Estimating Air Infiltration Into Houses:

This paper attempts to extract useful house air infiltration data from almost 20 years of scattered research work. The first portion of the paper highlights the important conclusions of these papers and gives some selected notes on the many variables involved. This information is then reduced and put into two tables. Two example problems using these data are also presented.

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THERE is, at present, no analytical step-by-step procedure for calculating air infiltration into houses. The difficulty lies in the wide variations in types and quality of construction, the shape and location of the house, and the type of heating system. Another unfortunate aspect is that infiltration due to wind, stack effect and pressurization appear to be of equal importance. Obtaining a correct analysis of one of these effects still means the problem is not solved.

Air pressurization studies on six houses of different construction[1] shows that windows and doors (with storm units) had from 15 to 24% of the total cracks in the house. Because the larger percentage of cracks are of the type that cannot be located and estimated for size, it is not possible to use the crack method with any engineering accuracy.

In recent years tracer gas techniques have been successfully used to determine infiltration into houses, often under actual living conditions. The final result of this type of analysis is to obtain infiltration rates in air changes per hour. Because of the many variables involved, the results, as would be expected, are quite scattered. Nevertheless these results are bracketed and some conclusions can be made. Four research groups[2,3,4,5] have analyzed a total of fifteen houses of varying styles and age. An overall observation is that for outdoor temperatures between 0°F and 32°F (indoor temperature from 70°F to 75°F), normal random wind speeds (from 0 to 15 mph), either gas or electric heating, and no appliance fans operating (clothes dryer, kitchen hood, shower fan, etc.), the air changes per hour varied from a low of 0.22 to a high of 0.99. If the tightest and loosest constructed houses were removed from consideration, all the remaining data for the thirteen houses would fall between 0.37 and 0.86 air changes per hour. Within this range the tighter constructed houses tend to have the lower values and older and loosely built new houses tend to have the higher values.

Determining specific trends within a large amount of tracer gas is very difficult. For stack effect, most researchers have used

$$I = B\,(\Delta T)$$

where I is the air change per hour

ΔT is the inside-outside temperature difference in °F

B is a constant determined from the experiments

One report[4] has used $B = 0.005$, another[2] has used $B = 0.010$, a third[7] used statistical analysis on two loosely constructed houses and found $B = 0.0164$ for one house and $B = 0.0105$ for the other. Statistical research[8] on a new townhouse gave $B = 0.0108$. Recent research[9] on nine houses using statistical analysis on large amounts of data showed that five of the houses had values of B between 0.006 and 0.012 with two houses below 0.006 and two above 0.012. The lower the value of B the tighter the construction of the house.

Some researchers have used $I = B_1 \sqrt{\Delta T}$ for the infiltration due to stack effect. Reference (4) uses this equation exclusively and the previously mentioned reports using statistical analysis[8,9] have also successfully applied their data to this equation. Because the inside-outside pressure difference due to the stack effect is a linear function of ΔT and the quantity of leaking air, Q, is given by $Q = (\text{Const.})(\Delta p)^n$, where Δp is the inside-outside pressure difference and where n equal to 2/3 is often used for cracks in houses, then the correct relation for the stack effect is $I = B_2\,(\Delta T)^{2/3}$. Considering the present state of the art it appears that little accuracy is gained by using these relations compared to the more simple $I = B\,(\Delta T)$.

Determining what variables effects the value of B by examining the experimental data is very difficult. One report[4] noted that for two similar houses, B for one house was almost double the value of B for the other house. Apparently an increased vertical distribution of cracks was the only reason for this. Another reference[2] noted that two-story houses appear to have larger values of B than one-story houses.

The relation most researchers have used for the effect of the wind is

$$I = D\,V_w$$

where V_w is velocity of the wind in miles per hour

D is a constant determined from experiments

The values of D obtained are $D = 0.017$ and $D = 0.020$ for two similar houses[4], $D = .013$ by another researcher[6] and a third report[2] estimates that $D = 0.030$. Statistical analysis[9] on nine houses showed that three houses had values of D between 0.015 and 0.030, with three houses having values of D below 0.015 and three having values above 0.030.

