THE USE OF SOUND TO LOCATE INFILTRATION OPENINGS IN BUILDINGS*

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Abstract:

Sound waves pass readily through many of the same openings in building envelopes that allow air infiltration. This fact permits the location of such air-infiltration openings by acoustic means.

The results of an experimental program, including laboratory tests of a specially constructed partition and field tests on eight buildings, are reported. On the average, openings that can be located acoustically transmit sound that is about twice as loud as that through adjacent, sealed locations. Laboratory studies indicate that the sound level increase through a leakage opening is roughly correlated with the logarithm of the local air flow rate when a steady differential pressure is established across the partition ($r = 0.67$).

Leak location with sound can be done by semiskilled workers with low-cost "hi-fi shop" equipment. The test procedure does not require pressure or temperature differentials across the building envelope.

Key Words:

Acoustic Leak Location
Air-Infiltration Paths
Sound Source
Infiltration Path Location
Listening Device
Sound Level

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INTRODUCTION

It is reported [1] that 30 to 50% of the heating load and 5 to 20% of the cooling load in residential buildings results from uncontrolled air leakage through the building envelope. Although this air flow is often through obvious openings – windows and doors, furnace flues, ventilation in kitchens and bathrooms – it also occurs through other paths whose existence is not obvious or even suspected, such as piping penetrations, structural joints, and heating ducts.

A simple method, involving simple equipment, can be used to locate many of the hidden openings through which air infiltrates buildings. The method is called "acoustic leak location," and it is based on a physical fact: sound moves through building crevices and openings just as air does. The method uses a sound-making device on one side of a building envelope and a small listening device close to the other side. To the user of the listening device, the sound coming through the barrier will seem almost twice as loud at locations where there are infiltration openings in the envelope. An opening, once identified, can be caulked or sealed, and the acoustic leak location method can be used again to make sure the sealing is adequate.

Laboratory and field tests have been done with acoustic leak location. Compared to other means of locating infiltration openings in buildings, acoustic location is low in cost. It is also easy for contractors and homeowners to implement, and the equipment required is uncomplicated and portable.

EXISTING LEAK LOCATION METHODS

There are three conventional methods for locating air leaks in buildings. They are thermography, smoke testing, and pressurization.

Thermography is a technique for visualizing small temperature differences on heat-radiating surfaces [2,3]. Its greatest utility is that it can locate flaws in the thermal insulation of a building envelope. Under some circumstances, air leaks can also be located. With skill, the method is semiquantitative.

The use of thermography for locating infiltration openings requires a temperature and pressure difference across the building envelope. Its greatest limitation, however, is that the necessary equipment is quite costly.

It is possible to fill a building with smoke and, perhaps with the aid of a small applied pressure, examine where the smoke comes out [4]. The method is inexpensive; obviously, however, it renders the building uninhabitable during testing and for some time thereafter.

A fan mounted in a window or door can be used to pressurize (or depressurize) a building. Pressurization testing is a widely used method for observing the air-flow rate through building envelopes [5]. It is pseudoquantitative in that it allows structures to be rank-ordered in about the way that they would be if infiltration caused by natural forces were observed.

During pressurization testing, it is possible to go around the building and feel air flow coming through leakage openings. In this way, the openings can be located in about the same length of time that would be required by the acoustic method.

The location of leaks during building pressurization is enhanced somewhat by a temperature difference across the wall and disturbed by windy conditions out-of-doors. It need not disrupt the ongoing activities of building occupants.

THE ACOUSTIC LEAK LOCATION METHOD: BACKGROUND

What we call sound is the result of small pressure fluctuations about the ambient pressure of the atmosphere. These pressure fluctuations propagate as longitudinal waves through the air. When sound waves strike a solid object such as a building wall, they cause it to vibrate. This vibration in turn produces a new sound on the other side of the wall. The sound produced on the "output" side of the wall is, in general, greatly reduced in amplitude compared to the sound that caused the wall to vibrate in the first place. The output sound will be altered in frequency content as well. The ratio of the input sound energy to the output sound energy of a wall, under carefully controlled conditions, is called the "transmission coefficient" of the wall. Ten times the logarithm of this ratio is the "transmission loss" of the wall, in decibels (dB). The transmission loss of typical residential structures varies from about 20 dB at 100 Hz to 40 or 50 dB at 2000 Hz or more. In general, the more massive a structure, the greater its transmission loss will be.

