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A Sonic Method for Building Air-Leakage Measurements*

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SUMMARY

The objective of this research is to obtain a correlation between air and sound leakages through slits. Audible sound, in the frequency range from 160 to 8000 Hz, is provided and sound pressure levels on both sides of the considered slit are detected by microphones, so that sound transmission losses can be obtained. Simultaneously, the air leakage through the slit under an inside outside pressure difference of 50 Pa is also measured. Two different slits are used, one of which is rectangular of narrow width (0·05–1·00 mm), and the other is of the same section but with bent portions of the passage, as might be encountered in building constructions.

The results show the correlation which represents graphically different curves for the source sound frequencies: ~2000 Hz is found favourable for the intended purpose.

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INTRODUCTION

For energy conservation of buildings, it is of importance to obtain accurate measurements of the air leakages or infiltrations through the building envelope. These lead to an inefficient use of energy for heating or cooling to achieve a comfortable indoor climate in the building. One example[1] of such an energy loss from a one-family house amounted to 30 or 40% of the total heat loss.

Recently many countries have begun to introduce standards or codes concerning building air tightness for constructed and already-used buildings. Swedish building standards,[2] for instance, state the necessary air change ventilation rate per hour to the whole volume of the building under an inside outside pressure difference of 50 Pa. The measurement of such energy losses is not so easy because air leakage is difficult to evaluate in practice. For the measurement of air tightness, the blower system has been employed: in this, the through-the-wall blower vent and pressure taps to pressurize or evacuate the inside of test building are introduced, and the air flow rate passing through the blower, that is equivalent to the air leakage or infiltration, is measured under some determined pressure difference between the inside and outside of the building. In making a precise measurement of the air leakage, the tracer-gas method has been investigated and developed during the last sixty years,[3,4] using CO, SF_6 and so on. Further the thermography method,[1] with the aid of an infra-red camera, is very useful and powerful for detecting insulation defects and air leakages in the building. But this requires a relatively expensive camera and also information obtained by this method does not always give quantitative results, but only relative, qualitative features for the building envelope. Thus another technique must be employed simultaneously so as to make the data quantitative.

The sonic method, in which the sound is used to measure air leakage is relatively new.[5-9] It is suggested that this method would be useful for locating air leakage openings (slits, cracks and so on) in buildings, although it would have limitations in use. Moreover research studies[10,11] proceeding in the USA showed the possibility of using the infra-sonic method in order to determine the composite effective size of all the air leakage passages in the building. In the reports, a significant influence is attributed to the wind gusts as well as the atmospheric pressure outside the building.

On the other hand, when constructing or repairing buildings, it is desirable to have an easy-to-use and also cheap method for measuring the degree of air tightness expected. The present research paper describes an attempt to use the sonic method, employing the audio-frequency range (160 to 8000 Hz) sound as a source for the quantitative measurement of building air leakages. The experiments were carried out in the laboratory, with simplified shaped slits, and air flow (leakage) rates and sound transmission losses were measured through them. The characteristics of sound transmission through such slits are complicated. Nevertheless it is hoped that a portable easy-to-use measuring instrument for obtaining air leakages through building envelopes in practical sites will eventually be developed as a consequence of this research.

The origin of this idea ensued from the experience that chimney sweepers could detect the cracks which occur at the inside wall of a chimney, by easy-to-use sound instruments[12] comprising sound transmitters and receiver earphones.

EXPERIMENTAL APPARATUS

Figure 1 shows a schematic diagram for the whole system for the measurement of air and sound leakages through slits, as set up in the measurement room, which has a high degree of sound (noise) insulation between its inside and outside. The test cylinder employed here is made of acrylic and on both ends of the cylinder, cover plates are provided. The shape of the slit built in the plate (see the left end in Fig. 1) is shown in Fig. 2. Two kinds of slits are employed here as representative of those involved in many research investigations[13-32] which have either been dealt with theoretically or experimentally in sound insulation problems. For different values of the slit width, ranging from 0·05 to 1·00 mm, and three path lengths of 5, 10 and 20 mm, each slit plate piece is carefully constructed so as to accurately maintain such a very thin clearance (width) along the path. Sealing tape is used tightly around the periphery of the slit plate, as otherwise some air and sound leakage comparable with those of the slit opening itself might occur especially for the smallest slit widths employed.

The air leakage through each slit was measured with several kinds of flow meter, such as 'bend type' (developed originally by one of the authors, F. Peterson), ordinary gas meter and variable area flow meter, under inside-outside pressure differences of 50 Pa. For the measurement

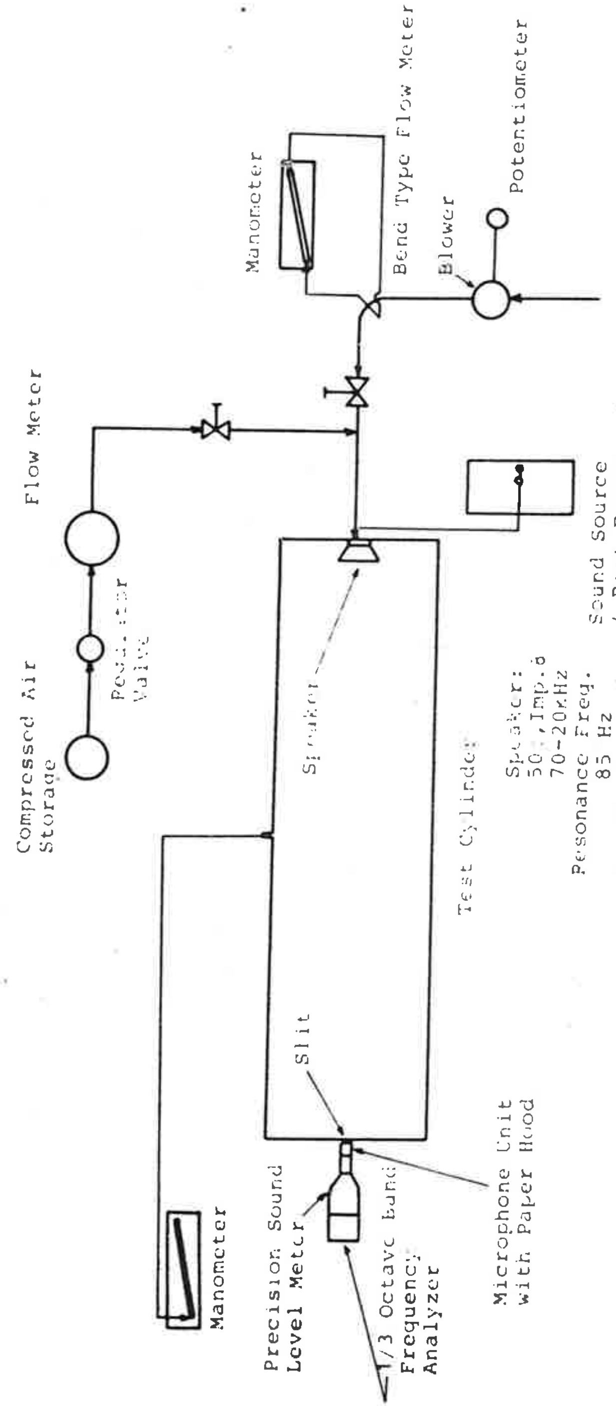

Fig. 1. Simplified schematic diagram of the measurement system.

