Air Leakage Characteristics and Weatherization Techniques for Low-Income Housing

Richard A. Grot
Roy E. Clark

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ABSTRACT

Data are presented on the air leakage characteristics of approximately 250 dwellings occupied by low-income households in 14 cities, in all major climatic zones of the United States. Two types of measurements were used: a tracer-gas decay technique using air sample bags, which was developed at the National Bureau of Standards to measure natural air infiltration; and a fan depressurization test that measures induced air exchange rates. The data presented here show that for this group of dwellings natural air infiltration rates are distributed approximately lognormally.

The induced air exchange rates are a measure of the tightness of building envelopes. There is little correlation between the natural air infiltration rates and the induced air exchange rates in these dwellings, unless the buildings are divided into classes of similar buildings. The use of fan depressurization as a diagnostic tool to assist weatherization crews in tightening buildings is discussed. Preliminary estimates are presented of the reduction in induced air exchange rates that may be achieved by applying building weatherization techniques.

INTRODUCTION AND DESCRIPTION OF SAMPLE

It has been widely recognized for some time that air leakage into and out of a dwelling is an important component of the heat loss of the building. Nevertheless, data on air leakage are available for only a miniscule sample of dwellings in the nation's housing stock, and for a limited number of climatic zones. Recent developments in measurement techniques permit measurement of the air leakage characteristics of large numbers of dwellings with moderate expenditures of effort and resources [1, 2]. This paper presents results from two of these techniques for more than 200 dwellings in 14 U.S. cities, namely: 1) natural air infiltration rates of dwellings under normal conditions, measured using a tracer gas and air sample bags, and 2) induced air exchange rates caused by fan depressurization. This effort was designed by the National Bureau of Standards (NBS) Center for Building Technology to evaluate the effectiveness of weatherization for a demonstration project sponsored by the Community Services Administration (CSA) [3]. The principal goal of the demonstration project is to provide data for determining the optimal level of weatherization for residences occupied by low-income families in various climatic zones in the United States.

The sites at which air infiltration measurements have been made are shown on the map in Figure 1, along with the normal degree days for each location. These sites represent the major degree-day ranges and climatic zones in the continental United States in which space heating is required.

The homes selected for this demonstration are typical of low-income families, although the percentage of each type of dwelling in the demonstration sample does not necessarily reflect its proportion of the total stock of low-income dwellings. The total number of dwellings in the 14 cities at which one or more air infiltration measurements have been made is 266. Approximately 68% of the buildings were frame, 16% masonry, and 11% masonry-veneer. Table 1 lists the types of buildings in the sample at each site. Table 2 shows the ages of the houses, the distribution being fairly uniform from 10 to 80 years, with a median age of about 45 years.

Dr. Grot is a mechanical engineer and Mr. Clark is an information specialist, both in the Center for Building Technology, National Bureau of Standards, Washington, D.C.

Approximately 62% of the houses use natural gas as a fuel source for space heating, 20% oil, 14% propane, 3% electricity, and 1% kerosene. About 38% have forced-air heating systems, 37% space heaters or floor furnaces, 20% hydronic or steam-heating systems, and 5% gravity air-heating systems.

NATURAL AIR INFILTRATION RATES OF LOW-INCOME HOUSING

The tracer-gas technique using air sample bags is described in detail in reference 1 and illustrated in Figure 2. Tracer gas (SF_6) is injected into the dwelling using a 30-ml graduated syringe, and allowed to mix for approximately 30 minutes. An air sample bag is then filled on each floor of the dwelling. After the tracer gas concentration has been allowed to decay for a period of one to two hours, a second air sample bag is filled on each floor. For the demonstration project, the air sample bags are shipped to NBS for determination of the initial and the final concentrations of tracer gas for each floor. The natural air infiltration rate over the sample time period is calculated using the relationship:

$$AI = \frac{1}{\Delta T} \ln (C_1/C_2) \qquad (1)$$

where: AI = the natural air infiltration rate, hr^{-1}
ΔT = time interval between air samples, hr
C_1 = initial concentration of tracer gas
C_2 = final concentration of tracer gas

(C_1 and C_2 can be expressed in any self-consistent units.)

Equation 1 was used to determine the natural air infiltration rate for each floor. The rate for the dwelling was then obtained by averaging the rates for all floors. Two people at each demonstration site were trained at NBS to carry out this test, and were instructed to perform it at each dwelling once a month from October to May. In practice, due to problems in initial organization of each site's activities, most of the tests were carried out in January to June 1979, averaging about four times for each dwelling.

Figure 3 is a histogram of the natural air infiltration rates for all of the sites. Figures 4 through 7 are similar histograms for Charleston, Colorado Springs, Fargo and Minneapolis-St. Paul -- sites at which a relatively large number of measurements were made. Table 3 presents, for each site, the percent occurrence of natural air infiltration rates in each 0.25 hr^{-1} interval from 0 to 5.0 hr^{-1}. The figures and Table 3 show that the distribution of natural air infiltration rates is approximately lognormal and is therefore not symmetric but skewed toward higher values. Table 4 summarizes the natural air infiltration rate measurements before weatherization for the 14 sites, including both lognormal and normal statistics. The most frequent natural air infiltration rates are smaller than the arithmetic means shown in Table 4, with approximately 60% of the rates occurring below the arithmetic mean, and the most probable rate in the range 0.5 to 0.75 hr^{-1}. Extremely high natural air infiltration rates, greater than 2.0 hr^{-1}, occur only 10% of the time.

The geometric mean natural air infiltration rate for all dwellings was 0.86 hr^{-1} [arithmetic mean 1.12 hr^{-1}] (Table 4). The homes in Fargo had the lowest geometric mean, 0.61 hr^{-1} [arithmetic mean 0.77 hr^{-1}]. Next were Tacoma and Colorado Springs, with geometric means of 0.81 hr^{-1} [arithmetic means 0.83 and 0.92 hr^{-1} respectively], Atlanta 0.73 hr^{-1} [0.92 hr^{-1}], Charleston 1.00 hr^{-1} [1.29 hr^{-1}], St. Louis 1.06 hr^{-1} [1.30 hr^{-1}], New Orleans 1.11 hr^{-1} [1.82 hr^{-1}], and Easton 1.24 hr^{-1} [1.69 hr^{-1}]. The leakiest homes were in Chicago, 1.52 hr^{-1} [1.19 hr^{-1}].