A simple opening through a barrier will have approximately zero transmission loss. Thus sound coming through such an opening will be far more intense than that radiated from the rest of the wall. This is basically why acoustic leak location works.

Several years ago, the National Bureau of Standards (NBS) published an extensive study of the acoustic and thermal properties of typical residential structures [6]. This study included experimental data on sound "leakage" through cracks located around windows and doors. Figure 1, calculated from the NBS data, illustrates the difference between sound coming through a crack and sound coming through a picture window.

Figure 1 is based upon an assumed sound pressure level (SPL) spectrum of 80 dB inside a room with a picture window in the wall. Just outside the picture window, the sound pressure level is 20 to 47 dB less, depending upon the frequency, as a result of the transmission loss of the window. However, when a 3-mm-wide crack is located around the window, the SPL just outside the crack is the same, or slightly greater than that inside the room. An observer, listening with a small microphone, could immediately discover the crack because the sound coming through it would be so much louder than that coming through the window pane.

The data in Fig. 1 are typical of what one observes with "simple" paths through structures. Sound propagation through such paths has been examined analytically by Gomperts [*7,8*], and by Ingerslev and Nielsen [*9*]. Available experimental data are in fair agreement with their analyses.

Some air-leakage paths through structures can be classed as "complex" paths, such as those illustrated in Fig. 2. In many cases, acoustic leak location will not identify the openings of such complex paths — particularly if the wall cavities are filled with insulation.

THE ACOUSTIC LEAK LOCATION METHOD: TECHNIQUE

The acoustic leak location method requires (1) a source of sound on one side of a building envelope and (2) equipment with which a user can listen to sound on the other side.

The sound source can be any one of many common household objects. For example, a home vacuum cleaner, a dishwasher, a washing machine, a noisy hair dryer, a television set, and a recording of organ music have been used. The sound, preferably, should be steady and predominantly high-pitched. During evaluation of the method, a taped, siren-like sound was used, reproduced through loudspeakers (Fig. 3).

The listening equipment is equally simple and available, with one stipulation: The user must be able to place it right against the wall and over a small spot, preferably less than one centimeter in diameter. Listening equipment has included a mechanic's stethoscope, a plastic headset of the kind handed out to airline passengers, small rubber hoses from auto-parts stores, and low-cost sound meters.

During development of the acoustic leak location method, a simple battery-operated listening system (Fig. 4) was used. Components of this system can be found in retail stores throughout the country, particularly those specializing in radio and "hi-fi" supplies.

One additional item proved useful for probing small cracks located close together, such as joints in the casing around door and window frames. It was a microphone end cap that restricted the listening area to a 3-mm circle and reduce interference from background noise.

With the sound source operating on one side of a wall, the user moves the listening device along the other side of, and very close to, the wall. At the location of a leakage opening, there will be a noticeable increase in the loudness of the sound — obvious to the human ear. For pinpointing leaks, the listener compares the loudness of places with openings to that at sealed spots nearby. For inexperienced listeners a quantitative measurement of sound is useful. This can be done with a sound meter to register the level of sound at the microphone.

Acoustic leak location can be used to test in either direction through a building envelope, though the sound sources described above were all used inside buildings. Traffic noise can serve as a source outside a building when a listener is inside. Most acoustic leak location testing is done outside, however, because the openings located will be on the side of the wall where they can be caulked.

DEVELOPMENT AND TESTING

Experimental work with the acoustic location method was done in three phases:

- Laboratory measurements, where both acoustic and air leakage were measured through known paths under controlled conditions
- Local field studies of buildings in the Boston area by BBN personnel
- Field applications of the method at several different locations in the United States, performed by building retrofit organizations.

Each of the phases is summarized below.

Laboratory Measurements

For the laboratory measurements, a typical residential exterior wall was built containing a number of known leakage paths. They included:

- Through a metal-flap mail slot in the door
- Between the door and the door jamb
- Between the structural framing and a prehung door
- From a duplex outlet through an uninsulated inter-stud cavity to a wiring hole drilled in the top plate
- From a duplex outlet through an insulated (R-11) inter-stud cavity to a wiring hole drilled in the top plate and to an exterior water faucet

- Between the sill plate and a solid concrete-block foundation
- Around a double-hung window sash, and through the meeting rail of the window
- Between a prehung window frame and the structural framing.

