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Author
Nazaroff, W.W.

Publication Date
1981-07-01

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To be presented at the
International Symposium on Indoor
Air Pollution, Health and Energy
Conservation, University of Massachusetts,
Amherst, Massachusetts, October 13-16, 1981

LBL-12564
Extended Summary

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W.W. Nazaroff, K.L. Revzan, and A.W. Robb

Building Ventilation and Indoor Air Quality Program
Energy and Environment Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

July 1981

DISCLAIMER

This work was supported by the Assistant Secretary for Environment, Office of Health and Environmental Research, Human Health and Assessments Division, and the Assistant Secretary for Conservation and Solar Energy, Office of Buildings and Community Systems, Buildings Division, of the U.S. Department of Energy under Contract NO. W-7405-ENG-48.

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INTRODUCTION

We have designed and built a highly automated monitoring and control system for studying radon and radon-daughter behavior in residences. The system has been installed in a research "house", a test space contained in a two-story wood-framed building, which allows us to conduct controlled studies of (1) pollutant transport within and between rooms, (2) the dynamics of radon daughter behavior, and (3) techniques for controlling radon and radon daughters. The system's instrumentation is capable of measuring air-exchange rate, four-point radon concentration, individual radon daughter concentrations, indoor temperature and humidity, and outdoor weather parameters (temperature, humidity, modules, wind speed, and wind direction). It is also equipped with modules that control the injection of radon and tracer gas into the test space, the operation of the forced-air furnace, the mechanical ventilation system, and the mixing fans located in each room. A microcomputer controls the experiments and records the data on magnetic tape and on a printing terminal. The data on tape is transferred to a larger computer system for reduction and analysis. As programmed, the computer allows substantial flexibility in experimental design, thus allowing us to collect large amounts of data from diverse experiments with relatively little manual effort.

The test space, three rooms on the first floor with a total floor area of 54 m^2, has been renovated to assure that the thermal and air-leakage characteristics of the envelope conform to current energy-efficient building practices. Heat is provided by a forced-air furnace with supply registers located in each room. The furnace fan draws air from the test space and from the outside, the proportions determined by the position of two motor-driven dampers in the return-air duct which are interfaced to the computer. Each room has several small blowers mounted on the walls to facilitate mixing. The speed of the blowers is controlled by variable transformers, and their power is switched under computer control. Except for the radon daughter analyzer, the instrumentation system is located in a fourth first-floor room that is isolated from the test space.

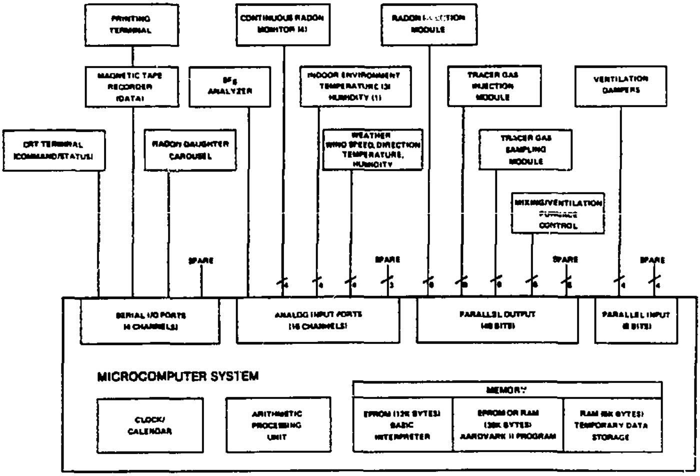
In this paper we describe the essential design and function of the instrumentation system, as a whole, singling out those components that measure ventilation rate, radon concentration, and radon daughter concentrations.

RESULTS

Microcomputer System

The microcomputer system is a modified commercial product (Intel 80/20-4) that has four circuit boards in a chassis with a power supply. The microcomputer chip is the key element of one board. Two of the remaining boards contain most of the system memory which is of two types: radom-access memory (RAM) for data and temporary program storage, and erasable programmable read-only memory (EPROM) for storing programs over long time periods. The fourth circuit board contains special circuits such as a real-time calendar/clock and a 16-channel analog multiplexer coupled to an analog-to-digital converter. The microcomputer system and its interfaces to the other components of the instrumentation system are shown schematically below.

INSTRUMENTATION SYSTEM — RADON RESEARCH HOUSE



The uncommitted interface links are available to accommodate additional instruments and/or to control other devices that future experimental goals may require.

The system software was designed to allow great flexibility in experimental specification and to be relatively easy and inexpensive to develop and modify. The program through which the user communicates with the system, written in Basic allows the user to command the system to automatically execute a series of quite different experiments. An interpreter for the Basic program resides in EPROM (McGoldrick et al., 1978).

