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A Low-Cost Method for Measuring Air Infiltration Rates in a Large Sample of Dwellings

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RATES IN A LARGE SAMPLE OF DWELLINGS

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A method for collecting air infiltration data in a large sample
of dwellings is presented. The method consists of a tracer-gas dilution
technique employing air sample bags which are analyzed in a central lab-
oratory. The method will be applied to a Community Services Administra-
tion optimal weatherization demonstration in approximately 300 dwellings
on 16 sites throughout the United States. The method will yield air
exchange rates under typical heating season condition for each dwelling
in the demonstrations. Preliminary data on air infiltration rates in
low-income housing in Portland, Maine are presented.

Key Words: Air infiltration; air sample bags; energy conservation;
            retrofit; sulfur hexafluoride; tracer gas; weatherization.

1. INTRODUCTION

The leakage of air into and out of the living space of a dwelling is one of the major components of heat loss of a home. Though recent advances in instrumentation have made it possible to automatically measure the air leakage rate of a building, the techniques to obtain actual air leakage rates are both expensive and difficult. In an attempt to measure the actual air infiltration rates in low-income housing and to determine the effectiveness of various weatherization measures on reducing the air leakage in a home, a measurement technique using a tracer gas and air sample bags has been developed. Preliminary data on air leakage rates from homes in Portland, Maine have been collected. These measurements are part of an evaluation of a weatherization project undertaken by the Community Services Administration.

The Community Services Administration (CSA), in order to assess how it might help poor people to cope with increasing energy costs, has undertaken a weatherization demonstration project whose major goal is to provide data for determining the optimal level of weatherization which should be applied to the residences occupied by the poor in various climatic zones in the continental United States. The Center for Building Technology of the National Bureau of Standards (NBS) has been given the role of providing technical assistance and support for this demonstration. This role involves selecting demonstration cities, selecting homes in each city, selecting weatherization options both for the building envelope and the buildings' mechanical system, supervising the collection of the data from the demonstration, developing test procedures for evaluating the effect of weatherization on the homes, and analyzing the results of the demonstration. The demonstration project is to be undertaken in 16 cities. These are graphically shown in Figure 1, along with the degree days for each location. At each site, approximately 20 to 30 homes will be weatherized.

The principal measure of the effectiveness of the weatherization of each dwelling will be the observed reduction in the utility bills of the dwelling. However, in order to assess in more detail the savings from each option and to explain anticipated variations in the amount of saving accrued among the homes, a series of tests for both the building envelope and the mechanical system has been developed. The building envelope tests currently being planned consist of: 1) a thermographic survey of the exterior of the dwellings, 2) air infiltration tests, 3) determination of the interior temperature stratification, and 4) the determination of the existence of heat by-pass mechanisms into attic and basement. The infiltration tests will consist of: 1) a test method for determining the actual air leakage rates in each dwelling, 2) a fan pressurization test, and 3) a test for locating the air leakage paths still existing in the dwelling after weatherization, employing fan depressurization and an infrared scanner. The topic of this paper is to describe the test method for determining the air leakage rate in each dwelling.

1

Figure 1. Site selected for demonstration.
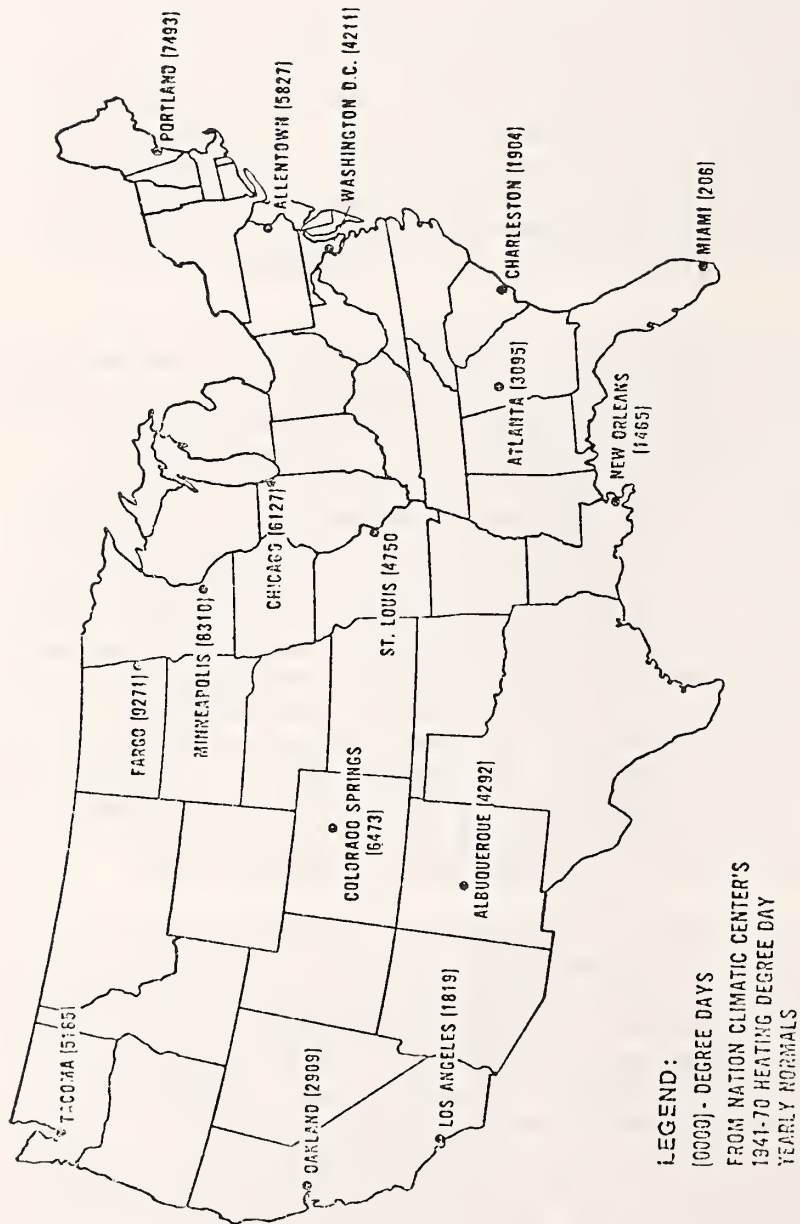
LEGEND:

(0000) - DEGREE DAYS

FROM NATION CLIMATIC CENTER'S
1941-70 HEATING DEGREE DAY
YEARLY NORMALS

PORTLAND [7493]

ALLENTOWN [5827]

WASHINGTON D.C. [4211]

CHARLESTON [1904]

MIAMI [206]

ATLANTA [3095]

NEW ORLEANS
[1465]

CHICAGO [6127]

ST. LOUIS [4750]

MINNEAPOLIS [8310]

FARGO [9271]

COLORADO SPRINGS
[6473]

ALBUQUERQUE [4292]

TACOMA [5185]

OAKLAND [2909]

LOS ANGELES [1819]

2

In attempting to assess the air leakage charcteristics of a dwelling, in the author's opinion, four classes of questions are usually asked: 1) what are the actual air leakage rates occurring in the structure under various climatic conditions and usage patterns; 2) how tight is the building compared with other buildings and with itself after certain measures are applied to the building; 3) where are the leakage paths in the structure; and 4) what is the severity of each air leakage path. The actual air infiltration rate of a building is usually determined by the tracer-gas dilution method [1, 2]. The tightness of a building can be obtained by the tracer-gas method, but the fan pressurization method is easier to perform [3-5]. The location of air leakage paths can be observed using thermography, either under normal weather conditions [6] or in conjunction with pressurization of the building [5]. It is very difficult to determine the amount of air leakage attributable to each air leakage path. Attempts at this level of quantification usually consist of sealing the observed openings and using either the tracer-gas method or the pressurization method to determine the reduction in air leakage.

As mentioned above, the actual air infiltration rates in dwellings are usually determined by the tracer-gas technique. In the CSA weatherization demonstration, one would like to know the actual air leakage rates in each of the demonstration homes, at least after weatherization has been performed and preferably both before and after weatherization. Though the tracer-gas technique has the reputation of being difficult to perform and requires both highly trained personnel and expensive equipment, it is the author's opinion that this method can be modified through the use of air sample bags such that it can be applied to a large collection of dwellings by relatively inexperienced persons (possibly even the building occupant) in an inexpensive manner. The method will provide actual air exchange rates under various weather conditions which can be used to assess the typical air leakage performance of the building. The following sections will describe this method.

2. DESCRIPTION OF TEST PROCEDURE

The normal tracer-gas technique for measuring air infiltration con-
sists of injecting a quantity of tracer gas into a building in such
a manner that the tracer gas is well mixed and then to measure the
rate of decay of this tracer gas using appropriate monitoring equip-
ment. Sulfur hexafluoride (SF_6) is becoming extremely popular for
this type of work and this paper will be restricted to that tracer
gas. Normally after assuring that the initial quantity of tracer-
gas is well mixed in the dwelling, concentration measurements are made
at 5- to 15-minute intervals. The air exchange rate is determined by
fitting the best exponential curve to the concentration decay data.
The main reasons that this method is complicated and expensive are:
1) the concentration monitoring equipment is costly; 2) its use
requires highly trained technicians; and 3) the duration of the test
is usually 2 to 4 hours. In principle, the method leads to a detailed
record of air exchange rates during the period of the test; however,
an error analysis (see Hunt [1]) shows that for short time durations
small errors in the determination of the concentration lead to signif-
icant errors in the determination of the air exchange rate. Also for
the purpose of assessing the effect of air infiltration on the building
heating load, the average air exchange rate over a period of one or
two hours is of primary interest. For the CSA weatherization
project, one would like to obtain for each weatherized dwelling this
average air exchange rate under 5 to 10 different weather conditions
which are more or less representative of the varying conditions expe-
rienced by the building during the heating season. It would require
at least one trained technician and one SF_6 concentration-monitoring
apparatus per city to obtain this quantity of data. The resources for
this, both monetary and personnel, are not available.