The wall divided the laboratory area into two rooms, designated the "inside" and the "outside" of a building. A differential pressure was established between the two test rooms in accordance with the procedures of ASTM E283-73 [5], with the "inside" of the partition at a negative pressure relating to the outside.

Measurements of the flow rate vs differential pressure were made at several pressures for each of the various leakage paths. Figure 5 is typical of the data obtained. Such results were extrapolated or interpolated to the flow rate at a differential pressure of 0.3 in. H_2O, corresponding to the stagnation pressure of a 25-mph wind.

The laboratory test data, summarized in Table 1, show that some major leaks occurred where they were easily seen (door jamb, window sash). However, the seriousness of other leaks (under the sill plate, around window and door frames) was discovered only by testing; those leaks were not obvious and in some cases not visible.

During the air flow tests, acoustic studies were of sound levels through known openings. These studies showed that a sound level increase of more than 5 dB(A)* at a crack is a strong indication that the crack will have a local flow of 100 ft/min or more at 0.3 in. H_2O pressure difference. Leaks typically transmitted sound levels that averaged 10 dB(A) more than those heard at nearby sealed areas. A summary of all the acoustic vs air flow data is showed on Fig. 6.

Field Studies

When the acoustic leak location method was tested in the field, eight structures built to withstand New England winters were found to be surprisingly leaky. In these structures, both air flow tests and the acoustic leak location method were used. The correlation between the two sets of results is good — +0.74, with a standard error of estimate of $\pm$ 3 dB (Fig. 7). Air flow tests also identified several "complex" leakage paths (i.e., through interior openings in sash-weight boxes) that were not found by the acoustic method.

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*The A-weighting of a sound level meter is an adjustment that approximates the way the human ear hears sound.

Use of Acoustic Leak Location by Other Organizations

Several retrofit organizations and contractors in Massachusetts and Washington, DC were trained and equipped to try the acoustic leak location method. In general, they were pleased with the application of the method to their work.

CONCLUSIONS

Acoustic leak location is a useful means of identifying many of the hidden openings in building envelopes through which air can move. It involves a sound source on one side of a wall, and a person with simple listening equipment at the other. To the listener, the sound at a crack or opening will seem approximately twice as loud as at a nearby sealed area.

Acoustic leak location is most useful in buildings that are drafty and therefore most in need of caulking and insulating. It works less well in tight, well-insulated buildings because sound does not propagate well through complex paths in building walls that are filled with fibrous insulating material.

Acoustic leak location is perhaps the simplest and least expensive method for finding hidden openings in buildings. Homeowners can do it themselves.

