relocating basement air supply outlets to floor level on tracer gas concentration.

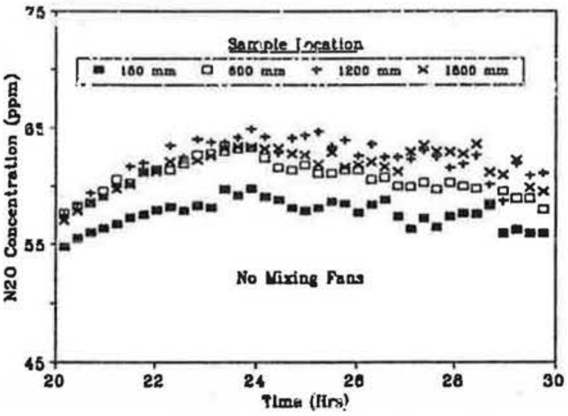

Figure 4. Tracer gas concentration profile for stratified basement with discharge from 1500 mm above the floor.

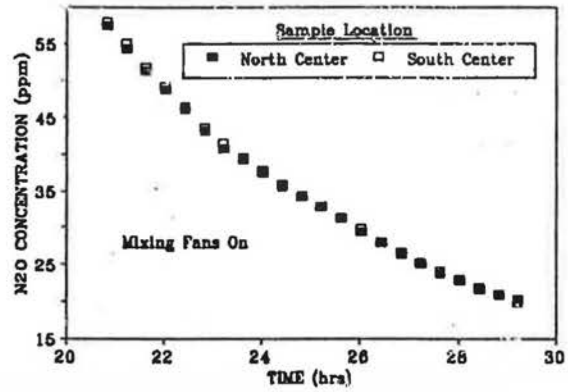

Figure 7. Tracer gas concentration profile for a well mixed basement with pulse-type injection from 1500 mm above the floor.

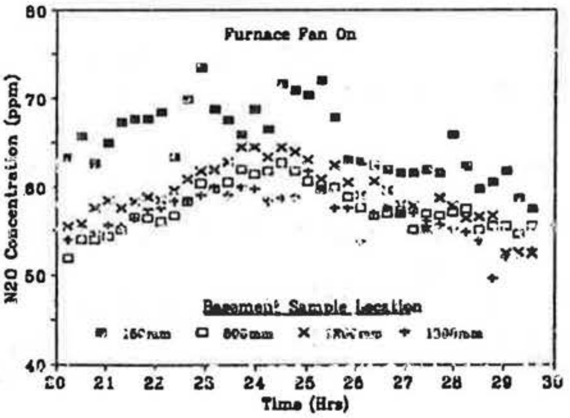

Figure 5. Effect of furnace fan operation on tracer gas concentrations in the basement.

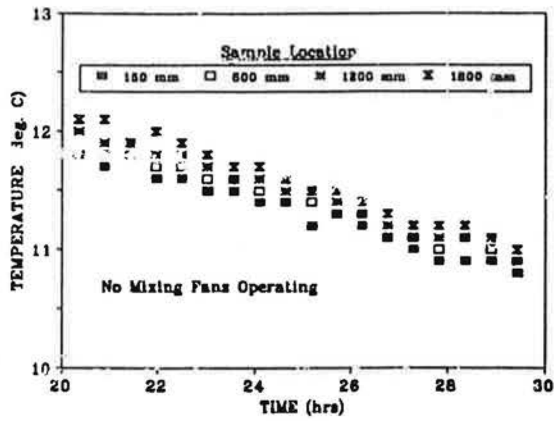

Figure 8. Temperature profile for a stratified basement.

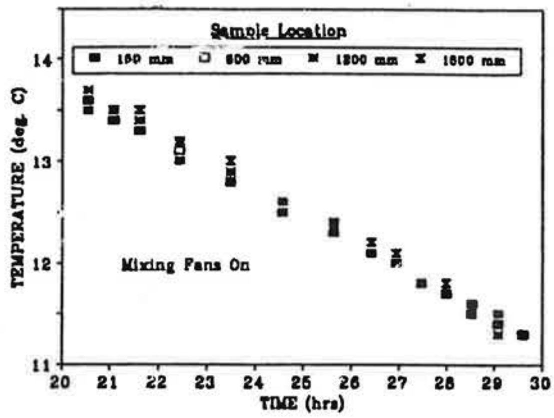

Figure 9. Temperature profile for a well-mixed basement.

Since no auxiliary heating was provided during the test periods shown in Figures 8 and 9, the average basement air temperature decreased during each test. For the case where mixing fans were used to circulate the air (Figure 9), the maximum temperature difference is 0.25°C. The temperature closest to the floor was, at times, even greater than the temperature measured closest to the ceiling. When no mixing fans were used (Figure 8), the difference in temperatures measured from the four sample locations increases to 0.5°C. Over the range of data shown in Figure 8, the temperature closest to the floor is always less than the temperature measured near the ceiling.

DISCUSSION & CONCLUSIONS

From the research work presented in this paper, several general observations can be stated. These are:

1) with no furnace fan or mixing fans operating, basement air tends to stratify with the cool air near the basement floor and the warm air near the ceiling. With this mode of operation, air contaminants supplied near the basement floor can become highly concentrated in the region close to the floor,
2) even with the furnace fan operating and air supplied and returned near the ceiling, basement air remained stratified in the bottom half of the basement. Under this mode of operation, high concentrations of tracer gas persisted in the bottom half of the basement,
3) introducing furnace supply air at basement floor level disrupts stratification and mixes the tracer gas uniformly throughout the basement, and
4) there was little or no measurable temperature or tracer gas stratification of basement air when air mixing was enhanced by auxiliary air circulation fans in the basement.

From these general observations of air movement in a house basement, it can be concluded that:

1) air contaminants, introduced at or near the floor of a house basement (e.g. radon gas), cannot be removed efficiently without modification to the normal or typical modes of air movement in the basement of a house (i.e. test conditions 1, 2, and 3).
2) continuously operating forced air circulation of basement air by either auxiliary fans on or near the basement floor or furnace air supply ducts near the basement floor are necessary to mix the entire basement air if contaminants introduced near the floor are to be removed by an air duct at or near the ceiling (i.e. test conditions 4 and 5).

ACKNOWLEDGEMENTS

The authors wish to extend their gratitude to the Building Science Division of the Saskatchewan

Research Council for their co-operation in the design of the experimental apparatus used in this project, and to the Saskatchewan Community Services - Housing Division for their financial support.

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