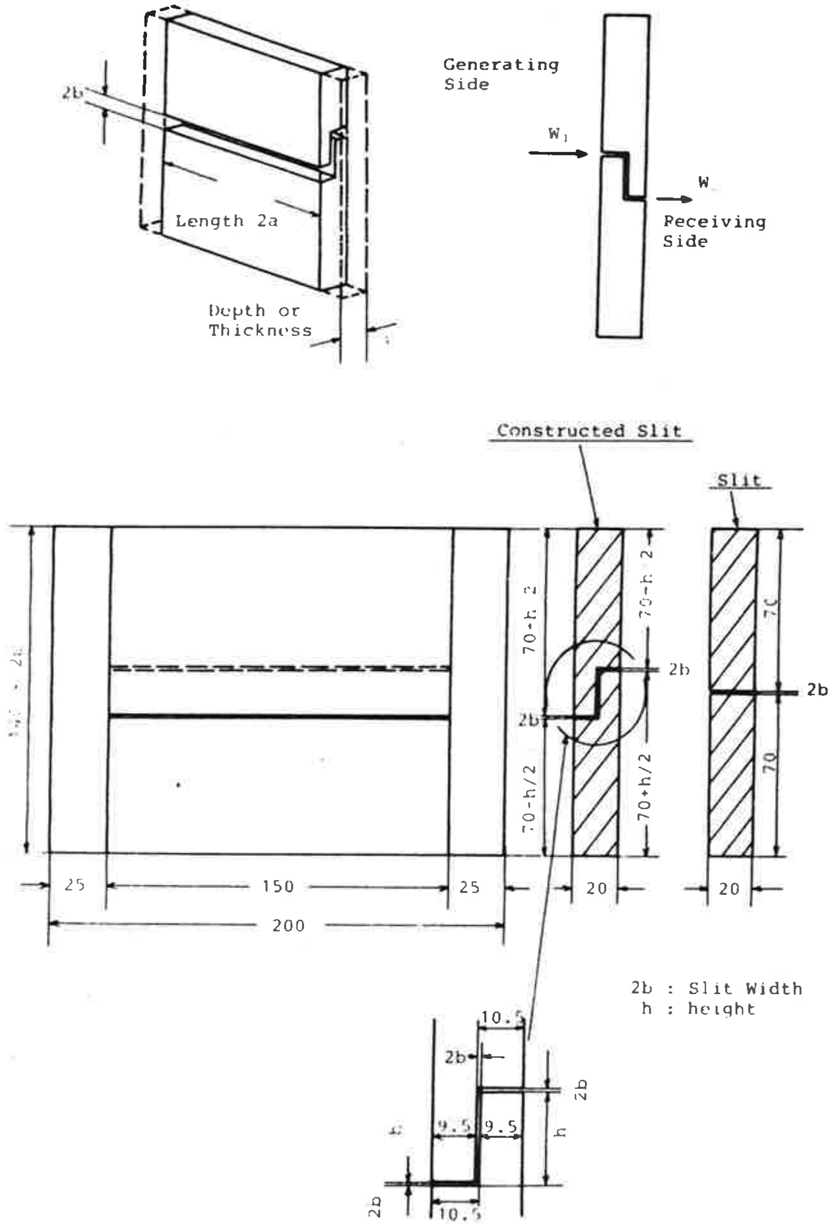

Fig. 2. Slit configuration: all dimensions are in mm.

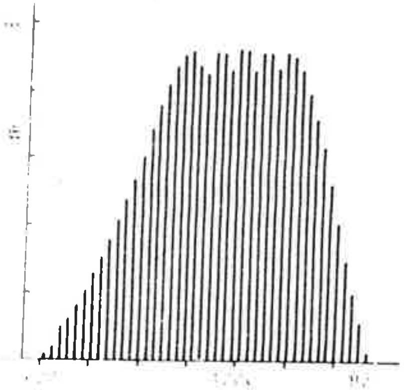

Fig. 3. Typical spectrum of a warble tone produced by a saw-tooth-type modulation signal. (Modulation 16 Hz, modulation swing 160 Hz, measuring frequency 1000 Hz.)

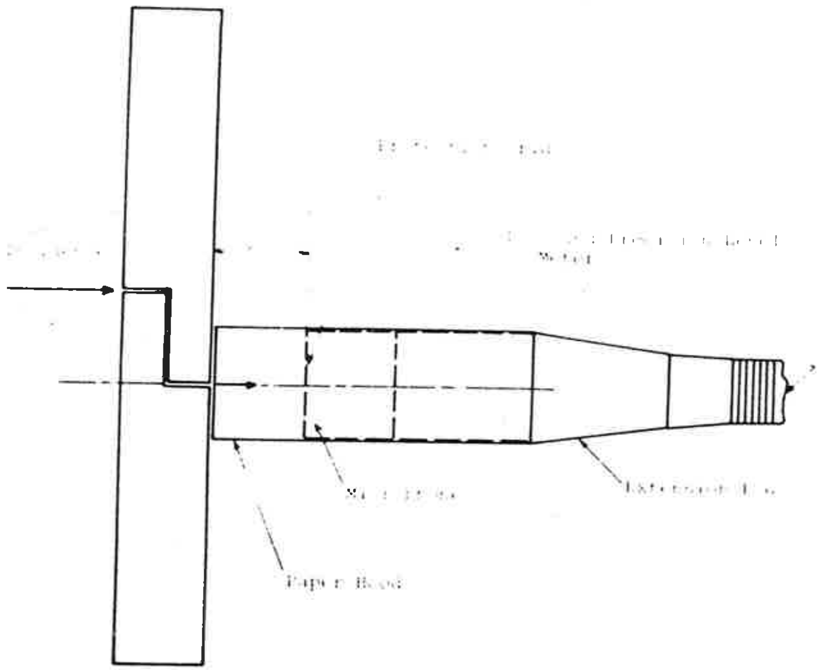

Fig. 4. Positioning of the microphone.

of pressures, ordinary inclined manometers were used, the resolution of which was 0·98 Pa.