INDUCED AIR EXCHANGE RATES IN LOW-INCOME HOUSING

Each dwelling was to have been tested by a fan depressurization procedure, but only 204 homes were actually tested. Each site purchased and used the same model 16-in. diameter smoke-ejector fan with a d.c. motor. The fan has a free air delivery of approximately 3300 ft^3/min at 1750 rpm. An assembly to hold this fan in a doorway was constructed out of 3/4-in. plywood, with 3-in. polyurethane foam glued around the edges of the plywood. An exterior door of the dwelling was removed and the plywood assembly installed over the door opening. The assembly was braced in place with either angle irons or boards in such a way that there was no air leakage between the assembly and the door frame of the dwelling. Figure 8 is a schematic drawing of the installation of the equipment for the fan depressurization test.

The site personnel were instructed to vary the power to the fan and to measure the fan rotation rate required to induce prescribed negative pressure differentials across the building envelope. The pressure differentials were specified at 0.05 in. water (12.4 Pa) intervals, from 0.05 in. of water (12.4 Pa) to 0.30 in. of water (74.9 Pa). If three readings could not be obtained using these instructions, then readings at intermediate pressure differentials were to be made. The flow through the fan was determined using the fan laws [4] and static pressure vs. flow curves supplied by the manufacturer of the fan:

$$F = \alpha \cdot \omega \cdot \exp(-\beta \Delta P/\omega) \tag{2}$$

where:

F = flow, ft^3/min (m^3/s)
ω = the fan rotation rate, or rpm (s^{-1})
α = 1.88 ft^3 (0.532 m^3)
β = 6.33×10^{6} in $H_2O^{-1} min^{-2}$ (7.07 $Pa^{-1} s^{-2}$)
ΔP = outside-inside pressure difference, in H_2O (Pa).

The measured induced air flow, F, was divided by the volume of the living area of the dwelling and a statistical fit was made to the data to obtain the parameters C and B of the equation

$$Q = C(\Delta P)^B \tag{3}$$

where: Q = 60 F/Volume = the induced air exchange rate, hr^{-1} .

(Note: if S.I. units are used in equation (2) then 60 is replaced by 3600 in the expression for Q).

A summary of the results of these tests for each site is given in Table 5, Q_{50}, where the induced air exchange rate at 50 Pa (0.20 in. H_2O), and the exponent B of equation 3 are listed. As measured by the fan depressurization test, the tightest dwellings in the demonstration were those in Portland, (15.9 hr^{-1} at 50 Pa), Tacoma (16.1 hr^{-1} at 50 Pa), and Fargo (17.4 hr^{-1} at 50 Pa). The leakiest dwellings were those in New Orleans (195.8 hr^{-1} at 50 Pa) and Charleston (61.0 hr^{-1} at 50 Pa). Figure 9 is a histogram of the measured induced air exchange rates for the 204 dwellings for which a fan depressurization test was performed. Figure 10 shows a corresponding histogram of the exponent B of equation 3. Physically, the exponent B should lie between 0.5 and 1.0. If B is less than 0.5, equation 3 is not strictly valid over the entire pressure range. This usually occurs with tight houses, and it can be seen by studying residuals about the fitted line, that the house is tightening itself at the higher pressure differences. Cases for which B is greater than 1.0 usually occur with very leaky houses, in which almost no depressurization occurs, and only two or three very low pressure readings can be obtained.

In an attempt to determine whether there is a relationship between induced air exchange and natural air infiltration rates measured, an equation of the form (see reference 2)

$$AI = a(Q_{50})^b \tag{4}$$

where a and b are regression coefficients, was fitted to the data gathered for each site, using least squares techniques. The results are presented in Table 6, where the coefficients a and b are given along with the standard error ϵ of fitting the data with equation 4, and the correlation coefficient R^2 of the fitted data. In Table 6, the second set of coefficients labelled "edited" was obtained by deleting those points which lie more than one standard deviation from the fitted curve.

As can be seen from Table 6, the fit of the data with equation 4 is not good, and it can be concluded that there is no clear relationship between natural air infiltration and induced air exchange rates. Some partial success was obtained for three of the sites when the data were edited. Whether a relationship would exist within classes of similar buildings with the same types of heating system is a question deserving further study. The findings of this analysis are in agreement with the results presented by Blomsterberg and Harrje [5] for a small sample of dwellings.

PRELIMINARY RESULTS OF THE EFFECTIVENESS OF RETROFITTING IN TIGHTENING DWELLINGS

The major purpose of the weatherization demonstration is to obtain data on the energy savings achievable from economically optimal weatherization techniques [3]. The two tests described in the previous sections were done to obtain data specifically bearing on the effectiveness of natural air infiltration-reducing measures.

The measures which were considered for application in this project were: 1) replacing broken glass; 2) resetting glazing; 3) replacing thresholds; 4) sealing structural cracks; 5) weatherstripping windows; 6) caulking windows; 7) weatherstripping doors; 8) caulking doors; 9) weatherstripping the attic hatch; 10) installing storm windows; 11) installing storm doors; and 12) installing flue/vent dampers. Whether a measure was to be applied in houses at a particular site was based on theoretical calculations of energy saving versus cost, contingent on a maximum payback period of 11 years. The options selected for each site are listed in Table 7. As the table indicates, prescribed techniques were not always implemented. This was due either to the inappplicability of an option to a particular dwelling or to inability to install the option due to field conditions.

