SERI/TP-254-1638
UC Category: 59c
Preprint

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June 1982

To Be Presented at the
Seventh National ASES Passive Conference
Knoxville, Tenn.; 29 Aug. - 1 Sept. 1982

Prepared Under Task No. 1053.00
WPA No. 02-304

Solar Energy Research Institute
A Division of Midwest Research Institute

1617 Cole Boulevard
Golden, Colorado 80401

Prepared for the
U.S. Department of Energy
Contract No. EG-77-C-01-4042

Printed in the United States of America
Available from:
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
Price:
Microfiche $3.00
Printed Copy $4.00

A MULTIZONE INFILTRATION MONITORING SYSTEM

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ABSTRACT

The Solar Energy Research Institute (SERI) has developed a multizone infiltration monitoring system (MIMS) using a single tracer gas. MIMS measures zonal infiltration and exfiltration as well as interzonal air movement rates. The system has been used at the 4-zone test house at the SERI interim field site, and this paper presents preliminary results. The present system can determine zonal infiltration rates, and the results show significant differences in infiltration rates for the various zones.

1. INTRODUCTION

An understanding of the basic thermophysical processes in buildings is necessary before one can make accurate predictions of energy loads and flows. Many heat flow mechanisms in buildings have been adequately described, and can be modeled quite accurately with existing algorithms. However, several other such mechanisms extremely important to building energy flows are neither well understood nor adequately described. These include heat transfer using natural air movement, ground coupling, and diffuse sky radiation. This paper describes work done on a system to monitor interzonal air movement and infiltration rates in a multizoned building using a single tracer gas and a single instrument to measure the tracer gas concentrations.

2. PREVIOUS WORK

There are several methods and variations thereof that directly and indirectly measure air infiltration rates in buildings. These techniques are generally classified as blower door and tracer gas methods.

The blower door method uses a fan, usually mounted in a frame that replaces an exterior door, to pressurize or depressurize a building. The air pressure differences between the inside and outside of the building and the corresponding air flow rates through the fan are measured. The air flow rates are determined by using fan curves and rpm measurements (1) or a calibrated nozzle at the inlet to the fan (2). The indoor/outdoor pressure differences and the air flow rates are compared, and a measure of the building's tightness, such as the effective crack area, is calculated by using a simple mathematical model [see e.g., Sherman (3)]. These results can then be used to calculate air infiltration rates if indoor/outdoor pressure differences are either assumed at some nominal value (2) or are determined from measured weather data (3). Blower door tests are relatively simple to perform, and data derived from them can be used to predict whole building infiltration rates to about 15%-30% as a function of time and weather conditions (3).

Tracer gas methods involve introducing a gas into the air in a building and measuring its subsequent concentration over a period of time. Two tracer gas techniques are generally used. The decay method involves the initial injection of a tracer gas and measuring its concentration over a period of time. Single tracer gas decays are useful for single mixed zones (4). Using a multiple tracer gas system has also been proposed for multizone buildings (5), but no results from these systems have been published to our knowledge. These systems require using a separate tracer gas measuring instrument for each gas.

The continuous infiltration monitoring system, developed at Lawrence Berkeley Laboratory, is another tracer gas method (6). The equipment and software used in this technique continuously monitor the tracer gas concentration in a building volume and constantly inject enough tracer gas to keep the concentration relatively level. This method has microprocessor-controlled hardware and can be used to obtain single-zone infiltration data over a relatively long period of time.

Tracer gas methods generally use either chromatographs (5) or infrared spectral analyzers [e.g., see Strong (6)] to measure gas concentrations. Typically, the measuring instrument is installed at the building being monitored, and gas samples enter the machine by pumps and tubing (6). Variations include using plastic bags to collect samples at remote sites for later analysis with a chromatograph or spectral analyzer (7). Tracer gas techniques can produce accuracies on the order of 5%-10% (4).

