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MEASURED EFFECT OF FORCED VENTILATION ON HOUSE INFILTRATION RATE*

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ABSTRACT

Tests were conducted over a period of 18 months at a house near Knoxville, Tennessee, to determine the effect of forced ventilation on the house infiltration rate. An outside-vented electric dryer was used as the power vent. The testing was carried out during a variety of weather conditions. The tracer gas technique using sulfur hexafluoride was employed to measure infiltration rates. A non-linear regression equation was developed based on measured data relating the change in the house infiltration rate to the vent rate. The equation has the form of an inverse exponential curve showing a greater increase in the infiltration rate of a tightly constructed house than of a loosely constructed house. Calculations were made for 17 cities across the United States showing the effect of a vented electric dryer on house HVAC energy consumption.

INTRODUCTION

The rate at which air enters or leaves a structure is an important factor in performing heating and cooling calculations for residences or other buildings. This air flow rate is called the air infiltration rate and usually is expressed in units of air changes per hour (ACPH). Infiltration occurs through cracks around doors, windows, walls, floors, etc., and its magnitude is determined by the quality of materials and construction and by existing weather conditions.

All infiltration is not bad, however, because it helps to replenish the oxygen supply in houses, deplete "used" air and contaminants, and

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furnish air for the use of fossil-fueled heating devices. In cases where infiltration is too high, a penalty is paid in terms of increased space-conditioning costs and personal discomfort.

Both the measurement of and the prediction of air infiltration in residences and other buildings are receiving a great deal of attention these days because of the contribution that infiltration adds to the house heating and cooling loads and indoor air quality. An old rule of thumb attributes 30% of the house heating load to infiltration.

There are many models and correlations used in infiltration modeling. Ross and Grimsrud,[1] Cole et al.,[2] Socolow et al.,[3] and Sepsy et al.[4] have described them in research sponsored by the Department of Energy, the Gas Research Institute, and the Electric Power Research Institute. Because of the many uncertainties affecting infiltration estimates, the most common methods used today are the 30% rule-of-thumb method and those described by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE)[5]. One ASHRAE method simply uses typical room air change rates based on past measurements and experience and sums them up for the entire structure. The ASHRAE crack-length method involves measuring the lengths of potential air leakage paths of the structure and multiplying them by empirical constants to obtain an average infiltration rate.

These methods are suitably accurate for calculating integrated infiltration loads over the course of a heating or cooling season. However, since the infiltration rate may constantly change because of fluctuating ambient conditions, these average values may be far from the true value at any given time.

In those instances in which measured infiltration and weather data are available for a given structure, the Achenbach-Coblentz method has been found to give relatively good correlations. The Achenbach-Coblentz correlation uses an equation of the form:

$$\text{infiltration rate} = A + [B \times \text{wind speed})] + [C \times |\text{house-to-ambient } \Delta T|],$$

where A, B, and C are empirical constants for the structure.

Many modifications of the Achenbach-Coblentz equation have been made, and refs. 1, 2, 3, and 4 summarize them well.

Quantitative measurements of air infiltration rates are presently best made using the tracer gas technique. This method involves introducing a tracer gas such as sulfur hexafluoride, ethane, nitric oxide, etc., into a structure and monitoring its concentration with a suitable instrument. Three variations of this method may be used: the dilution or decay method, the constant injection method, and the constant concentration method.[6] Each of the three variations requires its own specialized equipment and passesses its own advantages. However, for residential use, the dilution or decay method is usually employed.

The tracer gas decay technique requires measuring the concentration of a tracer gas (SF_6 in this case) versus time and using the data to calculate the infiltration rate. The mathematical model used in this form of the tracer gas technique is that of a first-order decay rate — that is, the rate of loss of the tracer gas from a structure is proportional to the amount of the tracer gas present at any instant in time. Expressed mathematically,

$$-\frac{\partial c}{\partial t} = kc ,$$

where

c = the concentration of the tracer gas in the structure at any time t,

k = the infiltration constant.

When this equation is integrated with the initial boundary conditions at $t = 0$, $c = c_o$, the solution is

$$\ln \frac{c}{c_o} = -kt.$$

If $\ln(c/c_0)$ is plotted versus t, there results a straight line going through the origin with a slope equal to -k, the infiltration rate in ACPH.

For the above equation to be valid, either perfect mixing of the tracer gas must take place, or the average concentration of the tracer gas in the structure must equal the average concentration of the tracer gas leaving the structure.

EXPERIMENTAL SETUP

To determine the effect that forced ventilation has on the infiltration rate of a dwelling, an experiment was conducted at the Tennessee Energy Conservation in Housing (TECH) complex in Knoxville, Tennessee. The complex is made up of the annual cycle energy system (ACES) house, a solar house, in which a solar heating and hot water system are used, and the control house, in which conventional heating and cooling systems are used.

Located on the agricultural farm of the University of Tennessee, south of Knoxville on Alcoa Highway, this complex is jointly operated by the University of Tennessee, Oak Ridge National Laboratory, and the Tennessee Valley Authority. The purpose of the TECH project, which has been in operation since August 1976, is to demonstrate energy conservation through improved thermal envelopes and through the use of innovative heating and cooling systems.

The infiltration experiment was conducted in the control house. Fig. 1 is a top view of the TECH Complex showing the overall layout.