Post-weatherization fan-depressurization tests had been performed on some of these dwellings at the time this article was prepared, and will be performed to collect natural air infiltration rates in all dwellings through one heating season after weatherization. Table 8 lists the pre- and post-weatherization data from fan depressurization tests for approximately 25 dwellings in Charleston, Washington, and Fargo. These tests indicate that induced air exchange rates were reduced by 5% to 97%. Additional air leaks not corrected by the original measures were observed during these tests. Whether or not the fan depressurization test can be used to predict the natural air infiltration rate of a dwelling, it seems to be a very effective tool for locating air leakage paths in a dwelling. Many weatherization crews in this demonstration were impressed by the ease with which air leakage paths could be observed, and surprised by the location of many of these leakage paths in unsuspected parts of the dwelling.

SUMMARY AND CONCLUSIONS

Natural air infiltration rates were measured, using tracer gas, in 266 dwellings of low-income families in 14 cities in the United States. Of a total of 1048 readings, it was found that approximately 19% were rates of less than 0.5 hr^{-1}; 40% were moderate rates between 0.5 and 1.0 hr^{-1}; 20% were high rates between 1.0 and 1.5 hr^{-1}; and 20% were very high rates of greater than 2.0 hr^{-1}. The results of fan depressurization tests on 204 of these dwellings showed that at a standard pressure difference of 50 Pa, two % could be considered tight, with induced air exchange rates of less than 10 hr^{-1}; 33% were moderately tight, with induced air exchange rates between 10 and 20 hr^{-1}; 29% were moderately leaky, with rates between 20 and 30 hr^{-1}; 18% were leaky, with rates between 30 and 40 hr^{-1}; and 18% were very leaky, with rates grater than 40 hr^{-1}. There seems to be little relationship between the natural air infiltration rates of a dwelling and the induced air exchange rate at 50 Pa from the fan depressurization test, if no attempt is made to subdivide the buildings into similar classes. The fan depressurization test is, however, an effective weatherization tool, which can be used by weatherization crews to assist in tightening a dwelling. Preliminary results indicate that building-tightening weatherization options can reduce the induced air exchange rate at 50 Pa from 5 to 96%.

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3. R. Crenshaw, R. Clark, R. Chapman, R. Grot and M. Godette, "Community Services Administration Weatherization Demonstration Project Plan", NBSIR 791076, March 1979.

4. Richard D. Madison, Ed., Fan Engineering, Buffalo Forge Co., Buffalo, NY, pp. 240-245, 1948.

5. A.K. Blomsterberg, and D.T. Harrje, "Approaches to Evaluation of Air Infiltration Energy Losses in Buildings," AHSRAE Trans. 85, Part 2, 797, 1979.

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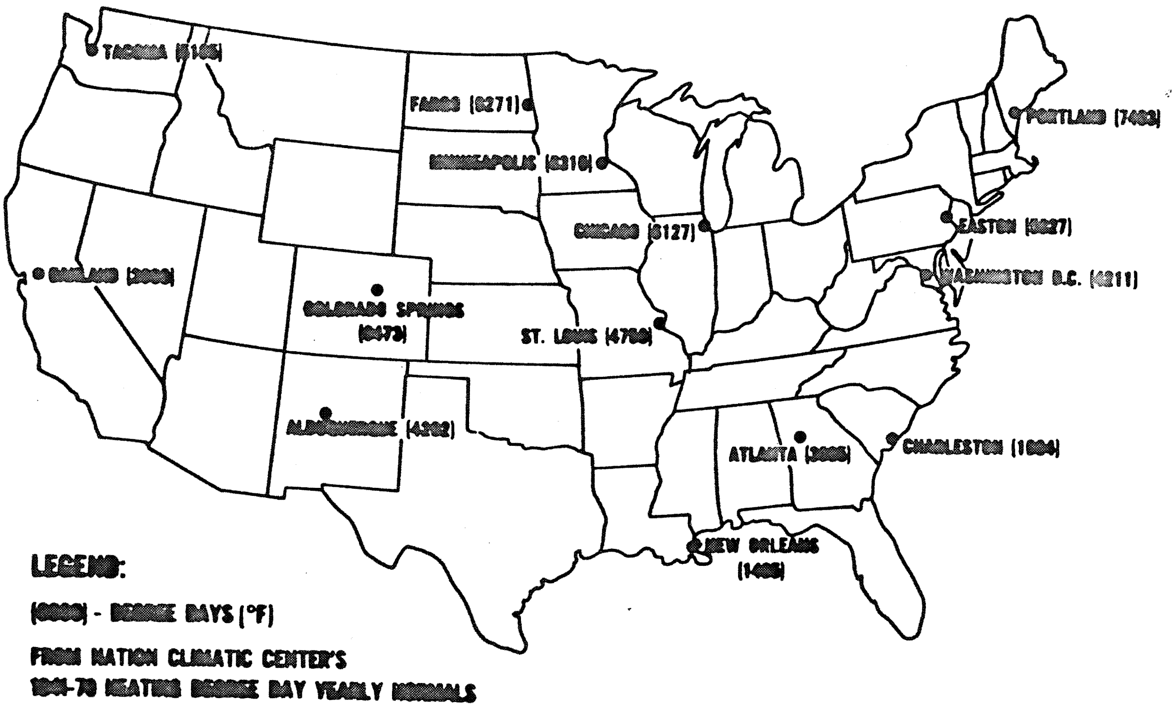

Figure 1. Optimum weatherization demonstration sites at which air infiltration measurements were performed