On the other hand, the sonic system consisted of a speaker with a connection to the sound source (a beat-frequency oscillator) and a receiver microphone placed either inside or outside the cylinder and near the slit orifice. The microphone signal was fed to a precision sound pressure level meter with one-third octave band frequency analyser.

The sound source employed here contained a built-in frequency-modulation device, whereby the signal can be warbled around the frequency under measurement. The frequency spectrum of such a 'warbled' signal is shown in Fig. 3. The function of this frequency-modulated, warbled tone does not lead to the formation of the standing wave pattern inside the cylinder.

Figure 4 shows the positioning of the microphone for the slit, which is with an extension rod and cover hood made of paper and mounted quite near the slit orifice. The reason for using this hood is to catch as much of the transmitted sound through the slit as possible, while eliminating undesirable sound such as that transmitted through other parts of the slit plate than the slit opening, other than transmitted sound from the cylinder itself, reflected sound or ordinary background noise. The positioning considerably influences the measured results, producing differences, depending on the mounting conditions, particularly on the small clearance between the tip of the hood and the slit orifice. Moreover the presence of the microphone close behind the slit orifice could alter the character of the sound flow. This made it difficult to correlate the results measured here by the already obtained theoretical formulae.[14,18,19]

The measurement of sound leakages through slits was achieved by setting a certain frequency (ranging from 160 to 8000 Hz) for both the generator (source) and receiver (microphone) sides for each slit.

MEASUREMENTS

Figures 5 and 6 show the air leakage flow rate Q, through the slits, with the stated inside outside pressure difference ΔP of the test cylinder, as a function of the slit width $2h$. In the figures, the term 'sealed' means the case of no slits present: it is the total undesirable air leakage through some jointed parts of the test cylinder apparatus under the stated pressure

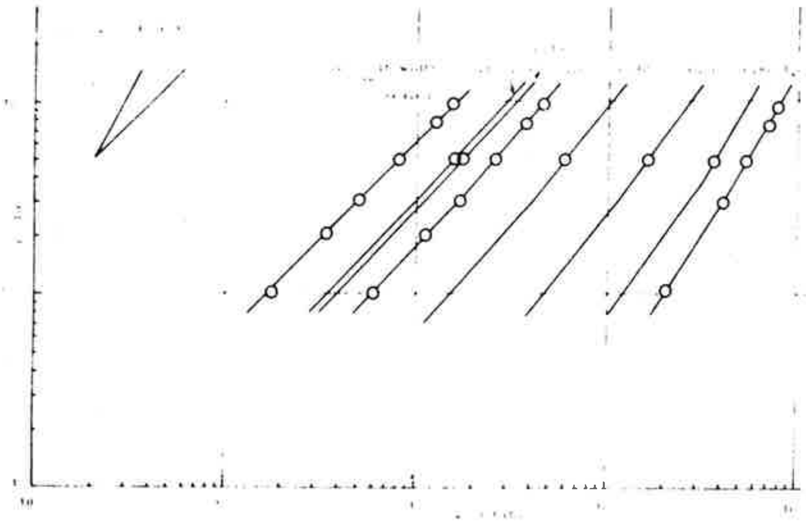

Fig. 5. Air leakages through slits.

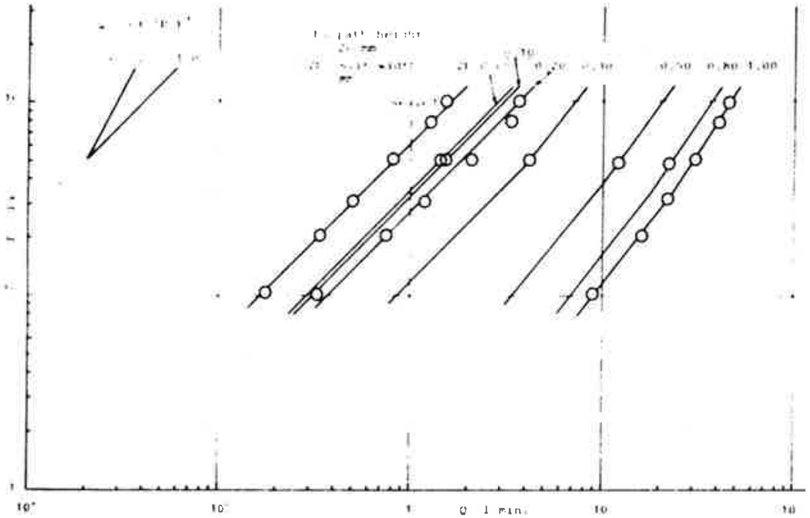

Fig. 6. Air leakages through constructed slits.

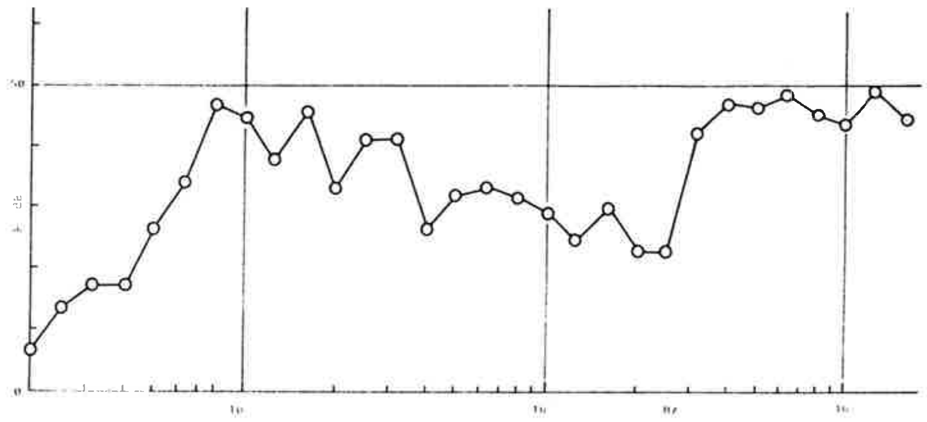

Fig. 7. Sound transmission loss R in the case of no slit.

difference. The well-known correlation between the flow rate and the pressure difference can be expressed by the following formula

$$Q = c(\Delta P)^{\alpha} \tag{1}$$

where c and α are constants, which should be determined for each case.