All three houses in the complex have similar floor plans. The houses are 167-m^2 (1800-ft^2) single-family residences consisting of three bedrooms, two baths, a great room, a kitchen, and a mechanical equipment room. The volume of the control house is 453 m^3 (16,000 ft^3).

The houses were built with better thermal envelopes than normally found in this climate zone, to reduce heating and cooling requirements.

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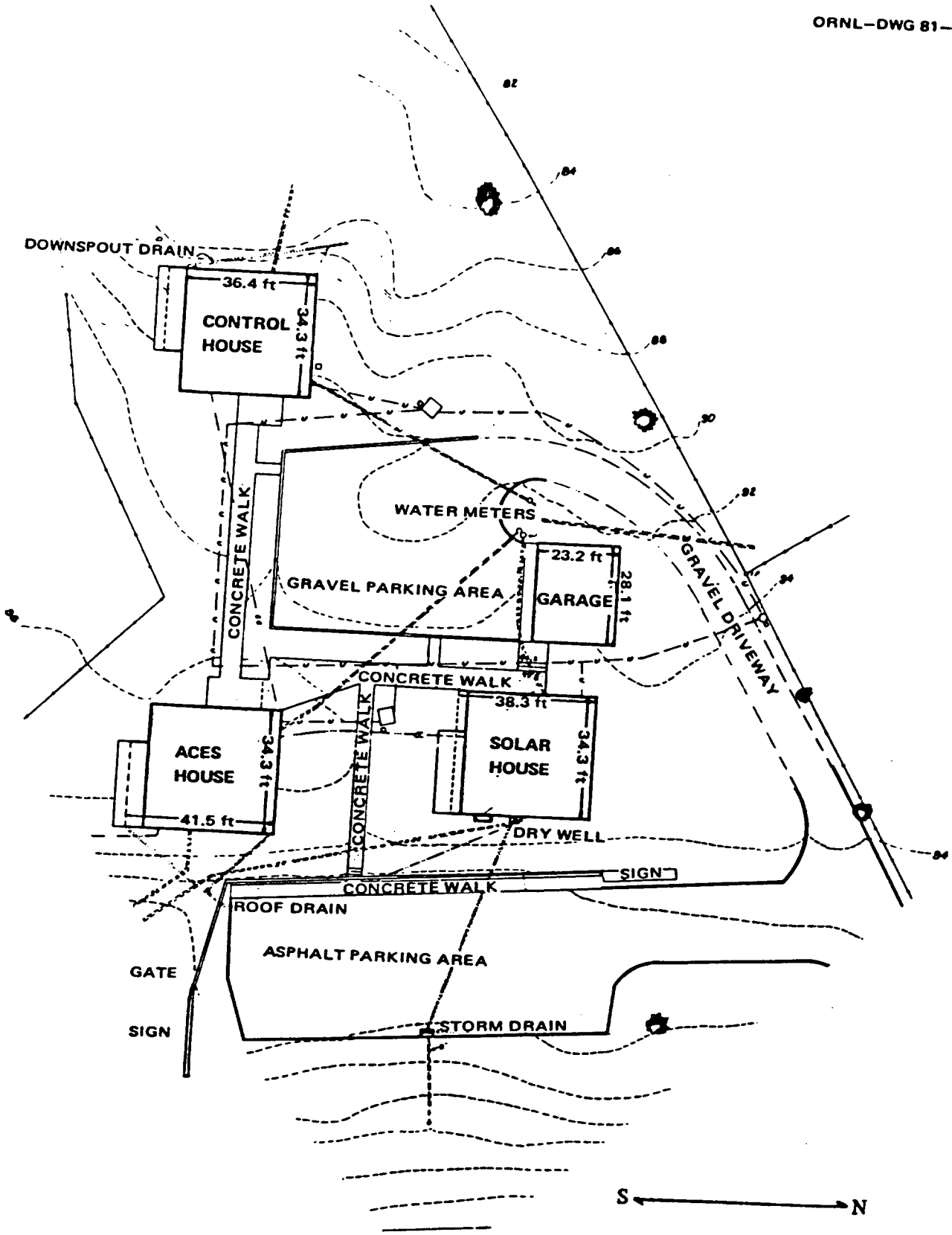

Figure 1. Overall Layout of the TECH Complex

Double-pane insulated glass was used throughout; R-38 insulation was used in ceiling areas where possible, and R-19 insulation was used in the crawl space and sidewalls, below the floor, and in the ceiling areas.

The tracer gas decay technique was used to measure the infiltration rate in the control house; SF_6 was used as the tracer gas. The instrument used to monitor the SF_6 concentration was a Systems, Science and Software model 215BGG Bench/Laboratory Tracer Gas Monitor. The instrument contains an electron-capture gas chromatograph and can easily measure SF_6 concentrations in air from a range of 10^{-9} to 10^{-12} (one part per billion to one part per trillion).

A Sears Kenmore large-capacity electric dryer, model 69801, was used as the ventilation source. About 2 m (7 ft) of flexible 0.1-m-diam (4-in.) plastic tubing and a standard metal through-the-wall vent kit were attached to the dryer vent.

Integrated wind speed, wind direction, and outdoor dry-bulb temperature were monitored every 15 min (weather readings were synchronized to SF_6 concentration readings) by the data acquisition system contained in the ACES house.