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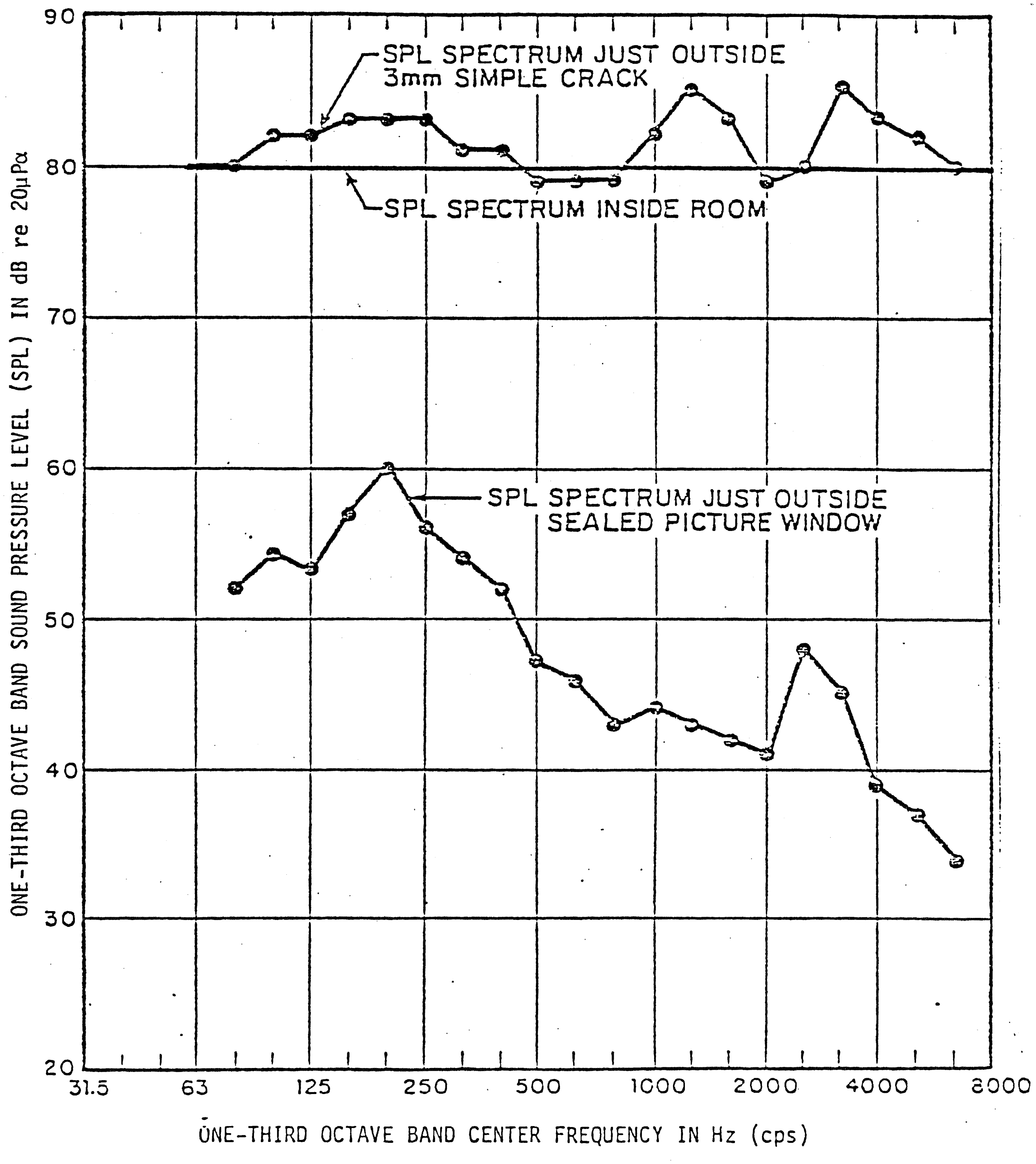


FIGURE 1. SOUND SPECTRA INSIDE AND OUTSIDE A PICTURE WINDOW WITH A SIMPLE, 3-mm WIDE PERIMETER CRACK. (CALCULATED FROM MEASURED DATA REPORTED BY NBS [Ref.6].

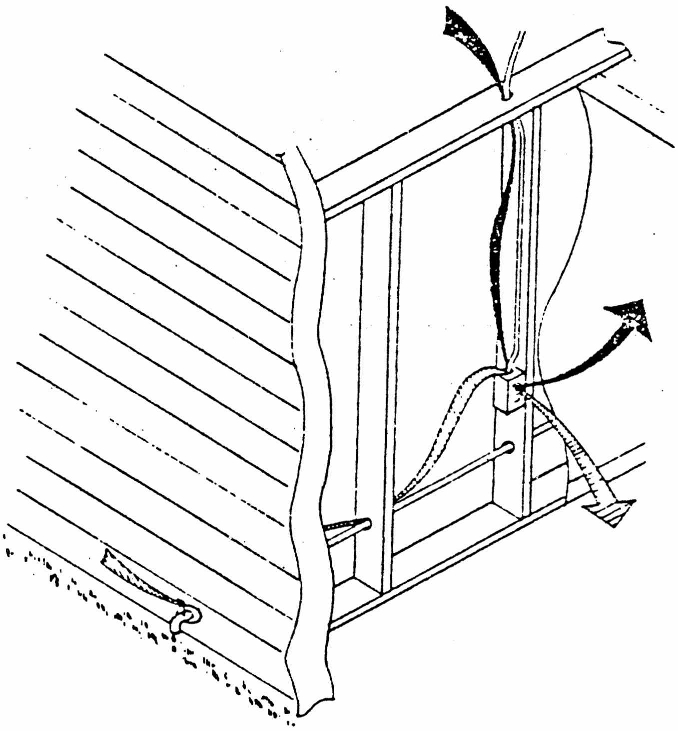


FIGURE 2. "COMPLEX" PATHS.