The proposed method for obtaining these data for the CSA weatherization
demonstrations consists basically of replacing the determination of the
decay rate of the tracer gas by concentration monitoring equipment
deployed in the building with the analysis in the laboratory of air
sample bags filled at intervals of one to two hours duration. The
testing of the building would be undertaken in a process consisting
of seven steps. The steps are graphically shown in Figure 2.

Step 1: Injection of Tracer Gas (SF_6) into the Dwelling

A predetermined quantity of the tracer gas SF_6 is initially injected
into the building such that the initial concentration of SF_6 is 100
to 150 parts per billion or approximately 10 to 15 mℓ of SF_6 per
1000 m^3 of living space. The author has been using 30 mℓ graduated
syringes for this injection. These can be prepared before the test
or filled from a bottle of compressed SF_6 at the site. The injection
is accomplished by slowly walking along the dwelling injecting gas into
each room in a quantity approximately portional to the volume of the
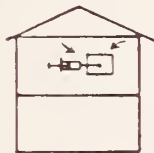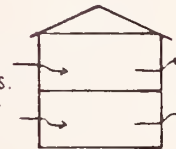room. The graduation on the syringe greatly aids in this process.

STEP 1
INJECTION

STEP 2
MIXING
½—1 hr.
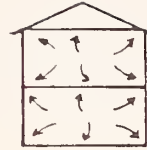
STEP 3
FILL SAMPLE
BAG

STEP 4
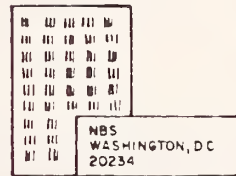WAIT 1—2 hrs.

STEP 5
FILL 2nd
SAMPLE BAG
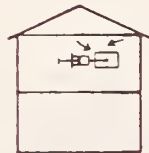
STEP 6
SHIP BAGS TO
LABORATORY

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STEP 7
DETERMINE
TRACER
CONCENTRATIONS
IN LABORATORY

SF_6 DETECTOR

FIELD
EQUIPMENT

SYRINGES OF
TRACER GAS SF_6

HAND SAMPLE
PUMP

AIR SAMPLE BAGS
(2 per floor)

Figure 2.   Outline of procedure.

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Step 2: Mixing of Tracer Gas in Dwelling

A waiting period of approximately 1/2 hour to 1 hour should then be
allowed for proper mixing of the tracer gas. For a building with a
forced air heating system, the fan on the furnace can be turned on to
assist in the mixing; however, the author's experience is that natural
convection currents even in dwellings without an air handling system
will well mix the tracer gas at least on each floor of the building
(if the doors between rooms are open). There does seem to be a ten-
dency for the concentration of the tracer gas to be higher on the
upper floors, probably due to the natural convection currents caused
by rising warm air.

Step 3: Fill Initial Sample Bags

After adequate mixing of the tracer gas an initial air sample bag is
filled for each floor of living space. This is accomplished by walk-
ing around the floor filling the bag in the process with a small sample
pump. This will provide an integrated sample. The author has been
using a 10-liter, five-layer air sample bag and either a hand pump
(the type used to fill footballs and basketballs) or a small portable
battery-powered pump. The important criterion is that the air sample
bag must be filled slowly, thus ensuring that an integrated sample be
obtained (the hand pump requires about fifty strokes to fill the bag,
the battery pump approximately five minutes).

Step 4: Decay of Tracer Gas

One then waits one or two hours for the tracer gas to decay. During
this period the occupants of the dwelling undergo their normal
activities and the mechanical system is left in its normal operating
mode.

Step 5: Fill Final Sample Bags

The procedure in Step 3 is repeated obtaining a second sample bag of
air for each floor of the building.

Step 6: Ship Sample Bags to Laboratory

The sample bags are then shipped to a center laboratory (in this case
the National Bureau of Standards) for analysis.

Step 7: Determination of Tracer Gas Concentration

The tracer gas concentrations are determined in the central labora-
tory using an electron-capture gas chromatograph. The air infiltra-
tion rate AI is then determined by the equation

$$AI = \frac{1}{\Delta \tau} \ln (C_1/C_2) \tag{1}$$

where C_1 and C_2 are the initial and final tracer gas concentrations respectively, and $\Delta\tau$ is the time interval in hours between filling of the sample bags. For periods of 1 to 2 hours, equation (1) is an accurate manner for determining the air exchange (see Ref. [1]). The above steps are graphically shown in Figure 2.