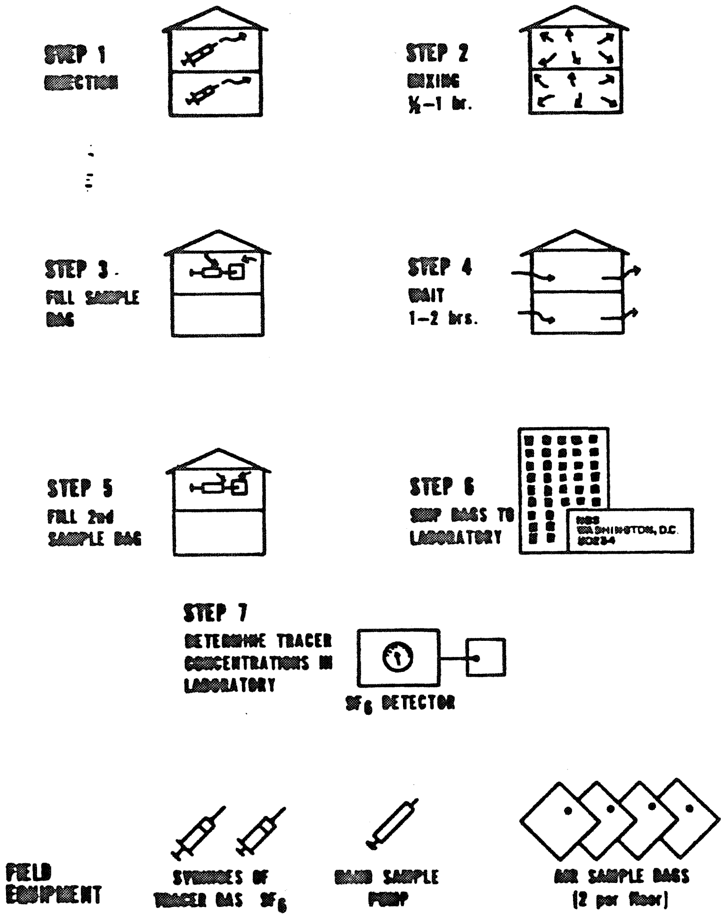

Figure 2. Procedure for collecting air infiltration rates using air sample bags

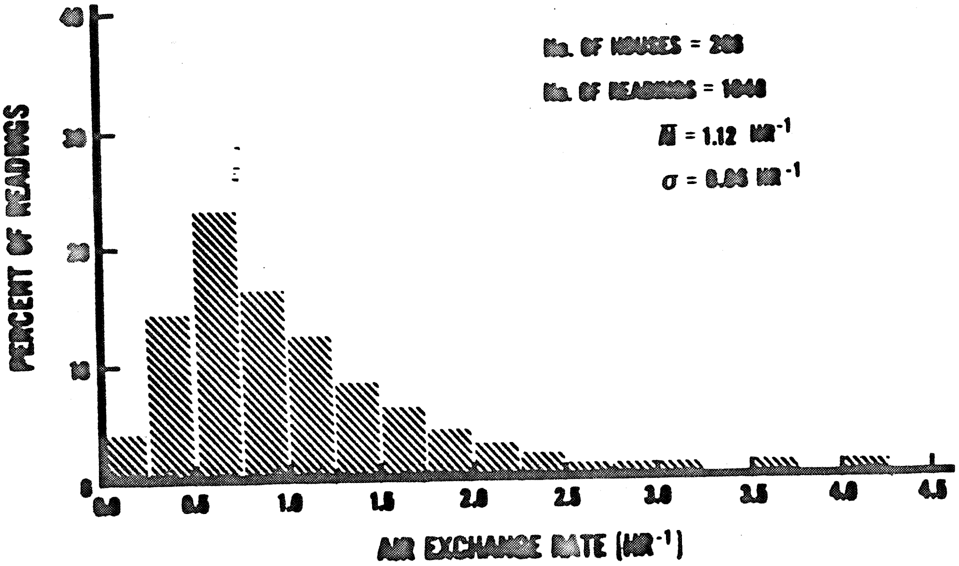

Figure 3. Histogram of measured natural air infiltration rates for 14 weatherization sites