3. A SINGLE GAS MULTIZONE SYSTEM

Our group at the Solar Energy Research Institute (SERI) is involved in both Class A instrumentation of multizone residential building and validation of building energy analysis simulation codes (8). After investigating existing techniques for measuring infiltration rates, we discovered that no affordable method was available to provide the detailed air movement information needed for these tasks. Blower door and single tracer gas techniques gave, at best, infiltration rates for a single mixed zone. Multiple tracer gas techniques provide enough detailed information, but require several relatively expensive gas detectors. We decided to develop a system with multizone infiltration and air exchange measurement capabilities, yet with only a single infrared spectral analyzer as a gas concentration detector.

The multizone infiltration measurement system (MIMS) was installed in our test house at the SERI test facility in Golden, Colo. The test house is designed to provide experimental data for all dominant energy transfer mechanisms in a typical but controlled, unoccupied residence. The data will be used initially to validate public domain building energy analysis codes on both the overall system and the thermal mechanism level (8).

4. THEORETICAL BASIS

A schematic of the test house is shown in Fig. 1, including zone numbers 0 through 4 with zone 0 as the outside. In general, if the same tracer gas is introduced into each zone (except outside) and allowed to decay, the instantaneous decay rate for each zone would be:

$$\frac{\partial \rho_i}{\partial \tau} = \sum_{j=0}^{4} C_{j\to i} (\rho_j - \rho_i) \qquad [1]$$

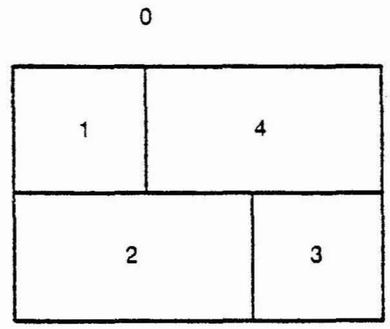

Figure 1. Schematic of the Test Building Showing Zone Numbers (0=outside)

where

$\frac{\partial \rho_i}{\partial \tau}$ = the instantaneous concentration decay rate in zone i

$C_{j\to i}$ = the air flow rate from zone j to zone i, $C_{j\to i} > 0$

ρ_j = the tracer gas concentrations in zone j, $\rho_o = 0$

τ = time.

Initial concentrations $\rho_j(0)$ are arbitrary, being set chiefly by measurement range. Hence, Eq. 1 constitutes a set of four coupled first order, ordinary differential equations, which are linear if $C_{i\to j}$ is assumed constant.

The ρ_j values for each zone can be measured as a function of time. If enough of these measurements are made, air flow rates $C_{j\to i}$ can be determined using regression techniques. A five zone situation requires that 25 $C_{j\to i}$ terms be defined. However, with our test building, we can reduce this number. First, we state

$$C_{ii} = 0 \quad . \qquad [2]$$

This means that a zone does not exchange air with itself. Second, it can be seen in Fig. 1 that zones 1 and 3 do not directly communicate with each other. Thus we see

$$C_{3\to 1} = C_{1\to 3} = 0 \quad . \qquad [3]$$

This leaves 18 undefined $C_{j\to i}$ terms. The problem also can be reasonably constrained if one assumes incompressible conditions and conservation of mass for the air in each zone; i.e.,

$$\sum_j C_{i\to j} = \sum_j C_{j\to i} \text{ for each } i > 0 \quad . \qquad [4]$$

5. SYSTEM HARDWARE AND SOFTWARE

The basic configuration of MIMS is shown in Fig. 2. Basically, a minicomputer controls sampling/injection valves and data lines through a standard control and data interface. The computer is a 250 Kbyte MODCOMP CLASSIC minisystem, with main peripherals including a 50-Megabyte disk for data storage, 9-track tape drive, and line printer. SERI has developed software to execute the basic injection/decay-monitoring pattern shown in Fig. 3. The software allows parameters to be input as desired to experimentally optimize the system operation. The parameters typically used imply that each zone is sampled about every 20 minutes, except when gas is injected. After each injection, data are analyzed to determine the actual injection rate. This calculated rate is then used to compute the time needed to keep the injection valves open to bring the zone concentrations all back to the desired maximum at the next injection. In these experiments, all zones are initialized at ρ_{max} = 225 ppm and allowed to run several hours (usually 10-14 hours) until any zone falls below 25 ppm (ρ_{min}). Gas injection then occurs in all four zones.