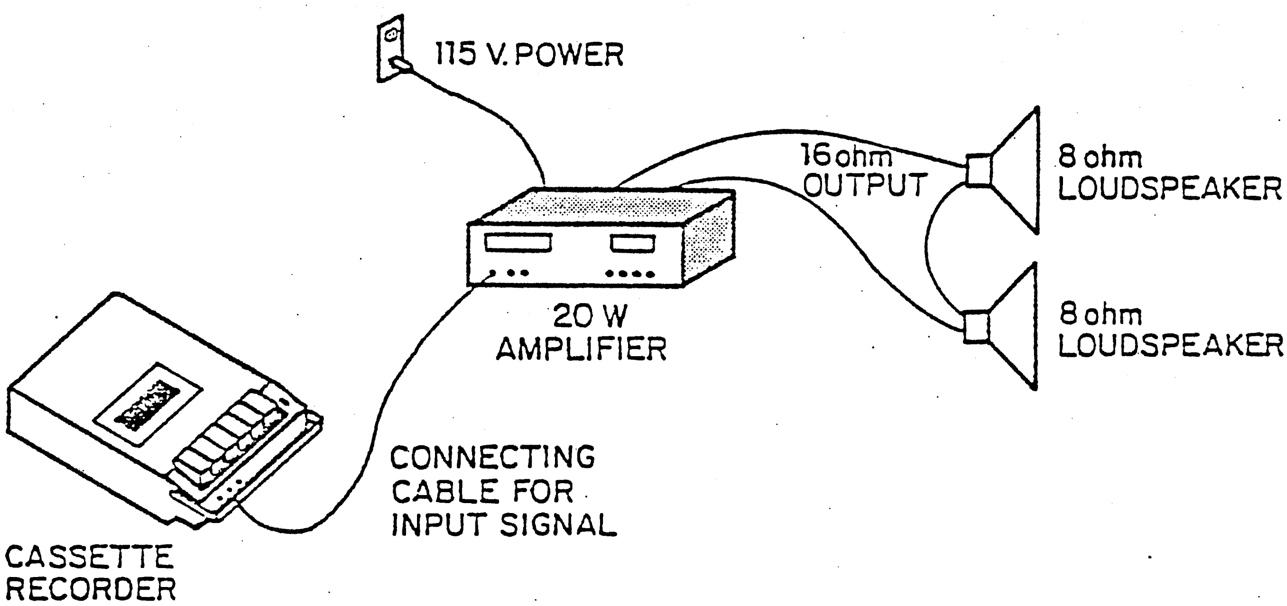
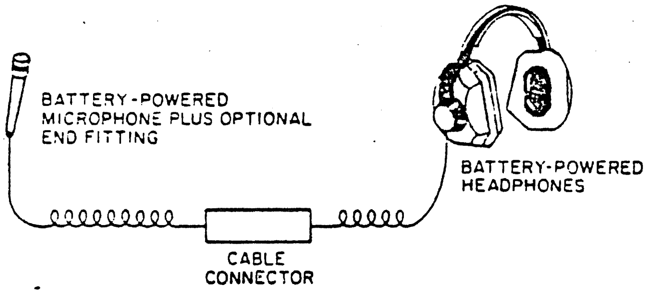


FIGURE 3. THE SOUND SOURCE USED FOR MOST FIELD TESTING.