The measured results for each slit width appear as shown in Figs 5 and 6, i.e. as a straight line having slope α on log-log paper.

Figure 7 shows the sound transmission loss R in the case of no slits, which indicates the sound absorption and transmission characteristics with each frequency of sound for the materials used. Here the sound transmission loss R can be obtained from the following.

$$R = 10 \log 1/q = 10 \log W_1/W_2 \,\text{dB} \tag{2}$$

where q is the transmissivity and W_1 and W_2 are the incident sound energy intensity just falling on the slit and the transmitted sound energy intensity just near the orifice of the slit respectively. These W_1 and W_2 values can be obtained by the measurement data of sound pressure levels recorded by the microphone. Figure 8 represents the transmission loss R in the case of slit width $2b = 0{\cdot}30$ mm for the whole frequency dealt with here. The transmission loss R shows higher values in the relatively lower and higher frequency ranges, in which the value of R for the bent constructed slit is observed to be smaller than that of the straight slit. Taking into consideration the precise sound transmission mechanism through the slits, especially for the constructed slits, complicated effects such as reflection, diffraction, interference, cancellation or resonance may occur

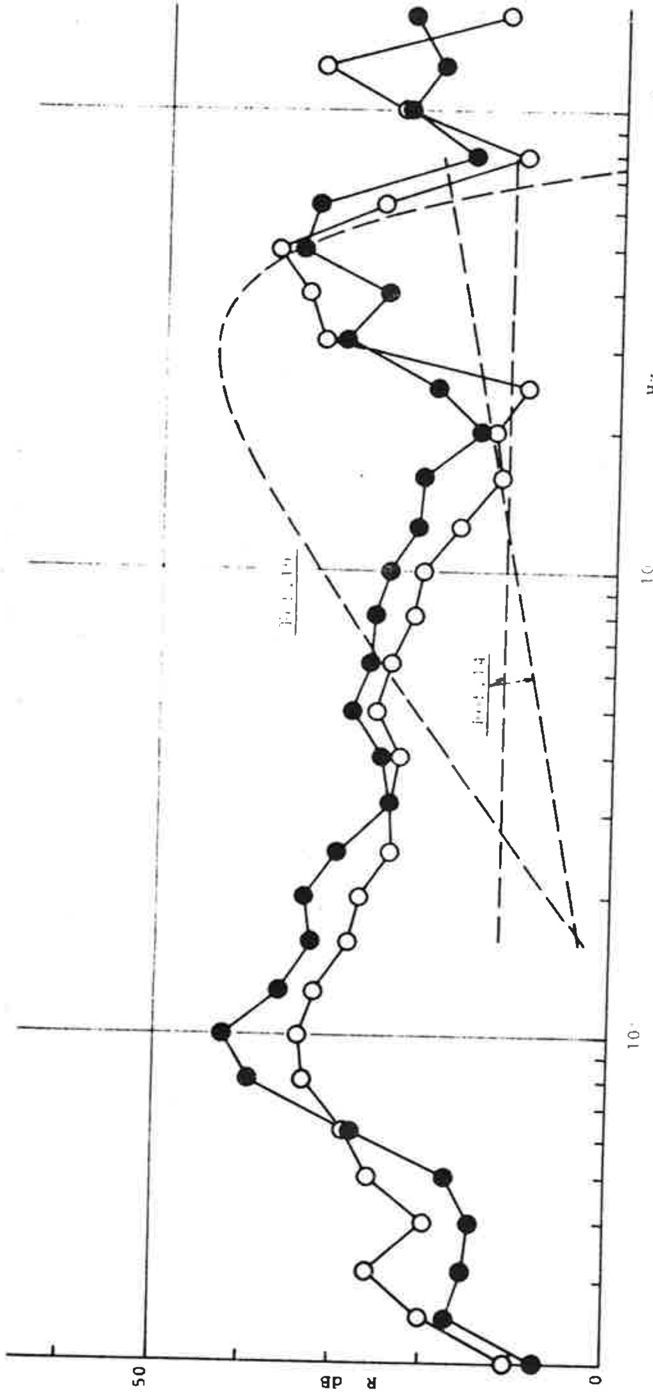

Fig. 8. Sound transmission loss R in the case of slit width $2h = 0{\cdot}03$ mm.

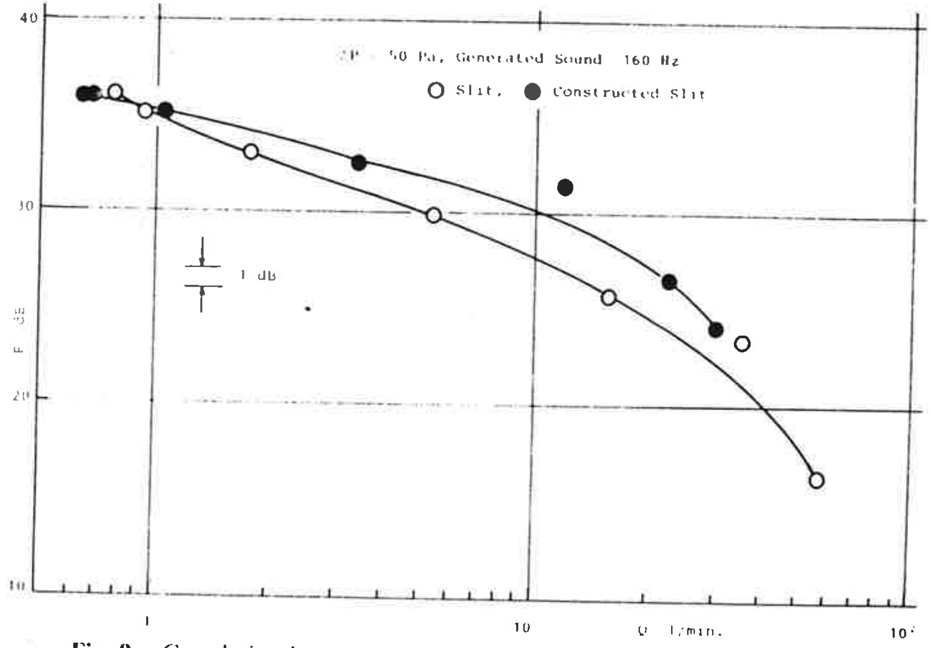

Fig. 9. Correlation between sound transmission loss R and air leakage Q.

in the slit passage according to dimensions and shape of the slit, which could not be easily determined. At $l = \lambda/2, \lambda, 3\lambda/2, \ldots$, ($l$, being the wall thickness and λ, the wave length), resonance effects of the slit occur and these may also affect the results. The decrease in R around the frequency of 8000 Hz can be possibly explained by resonance occurring: the resonance frequency is obtained as 8600 Hz from $l = \lambda/2$. In Fig. 8 the theoretically calculated results for the transmission loss R are partly expressed; these are obtained from the formulae in some of the references.[14,18,19] They do not agree well with measured values in this experiment.