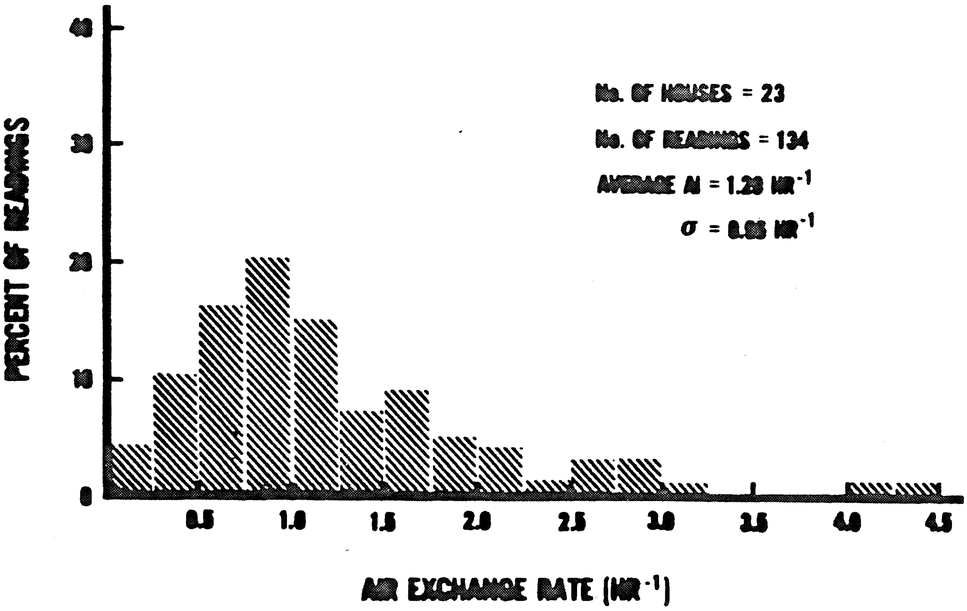

Figure 4. Histogram of measured natural air infiltration rates for Charleston

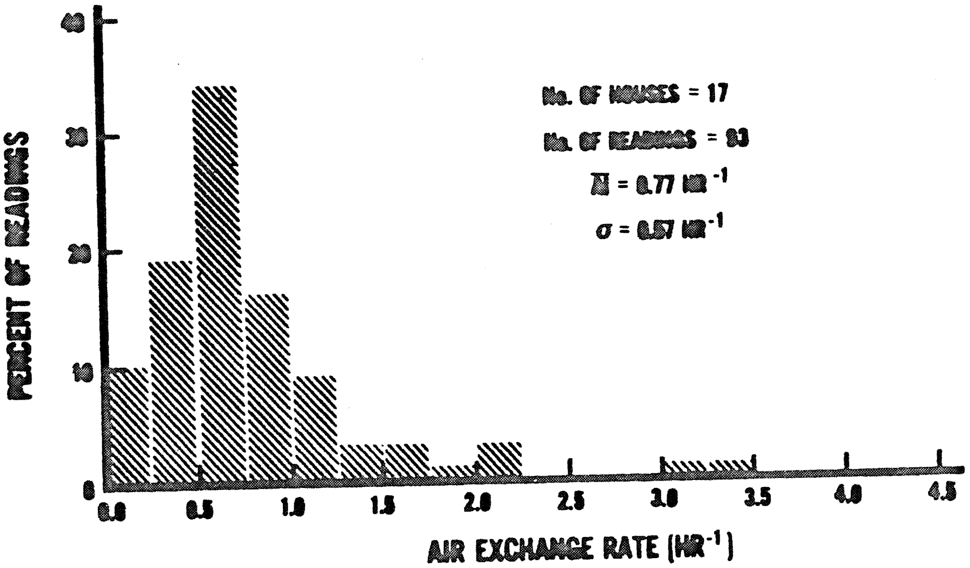

Figure 5. Histogram of measured natural air infiltration rates for Fargo

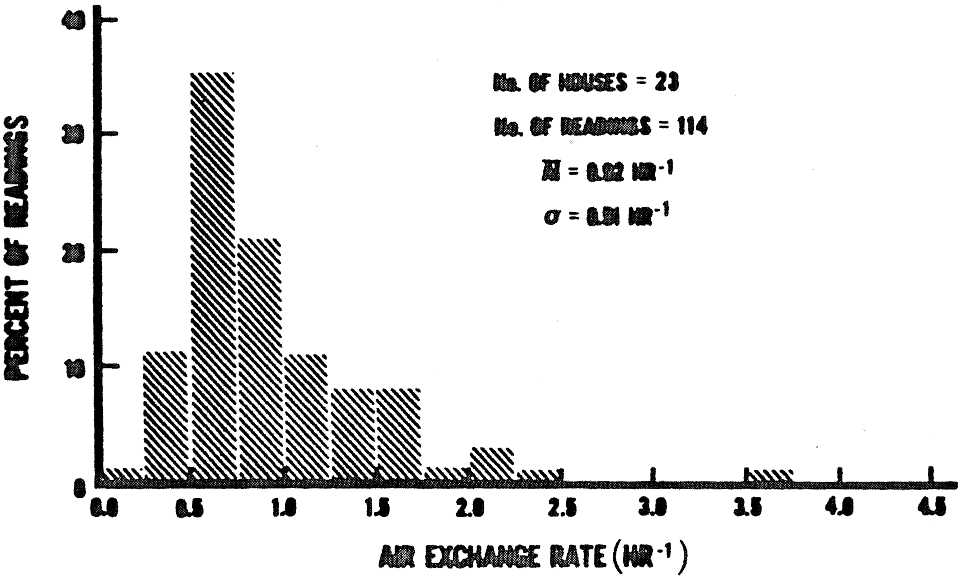

Figure 6. Histogram of measured natural air infiltration rates for Colorado Springs

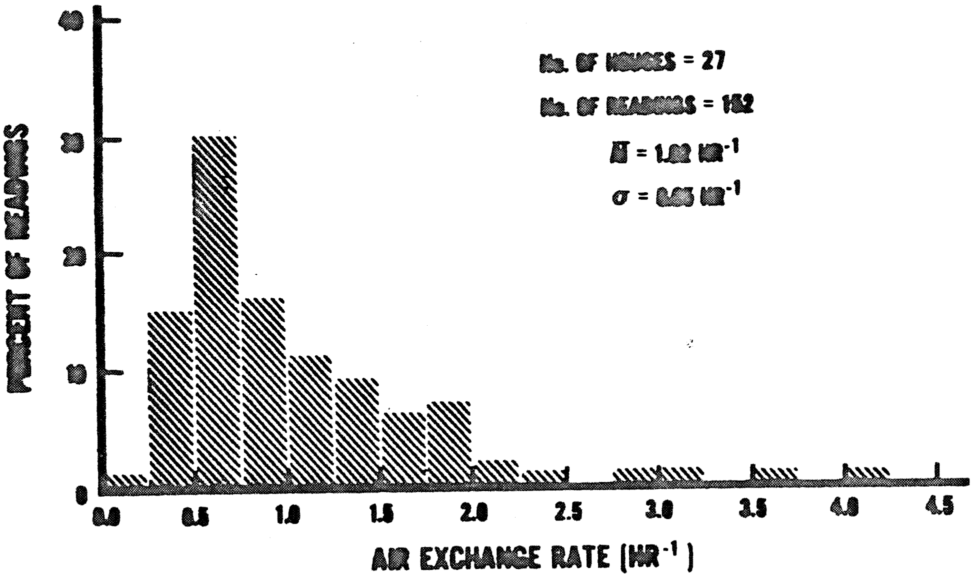

Figure 7. Histogram of measured natural air infiltration rates for Minneapolis-St. Paul