Ventilation Measurement

Ventilation rate is measured by tracer gas decay using sulfur hexafluoride (SF_6). In the simplest case, where the air within the test space is considered to be well-mixed, the time constant in the exponential decay of the tracer gas concentration gives the ventilation rate. Our system can sequentially sample the concentration at four points with a minimum interval of one minute between samples, the limiting facter being the response of the SF_6 analyzer. Nominally, three of these points would be used to measure the concentration of SF_6 in the three rooms, allowing us to determine the degree of mixing among the rooms. We have also provided four injection lines that are switched on and off by the computer; the flow rate for the tracer is adjuster manually. Three of these lines, their outlets placed near mixing fans, are used to supply SF_6 independently to the three rooms; the fourth line is installed in the furnace return duct to supply the entire test space. The SF_6 concentration is measured by a commercially-available, non-dispersive infrared (NDIR) analyzer (Foxboro Wilks, Model Miran 101), calibrated using three compressed-air tanks containing known concentrations of SF_6.

In addition to using SF_6 for measuring ventilation rates, we plan to use this tracer gas to examine air movement and mixing within a room and between rooms.

Radon Injection and Measurement

We inject radon into the test space up to a concentration of about 50 pCi/l--the high end of the range of concentrations found in houses. Setting the concentration at this level allows us to measure radon and radon daughters fairly precisely and is also high enough to assure that contributions of outdoor levels of radon and daughters will not affect indoor levels. The radon we inject is derived form 200 microcuries of ^{226}Ra, precipitated as a stearate. The radium is contained between two filters in a specially-designed, stainless-steel holder. Air is blown through the holder and distributed to four points: one in each of the three rooms, and one mounted below the roof eave outdoors.

The radon concentration is measured with a Continuous Radon Monitor (CRM) after the design of Thomas (Thomas and Countess, 1979). Filtered air is drawn through a scintillation cell, 170 ml in volume. Alpha particles that are created within the cell from the decay of radon and two of its daughters, ^{218}Po and ^{214}Po, produce light flashes when they strike the phosphor. The light is detected by a photomultiplier tube; the signal is then amplified and the pulses counted. There are four CRMs in this instrumentation system--one for each room with the fourth uncommitted. Each radon monitor is interfaced to the computer through an analog input channel. The output voltage of the CRM is proportional to the total in its counter, which resets automatically after reaching 1023 counts. The radon monitors are calibrated by comparing their response to that of a scintillation cell calibrated with standard reference method ^{226}Ra solution (National Bureau of Standards). The sensitivity of the monitor, defined as the concentration at which the relative standard deviation in the measurement is 50%, is 0.2 pCi/l for a three-hour integration interval.

Radon Daughter Measurement

Radon daughter concentrations are measured with an automated instrument, the Radon Daughter Carousel (RDC), which has seven filter holders mounted near the edge of and uniformly spaced around a platter, 25 cm in diameter. Air is drawn through a filter (Millipore, 25 mm diameter, 0.4-0.8 micron pore size) nominally at 10 l/m for 10 minutes. The filter is then advanced to the counting station where a solid-state detector and associated electronics count separately the alpha decays from ^{218}Po and ^{214}Po. The sampling and counting stations are fixed; the platter is rotated to select which filter is used for sampling or is counted . The results from two counting intervals are used to calculate the concentrations in air of the radon daughters: ^{218}Po, ^{214}Pb, and ^{214}Bi. With a detector efficiency of 0.2 (counts/disintegration), and a total measurement time of 40 minutes, the individual daughter concentrations are measured with a relative standard deviation of 20% at concentrations of roughly 0.5 pCi/l (Nazaroff et al., 1981). A dedicated microprocessor controls the operation of the RDC. It can be programmed to operate over a wide range of timing schemes. The microprocessor communicates with the main microcomputer system through a serial port.

CONCLUSIONS

This automated instrumentation system is completely operational with the exceptions of the radon daughter carousel, the radon source module, and the ventilation dampers, all of which are in the final stages of development. Already the system has proved useful in studying the rates of mixing within a room, with and without forced convection. In the first few months of using the system, we experienced a few problems that appear to be related to the quality of the 115 VAC power in the research house; to correct these problems we plan to add an isolation transformer and a back-up power supply to the system. We are presently planning a wide range of experiments using this system and, because expansion capabilities have been designed-in, we are assured of being able to accommodate future research goals. Although built for a specific research project on indoor radon, the system could easily be reconfigured for use in other indoor air quality research projects.

ACKNOWLEDGEMENT

This work was supported by the Assistant Secretary for Environment, Office of Health and Environmental Research, Human Health and Assessments Division, and the Assistant Secretary for Conservation and Solar Energy, Office of Buildings and Community Systems, Buildings Division, of the U.S. Department of Energy under Contract No. W-7405-Eng-48.

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