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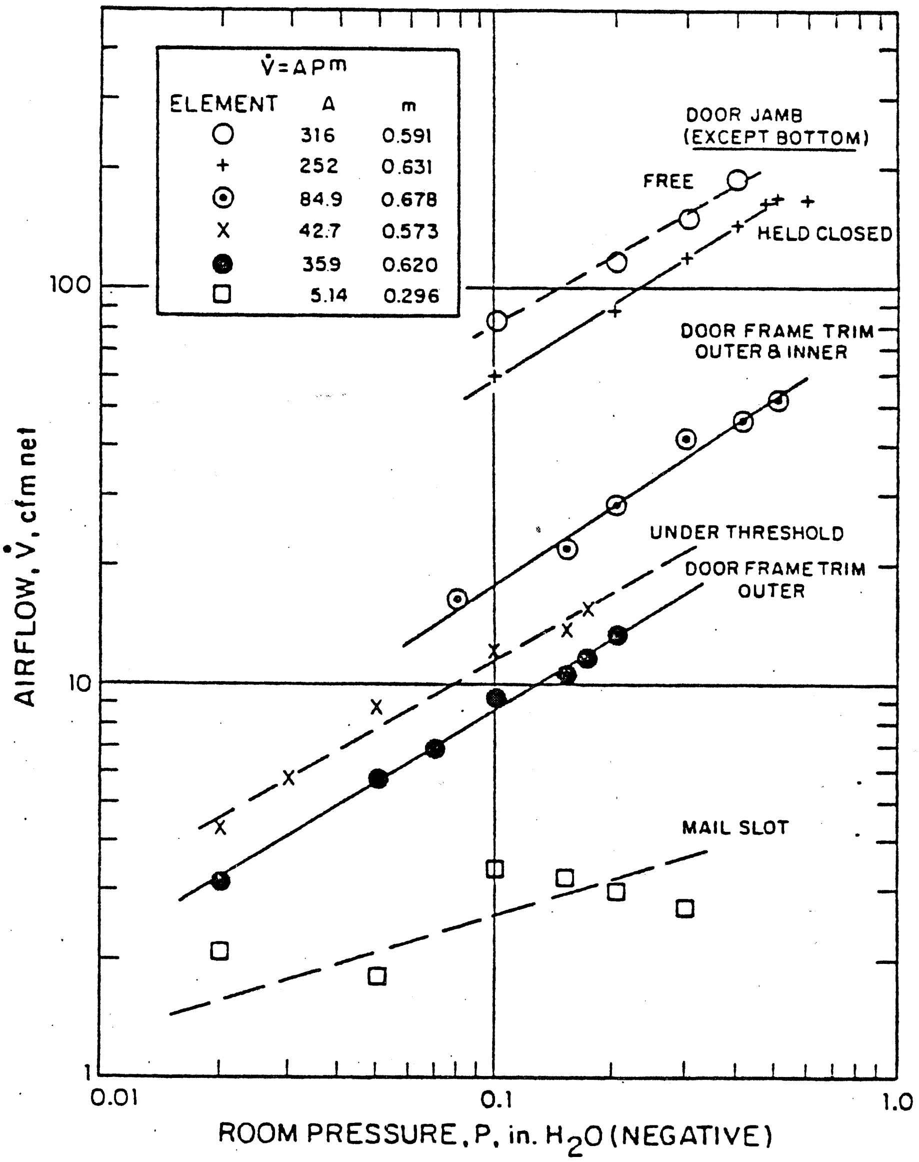

FIGURE 5. MEASURED AIR LEAKAGE THROUGH DOOR ELEMENTS (NET).