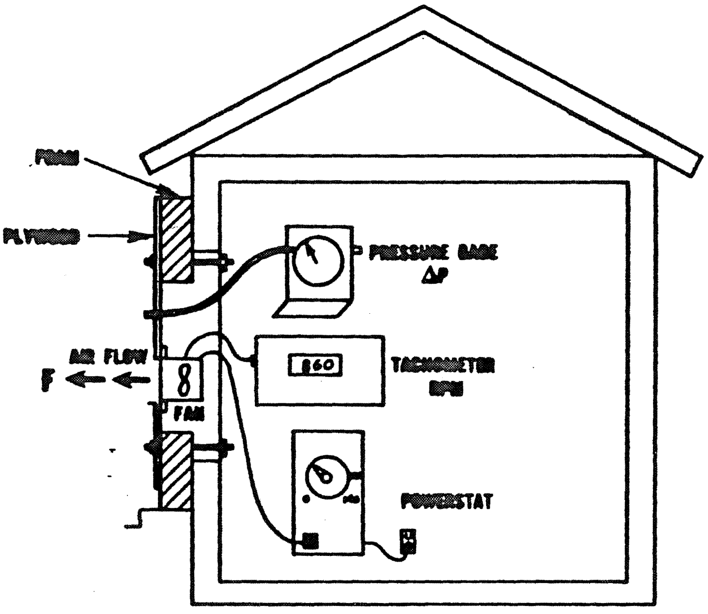

Figure 8. Schematic drawing of setup for fan depressurization tests

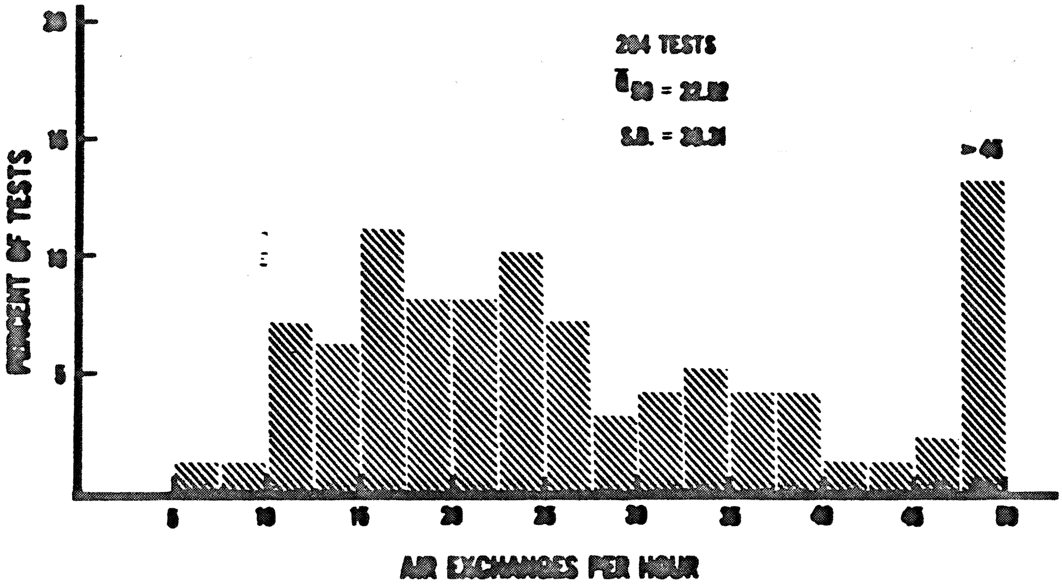

Figure 9. Histogram of induced air exchange rates from fan depressurization at $\Delta P = 50$ Pa

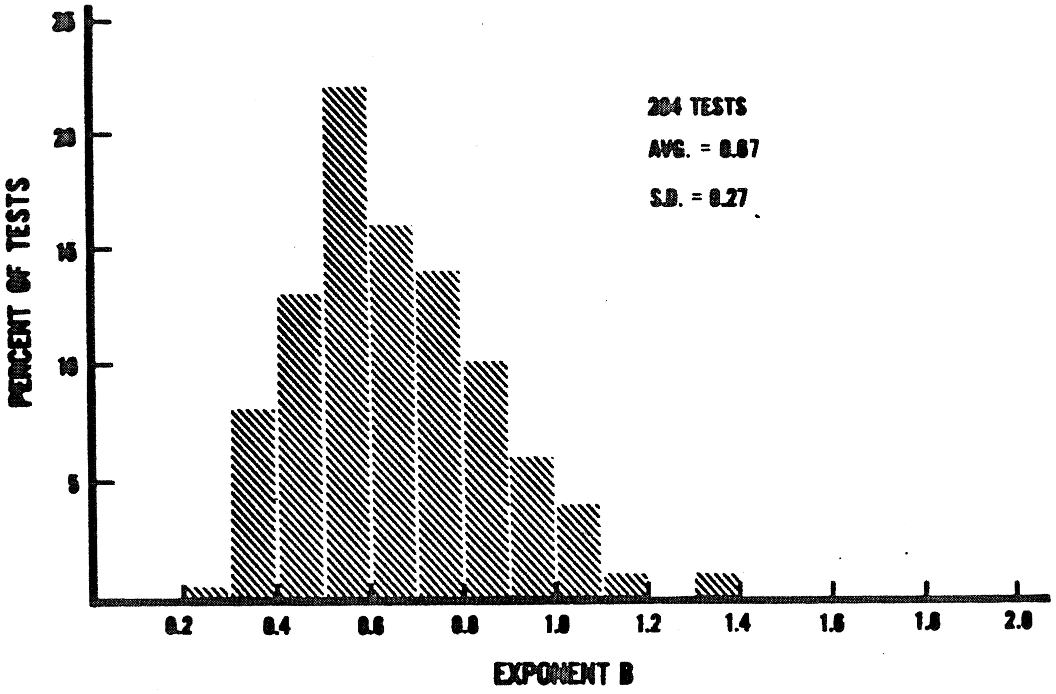

Figure 10. Histogram of exponent B of equation $Q = C\ (\Delta P)^B$ for fan depressurization tests

Table 1. Distribution of Weatherization Demonstration Sample Dwellings by Construction Type and Building Type

Construction Type:	Frame			Masonry				Adobe	Masonry-Veneer			Other	Total
Floors (full stories):*	1-D	1 1/2-D	2-D	1-D	2-D	2 1/2-D	2-A	1-D	1-D	1 1/2-D	2-D		
City:													
Albuquerque NM	9			2				2	1			4	18
Atlanta GA	7	2		7								1	17
Charleston SC	6			11					6				23
Chicago IL	3	4	5		2					5	4		23
Colorado Springs CO	14	4	4									1	23
Easton PA	5		5		1		6						17
Fargo ND	15	2											17
Minneapolis/ St. Paul MN	7	6	14										27
New Orleans LA	16								2			7	25
Oakland CA	7	1	2	3	1								14
Portland ME	3	4	8										15
St. Louis MO	3		3	6	6	4							22
Tacoma WA	7	3											10
Washington DC	9	1	3	1					1				15
TOTAL	111	27	44	10	10	4	6	2	10	5	4	13	266