We used an infrared analyzer to measure the tracer gas, sulfurhexafluoride (SF_6), concentration in the range 0-250 ppm. Instrument accuracy varies from about 5% to 30%, depending on signal magnitude and how the significant zero drift is accounted for. The analyzer air input was controlled by positive-closure solenoid valves. We installed a booster pump on the analyzer air output to properly balance the air flow rates through the long sampling lines.

6. DATA ANALYSIS TECHNIQUE

Data, in the form of tracer gas concentrations, are available at a series of times, sequenced through the four zones (see Fig. 4). The parameters, $C_{j\to i}$, in Eq. 1

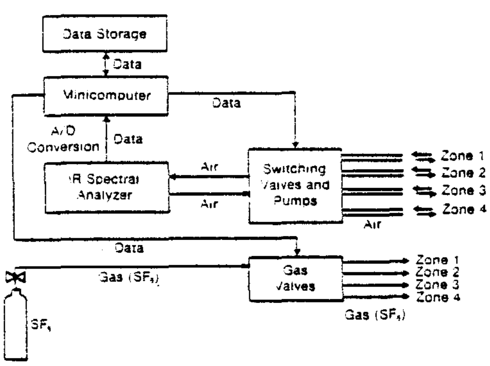

Figure 2. Flowchart of MIMS for Four Zones

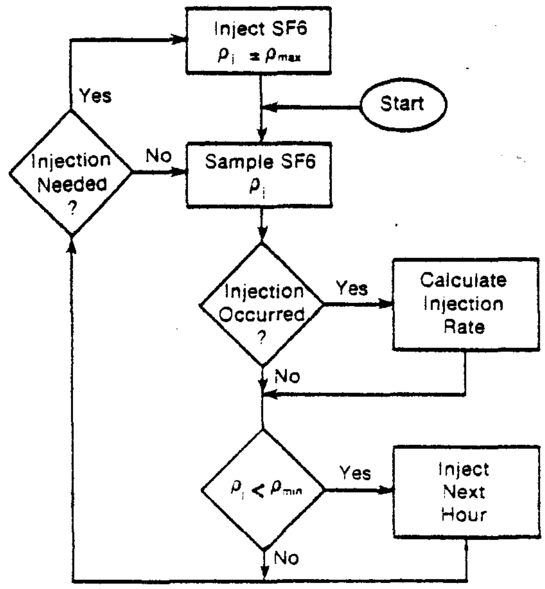

Figure 3. Flowchart of the Tracer Gas Injection and Decay Monitoring

are subject to the constraints in Eqs. 2, 3, and 4 and are estimated using a constrained nonlinear parameter search technique. This technique efficiently finds parameter sets that define local minima of the sum of the residuals between the calculated and measured tracer gas concentrations.

Each $C_{j\to i}$ term generally is not a constant over a period of time. The parameter estimation technique will give average values over a data sampling period. We chose hourly windows as our period since this fulfills the input needs of our validation work. We determined that we needed at least five sample concentration measurements from each house zone, 20 in all, for a meaningful estimation of the 18 parameters. (The sampling scheme is shown in Fig. 4.) Samples for each zone are taken approximately 20 minutes apart, and samples from before the hour begins and after it ends are used. Each sample point in Fig. 4 is determined by taking several measurements over a few minutes and using a regression technique to derive a concentration at the beginning of the period.