In Figs 9 to 19 the transmission loss R versus the air leakage flow rate Q of each slit under a constant pressure difference $\Delta P = 50$ Pa are shown for each frequency. The difference of the air leakage flow rate Q at a certain sound transmission loss are observed. In the case of 2000 Hz sound source, this difference almost disappears and a single correlation curve results. Hence the air leakage flow rate can be obtained from the sound transmission loss.

Figures 20 and 21 show the effect of slit path height h on the sound transmission loss and the air leakage flow rate.

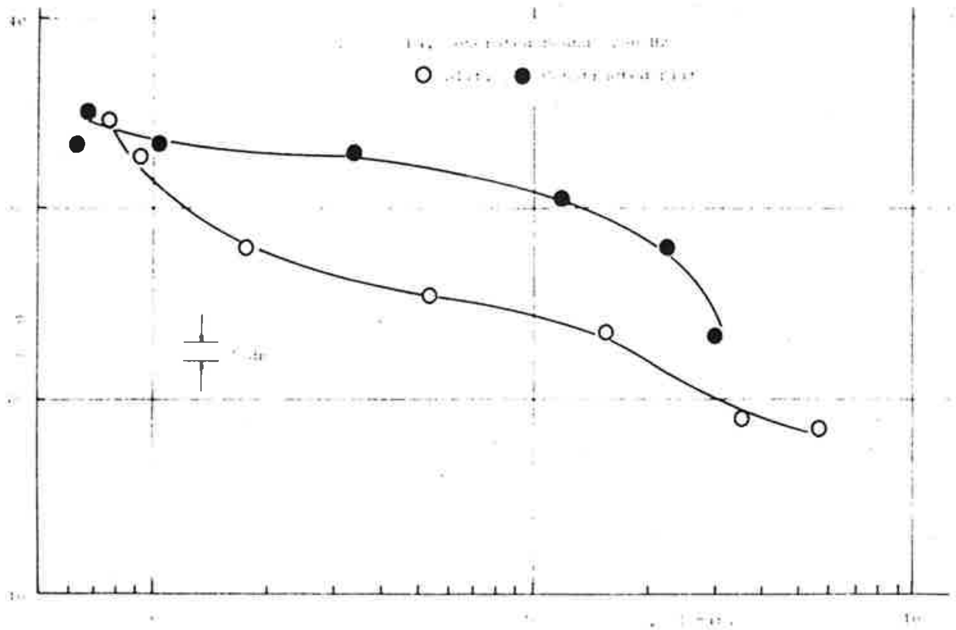

Fig. 10. Correlation between sound transmission loss *R* and air leakage *Q*.

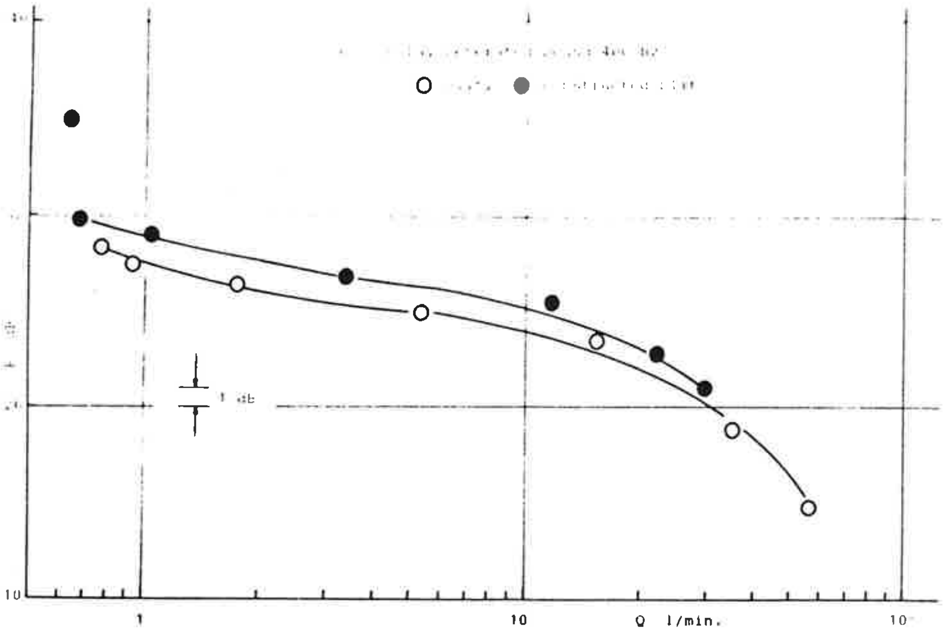

Fig. 11. Correlation between sound transmission loss *R* and air leakage *Q*.

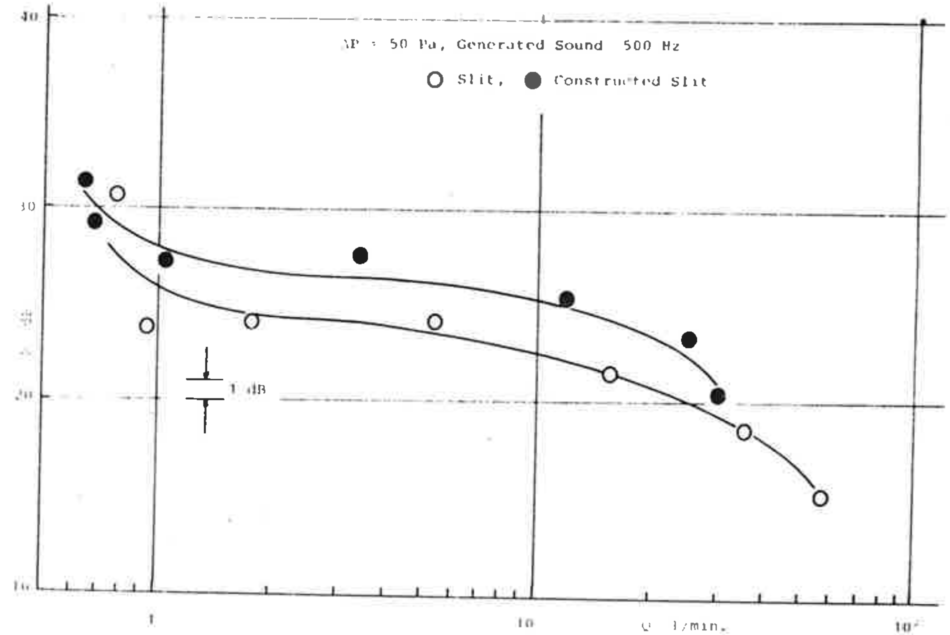

Fig. 12. Correlation between sound transmission loss *R* and air leakage *Q*.