The above-described method is easy to perform and inexpensive, and if several homes are grouped together can be accomplished at the rate of about 1 house per hour.

3.   RESULTS OF PRELIMINARY TESTING

In order to assess the viability of the method for collecting air infiltration data, series of tests were run both in Portland, Maine in the dwellings that are being weatherized,and in a home in Maryland near the National Bureau of Standards. The first series of tests in Portland was done in order to obtain primary air exchange rates and in order to test the assumption of uniform mixing when the previously described injection procedure was applied. The concentration of SF_6 was measured at several points on each floor of the tested building. Usually no variations in tracer concentration occurred which would lead to appreciable errors in the air exchange rate for the floor. As mentioned previously, there was a tendency for the concentration of the tracer gas to be higher on the upper floors than on the lower floors. This observation was the main reason for specifying in the test procedure that separate air sample bags be used for each floor of the building. A summary of the air exchange rates for this test is given in Table 1. The house numbers marked with an asterisk* are buildings which have already been weatherized. These data showed that these buildings were experiencing relatively high air exchange rates.

In order to test the feasibility of using air sample bags, tests were run in a home in Maryland. The sample bags were first analyzed the day immediately following the collection of the sample. An air infiltration rate of 0.34 air exchange per hour was found. After a period of three weeks the sample bags were reanalyzed and an air infiltration rate of 0.31 was obtained. Any change in concentration in the gas sample was within the errors of the experiment, since no care was taken to calibrate the instrument at these times.

4.   CONCLUSIONS

The preliminary testing of this method has indicated that it is a feasible method for obtaining air infiltration data at a low cost and using inexperienced personnel. Although the method does not produce a detailed trace of air exchange rate over a period of one to two hours, it does give the total air leakage of that period, and this is usually of primary interest to energy conservation analysis. The technique also produces integrated air samples for each floor and therefore minimizes the effects of non-uniform mixing.

TABLE 1

SUMMARY OF AIR INFILTRATION RATES - PORTLAND, ME.

House #	Air Exchange Rate (hr^{-1})			Duration Test (hr)	Inside Temp (°C)	Outside Temp (°C)	Wind Direction & Speed km/hr	House Volume (m^3)
	First Floor	Second Floor	Third Floor					
7	0.78	0.98	–	1.4	21.1	-7.8	N-NW 0-16	311
10*	0.93	–	–	2.0	24.4	2.8	N-NW 0-16	224
11	0.95	0.93	–	2.4	21.6	0.0	N-NW 0-16	161
12*	1.52	1.57	–	1.6	20.5	-5.6	N-NW 0-16	274
15	1.96	1.99	1.67	1.4	20.0	-0.6	N-NW 0-16	747
18	1.10	1.17	–	2.5	21.6	0.0	N-NW 0-16	490
19	1.83	1.68	1.97	1.4	21.1	2.8	N-NW 0-16	441
23*	0.99	1.19	–	2.0	22.2	0.0	N-NW 24-48	498
25*	0.80	0.87	–	2.5	18.9	0.6	N-NW 0-16	501
26*	1.21	1.578	–	0.8	20.0	0.0	N-NW 24-46	453

* These homes have been weatherized.

The analysis of the air sample bags in the laboratory permits the use
of standard laboratory techniques, such as dilution of the sample if
the concentration of gas is above the saturation concentration of the
detector, and the use of reference concentrations for each range of
sensitivity of the detector--techniques which are difficult to apply
in the field. The major disadvantage of this method is that it is a
blind test and there are no checks in the field which can assure the
accuracy to which the instructions are followed. It is planned to mod-
ify the automatic air infiltration equipment described in Reference [7]
such that it can automatically handle 40 bags at a time. The possi-
bility of automatically processing the air sample bags is the reason
that air sample bags as large as 10 liters were chosen. The technique
will be applied during the 1978-1979 heating seasons to the CSA weather-
ization demonstrations and further verification of its accuracy and
reliability will be undertaken.

5. REFERENCES

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15. SUPPLEMENTARY NOTES

[ ] Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

A method for collecting air infiltration data in a large sample of dwellings is presented. The method consists of a tracer gas dilution technique employing air sample bags which are analyzed in a central laboratory. The method will be applied to a Community Services Administration optimal weatherization demonstration in approximately 300 dwellings on 16 sites throughout the United States. The method will yield air exchange rates under typical heating season condition for each dwelling in the demonstrations. Preliminary data on air infiltration rates in low-income housing in Portland, Maine are presented.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Air infiltration; air sample bags; energy conservation; retrofit; sulfur hexafluoride; tracer gas; weatherization.

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