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An Analytical Approach

Some researchers[1,9] have used $I = D_1 V_w^2$ for the infiltration due to the wind. Because the inside-outside pressure difference due to the wind is proportional to the wind velocity squared and $Q = (\text{Const.})(\Delta p)^n$, then $I = D_2 V_w^{2n}$. If n would be 2/3 for a house then the actual relation would be $I = D_2 V_w^{4/3}$. Again the present state of the art does not warrant such refinement and $I = D V_w$ is recommended for most situations.

Research has not as yet pinpointed exact relations between values of D and important house variables, but certain trends have been noted. The number and size of windows and doors are more important for wind effect than they are for the stack effect. They are not, in many instances, the major source of wind infiltration. One test[4] shows that under combined wind and stack effect there was an approximate 12% reduction in infiltration when the cracks of all the operable windows were taped closed. The area of the wall facing the wind is also important. Tests[5] show that there is at least 30% less infiltration when the wind blows on the narrow end of a house compared to blowing broadside on a house. Cracks in the walls and types of construction are also very important. One report[1] determined that stucco walls have less than a fifth of leakage than do walls of brick, aluminum siding or asbestos shingles.

Strictly speaking the infiltration due to wind cannot be added directly onto the infiltration due to the stack effect. Only pressure differences can be added and the total infiltration found by $Q_{total} = (\text{Const.})(\Delta p_{wind} + \Delta p_{stack})^n$. With the present engineering accuracy, however, adding the air changes of the wind and stack effect together is acceptable. The equation commonly used is

$$I_{total} = A + B(\Delta T) + DV_w$$

The tracer gas experimental method usually determines A, a constant, to have an approximate value of 0.10. The magnitude of A or even its existence has never been satisfactorily explained. Estimations of tracer gas diffusion through cracks and absorption on surfaces do not fully account for the value of A.

Pressurizing a house (actually applying a negative gauge pressure) by way of various appliance fans can be a very important cause of infiltration[2]. In one test house just a shower fan would produce 0.47 air changes per hour and a shower and kitchen fan together would produce 1.01 changes per hour. A clothes dryer gave 0.58 changes per hour under actual house operation conditions. For periods of short duration a typical house with an average winter air change rate of .50 might jump to 1.50 with two appliance fans operating. These air changes are for a house of average volume. The values of the air changes per appliance will be smaller for a larger house and larger in value for a small house.

The operation of a gas or oil-fired furnace and the accompanying effect of the chimney is difficult to separate from the wind and stack effect. It appears that much of the exfiltration will go out the chimney when this type of furnace is in operation[4]. This, of course, will raise the neutral pressure level and thus increase the number of cracks exposed to a pressure difference favorable to infiltration. The amount of air change per hour caused by a fuel fired furnace varies with the furnace size to house volume. The air change per hour due just to the furnace operating (due to air for combustion and chimney dilution air) was 0.40 for a house in Ontario, Canada[4] and 0.19 for a house in Illinois[7]. For intermittent furnace operation, such as might be found in typical cold weather operation, perhaps half of these air change values should be used for realistic overall infiltration rates. Another test[5] involved two identical houses except one had a gas furnace and a chimney and the other had electric heating with no chimney. The results showed that the house with the gas furnace had infiltration rates up to 50% greater than the house with electric heating. Other tests[8] show that gas heating causes only 12% increase in infiltration over electric heating.

It is important for the user of this information to appreciate the many variables involved in the experiments under which this data was collected. This data was collected in the northeast and mid-west of U.S. and in Canada. To apply this information to typical house in say, Florida, might produce large errors. Also this information cannot be safely applied to houses of unconventional design or built with materials that are not commonly used in typical house construction. Because of the nature of tracer gas testing procedures the entire conditioned space of the house must be used as the house volume.

$$Q = I \times (\text{House Volume})$$

where Q is the air infiltration rate in cubic feet per hour.