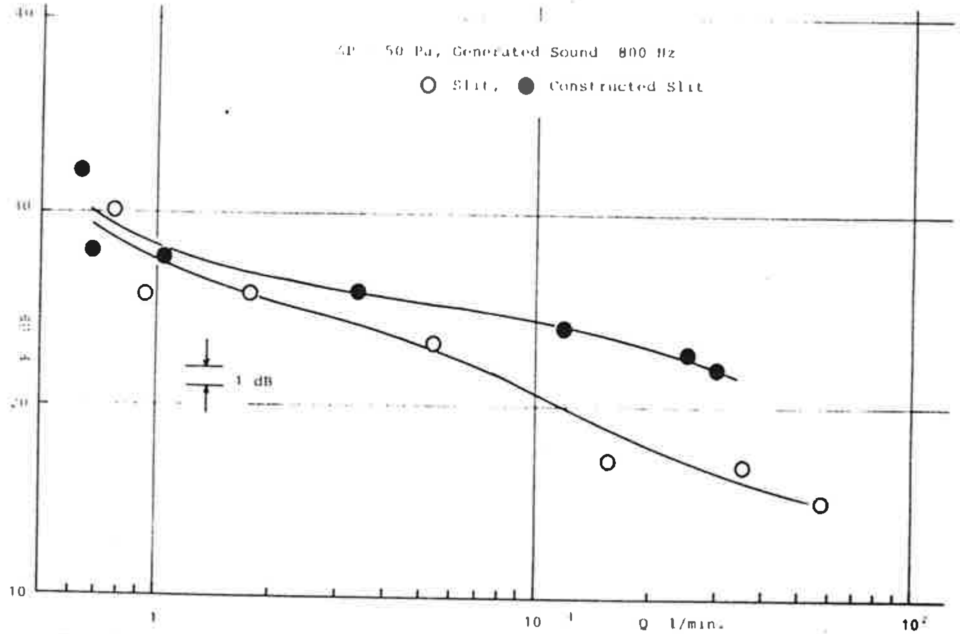

Fig. 13. Correlation between sound transmission loss *R* and air leakage *Q*.

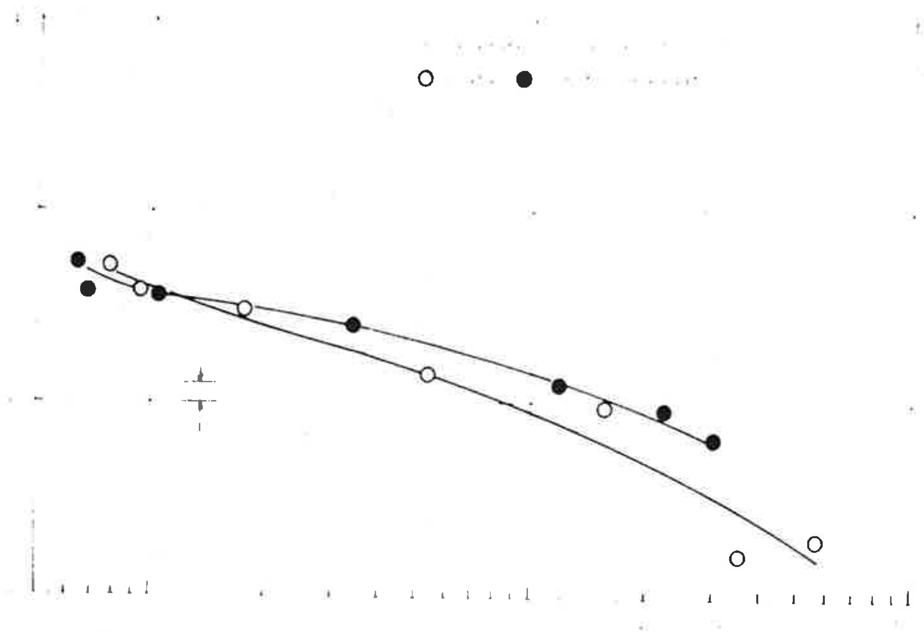

Fig. 14. Correlation between sound transmission loss *R* and air leakage *Q*.

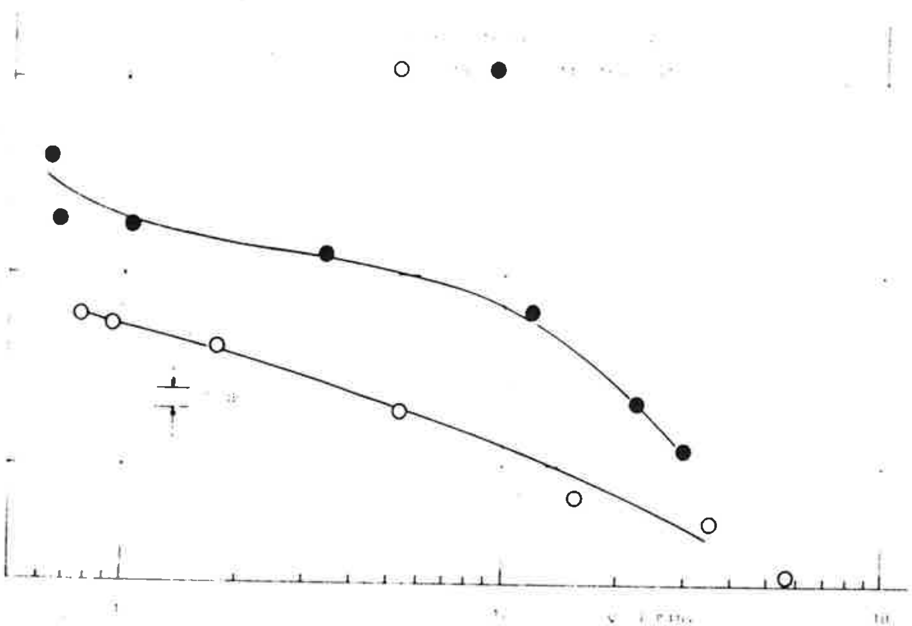

Fig. 15. Correlation between sound transmission loss *R* and air leakage *Q*.