Test runs were made over an 18-month period in order to include weather encompassing all the seasons. Most testing was done on days when the wind speed and dry-bulb temperature varied little. All infiltration measurements were made with the central blower fan of the HVAC system operating to ensure good mixing of the house air. The probe used to gather inside air samples was located at the entrance of the central return air duct.

Initial testing showed that the tracer gas monitor was able to accurately measure gas samples at 15-min intervals, so most infiltration determinations consisted of five readings taken over the course of an hour.

A typical test day consisted of a 1-h run with the dryer off, a 1-h run with the dryer operating, and another 1-h run with the dryer off. Two ml of SF_6 were injected into the blower inlet and allowed to equilibrate in concentration throughout the house for approximately 30 min prior to the first run each day. Concentration and weather readings were then taken at 15-min intervals during each run.

The dryer was moved to two different locations in the house to determine if its location had an effect on the results. Several runs were also made with the outside vent blocked off to determine its effect on the infiltration rate without the dryer operating.

RESULTS

Table 1 contains a summary of the infiltration testing from November 16, 1978, to June 4, 1980. Figure 2 shows the decay plots for runs 37 and 38. This plot is typical of the experimental data obtained during the course of the testing.

Several correlations of the data were made using the Achenbach-Coblentz equation. These initial trials showed that neither dryer location, the presence of an outside vent (with the dryer off), nor wind direction affected the regression coefficients significantly, so these quantities were not treated as variables in this work.

About halfway through the time period over which the infiltration data were being gathered, a new heat pump and some external (crawl space) ductwork were installed in the control house. The house displayed tighter infiltration characteristics after the installation was completed (probably because the new ductwork was more leak free than the old). Table 2 contains the infiltration data (vent not operating) and the corresponding equation to fit the data before the modification, and Table 3 contains the data and equation for the house after the modification, again with the vent not operating. The sensitivity of the house infiltration rate to wind decreased by 31% [0.027 ACHP/(km/h) to 0.0186 ACPH/(km/h)] and the sensitivity to temperature difference decreased by

Table 1. Summary of Control House Infiltration Measurements

Run No	Date	Dryer Loc	Dryer On	Temperature Inside (C)	Temperature Outside (C)	Temperature Delta (C)	Wind Speed (KM/H)	Wind Dir	Infil Rate (ACPH)
1	16 Nov78	NV	n	21.11	15.56	5.56	0.00	W	0.196
2	3 Jan79	NV	n	18.33	-8.56	26.89	16.09	W	1.049
3	5 Jan79	NV	n	20.00	2.17	17.83	10.14	SW	0.814
4	5 Jan79	UR	y	20.00	1.56	18.44	12.87	SW	0.835
5	10 Jan79	UR	n	19.83	-0.17	20.00	4.83	E	0.701
6	10 Jan79	UR	y	21.11	4.44	16.67	4.83	E	0.843
7	12 Jan79	UR	n	20.89	4.39	16.50	8.27	NE	0.618
8	12 Jan79	UR	y	21.11	6.11	15.00	8.85	NE	0.687
9	12 Jan79	UR	n	21.11	6.67	14.44	8.05	NE	0.600
10	17 Jan79	UR	n	20.78	7.28	13.50	5.47	SW	0.658
11	17 Jan79	UR	y	21.11	8.61	12.50	15.77	SW	0.780
12	17 Jan89	UR	n	21.11	8.56	12.56	15.13	SW	0.663
13	6 Feb79	K	n	20.00	-0.22	20.22	8.05	NE	0.809
14	6 Feb79	K	y	20.00	0.83	19.17	8.05	NE	0.883
15	6 Feb79	K	n	20.00	1.11	18.89	8.05	NE	0.837
16	21 Feb79	K	n	21.11	8.44	12.67	11.27	SW	0.745
17	21 Feb79	K	y	22.22	11.72	10.50	8.69	SW	0.587
18	21 Feb79	K	n	22.22	12.22	10.00	9.66	SW	0.597
19	1 Mar79	K	n	21.67	15.00	6.67	22.53	SW	0.928
20	1 Mar79	K	y	21.67	17.06	4.61	22.05	SW	0.854
21	23 Mar79	K	n	21.67	16.94	4.72	15.29	SW	0.742
22	4 Apr79	K	n	21.67	20.72	0.94	8.53	W	0.425
23	4 Apr79	K	y	22.78	18.00	4.78	24.46	W	0.624
24	31 May79	NV	n	24.56	20.00	4.56	4.83	W	0.286
25	1 Jun79	NV	n	24.83	23.50	1.33	6.44	SW	0.270
26	4 Jun79	NV	n	25.56	24.67	0.89	8.05	NE	0.267
27	13 Aug79	NV	n	25.22	26.67	1.44	4.99	SW	0.316
28	14 Aug79	K	n	25.56	25.56	0.00	6.44	SW	0.286
29	14 Aug79	K	y	25.56	28.89	3.33	7.72	W	0.614
30	14 Aug79	K	n	26.11	29.06	2.94	9.66	SW	0.329
31	5 Sep79	K	n	26.56	27.67	1.11	10.30	NW	0.372
32	5 Sep79	K	y	27.56	28.56	1.00	11.91	NW	0.616
33	5 Sep79	K	n	28.33	29.11	0.78	12.87	NW	0.462
34	22 Oct79	K	n	25.00	25.17	0.17	3.70	SW	0.272
35	22 Oct79	K	y	26.22	28.11	1.89	14.16	SW	0.668