This infiltration data is now arranged into two tables. The information in Table 1 represents the extremes of tracer gas data collected from 13 houses under actual winter conditions. The houses had either gas or electric heating, but no appliance exhaust fans operating. The outside temperature varied from 0°F to 32°F and the wind speed varied from 0 to 15 mph. The information in Table 2 represents approximate formulas for the stack and wind effect. The choice of these numbers come from the previous discussions.

A tightly constructed house is a new house where care has been taken during construction to prevent infiltration or

Table 1

	Tightly Constructed Houses		Loosely Constructed Houses
Air Changes/Hour	0.37	to	0.86

Table 2

	Tightly Constructed Houses	Loosely Constructed Houses
Stack Effect (Air Changes/Hour)	$.006\,\Delta T$	$.012\,\Delta T$
Wind Effect (Air Changes/Hour)	$0.15\,V_w$	$.030\,V_w$

an older house where the building envelope has been throughly reworked. The windows and doors must be tight fitting. A loosely constructed house is a new house where no special effort has been made to make it tight or it is an older house where cracks exist and normal wear of windows and doors have produced gaps allowing air leakage.

The contents of Table 2 are to be used in the formula

$$I = 0.10 + B(\Delta T) + D(V_w)$$

where I is air changes per hour.

For a fuel-fired furnace add on an air change/hour of .10 for winter conditions in northern United States. For poorly insulated houses or for very cold conditions a value larger than .10 should be used.

FIRST EXAMPLE

Determine the winter infiltration for a typical new brick house of 15,000 cubic feet volume to be built in Pennsylvania. The contractor has no specific techniques to prevent infiltration but promises to be careful during the construction of the envelope of the house. The house will have a gas furnace and storm units on all windows and doors.

• *Solution*: The winter conditions in Pennsylvania are similar to the conditions under which the information was gathered for Table 1. Because the house will be new and standard methods are used to reduce infiltration the house will tend to be tight. The gas furnace, however, will increase the air change rate. For this reason a value of .50 is selected. The infiltration, Q, is

$$Q = .50\,\frac{ft^3}{ft^3 \cdot hr} \cdot 15{,}000\ ft^3 \cdot \frac{1\ hr}{60\ min} = 125.0\ cfm$$

As the house becomes older this will increase unless some care is taken. For this reason an additional amount of infiltration could be added on for a long term energy analysis or for sizing of heating equipment. Resolve this example using Table 2.

• *Solution*: Because the house is new and is built with care, .006 ΔT is chosen for the stack effect. With strom units and the fact the rest of the house is tightly constructed .015 V_w is chosen for the wind effect. The average weather conditions under which the information of Table 1 was gathered might be an outside temperature of 20°F and a 5 mph wind, thus

$$I = .10 + .006\,(50) + .015\,(5) = .475$$

To this an air change of .10 is added to allow for the gas furnace. This will be about a 21% increase in infiltration due to the furnace.

$$Q = .575 \cdot 15{,}000 \cdot \frac{1}{60} = 144\ cfm$$

SECOND EXAMPLE

Determine the infiltration for a typical new house of 15,000 cubic feet to be built where the inside-outside temperature differences is most often less than 10°F. Constant 10 mph winds are common in this area and will blow broadside on the house. The electrically heated stucco house does not have storm units.

• *Solution*: From the description of the weather conditions Table 1 cannot be used. A stucco house tends to be a tight house (say .006 ΔT for the stack effect) but having no storm units and broadside blowing will increase the wind leakage (say .020 V_w). From Table 2 the following relation is used.

$$Q = (.10 + .006 \cdot 10 + .020 \cdot 10) \cdot \frac{15{,}000}{60}$$

$$= .36 \cdot \frac{15{,}000}{60} = 90\ cfm$$

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