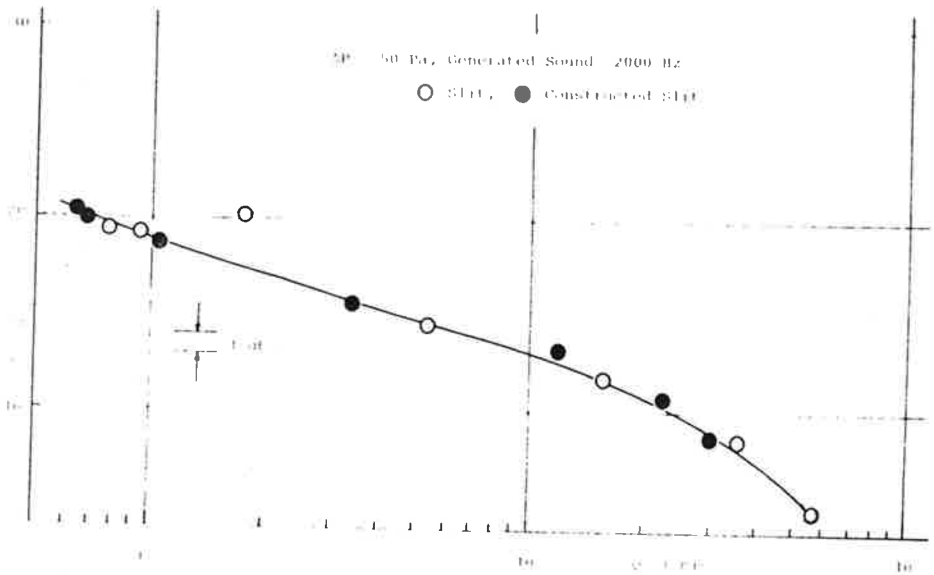

Fig. 16. Correlation between sound transmission loss *R* and air leakage *Q*.

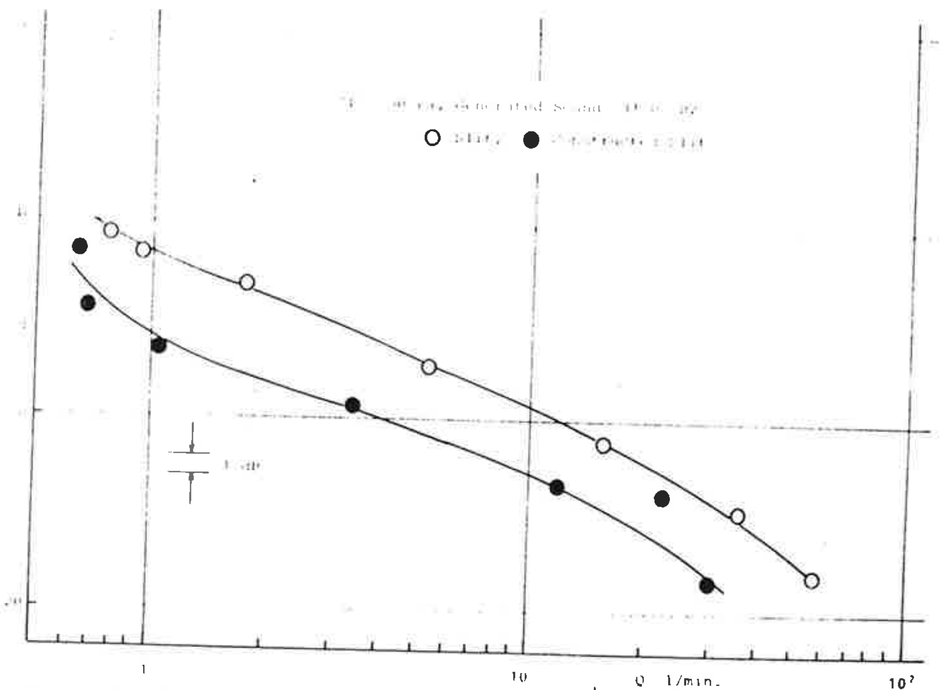

Fig. 17. Correlation between sound transmission loss *R* and air leakage *Q*.

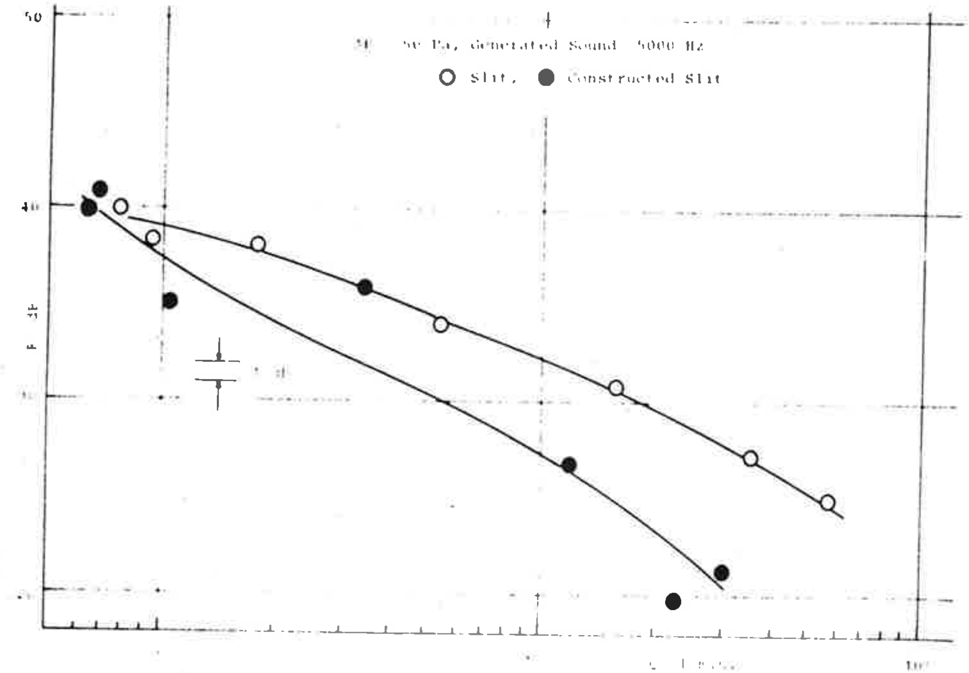

Fig. 18. Correlation between sound transmission loss *R* and air leakage *Q*.