Note: NV = Vent Blocked Off
K = Kitchen
UR = Utility Room

Table 1 (continued)

Run No	Date	Dryer Loc	Dryer On	Temperature Inside (C)	Temperature Outside (C)	Temperature Delta (C)	Wind Speed (KM/H)	Wind Dir	Infil Rate (ACPH)
36	22 Oct79	K	n	27.11	26.89	0.22	19.96	SW	0.658
37	10 Jan80	K	n	20.94	4.56	16.39	5.63	NE	0.392
38	10 Jan80	K	y	21.22	7.61	13.61	3.70	W	0.560
39	10 Jan80	K	n	21.56	8.78	12.78	3.54	W	0.336
40	18 Jan80	K	n	21.67	12.78	8.89	7.08	N	0.313
41	18 Jan80	K	y	21.67	13.22	8.44	7.24	N	0.528
42	24 Jan80	K	n	20.17	7.50	12.67	28.65	SW	0.768
43	24 Jan80	K	y	21.00	10.67	10.33	41.52	SW	1.290
44	24 Jan80	K	n	21.11	10.89	10.22	40.56	SW	1.060
45	29 Jan80	K	n	20.00	1.39	18.61	6.44	NW	0.524
46	29 Jan80	K	y	20.11	1.22	18.89	7.40	N	0.696
47	29 Jan80	K	n	20.56	1.67	18.89	7.72	N	0.505
48	2 Feb80	K	n	18.33	-5.67	24.00	10.14	NW	0.600
49	2 Feb80	K	y	19.11	-4.67	23.78	9.66	N	0.805
50	2 Feb80	K	n	19.44	-4.11	23.56	8.69	N	0.632
51	15 Feb80	K	n	21.11	11.28	9.83	6.12	SW	0.355
52	18 Feb80	K	n	19.61	2.94	16.67	5.95	SE	0.460
53	18 Feb80	K	y	20.33	6.44	13.89	5.79	SW	0.649
54	18 Feb81	K	n	20.72	6.56	14.17	6.44	SW	0.496
55	20 Feb80	K	n	20.72	5.39	15.33	2.74	SW	0.394
56	20 Feb80	K	y	21.11	5.94	15.17	2.74	SE	0.538
57	20 Feb80	K	n	21.11	6.67	14.44	4.35	SW	0.398
58	20 Feb80	K	y	21.11	6.67	14.44	4.35	SW	0.605
59	20 Feb80	K	n	21.11	6.67	14.44	3.22	SW	0.386
60	20 Feb80	K	y	21.11	6.67	14.44	4.35	SW	0.514
61	28 Feb80	K	n	21.61	14.50	7.11	28.49	SW	0.753
62	28 Feb80	K	y	22.11	19.11	3.00	28.65	SW	0.823
63	28 Feb80	K	n	22.22	20.44	1.78	31.06	SW	0.773
64	29 Feb80	K	n	21.00	4.33	16.67	14.97	N	0.546
65	29 Feb80	K	y	21.11	4.89	16.22	14.48	N	0.679
66	29 Feb80	K	n	21.28	5.28	16.00	14.48	N	0.526
67	29 Feb80	K	n	21.67	5.94	15.72	15.61	N	0.509
68	29 Feb80	K	y	21.67	6.00	15.67	15.77	N	0.662
69	4 Jun80	NV	n	25.56	29.89	4.33	7.72	E	0.332