After sampling for one hour, the window is moved one hour ahead in time. Each hour's data can be used to estimate a complete set of parameters $C_{j\to i}$. Thus, we can calculate each air flow and infiltration rate as an hourly averaged function of time. The hourly averages for each flow path can be correlated to measured weather data, for example:

$$C_{j\to i} = A_{j\to i} + B_{j\to i}(T_j - T_i)^L + D_{j\to i}(V_{ew}^n) + E_{j\to i}(V_{ns}^n) \quad [5]$$

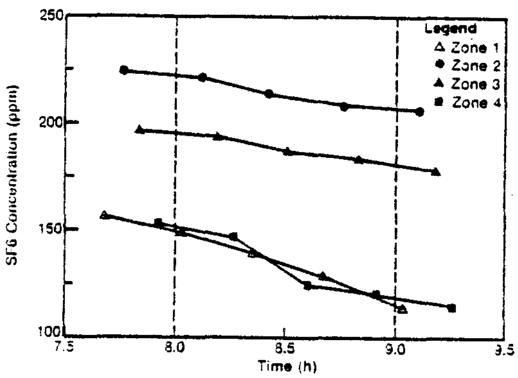

Figure 4. Sample Data for One Hour, Four Hours After All Zones Were Initialized at About 225 ppm

where

$A_{j\to i}, B_{j\to i}, D_{j\to i}, E_{j\to i}, L, m, n$

= constants

T_i = temperature of zone i

V_{ew} = east-west component of the wind velocity

V_{ns} = north-south component of the wind velocity.

Once these correlations are developed, they can be used to extrapolate to times outside of the experimental period, or to interpolate to fill in gaps in the data.

7. STATUS OF RESULTS

We ran MIMS in the Class A test house during the spring of 1982. We operated the system so that SF6 concentrations after a gas release were about 225 ppm in each zone. Analysis of the data showed that several of the hourly air flow rates could be consistently determined when the regression search technique was started from different points in the 18-parameter space (see Fig. 5). In fact, these results were developed by using two starting points on ten sets of consecutive hourly data. These flow rates were, in general, associated with the greatest difference in SF6 concentrations between the zones. Since $P_0 = 0$, these include the infiltration rates for each zone $C_{0\to i}$. It should be noted that these paths are also the most important from a thermal point of view. The other flow rates could vary greatly, depending on the starting point for the regression search.

8. FUTURE WORK

We are developing an approach to increase the experimental sensitivity to all the air flow rates. This involves initializing tracer gas concentrations at systematically different levels, thus ensuring that large differences in concentration exist between adjacent zones. (This strategy involves only software changes.) If this approach is inadequate, the system can easily be converted to a multigas system using multiple gas detectors in series.

9. CONCLUSIONS

MIMS has been used in a 4-zone residence. Preliminary results indicate that zone-by-zone infiltration rates can be derived using a single tracer gas, but interzonal rates are generally not well determined. Infiltration rates in the various zones differ greatly, implying that zone-by-zone validation of computer simulations is very questionable without some input of the infiltration characteristics of each zone. Work is proceeding to better determine interzonal rates. This will open the door to the study of natural convection from high insolation zones, such as sunspace or direct gain designs.

10. ACKNOWLEDGMENTS

We are extremely indebted to several individuals who made the development of MIMS possible. Kelvin Harr was primarily responsible for procuring materials and designing the gas distribution systems. Charles Morgan built MIMS and designed some of the electronic circuitry needed to interface with the minicomputer. Mark McDade was responsible for implementing

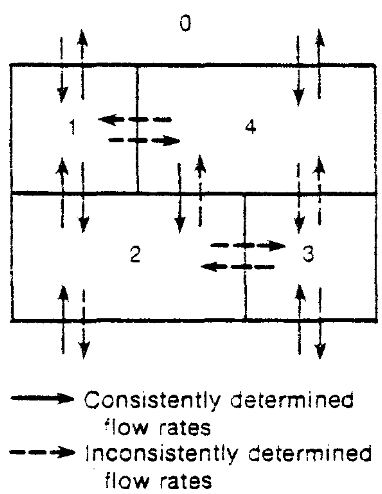

Figure 5. Air Flow Rates That Can Be Determined Using Current Experimental and Analysis Schemes

the control algorithms on the minicomputer. Robert O'Doherty developed the multiparameter, nonlinear regression technique.

This work was funded by the U.S. Department of Energy Systems Research and Development Branch, Passive and Hybrid Solar Heat Technologies.

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