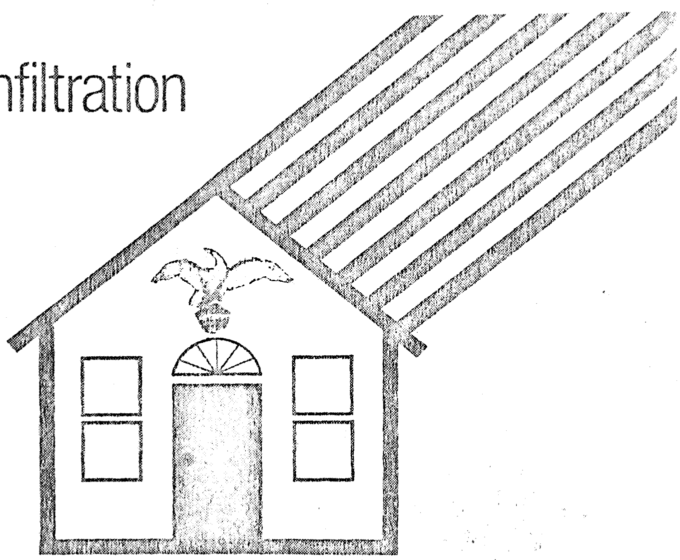
Simplified Determination of Air Infiltration

or

THE CITIZEN AS AN ENERGY MANAGER



Federal policy currently leans toward better insulation of occupied spaces. Air infiltration is also an important factor and valuable for comparing identical houses, but its measurement is quite difficult. This paper shows how average homeowners make this determination.

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THE weakest link in the home energy conservation chain is the determination of air infiltration on an average basis and under regular use, rather than on specific times with a tracer gas[1,2] or pressure measurement under specific flow conditions.[3]

A simplified heat transfer equation suggests an averaging method, easy enough for perceptive homeowners to use. They merely select a winter month and read the gas meter daily. With these minimum data and summary data from the Weather Bureau, they can determine average infiltration for the month, plus other valuable data such as the relative magnitude of conduction vs. infiltration losses.

This technique, referred to here as the determination of the heat-loss profile of the heated structure and based on a heat-transfer rate equation, is to be verified by a graph shown in Fig. 1.

The graph requires the daily gas consumption and its Btu content, with readings taken as close to midnight as possible to conform with Weather Bureau data, and National Weather Service information—degree-days, average daily wind velocity, and daily percent sunshine—for the nearest station.

The next section shows the logic behind the use of Fig. 1, and for the statements that the y-intercept represents conduction losses and the slope of the infiltration effect. At a standard wind velocity, one can report two numbers, b and c, to represent the heat-loss profile of a home or other enclosure and the ratio of the two—the proportion of heat loss due to conduction vs. air infiltration.

THEORY

The derivation of the heat-transfer equation follows, and it is the theoretical basis for the correlation presented.

Heat-Loss/Day = Loss Through Insulation + Heat for Cold Air Leaking In

$$q = \frac{A_c \cdot \Delta t}{\Sigma R} + \dot{m} \cdot c_p \cdot \Delta t \qquad (1)$$

A_c = the conduction area of the house.
Δt = the temperature difference between indoor and outdoor.
ΣR = the resistance to heat transfer, characteristic of the construction.
$\dot{m}$ = the mass of air leaking into the house in lb_m/day.
c_p = the heat capacity of the air.

Equation 1 is further expanded:

$$\dot{q} = \frac{A_c \cdot DD'}{\Sigma R} + k \cdot V_w \cdot A_1 \cdot \varrho \cdot C_p \cdot DD' \qquad (2)$$

DD' = the degree-days corrected for the amount that the house temperature deviates from the standard for DD, or 65°F (18.3C).
$DD' = DD + (t_{room} - 65)$
k = a proportionality constant of wind to leakage velocity.
V_w = the wind velocity. It will be shown later that the leakage velocity may be assumed equal to the wind velocity.
A_1 = the total area for leakage of air.
ϱ = the density of the leakage air.