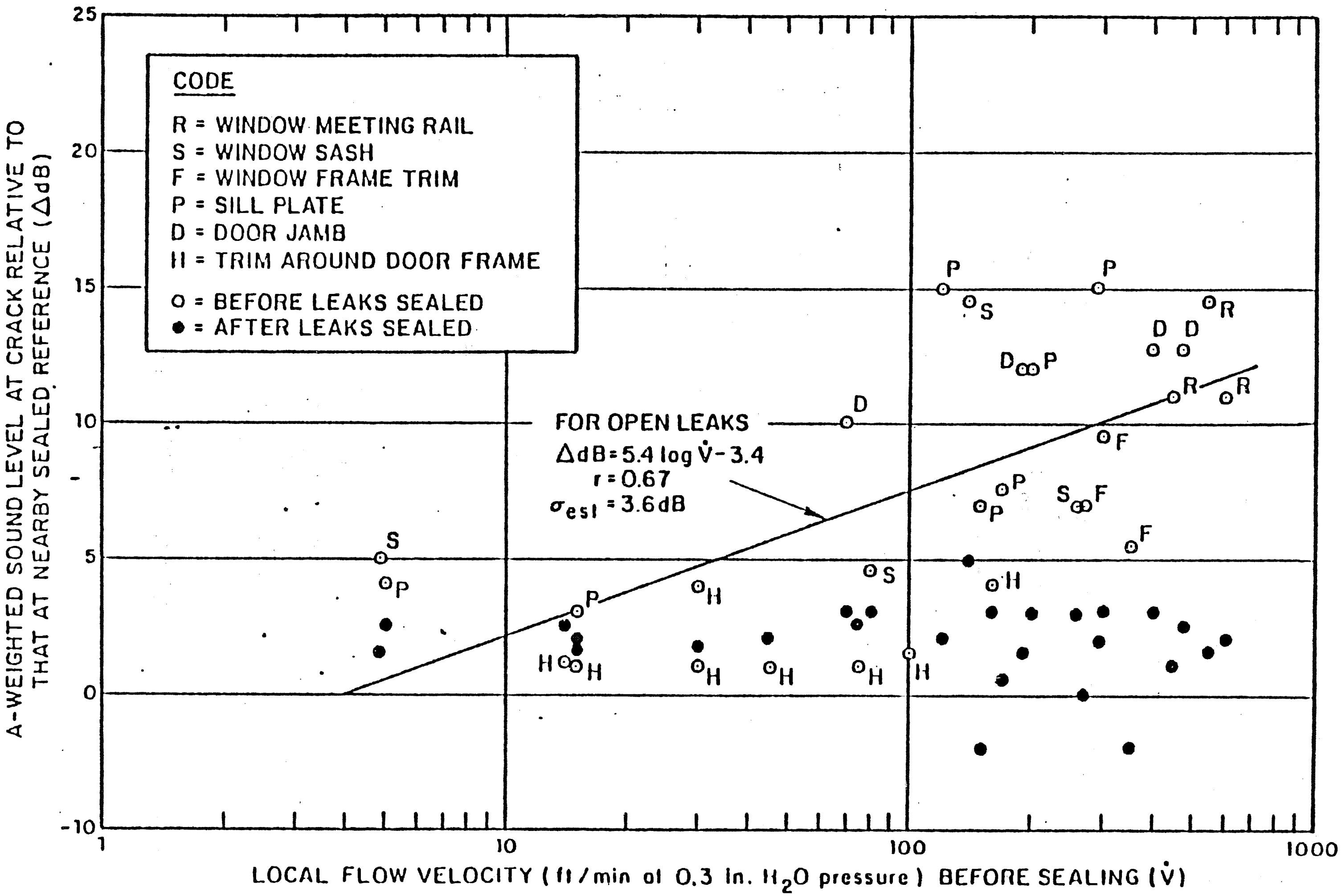

FIGURE 6. INCREASE IN SOUND LEVEL NEAR CRACK VS LOCAL AIR FLOW FROM CRACK AT 0.3 in. PRESSURE DIFFERENTIAL.

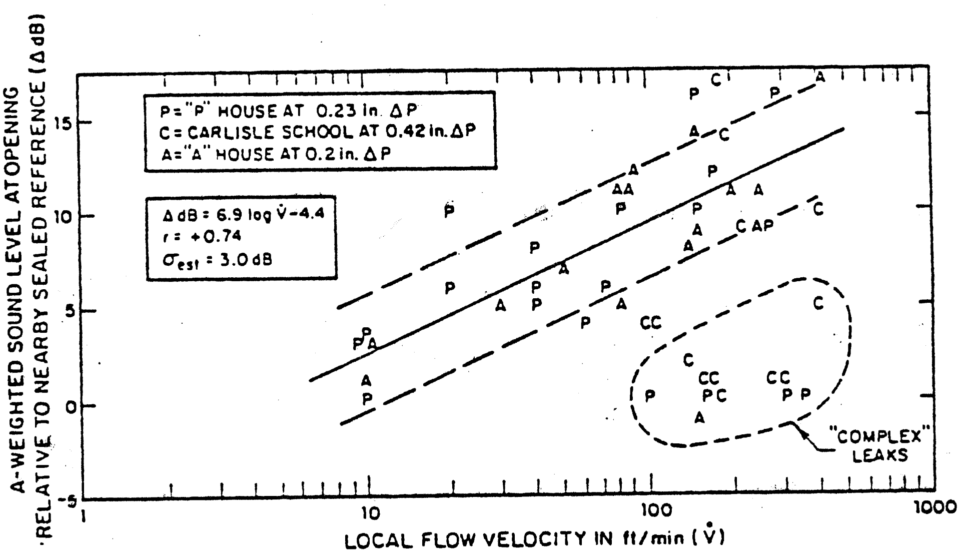

FIGURE 7. INCREASE IN SOUND LEVEL NEAR CRACKS VS LOCAL AIR FLOW FROM SAME CRACK.