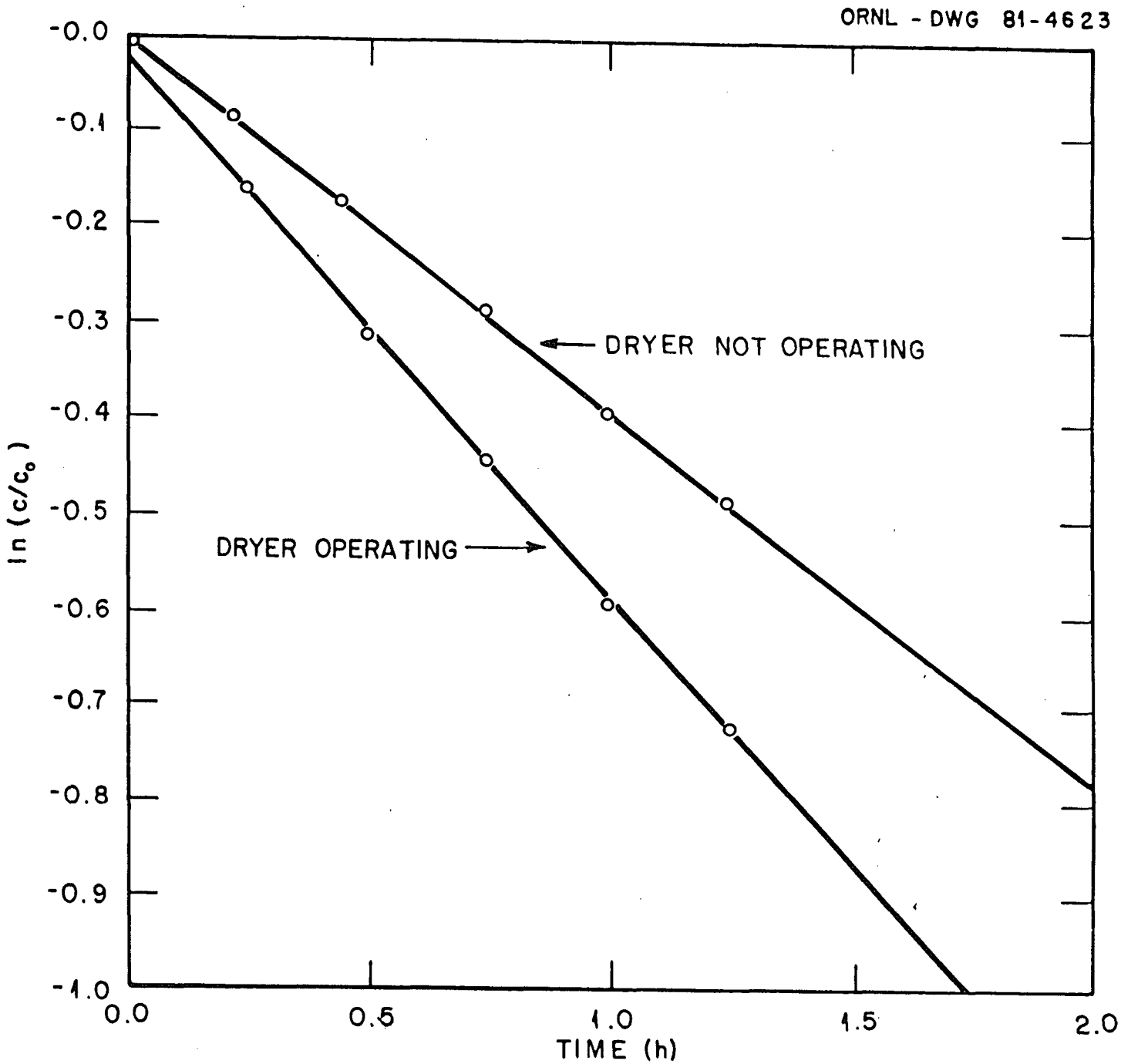

Figure 2. Plot of Infiltration Data, January 10, 1980

Table 2 Comparison of Measured And Predicted Infiltration Rates Before House Modifications

Temp Diff (C)	Wind Speed (KM/H)	Wind Dir	Infiltration Rate (ACPH) Meas	Pred	Delta (ACPH)	% Diff
5.56	0.00	W	0.196	0.231	0.035	17.97
26.89	16.09	W	1.049	1.135	0.086	8.21
17.83	10.14	SW	0.814	0.775	-.039	-4.78
20.00	4.83	E	0.701	0.679	-.022	-3.09
16.50	8.27	NE	0.618	0.695	0.077	12.52
14.44	8.05	NE	0.600	0.644	0.044	7.34
13.50	5.47	SW	0.658	0.554	-.104	-15.85
12.56	15.13	SW	0.663	0.794	0.131	19.71
20.22	8.05	NE	0.809	0.771	-.038	-4.68
18.89	8.05	NE	0.837	0.742	-.095	-11.37
12.67	11.27	SW	0.745	0.692	-.053	-7.14
10.00	9.66	SW	0.597	0.590	-.007	-1.22
6.67	22.53	SW	0.928	0.864	-.064	-6.90
4.72	15.29	SW	0.742	0.626	-.116	-15.68
0.94	8.53	W	0.425	0.360	-.065	-15.28
4.56	4.83	W	0.286	0.340	0.054	18.73
1.33	6.44	SW	0.270	0.312	0.042	15.61
0.89	8.05	NE	0.267	0.346	0.079	29.52
1.44	4.99	SW	0.316	0.275	-.041	-12.82
0.00	6.44	SW	0.286	0.283	-.003	-1.12
2.94	9.66	SW	0.329	0.434	0.105	32.06
1.11	10.30	NW	0.372	0.412	0.040	10.63
0.78	12.87	NW	0.462	0.474	0.012	2.54
0.17	3.70	SW	0.272	0.213	-.059	-21.84
0.22	19.96	SW	0.658	0.653	-.005	-0.81

Note: The Regression Equation used is
$I = 0.109 + 0.022 * DT + 0.027 * WS$
The value of R^2 is 0.922
There is no forced ventilation present

Table 3 Comparison of Measured And Predicted Infiltration Rates After House Modifications

Temp Diff (C)	Wind Speed (KM/H)	Wind Dir	Infiltration Rate (ACPH) Meas	Pred	Delta (ACPH)	% Diff
16.4	5.63	NE	0.392	0.431	0.039	9.83
12.8	3.54	W	0.336	0.349	0.013	3.97
8.9	7.08	N	0.313	0.370	0.057	18.12
12.7	28.65	SW	0.768	0.815	0.047	6.12
10.2	40.56	SW	1.060	1.008	-.052	-4.91
18.6	6.44	NW	0.524	0.471	-.053	-10.02
18.9	7.72	N	0.505	0.499	-.006	-1.25
24.0	10.14	NW	0.600	0.603	0.003	0.56
23.6	8.69	N	0.632	0.571	-.061	-9.61
9.8	6.12	SW	0.355	0.363	0.008	2.20
16.7	5.95	SE	0.460	0.440	-.020	-4.40
14.2	6.44	SW	0.496	0.419	-.077	-15.43
15.3	2.74	SW	0.394	0.364	-.030	-7.54
14.4	4.35	SW	0.398	0.384	-.014	-3.56
14.4	3.22	SW	0.386	0.363	-.023	-5.99
7.1	28.49	SW	0.753	0.747	-.006	-0.79
1.8	31.06	SW	0.773	0.733	-.040	-5.24
16.7	14.97	N	0.546	0.607	0.061	11.24
16.0	14.48	N	0.526	0.591	0.065	12.28
15.7	15.61	N	0.509	0.608	0.099	19.51
4.3	7.72	E	0.332	0.328	-.004	-1.09