* The numbers in this row indicate the number of full stories of the dwelling.
D = detached
A = attached (i.e., row houses)

Table 2. Age Distribution of Sample Dwellings

Age / City	0 to 10 yrs.	11 to 20 yrs.	21 to 30 yrs.	31 to 40 yrs.	41 to 50 yrs.	51 to 60 yrs.	61 to 70 yrs.	71 to 80 yrs.	81 to 90 yrs.	91 to 100 yrs.	100 + yrs.	?
Albuquerque		3	6	5								4
Atlanta	2	4	4	2	1		2				1	1
Charleston	8	8	3	1	2	1						
Chicago	1	2	1	1	2	3	6	1	3		3	
Colorado Springs	8	1	1	2		1	4	4	1		1	
Easton	2	1	1	1	2		4	3	1		2	
Fargo		2	2	1	2	8	1	1				
Minneapolis/St. Paul		3	1		3	5	5	3	4		2	1
New Orleans		2	6	4	2							11
Oakland					1	3	4	1	2			
Portland			2	1		3		4	2		3	
St. Louis	1		1		1	9	4	1	3	1	1	
Tacoma	2	1	3	1	1	1			1			
Washington	1	4	1	1	5	1	1	1				
TOTAL	25	31	32	20	25	35	31	19	17	1	13	17

Table 3. Distribution of Natural Air Infiltration Rates for Each Site

				Percent of Readings Giving Air Infiltration Rates (air changes/hour) of:																			
City	No. of Rdgs.	Avg. AI Rate	Std. Dev.	0 to 0.25	.25 to .50	.50 to .75	.75 to 1.00	1.00 to 1.25	1.25 to 1.50	1.50 to 1.75	1.75 to 2.00	2.00 to 2.25	2.25 to 2.50	2.50 to 2.75	2.75 to 3.00	3.00 to 3.25	3.25 to 2.50	3.50 to 3.75	3.75 to 4.00	4.00 to 4.25	4.25 to 4.50	4.50 to 4.75	4.75 to 5.00
ALB	51	1.01	.73	10	14	22	18	8	4	12	4	4	0	2	2	0	0	2	0	0	0	0	0
ATL	43	.92	.67	5	23	26	21	5	7	0	2	2	5	2	0	2	0	0	0	0	0	0	0
CHA	134	1.29	.96	4	10	16	20	15	7	8	5	4	1	3	3	1	0	0	0	1	1	1	1
CHI	46	1.52	1.12	2	9	15	11	9	22	9	4	0	4	2	2	0	2	0	2	0	0	7	0
CSP	114	.92	.51	1	11	35	21	11	8	8	1	3	1	0	0	0	0	1	0	0	0	0	0
FAR	93	.77	.57	10	19	34	16	9	3	1	3	2	0	0	0	1	1	0	0	0	0	0	0
EAS	25	1.64	1.06	0	24	4	8	0	8	8	12	12	4	4	4	4	4	0	0	0	4	0	0
MSP	152	1.02	.65	1	15	30	16	11	9	6	7	2	1	0	1	1	0	1	0	1	0	0	0
NOR	83	1.82	1.41	8	14	6	2	7	12	7	6	2	8	1	4	2	1	4	2	4	1	1	5
OAK	62	1.00	.43	0	6	29	21	21	13	3	2	5	0	0	0	0	0	0	0	0	0	0	0
POR	31	1.11	.68	3	19	16	19	3	6	13	6	6	3	3	0	0	0	0	0	0	0	0	0
STL	44	1.30	.74	5	5	16	20	9	9	9	7	9	5	0	5	2	0	0	0	0	0	0	0
TAC	76	.83	.59	8	22	25	17	12	4	3	1	7	0	0	0	0	1	0	0	0	0	0	0
WAS	94	1.07	.81	6	17	23	14	12	1	6	6	1	6	1	2	2	0	0	0	1	0	0	0
	1048	1.12	.86	4	14	23	16	11	8	6	4	3	2	1	1	1	0	1	0	1	0	0	0

Table 6. Coefficients and Statistics of Equation AI = a $(Q_{50})^b$ for Relationship Between Natural Infiltration and Induced Air Exchange Rates

	All Dwellings					Edited				
	No. of Houses	a	b	R^2	ε	No. of Houses	a	b	R^2	ε
Albuquerque	10	0.09	0.76	0.22	0.38	8	0.11	0.69	0.37	0.25
Atlanta	15	0.18	0.48	0.30	0.43	11	0.14	0.52	0.35	0.29
Charleston	22	1.31	-0.03	0.00	0.48	14	1.38	-0.06	0.04	0.29
Chicago	18	0.49	0.26	0.06	0.38	13	0.15	0.51	0.29	0.49
Colorado Springs	23	0.12	0.60	0.40	0.40	15	0.15	0.52	0.54	0.15
Easton	12	0.78	0.19	0.02	1.02	9	0.45	0.39	0.23	0.62
Fargo	16	0.54	0.11	0.01	0.41	14	0.48	0.11	0.03	0.20
Minneapolis-St. Paul	18	0.28	0.43	0.36	0.34	13	0.23	0.50	0.72	0.22
New Orleans	11	0.93	0.17	0.39	0.63	10	1.05	0.13	0.45	0.37
Oakland	12	0.41	0.25	0.25	0.17	8	0.31	0.33	0.62	0.13
Portland	11	0.08	0.93	0.27	0.47	10	0.02	1.14	0.70	0.26
St. Louis	12	0.85	0.09	0.02	0.57	8	0.20	-0.16	0.06	0.29
Tacoma	10	1.87	-0.31	0.08	0.29	8	0.78	-0.04	0.00	0.13
Washington	14	0.28	0.36	0.07	0.57	11	0.44	0.16	0.03	0.24