It is important for the correlation in Eq. 1 that wind velocity appear only in the second term. One immediately questions whether the characteristic resistance of the house, ΣR, is not also dependent on the wind velocity. To answer this question, typical values of the resistance to heat flow through an insulated wall were selected from the ASHRAE Handbook of Fundamentals[4]:

Total Resistance
= Indoor Air Film + Plaster + Insulation Fill
+ Insulation Board + Siding + Outdoor Air Film

$R = 0.7 + 0.5 + 11.7 + 1.3 + 1.8 + 0.2 = 16.2\ ft^2 . hr. F/Btu$

The outdoor air resistance was taken at about 10 mi/hr. Thus, it is seen that the term affected by wind velocity (outdoor air film) amounts to less than 2% of the total resistance. The effect of the wind velocity in the first term of Eq. 1, therefore, can be neglected. In an uninsulated house, the effect of wind on the resistance to heat transfer would be greater, of course, in the order of 10%. The wind effect that the average person is aware of is its effect on air infiltration. On the leeward side the effect would be 4%. A double-pane window would show an 8% effect on the windward side and a 20% effect on the leeward.

Most of the variables in Eq. 1 can be considered constant and lumped together, giving

$$\dot{q}/DD' = b + c \cdot V_w \qquad (3)$$

This is the equation that will be tested with the actual data, and it has

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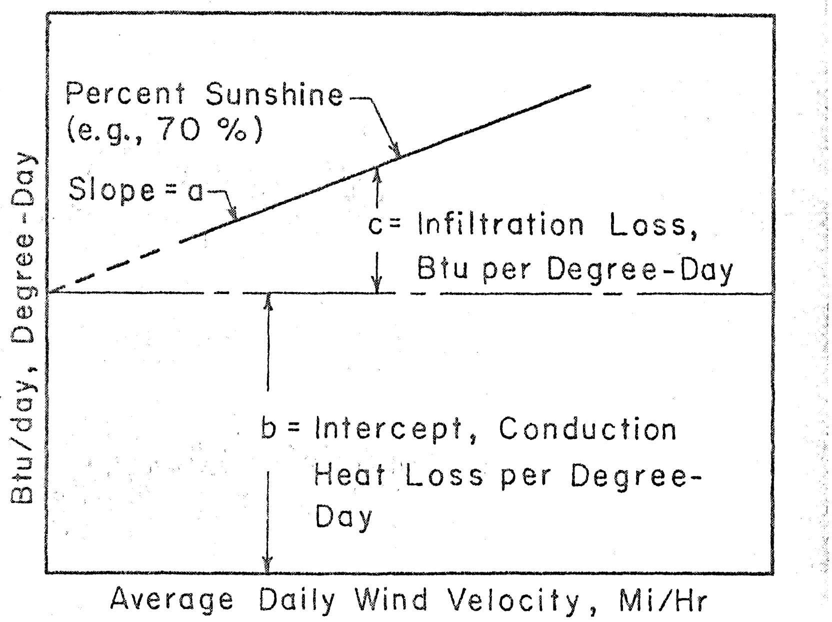

Fig. 1 Anticipated correlation

been simplified to the maximum extent possible. A graph of experimental data for a house should show a straight line when plotted as $\dot{q}/DD'$ vs. the average daily wind velocity.

DATA

Data were recorded on a residence in Angola, IN, from January 9 to January 31, 1978. The house is 15 years old, one-story, poured concrete, uninsulated basement with 4″ fiberglass in the ventilated attic space. The house faces south, with a thermal pane picture window, attached unheated garage (furnace is in the basement). A family room to the north has no basement and has three sides exposed. White aluminum siding is used except for brick veneer on the lower half of the south side. The area of the basement is 1400 sq. ft. and that of the family room is an additional 200 sq. ft. Weather data came from the National Weather Service at Baer Field, 50 miles south of Angola. This information is given on Table 1.

ANALYSIS

Data in Table 1 are used to determine if Eq. 4 can provide a suitable correlation. Results are summarized in Table 2. Needed are $\dot{q}$, DD′, V_w and % sun. The heat from the natural gas was taken as 1000 Btu/cu. ft.[5]

1. *Wind Velocity, V_w*—In order to translate leakage velocity, V_l, into wind velocity, V_w, one has the choice of modeling the leaks as orifices or as capillary tubes. Logic and the test results both indicate that the orifice assumption is satisfactory, and this is the model used.