Note: The Regression Equation used is
$I = 0.134 + 0.0117 * DT + 0.0186 * WS$
The value of R^2 is 0.937
There is no forced ventilation present

47% (0.022 ACPH/C° to 0.0117 ACPH/C°). The house constant for no wind or temperature differences remained essentially unchanged at 0.12 ACPH.

The maximum difference between measured and predicted infiltration rates is 0.13 ACPH in Tables 2 and 3, with most values differing by less than ±0.06 ACPH.

Even though an effort was made to conduct the testing on days when weather conditions were not changing, the conditions did change slightly between test runs on any given day. Therefore, the infiltration rates measured with no forced ventilation were normalized to those weather conditions prevailing during the corresponding infiltration measurement with forced ventilation. The slopes for the wind speed and temperature difference factors in Tables 2 and 3 were used for the normalization. Table 4 contains the normalized data for each set of corresponding runs.

The laboratory measured dryer vent rate was 3.49 m^3/min (123 cfm) and Sears' Engineering Laboratories in Chicago quoted a value of 3.4 m^3/min (120 cfm) for the vent rate of the dryer with hose and vent kit attached. The dryer vent rate of 3.4 m^3/min amounts to equivalent infiltration rate of 0.45 ACPH in the control house.

Figure 3 is a plot of the infiltration/vent rate, $X = NI/VR$ versus the infiltration rate increase/vent rate, $Y = (VI-NI)/VR$, caused by the forced ventilation. The boundary conditions for the resulting curve are that at $X = 0$, $Y = 1$, and that at $X = \infty$, $Y = 0$. These boundary conditions mean that when the infiltration rate of the house is 0 and the vent is turned on, the house infiltration rate must be equal to the forced ventilation rate; and when the house infiltration rate is infinitely large, the change in the ilfiltration rate caused by forced ventilation is infinitesimal.

Although other models may fit the data in the limited range covered, for the more general case, the boundary conditions dictate an exponential curve fit of the form $Y = e^{-AX}$ for the data. The value of the exponent A which minimizes the sum of the squares of the differences

Table 4. Normalized Infiltration Data

Run Nos NV & V	Meas I (ACPH)	Differences Temp (C)	Differences Wind Sp (KM/H)	Norm I [NI] (ACPH)	Vent I [VI] (ACPH)	VI-NI (ACPH)	NI/VR	(VI-NI)/VR
3 & 4	0.814	-0.61	-2.74	0.901	0.835	-0.066	2.003	-0.147
5 & 6	0.701	3.33	0.00	0.628	0.843	0.215	1.395	0.479
9 & 8	0.600	-0.56	-0.80	0.634	0.687	0.053	1.409	0.118
12 & 11	0.663	0.06	-0.64	0.679	0.780	0.101	1.509	0.224
15 & 14	0.837	-0.28	0.00	0.843	0.883	0.040	1.874	0.089
18 & 17	0.597	-0.50	0.97	0.582	0.587	0.005	1.293	0.011
19 & 20	0.928	2.06	0.48	0.870	0.854	-0.016	1.933	-0.035
22 & 23	0.425	-3.83	-15.93	0.940	0.624	-0.316	2.088	-0.701
30 & 29	0.329	-0.39	1.93	0.285	0.614	0.329	0.634	0.730
33 & 32	0.462	-0.22	0.97	0.441	0.616	0.175	0.980	0.389
36 & 35	0.658	-1.67	5.79	0.538	0.668	0.130	1.196	0.288
39 & 38	0.336	-0.83	-0.16	0.349	0.560	0.211	0.775	0.469
40 & 41	0.313	0.44	-0.16	0.311	0.528	0.217	0.691	0.483
44 & 43	1.060	-0.11	-0.97	1.079	1.290	0.211	2.398	0.468
45 & 46	0.524	-0.28	-0.97	0.545	0.696	0.151	1.212	0.335
50 & 49	0.632	-0.22	-0.97	0.653	0.805	0.152	1.450	0.339
54 & 53	0.496	0.28	0.64	0.481	0.649	0.168	1.068	0.374
55 & 56	0.394	0.17	0.00	0.392	0.538	0.146	0.871	0.324
57 & 58	0.398	0.00	0.00	0.398	0.605	0.207	0.884	0.460
63 & 62	0.773	-1.22	2.41	0.742	0.823	0.081	1.650	0.179
66 & 65	0.526	-0.22	0.00	0.529	0.679	0.150	1.175	0.334
67 & 68	0.509	0.06	-0.16	0.511	0.662	0.151	1.136	0.335