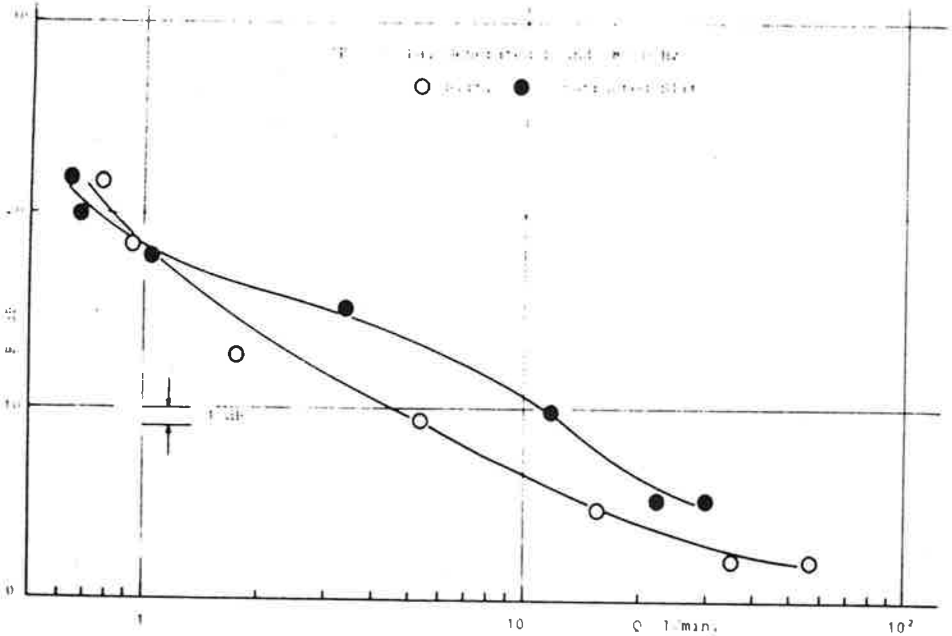

Fig. 19. Correlation between sound transmission loss *R* and air leakage *Q*.

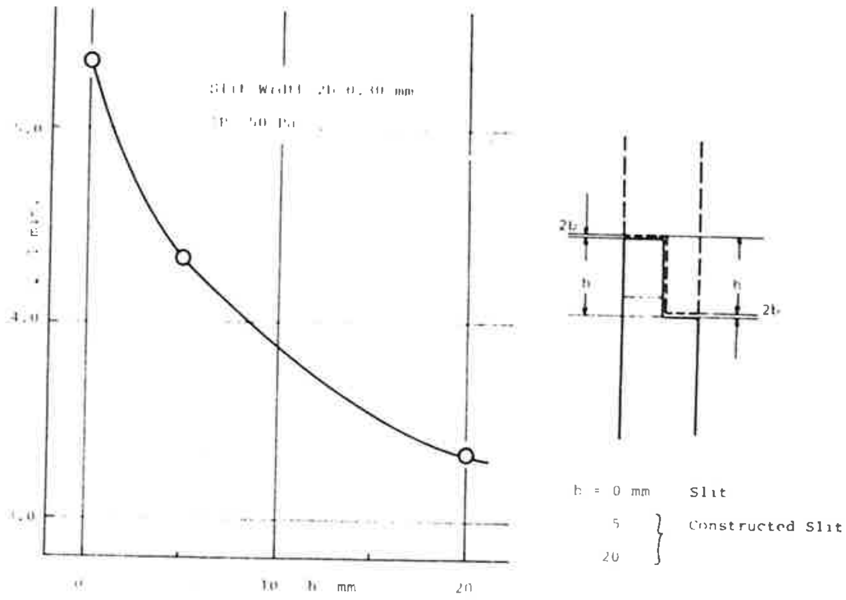

Fig. 20. Air leakage *Q* with slit path height *h*.

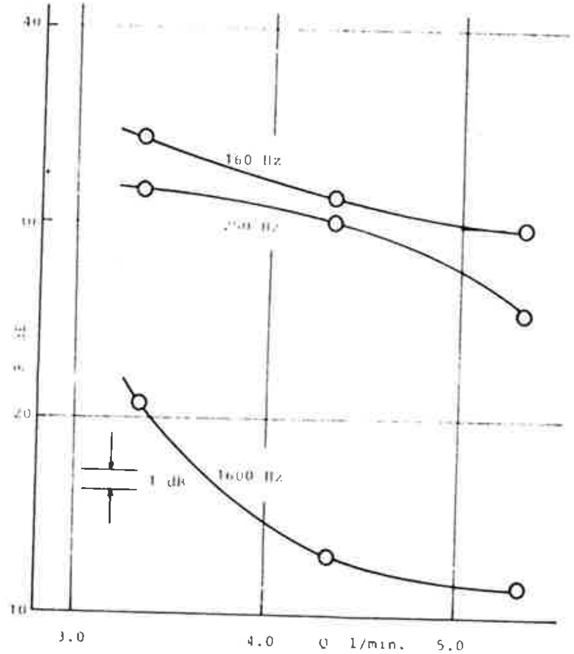

Fig. 21. Correlation between sound transmission loss *R* and air leakage *Q* with slit path height *h*.

CONCLUSIONS

The purpose of this investigation was to obtain experimentally the correlation between air and sound leakages through slits.

Air leakage was measured with several kinds of flow meter according to flow range, under an inside outside pressure difference of 50 Pa. The sound leakage was detected by a microphone with a hood, connected to the sound pressure level meter with a frequency analyser. There exists a correlation between air and sound leakages. At the selected source frequency (2000 Hz) a relatively favourable correlation, not depending on the slit shapes employed, was obtained.

Further investigations and measurements are required for various shaped-slits or cracks.

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Maximising the ... Exchangers Expe...

S. Naik, S...

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Steady-state free and ... 3 mm thick, 250 mm ... vertically upwards fr... was investigated.

For each combina... flow-rate in the dire... optimal fin spacing ... has been deduced. A... this optimal value ri... declines slightly in t...

The temperature ... when the fin base wa... 60 °C or 80 °C above ... depressions occurre... convection, wherea... were present under...

h_c Local valu... a flat surf...
H Fin protru...
k_f Thermal c... spacer ba...

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