Wind develops a pressure on the windward side of a house and a corresponding vacuum on the leeward side. These pressure differences result in air infiltration. The relationship between V_w and V_l is now developed. Bernoulli's equation gives the pressure increase at the wall of the house for a given wind velocity:

$$\frac{\Delta P_o}{\varrho} = \frac{\Delta V^2}{2} \quad (4)$$

$\Delta P_o = P_{wall} - P_{wind}$; $P_{wind} = P_{ATM} = 0$ (gage); $V_{wall} = 0$

Eq. 5 becomes

$$\Delta P_o = \frac{\varrho V_w^2}{2} \quad (5)$$

Assuming that an orifice represents the leaks,

$$\varrho V_l^2 = 2\,\Delta P_l = 2(P_{wall} - P_{indoor});\quad P_l = P_{ATM} = 0\text{ (gage)}, \quad (6)$$

assuming the upwind leakage area equals the downwind leakage area. The vacuum on the leeward side is not normally as large as is the pressure on the windward side, so the house may be pressurized somewhat. Approximately,

$$\Delta P_o = \Delta P_l \text{ and } V_l = V_w. \quad (7)$$

The capillary-tube model would require that Fig. 1 use $V_w^{0.5}$ on the x-axis. Thus, the daily average wind velocity as reported by the Weather Bureau would not necessarily be the correct daily mean for the correlation. We are, therefore, fortunate that the orifice model seems to correlate well.

With the orifice model and using a plot linear in V_w, there is no advantage in using the 3-hour averages reported by the Weather Bureau.

2. *Percent Sunshine*— When it was determined that the Weather Bureau kept a record of the percent sunshine, this variable was introduced into the correlation, Fig. 2, which made the difference between a good correlation of the data and none at all! The % sunshine data from the Weather Bureau are not obtained from a radiometer, but by a shadow technique, so that the magnitude of solar radiation is perhaps not accurately represented by % sunshine as would be desired.

RESULTS

Results are tabulated in Table 2, and the correlation of Eq. 1 is shown on Fig. 2.

- *% Sunshine.* The percentage of sunshine is very important with a 20% decrease in heat loss when going from 35 to 95% sunshine. Rough calculations show that the effect of the sun is divided, with one-third of the radiation coming through the south windows, including the picture window, and two-thirds apparently being the lowered heat loss due to the warming-up of the outside wall. With snow on the ground, the north side could have had some effect as well.
- *Wind Direction.* The wind direction (at the time of the highest wind velocity during the 24-hour period) is given in Table 1, but no correlation was noted on Fig. 2. Perhaps this result can be explained. It is reasonable to expect air leaks to occur on all sides of the house, particularly through doors and windows. For infiltration to take place, there must be a leak *in* as well as a leak *out*, otherwise the house is just being put under pressure or vacuum. This could explain why wind direction does not enter into the correlation in any definitive way. Elkins[6] states that wind along the length of the house would show lower infiltration.
- *Conduction Heat Loss.* Eq. 4 indicates that the y-intercept on Fig. 2 should be a measure of the conduction heat loss divided by the degree-days (at a selected value of % sunshine).

Other gas loads in the house would affect this plot, since even if they were constant, they are divided by degree-days and thus would introduce a scatter to the data. The literature tends to give the figure of 15-20% of the heat load as being required for domestic hot water. In the present case, with only two adults living in a three-bedroom house, the fraction of gas used for hot water would be on the low side. One should thus take note of the specific uses of gas for other purposes, such as clothes washing and drying. The data in this paper took no note of these events.