Table 8. Air Leakage Reduction Due to Installation of Weatherization Options

		Before Weatherization		After Weatherization	
City	#	AI (HR^{-1})	Q_{50} (HR^{-1})	Q_{50} (HR^{-1})	Percent Reduction %
CHA	1	1.51	----	58.1	
CHA	2	0.71	35.7	26.7	25.2
CHA	3	0.97	25.4	20.0	21.2
CHA	8	1.11	28.9	15.0	48.2
CHA	9	2.02	28.1	21.1	24.9
CHA	16	1.01	32.2	26.0	19.3
CHA	18	0.72	548.8	17.2	96.9
CHA	20	1.08	27.0	23.4	13.3
CHA	22	1.83	47.5	45.2	4.8
CHA	25	1.97	42.1	33.8	19.7
CHA	27	1.60	36.5	28.6	21.6
CHA	33	0.75	39.6	31.7	19.9
CHA	39	1.53	39.2	26.5	32.4
CHA	42	1.96	36.5	18.4	49.6
CHA	44	1.54	161.2	27.5	82.9
CHA	47	1.05	30.6	25.1	21.2
CHA	49	1.32	32.1	24.6	17.1
WAS	2	0.79	25.5	7.7	69.8
WAS	7	1.58	24.1	19.8	17.8
WAS	8	0.73	39.6	9.0	77.3
WAS	24	0.82	33.0	12.7	61.5
WAS	27	0.72	45.2	27.8	38.4
FAR	5	0.86	30.5	25.0	18.0
FAR	15	0.77	17.5	14.9	14.9
FAR	32	0.34	11.9	10.7	10.1

CHA = Charleston
WAS = Washington
FAR = Fargo

Table 4. Average Natural Air Infiltration Rates Measured at Each Demonstration Site

			Lognormal Statistics			Normal Statistics	
	No. of Houses	No. of Readings	Average of ℓn (AI)	Standard Deviation ℓn (AI)	Geometric Average Natural Air Infiltration Rate (hr^{-1})	Arithmetic Average Natural Air Infiltration Rate (hr^{-1})	Standard Deviation
Albuquerque	18	42	-0.26	0.80	0.77	1.01	0.73
Atlanta	17	43	-0.31	0.66	0.73	0.92	0.67
Charleston	23	134	0.00	0.78	1.00	1.29	0.96
Chicago	23	46	0.18	0.69	1.19	1.52	1.12
Colorado Springs	23	114	-0.21	0.49	0.81	0.92	0.51
Easton*	17	25	0.21	0.83	1.24	1.64	1.06
Fargo	17	93	-0.50	0.74	0.61	0.77	0.57
Minneapolis	27	152	-0.15	0.57	0.86	1.02	0.65
New Orleans*	25	83	0.10	1.26	1.11	1.82	1.41
Oakland	14	62	-0.09	0.44	0.91	1.00	0.43
Portland	15	31	-0.11	0.69	0.90	1.11	0.68
St. Louis	20	44	0.06	0.69	1.06	1.30	0.74
Tacoma	10	76	-0.41	0.69	0.67	0.83	0.59
Washington	15	94	-0.22	0.82	0.80	1.07	0.81
TOTAL	266	1048	-0.15	0.77	0.86	1.12	0.86

*Mostly summer readings taken with house closed up.

Table 5. Air Leakage Characteristics of Dwellings at Each Site as Measured by Fan Depressurization Tests

		Q_{50} Induced Air Exchanges Per Hour at 50 Pa		B Flow-Pressure Exponent	
	Number of Houses	Average	Standard Deviation	Average	Standard Deviation
Albuquerque	10	18.9	6.4	0.51	0.19
Atlanta	15	28.7	19.9	0.65	0.29
Charleston	22	61.0	111.1	0.61	0.25
Chicago	18	36.1	20.5	0.76	0.18
Colorado Springs	23	28.7	12.6	0.68	0.08
Easton	12	24.3	13.5	0.63	0.19
Fargo	16	17.4	5.8	0.73	0.18
Minneapolis-St. Paul	18	22.0	11.4	0.85	0.26
New Orleans	11	195.8	268.3	0.82	0.26
Oakland	12	29.5	12.1	0.63	0.19
Portland	11	15.9	4.3	0.51	0.05
St. Louis	12	48.5	51.3	0.89	0.59
Tacoma	10	16.1	4.5	0.47	0.10
Washington	14	29.7	10.4	0.52	0.22
TOTAL	204	36.6	83.9	0.67	0.28

Reducing Techniques by Site

Sites	Replace broken glass	Reset glazing	Replace threshold	Seal structural cracks	Weatherstrip windows	Caulk windows	Weatherstrip doors	Caulk doors	Weatherstrip attic hatch	Storm windows	Storm doors	Flue/vent damper
	Infiltration-Reducing Techniques											
Albuquerque	12 7	12 2	12 6	12 2	12 12	12 12	12 12	12 12	12 0	12 6	0 0	-
Atlanta	11 0	3 1	11 2	11 4	3 3	3 3	3 3	3 3	3 3	0 0	3 0	0
Charleston	18 16	18 11	18 17	18 18	17 16	18 18	17 16	17 17	17 16	1 1	0 0	0
Chicago	26	26	26	26	26	26	26	26	26	26	26	20
Colorado Springs	18 15	18 13	18 17	18 14	18 7	18 18	18 18	18 18	18 11	18	0 0	12
Easton	17	17	17	17	17	17	17	17	17	0	13	-
Fargo	13 2	13 5	13 1	13 7	13 13	13 11	13 11	13 13	13 11	0 0	0 0	9 9
Minneapolis–St. Paul	21 14	21 14	21 0	21 0	21	21	21	21	21	21	3	-
Oakland	10 8	0	10 10	10 5	0	0	0	0	0	0	0 0	-
Portland	19	19	19	19	19	19 19	19 19	19	19	0	19	18 12
St. Louis	24	24	24	24	0	24	0	24	0	24	0 0	18
Tacoma	5 1	5 0	5 0	5 0	5 5	5 5	5 5	5 5	5	5 5	0 0	1
Washington	10 1	10 1	10 2	10 0	10 1	10 10	10 10	10 10	10 1	10 10	5 2	4

Upper figure is number of houses for which option was prescribed.
Lower figure is number of houses in which option was actually installed.
- Indicates mechanical options not yet selected.
Blank indicates data not yet available.