Notes:
NV = No Ventilation
V = With Ventilation
VR = Forced Ventilation Rate (0.45 ACPH)
Meas I = Measured Infiltration Rate With No Ventilation (ACPH)
Norm I = NI = Normalized Infiltration Rate With No Ventilation (ACPH)
Vent I = VI = Measured Infiltration Rate With Ventilation (ACPH)

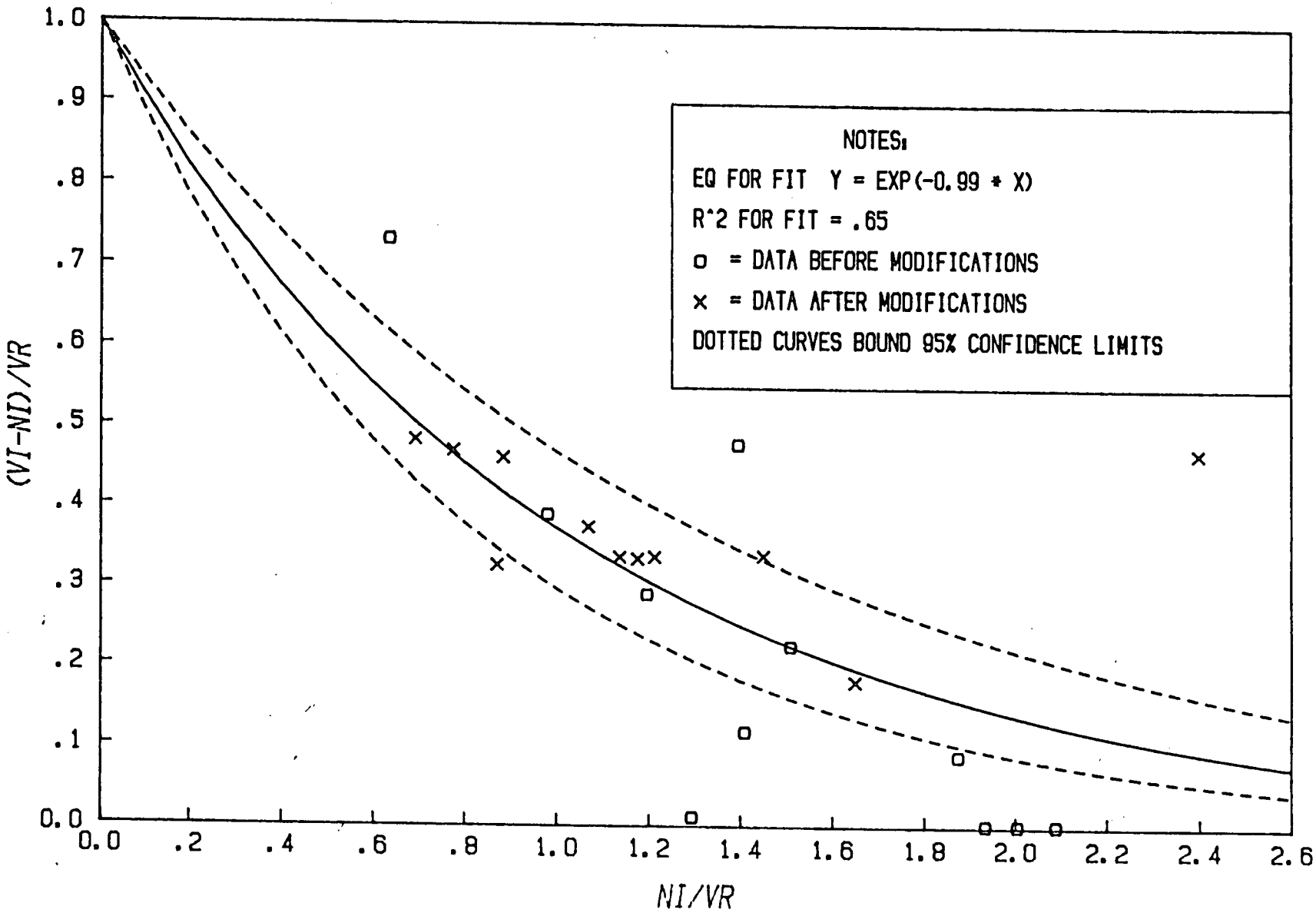

Fig 3. EFFECT OF FORCED VENTILATION ON INFILTRATION RATE

between the observed and predicted values of Y is -0.993. Hence, the equation best describing the data is

$$Y = e^{-0.993X}$$

Little accuracy is lost by rounding off the exponent from -0.993X to -X. Therefore, the above equation may be written

$$Y = e^{-X}.$$

This equation may be rewritten in the more convenient form

$$VI = NI + VR\ e^{-(NI/VR)},$$

where

VI = the infiltration rate with forced ventilation,

NI = the infiltration rate with no forced ventilation,

VR = the vent rate.

Table 5 contains a comparison of the measured and predicted infiltration rates with forced ventilation. The predicted infiltration rates were calculated using the equations generated from Tables 2 and 3 and Fig. 3.

To utilize the results of this study and put them into the proper perspective so far as venting clothes dryers is concerned, an analysis was done to determine the effect of a vented dryer on the control house's central heating and cooling system. Temperature bin and wind speed weather data,[7,8] for 17 different cities in the United States were used to calculate monthly heating and cooling loads on the control house, assuming it were located in each of those cities. The additional house load caused by venting the dryer was calculated for each city assuming a monthly dryer usage of 34 loads per month. Table 6 contains a summary of the annual effect of the vented dryer in each of the listed cities for houses containing central heat pumps or electric resistance heat with central air conditioners.