Table 1
Original Data

Date 1978	Time	Gas Meter Reading 100's of cu. ft.	Degree-Days DD	% Sunshine & Wind Velocity V_x, Mi/Hr.	Wind Dir. for Pk. Vel.	Thermo.
1/9	11:10	26.9				
1/10	6:45	38.3	61	19.1	W	
1/11	10:37	52.6	55	12.3	W	No Turndn.
1/12	10:40	65.5	51	6.2	E	
1/13	10:02	75.3	44	10.3	NE	
1/14	10:35	86.7	47	13.6	NE	
1/15	9:50	97.6	55	10.2	W	
1/16	11:30	110.8	56	6.7	E	No Turndn.
1/17	10:00	121.6	47	17.5	NE	
1/18	10:35	132.0	48	5.8	N	
1/19	11:05	142.3	46	13.1	NE	
1/20	10:50	153.2	43	15.5	NE	
1/21	10:50	164.0	54	10.1	W	(Normally,
1/22	10:30	174.4	62	3.5	SW	16 hrs. at
1/23	9:48	184.5	52	4.8	SW	68 °F and
1/24	10:50	195.0	41	7.2	SW	8 hr. at
1/25	10:43	203.9	34	12.4	NW	62 °F)
1/26	10:40	215.3	49	33.8	W	
1/27	9:20	227.4	58	24.9	W	
1/28	10:50	238.9	57	17.5	W	
1/29	9:55	249.5	56	16.5	W	
1/30	11:05	260.7	60	9.4	W	
1/31	11:50	271.8	56	12.8	W	

Degree-Days, Wind Velocity, % Sunshine & Wind Direction from National Weather Service, Baer Field, Fort Wayne, IN.

Table 2
Derived Data

Date 1978	Gas Consumption Cu. Ft.	Duration of Gas Readings, Hr.	Degree-Days DD′	$\dot{q}$ /DD′ Btu/Day, DD′	V_w	% Sun
1/10	114	19.58	62	22,540	19.1	99
1/11	143	27.87	58	21,230	12.3	98
1/12	129	24.05	52	24,760	6.2	27
1/13	98	23.37	45	22,365	10.3	68
1/14	114	24.55	48	23,215	13.6	73
1/15	109	23.25	56	20,090	10.2	94
1/16	132	25.67	59	20,915	6.7	69
1/17	108	22.50	48	24,000	17.5	56
1/18	104	24.58	49	20,720	5.8	77
1/19	103	24.50	47	21,470	13.1	54
1/20	109	23.75	44	25,030	15.5	58
1/21	108	24.00	55	19,640	10.1	69
1/22	104	23.67	63	16,740	3.5	83
1/23	101	23.30	53	19,630	4.8	95
1/24	105	25.03	42	23,970	7.2	41
1/25	89	23.88	35	25,560	12.4	42
1/26	114	23.95	50	22,850	33.8	62
1/27	121	22.67	59	21,710	24.9	75
1/28	115	25.50	58	18,,660	17.5	81
1/29	106	23.08	57	19,340	16.5	71
1/30	112	25.17	61	17,510	9.4	79
1/31	111	24.75	57	18,880	12.8	86

Data 1/10:

Eq. 5 $$\dot{q} = \frac{3{,}830 - 2{,}690}{19.58} \times 1000 \frac{\text{Btu}}{\text{ft.}^3} \times 24 \text{ hrs./day} = 1.397 \times 10^6 \text{ Btu/day.}$$

Eq. 6 $$DD' = 61 + \frac{(68\text{-}65)16 + (62\text{-}65)8}{24} = 62$$

y-axis, $$\frac{\dot{q}}{DD'} = \frac{1.40 \times 10^6}{62} = 22{,}540 \text{ Btu/day, degree-day.}$$

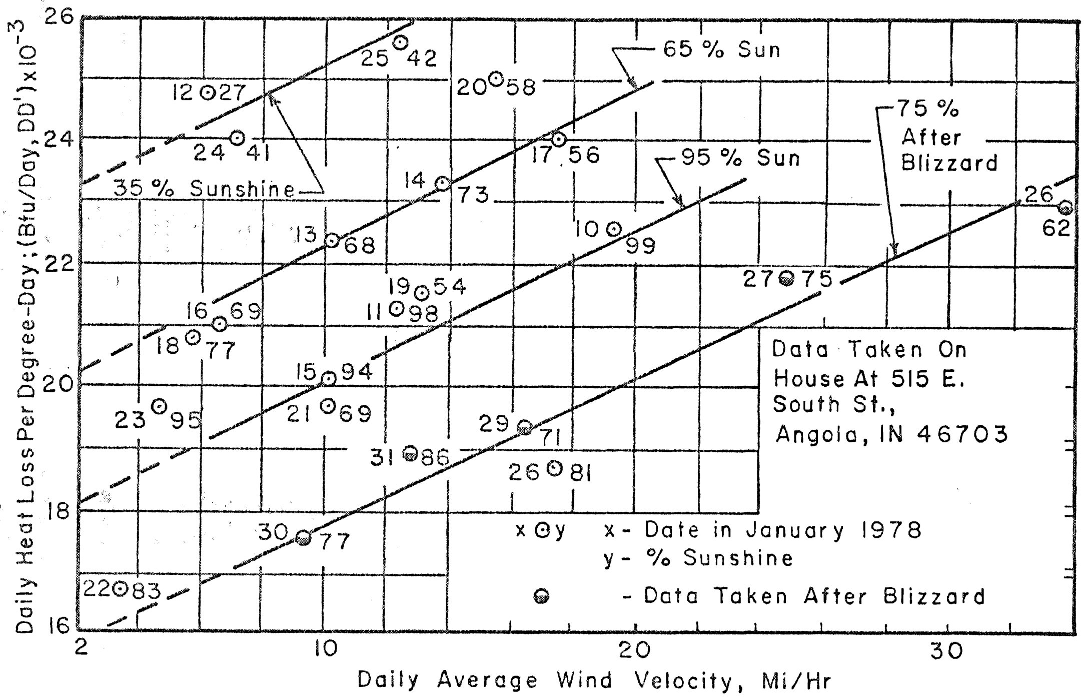

Fig. 2 Heat-loss profile of typical residence

• *Air Infiltration.* All infiltration air must be heated from the outdoor temperature to the house temperature (the DD'). The infiltration rate can be calculated from Eq. 2 and Fig. 2. The mean wind velocity (for January, 1977) was 11.6 mi/hr. At this wind speed, the calculated air leakage from the data on Fig. 2 was 38% of an air change per hour. The house, built 15 years ago, would be expected to have a higher value. Since it is occupied by a married couple with no children, however, this might explain the lower-than-expected infiltration rate!

• *Effect of Blizzard of 1978.* A dramatic aspect of the data in Fig. 2 is the effect of the blizzard on home heat loss (the lowest curve). For the week from Thursday, January 26, the percent sunshine was relatively constant, and the wind gradually tapered off from 34 mi/hr to 9, providing for a good spread on the x-axis of Fig. 2. It was found that the heat loss had decreased about 20% at a given wind velocity, perhaps as a result of the snow piling up around the house, with air infiltration unchanged. Rough calculations on the 1420 sq. ft. of poured concrete basement indicate that this insulating effect of the snow would be possible. Insulation of the basement wall is, therefore, indicated. No data are given starting a week after the blizzard, for any melting of snow around the house foundation could cause a scattering of the data, because of this 20% effect, measured above, becoming smaller by the day.

• *Data Only During Winter Months.* The correlation in Fig. 2 will be better during the coldest months, when the degree-days and heat losses are large, otherwise a significant error could appear in the $\dot{q}$ /DD' term. Also, one should take note as to whether the ground is covered with snow, thus producing extra radiation effects (perhaps to warm up the outside walls).

• *Better Weather Data.* The percent sunshine data were not taken by radiometer. Also, the Weather Bureau data were taken 50 miles south and thus introduce some additional error, particularly as Angola has a "lake" pattern of weather differing from Fort Wayne at times. Once better data are obtained, better curve-fitting techniques can be used; curves were drawn in arbitrarily.

• *Data Scatter.* The gas meter must have sufficient precision for a reasonable accuracy, and the occupant must learn to read it properly. It is easy to read the last dial in error. By interpolating between the numbers on the last dial (1000 cu. ft. of gas, the skilled reader can read to 2%; others might have 5-10% error. The degree-day reading at 50°F would have a 2% error as well. When data for adjacent days (e.g., 1/22 & 1/22) show one point high and one point low, a misreading of the gas meter is a likely explanation.

CONCLUSIONS

Heat loss from a home is quite complex and criticism could be leveled that the theoretical model used is much too simple. The important question to be asked, however, is, "Is it useful?" Certainly more houses should be tested. For the citizen, the degree of complexity should not be greater than presented here.

A main lesson to be learned from this paper is that the citizen, in energy matters, must begin to depend on meters and to draw conclusions from quantitative results.

This technique should enable homeowners to determine the value of extra insulation, tightening up the house, closing off rooms, turning down the thermostat, closing the fireplace flue (and teaching the children to close doors).

REFERENCES

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