Table 5 Comparison of Measured and Predicted Infiltration Rates With Forced Ventilation

Run No	Temp Diff (C)	Wind Sp (KM/H)	Predicted NI (ACPH)	Predicted VI (ACPH)	Meas VI (ACPH)	Delta (ACPH)	% Diff
4	18.4	12.87	0.862	0.929	0.835	0.094	11.32
6	16.7	4.83	0.606	0.724	0.843	-0.119	-14.10
8	15.0	8.85	0.678	0.779	0.687	0.092	13.36
11	12.5	15.77	0.810	0.885	0.780	0.105	13.49
14	19.2	8.05	0.748	0.834	0.883	-0.049	-5.51
17	10.5	8.69	0.575	0.701	0.587	0.114	19.47
20	4.6	22.05	0.806	0.882	0.854	0.028	3.25
23	4.8	24.46	0.875	0.940	0.624	0.316	50.63
29	3.3	7.72	0.391	0.581	0.614	-0.033	-5.40
32	1.0	11.91	0.453	0.618	0.616	0.002	0.38
35	1.9	14.16	0.533	0.672	0.668	0.004	0.56
38	13.6	3.70	0.362	0.564	0.560	0.004	0.80
41	8.4	7.24	0.368	0.567	0.528	0.039	7.48
43	10.3	41.52	1.027	1.074	1.290	-0.216	-16.76
46	18.9	7.40	0.493	0.644	0.696	-0.052	-7.41
49	23.8	9.66	0.592	0.714	0.805	-0.091	-11.34
53	13.9	5.79	0.404	0.589	0.649	-0.060	-9.30
56	15.2	2.74	0.362	0.565	0.538	0.027	4.95
58	14.4	4.35	0.384	0.577	0.605	-0.028	-4.67
62	3.0	28.65	0.702	0.798	0.823	-0.025	-3.09
65	16.2	14.48	0.593	0.715	0.679	0.036	5.26
68	15.7	15.77	0.611	0.728	0.662	0.066	9.91

Notes:
NI = Infiltration Rate With No Ventilation (ACPH)
VI = Infiltration Rate With Ventilation (ACPH)

Table 6 ANNUAL EFFECT OF VENTED DRYER ON TWO TYPES OF HVAC SYSTEMS

CITY	DELTA HVAC LOAD (KWH/YR) ELEC RES & A/C HOUSE			ELEC HEAT PUMP HOUSE		
	HEAT	COOL	TOTAL	HEAT	COOL	TOTAL
ALBUQUERQUE NM	47.8	3.7	51.5	25.3	3.7	29.0
ATLANTA GA	32.2	5.5	37.8	16.4	5.5	22.0
BOSTON MA	39.5	1.2	40.6	22.9	1.2	24.1
CHICAGO IL	49.3	2.2	51.5	29.5	2.2	31.8
DENVER CO	55.9	1.0	56.9	32.3	1.0	33.3
FT WORTH TX	22.9	7.2	30.1	11.6	7.2	18.9
KNOXVILLE TN	46.0	4.8	50.8	24.0	4.8	28.7
LOS ANGELES CA	38.1	0.0	38.1	18.0	0.0	18.0
MINNEAPOLIS MN	55.5	0.8	56.3	36.8	0.8	37.6
NEWARK NJ	46.4	2.5	48.9	25.0	2.5	27.4
PITTSBURGH PA	51.5	0.7	52.2	29.5	0.7	30.1
SAN FRANCISCO CA	47.5	0.0	47.5	22.5	0.0	22.5
SEATTLE WA	67.6	0.0	67.6	33.3	0.0	33.3
TAMPA FL	11.1	10.8	21.9	5.3	10.8	16.1
WASHINGTON DC	40.6	3.6	44.2	21.8	3.6	25.5
WESTHAMPTON NY	43.3	1.2	44.5	23.7	1.2	24.9
WILMINGTON DE	49.6	2.3	51.9	26.7	2.3	29.0

Note: Average Monthly Temperatures and Wind Velocities Used

The additional electrical energy used by the house's HVAC system varies from a minimum of 16 kWh for a heat-pump-equipped house in Tampa to a maximum of 67.6 kWh for a resistance-heated house in Seattle. The typical electric dryer uses about 1100 kWh/year,[9] so the added energy used by the house HVAC system caused by the vented dryer is usually less than 5% of the energy used by the dryer.

DISCUSSION AND CONCLUSIONS

Although the work described in this paper was performed to characterize a clothes dryer vent and its effect on the house HVAC system, the basic equation describing the effect of the vent on house infiltration should apply to similar forced ventilation systems.

Two limitations of the work which may hinder a general application of the derived relationship are: 1) the work was carried out in the same house, which may relate the dependence of the exponent in the expression $Y = e^{-AX}$ on building structure, and 2) all the testing was done at a constant-forced ventilation rate equal to 0.45 ACPH (120 cfm).

The fact that the test house was "tightened up" halfway through the testing may add some universal applicability to the exponent, but comparisons with similar data from other sources are needed to verify general use of the relationship.

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